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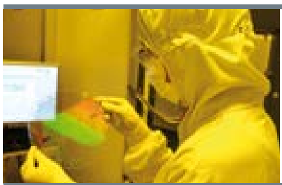
Optical Components
Essential Materials and Processes for Nano-Imprinted Optics


Spectroscopy
QCL Dual-Comb Spectroscopy Matures for Applications

published in media partnership with EPIC European Photonics Industry Consortium

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Cautious Optimism for Photonics in 2021

Photonics benefit from being crucial for recession-proof key markets such as quantum technology, medical, life sciences and defense

Basil Garbabet
member of the EPIC board
president & CEO, NKT Photonics

Despite the impact of the global CD-19 pandemic, the mood we are getting for 2021 from our own marketing people and from customers across Europe, the US and China is quite upbeat. The continuing healthy appetite for photonics products is reflected in the share prices of photonics companies, many of which are showing better results. In our own case, our Q3 results were slightly ahead of last year and many public photonics companies are showing the same picture.

As regards particular industries, the only weakness we see is in manufacturing, across the board and in all regions, including China, which probably won't recover until the second half of 2021.

But all other segments look healthy. For example, as confirmed by recent announcements from ASML, the semiconductor industry is doing well, which is good news for our customers supplying lithography and metrology tools for the semiconductor fabs. Aerospace and defense seem to have a momentum of their own and we are seeing a healthy wave in imaging for the medical sector along with quantum technology, which is attracting heavy investment across the globe.

There are two other grounds for optimism. The first is the positive impact that a less combative and more open Biden administration will have on US relations with China and Europe. This will hopefully result in a lot more collaboration and make things smoother.

The second, is the work that is being done by EPIC, which is now the world's largest photonics industrial consortium, to create a European photonics ecosystem beyond R&D. While Europe needs to retain its position as a global leader in photonics innovation, it also needs an ecosystem that can grow companies large enough to manufacture innovative products and compete at a global level. Although a lot of work remains to be done, EPIC is working hard to address this issue.

An important unknown going forward is the impact of the second Coronavirus wave, although this has been mitigated somewhat by the recent availability of CD 19 vaccines. The other wild card is the possibility of a recession coming behind the pandemic; however, I think this is unlikely to have much of an effect on photonics because key markets such as medical, life sciences and defense are, to a large extent, recession-proof.

Of course, the proof for the future of photonics will be in the pudding, but from current indicators, I think we have grounds for cautious optimism for both 2021 and beyond.

Wishing you all a happy, safe, and healthy 2021

Basil Garbabet

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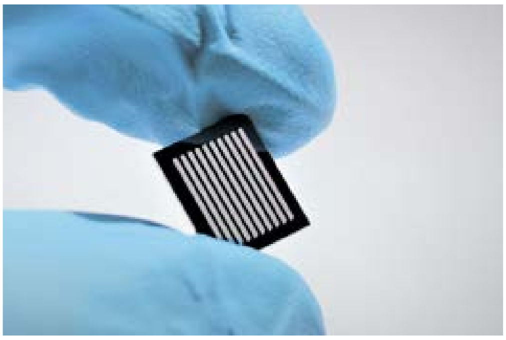

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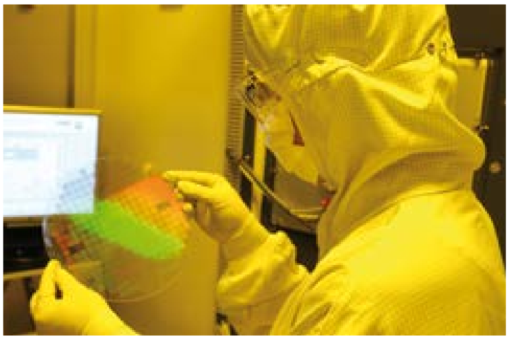

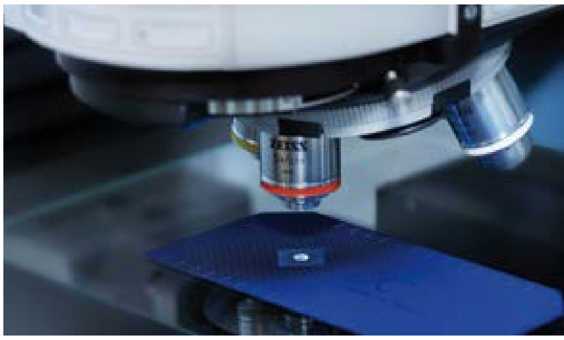

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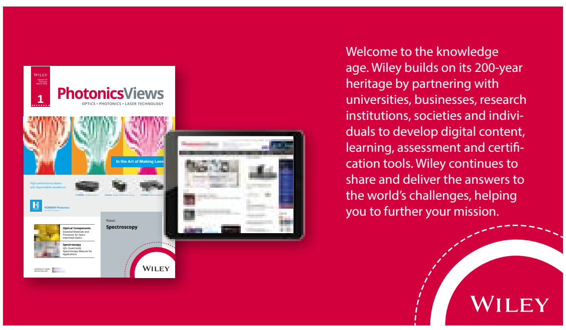
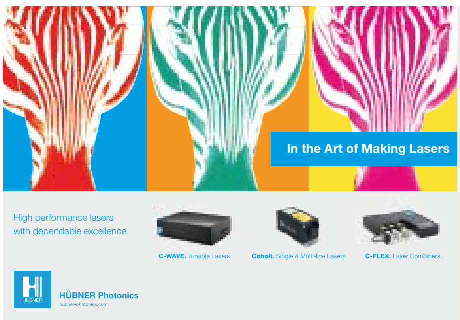




Cover:

Hübner Photonics is one of the leading manufacturers of high performance lasers for research and analytical instrumentation p. 15

Wallonian Merger: Lasea Acquires Optec

The Lasea group, active in the design and manufacture of precision laser machines, purchased the majority shares of the Optec company.

Based in Frameries (Belgium) and in San Diego (USA), with a strong presence in the USA and Asia, Optec is specialized in UV and ultra-short pulse lasers. The new group offers all subtractive and additive laser solutions for four preferred sectors: luxury goods, medical, electronics, and academic.

New Lasea building in Belgium (4,000 m²; source: Lasea)

Thanks to this merger, the Belgian group, based in Wallonia, has achieved a critical size on the world stage. With more than 110 employees in four countries, more than a thousand systems installed on five continents and counting several clients who are giants in their industry, it confirms its strategic position as a European expert in micro-machining applications.

Founded in 1991 and born out of the Label company, a spin-off from the University of Mons, Optec designs and manufactures laser micro-machining machines for the medical and electronics sectors and for safety marking. For over thirty years, it has specialized in precision machining of polymer materials using Excimer lasers (short pulse, UV lasers). It is also a major player in the field of ultrashort pulse lasers. These two athermal processes are capable of micron-size precision, offering very high performance both from a quality and a reliability point of view for cutting-edge applications.

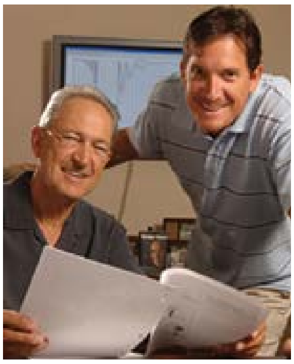
Installed in Frameries since 2003, it expanded its facilities in 2005 and 2016 in order to meet growing demand coming from Japan (Beams Inc.) and the United States (Optec LLC) several times. Today, Optec occupies a surface area in Belgium of more than 1500 m², 100 m² of which are ISO7-class clean rooms and has a subsidiary in San Diego (USA).

www.lasea.eu

Edmund Optics Acquires Quality Thin Films

Provider of optical and imaging components Edmund Optics (EO), has acquired Quality Thin Films. QTF, located outside of Tampa, Florida, offers a wide range of optical components with high laser damage and laser crystal coatings from the UV to the far IR.

For nearly eighty years, EO has led the optics industry and continues to aggressively invest in laser grade optical technology. This acquisition, with its 14,000 square foot facility and laser optics experts, supports Edmund Optics to further expand its laser optics manufacturing capabilities.



Karl George Sr. (left) and Karl George Jr. (Source: QTF)

As part of this acquisition, Karl George Sr., president and CEO of QTF, will retire and his son, Karl George Jr., will continue to oversee the facility and its thirty employees.

www.edmundoptics.com

Trumpf to Acquire Joint Venture with Sisma

The high-technology company Trumpf plans to strengthen its additive manufacturing division: The Ditzingen-based company is in advanced talks with its Italian partner Sisma, a leader of manufacturing high-technology machines, to acquire the joint venture Trumpf-Sisma SRL completely. Up to now, Trumpf held 55 percent of the shares.

In addition, Trumpf intends to continue Sisma's additive manufacturing business activities in the industrial, dental and medical sectors.

Simultaneously with its divestment from the joint venture, Sisma plans to focus on the jewelry and fashion industry and for this purpose to enter into a cooperation with Trumpf in 3D printing.

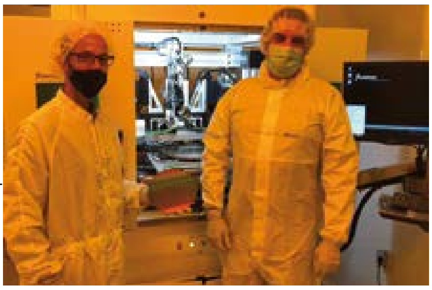
Trumpf-Sisma was founded as a joint venture in 2014 and is based in Schio in northern Italy. Around sixty employees work there in the development and production of metal 3D printing machines with laser metal fusion technology.

The transaction is expected to be completed in the first quarter of 2021. The two companies did not provide further details.

www.sisma.com
www.trumpf.com

Hitachi Acquires VLC Photonics

VLC Photonics has become a Hitachi High-Tech subsidiary company in November to provide photonic integrated circuit (PIC) engineering services as part of the Japanese company's broader offering.



Source: @vlcphotonics

In October, VLC installed a Ficontec T1200 to do optical and electrical wafer-level testing and measurements of different materials.

PICs have immediate applications in transceivers for optical communications. Recently, internet traffic has been continuing to increase significantly due to the data arising from social media, video streaming services, working from home, IoT and the overall digitization of our economy and environment.

A long-term provider of components and services to the optical communications industry, Hitachi High-Tech is reacting to the increasing need of customers for greater integration and innovation. As the foremost independent provider of PIC design, test and engineering services, VLC from Spain is in an excellent position to help serve the new requirements of its existing customers as well as to provide a base for the development of new service provisions.

Besides the optical communications market, PICs are also becoming a critical platform technology within many industrial sectors such as automotive sensing, environmental testing, health sciences and quantum technology. Going forward, Hitachi High-Tech will leverage the strengths of both companies.

www.vlcphotonics.com
www.hitachi.com

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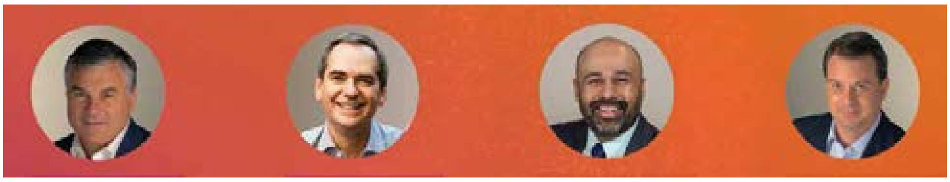
Lumentum Acquires Coherent

Lumentum Holdings and Coherent have entered into a definitive agreement under which Lumentum will acquire Coherent in a cash and stock transaction valued at 5.7 billion US dollars. Under the terms of the agreement, which has been unanimously approved by the boards of directors of both companies, Coherent stockholders will receive $100.00 per share in cash and 1.1851 shares of Lumentum common stock for each Coherent share they own. At closing, Coherent stockholders are expected to own approximately 27 % percent of the combined company.



Participants of the conference phone call, January 19: Alan Lowe, President & CEO, Lumentum; Andy Mattes, President & CEO, Coherent; Wajid Ali, EVP & CFO, Lumentum; and Chris Coldren, SVP Strategy and Corporate Development, Lumentum (Source: Lumentum / Coherent)

The combination unites Coherent's leading photonics and lasers businesses, including in the microelectronics, precision manufacturing, instrumentation, and aerospace and defense markets, with Lumentum's leading telecom, datacom, and 3D sensing photonics businesses, creating a diversified photonics technology company with significantly increased scale and market reach. The combination accelerates Lumentum's penetration of the more than ten billion dollar market for lasers and photonics outside of communications and 3D sensing applications. The powerful R&D engine of the combined company will be primed to accelerate innovation in existing and future markets that need the unique capabilities that photonics bring. The combined company will be better positioned to serve the needs of a global customer base increasingly dependent on photonics to enable important end-market transitions. These include, for example, the shift to digital and virtual approaches to work and life, the transition to 5G in wireless networking, advanced bioinstrumentation, advanced microelectronics, and new materials for next generation consumer electronic devices, flat panel and OLED displays, communications equipment, electric and autonomous vehicles, and energy storage.

"Today's announcement is an important advancement of Lumentum's strategy," said Alan Lowe, Lumentum President and CEO. "In our five years as a standalone public company, we have focused on developing the most innovative products and technology in our industry and partnering with market leading customers to help them compete and win in their markets. As we look ahead, we are thrilled to join forces with Coherent to create one of the world's largest and most diverse photonics technology companies with leading positions in the growing market for photonics. Coherent brings one of the most recognizable and respected brands in the photonics industry."

www.coherent.com
www.lumentum.com

Teledyne Buys FLIR

On January 4, Teledyne Technologies and Flir Systems jointly announced that they have entered into a definitive agreement under which Teledyne will acquire Flir in a cash and stock transaction valued at 8.0 billion US dollars. Under the terms of the agreement, Flir stockholders will receive $28.00 per share in cash and 0.0718 shares of Teledyne common stock for each Flir share, which implies a total purchase price of $56.00 per Flir share based on Teledyne's 5-day volume weighted average price as of December 31, 2020. The transaction reflects a 40 % premium for Flir stockholders.

Teledyne expects the acquisition to be immediately accretive to earnings, excluding transaction costs and intangible asset amortization, and accretive to GAAP earnings in the first full calendar year following the acquisition. "At the core of both our companies are proprietary sensor technologies. Our business models are also similar: we each provide sensors, cameras and sensor systems to our customers. However, our technologies and products are uniquely complementary with minimal overlap, having imaging sensors based on different semiconductor technologies for different wavelengths," said Robert Mehrabian, executive chairman of Teledyne. "For two decades, Teledyne has demonstrated its ability to compound earnings and cash flow consistently and predictably. Together with Flir and an optimized capital structure, I am confident we shall continue delivering superior returns to our stockholders."

"Flir's commitment to innovation spanning multiple sensing technologies has allowed our company to grow into the multi-billion-dollar company it is today," said Earl Lewis, chairman of Flir. "With our new partner's platform of complementary technologies, we will be able to continue this trajectory, providing our employees, customers and stockholders even more exciting momentum for growth. Our Board fully supports this transaction, which delivers immediate value and the opportunity to participate in the upside potential of the combined company."

Jim Cannon, president and CEO of Flir, said, "We could not be more excited to join forces with Teledyne through this value-creating transaction. Together, we will offer a uniquely complementary end-to-end portfolio of sensory technologies for all key domains and applications across a well-balanced, global customer base. We are pleased to be partnering with an organization that shares our focus on continuous innovation and operational excellence, and we look forward to working closely with the Teledyne team as we bring our two companies together to capitalize on the important opportunities ahead."

TELEDYNE TECHNOLOGIES

FLIR

Teledyne to acquire Flir Systems, cash and stock transaction at $8.0B. (Source: Teledyne / Flir)

www.flir.com
www.teledyne.com

LPKF Opens Cleanroom Fab

Tech company LPKF – which has just celebrated its 20th anniversary – has put a new cleanroom fab into operation to produce thin-glass components for applications in the electronics and semiconductor industry. The in-house developed 'laser-induced deep etching' process LIDE enables rapid and high-precision structuring of thin glass without impairing surface properties. The original stability of the glass remains fully intact. This process facilitates the use of glass in, for example, the production of microsystems, sensors, display components, and microchips.

The fab was constructed in record time. Due to the considerable interest shown by the semiconductor and electronics industry in this innovative method of processing thin glass, rapid completion was required. Despite the difficult circumstances encountered with travel restrictions among service providers and delivery issues involving some manufacturers, the fab was constructed within just 13 months.

Dirk Neizel, operations manager at LPKF, said: "We now have a very flexible hall that we can equip in accordance with customer requirements, thus allowing the required production processes in each case to be offered as quickly as possible.

www.vitrion.com
www.lpkf.com

Employees engaged in wafer production in the cleanroom (Source: LPKF)

New Optical Fabrication Design Tool

There is a big, well-known problem in the optical industry. The interface between optical design and the subsequent optical fabrication is still today based mainly on human-to-human contacts. During the design stage is not possible to simulate the required optical fabrication chains. As a result, companies often waste money by producing optical designs that are not optimized for producibility and may be far from the design-to-cost goal. Hence, optics may be purchased too expensively because it is difficult to choose the right supplier.

The human-to-human interface between design and manufacturing is now supported by the novel data-based PanDao software tool. Based on design data, it determines the cost-optimized production chain, including information about producibility, the required fabrication technologies, expected manufacturing cost, and literature references.

PanDao is a start-up in St. Gallen, Switzerland, founded in 2018. The software tool has been developed by a team of three senior experts in optics systems manufacturing with profound experience in research and industrial projects. After succesfully passing through intense field testing by various senior optical design specialists throughout Europe and USA, the tool was launched in early 2020.

During the design stage, PanDao supports optical designers to check optical designs for producibility, optimize optical designs for minimum cost and risk by investigating the influence of design parameters on manufacturability and on production cost, and compare competing designs in terms of fabrication risk and cost.

www.pandao.ch

Developing Novel Material Systems

The Foundry Institute at the RWTH Aachen in Germany has put a new Lunovu LMD system into operation. Sited at its new premises, the Research Center for Digital Photonics Production (RCDPP), the laser material deposition (LMD) system is designed to suit the special requirements of the foundry institute. A hermetically sealed inert gas chamber (glove box) is used for contamination-free processes.

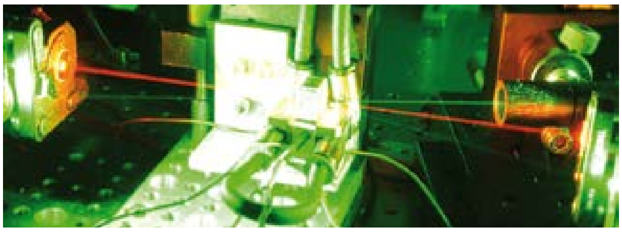
"The new LMD system is ideal for our research applications. We are now in a position to produce metal powder with our in-house atomization system, which can be immediately used in the LMD system to produce material samples," states Dr Iris Raffeis, head of the research group for additive manufacturing.

Dr Rainer Beccard, managing director at Lunovu in Herzogenrath, Germany, adds: „A special focus was put on the large number of potential applications. The combination of wire and powder-based processes in an inert gas system offers maximum flexibility and makes the system ideal for complex research tasks."

www.gi.rwth-aachen.de
www.lunovu.com

iLMD machine at the Foundry Institute of RWTH (Source: Lunovu)

Novel Membrane Laser Module



Source: Ana Ćutuk / Fh. IAF

Laboratory setup of a membrane laser

The Fraunhofer Institute for Applied Solid State Physics IAF and the start-up Twenty-One Semiconductors (21s) are developing a laser module that can be used in flow cytometry. This spectral measurement method has long been used as a routine procedure in medicine, where laser light irradiates cell suspensions. This requires laser modules with central wavelengths in the visible spectral range. The demand for such modules is growing and they find broad application in spectroscopy and fluorescence microscopy.

A novel laser concept for a "membrane external-cavity surface-emitting laser," MECSEL for short, will reach the desired frequencies in the ultraviolet range more efficiently and compactly than established laser modules. The idea for this laser concept comes from the founders of 21s, who have joined forces with Fraunhofer IAF in order to transfer the concept of their MECSEL into industrial application and develop a market-ready laser module to be used in flow cytometry.

www.21semiconductors.com
www.iaf.fraunhofer.de

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Zeiss, Trumpf and Fraunhofer IOF Research Team Awarded Zukunftspreis

The German Federal President Frank-Walter Steinmeier announced the winners of the German Future Prize 2020 at a ceremony in Berlin on November 25. The Federal President honored the team made up of Dr Peter Kürz from the Zeiss Semiconductor Manufacturing Technology segment, Dr Michael Kösters from Trumpf Lasersystems for Semiconductor Manufacturing, and Dr Sergiy Yulin from the Fraunhofer Institute for Applied Optics and Precision Engineering IOF, giving them his technology and innovation award for their EUV lithography project.

The winning team made a significant contribution to developing extreme ultraviolet technology and preparing it for industrial series production. The result is future-proof technology, backed by more than 2,000 patents, which forms the basis for the digitalization of our daily lives and enables applications such as automated driving, 5G, Artificial Intelligence and other

The team was awarded the trophy of the Deutscher Zukunftspreis 2020 by German Federal President Frank-Walter Steinmeier (left; source: Deutscher Zukunftspreis / Bildschön)

future innovations. Thanks to EUV, over 3,300 high-tech jobs have been created at Zeiss and Trumpf to date and an annual turnover of more than one billion euros was generated in 2019.

www.deutscher-zukunftspreis.de

LaVa-X Receives Innovation Award

The West German company Lava-X is one of the first four winners of the 'Rheinland Genial' innovation award. The Metropolregion Rhineland honored the company with this aware for its technical innovation. It has developed a special process for laser beam welding in a vacuum, which promises a pore and crack-free result even with difficult materials, among other things due to the low energy consumption.

Lava-X has developed a special laser beam welding process that enables pore and crack-free welding for almost all materials and mixed connections in a vacuum. At the same time, the new process increases the

Source: Lava-X

Dr Christian Otten

welding depths, the welding process becomes more efficient and the required energy consumption is significantly reduced. "We would like to thank those responsible for the award, which once again confirms how important our work on new technologies is," says Dr. Christian Otten, managing director of Lava-X.

metropolregion-rheinland.de

Jennifer Zhao Named "Woman of the Year"

At Questex's Sensors Innovation Week 2020, Jennifer Zhao, EVP and general manager of AMS' advanced optical sensors division, received the Woman of the Year award on November 14, 2020. "Having Questex recognize her is both a great honor and a strong testament that the work she is doing truly has a positive impact on people's lives," says Alexander Everke, CEO at AMS. "Jennifer and her team drive innovation and build differentiated solutions from sensors for the smartphone industry to using the same technology platform to help the world fight Covid-19."

"Miniaturized spectral sensing is more valuable than

Source: AMS AG

ever for healthcare applications. Detecting colorimetric and fluorescence information through a tiny, yet powerful, optical sensor enables widespread rapid testing at disposable cost levels," Jennifer commented. She holds a BSc in mathematics and economics from Beijing University in China and an MBA from Suffolk University in the US.

https://ams.com

Early Detection of Skin Cancer

About 23,000 people get skin cancer every year in Germany, and around 3,000 die from it annually. Up to now, examinations for early detection of skin cancer have been highly dependent on the experience of the investigating physician who does the biopsies.

Ulm scientists have now developed a novel method for early detection of skin cancer, which makes diagnostics more precise, cost-effective and simpler. Using a hyperspectral camera system combined with structured lighting, precursors of malignant melanoma and the smallest differences in the microstructure of the tissue can be reliably detected.

For their achievements, Dr Karl Stock and Steffen Nothelfer, MSc, from Ulm University, were awarded the 2020 Otto von Guericke Prize of the AiF in Cologne. The project was carried out by the AiF member Research

Steffen Nothelfer (left), Dr Karl Stock (Source: AiF)

Association for Fine Mechanics, Optics and Medical Technology, FOM. The prize is awarded once a year for outstanding achievements in the field of industrial collective research and is endowed with 10,000 euros.

www.aif.de

www.dioptic.de

Cycle Lasers Appoint Daniel Seiler as CEO

Cycle GmbH, manufacturer of laser-based time distribution and synchronization systems, is expanding its management team. For the position of the CEO, Cycle was able to recruit Daniel Seiler who has been working for the young Hamburg-based company since August 1, 2020. The 42-year-old has 15 years of experience in the photonics industry and was most recently managing director of a successful medium-sized manufacturer of industrial cameras. The founder of Cycle, Prof. Dr.-Ing. Franz X. Kaertner, will remain with the company in a central strategic role and focus on optical technologies.

Source: Cycle

Franz X. Kaertner (l.), Daniel Seiler

Kaertner says: “With Daniel, we have been able to gain an experienced manager who brings exactly the right skills in the development and production of electro-optical components and in the internationalization of a young company. I am convinced that together we will continue and increase the success of Cycle.”

Seiler has a diploma in electrical engineering as well as business management knowledge from a part-time MBA program. He will take over full-time operational management of Cycle, including engineering and sales.

www.cyclelasers.com

Rockley CCO to Target Healthcare Market

Rockley Photonics, an integrated optics solutions provider with offices in Pasadena, San Jose, Oxford, Cardiff, Cork, and Helsinki, appointed Vafa Jamali as chief commercial officer.

Source: Rockley Photonics

Vafa Jamali

Mr Jamali will be responsible for the company’s commercial strategy, driving business growth and market share. With over 25 years experience in the medical device industry, most recently at Medtronic, he has extensive medical device knowledge across several specialties and patient conditions.

“We’re excited to welcome Vafa to Rockley,” said Andrew Rickman, CEO, Rockley Photonics. “Our optical sensing chipsets, with their unique analytical capabilities, bring benchtop testing capabilities to healthcare and wellbeing markets within handheld and wearable devices. Vafa’s extensive experience in the medical devices field will help to position Rockley for growth in this multibillion-dollar, high-volume market.”

“Personalized monitoring of multiple biophysical and biochemical biomarkers will revolutionize the way we look after our health and wellbeing,” said Jamali.

https://rockleyphotonics.com

Avi Cohen Joins Nanofabrica as Sales EVP

Micro-3D printing technology innovator Nanofabrica announced that highly experienced additive manufacturing influencer Avi Cohen has joined the company as executive vice president of sales.

Nanofabrica exists at the interface of micro and additive manufacturing, and through hardware, software, and material innovation presents industry with a true blue-ocean technology that is disrupting the manufacture of micro parts or components or smaller parts with micron features. As such, the company is at the forefront of the drive towards the use of 3D printing as a truly viable production technology, and sees Cohen’s experience and insights as critical to its future success.

Cohen’s career started in sales, marketing, and high-level management positions in various bio-medical companies, his over 20-year association with the additive manufacturing sector beginning in 1999 when he joined Stratasys (formally Objet). At Stratasys for 16 years, Cohen became director of healthcare sales and marketing. He comes to Nanofabrica after a 5-year stint as the vice president for healthcare and education at XJet, a position he took up after moving on from Stratasys in 2015.

www.nano-fabrica.com

Jon Donner (left) and Avi Cohen, standing in front of a Tera 250 (Source: I. Gil / Nanofabrica)

New CEO at Satisloh Group

After five years with Satisloh, first as head of region North America and for the last two years as president and CEO for the global Satisloh group, Pete Lothes has taken on a new leadership role within Essilor of America as SVP operations and supply chain effective November 2nd, 2020. In this new role, he is responsible for all manufacturing and supply chain activities across Essilor of America.

Source: Satisloh

Bruno Fischer

“I look forward to the new challenge and opportunity but at the same time know that I will miss the great customers and staff that I had the privilege to work with at Satisloh. What I am truly happy about, though, is that I am able to pass on the baton to a successor that is uniquely qualified to lead the group,” said Lothes.

Bruno Fischer becomes the new CEO of the global Satisloh group, a leading provider of optical manufacturing equipment. He joined Satisloh in 2001. For many years he has been serving as CFO in the group and took over several other responsibilities. He was COO from 2010 to 2014 and most recently has been leading Finance, HR, IT and the order management process with a laser sharp focus on optimizing the company’s processes to better serve its customers.

Fischer holds a master degree in financial management from Zurich University and an MBA from IMD Lausanne.

www.satisloh.com
www.essilor.com

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Olaf Berlien, Stefan Kampmann to Leave Osram, Bank to Become CEO


Source: Osram

Dr Stefan Kampmann


Source: Osram

Dr Olaf Berlien


Source: Osram

Ingo Bank

At its meeting on November 5, 2020, the supervisory board decided to downsize the management board of Osram Licht AG from three to two individuals. Following approval of the domination and profit and loss transfer agreement with AMS by the Osram shareholders, it is foreseeable that the areas of responsibilities for technology will be reorganized within the combined company. At Osram, the integration of corporate innovation into the business units had already reduced major activities from the responsibilities of the chief technology officer. The Osram supervisory board will therefore enter into negotiations with CTO Stefan Kampmann (57) to terminate his contract prematurely.

To further align with its new management structure as part of the AMS group, the supervisory board will therefore enter discussions with CEO Olaf Berlien about the termination of his contract with effect from February 28, 2021. Since taking office in January 2015, Berlien has consistently driven the company's transformation from a traditional light bulb manufacturer to an innovative high-tech champion. Most recently, he has steered Osram through a competitive bidding process, which culminated in a domination and profit and loss transfer agreement with AMS. This agreement was accepted by a large majority of the shareholders.

The new situation is also being reflected in the supervisory board: Peter Bauer will resign as chairman and as a member of the supervisory board in mid-December. He has used his experience to carefully guide and support Osram through turbulent times since the IPO in 2013.

The Osram supervisory board plans to appoint Ingo Bank as the new CEO with effect from March 1, 2021. Ingo Bank, the current CFO of AMS and former CFO of Osram, will take on a dual role. The new chairman of the supervisory board will be Thomas Stockmeier, who is a current member of the supervisory board of Osram and also a member of the management board of AMS.

www.osram.com

http://ams.com

Nuburu Expands Team with CEO, CFO Appointments

Nuburu, a provider of high power and high brightness industrial blue lasers, announced the executive appointments of Dr Guy Gilliland as CEO and Chris Baldwin as CFO.


Source: Nuburu

Dr Guy Gilliland


Source: Nuburu

Chris Baldwin

Gilliland brings over twenty years of management experience from the Boston Consulting Group (BCG) where he led the firm's global and North American technology practice and advised several of the world's largest telecommunications, technology, electronics and photonics companies. He has a deep background in laser physics and served as a postdoctoral fellow at the IBM T.J. Watson Research Center and a faculty member at Arizona State University and Emory University.

Baldwin joins with nearly thirty years of financial management experience across the photonic, telecom and medical device industries. He most recently served as the CFO at Axsun Industries, a leading developer and supplier of MEMS-based photonic engines for medical imaging and industrial spectroscopy.

https://nuburu.net

Chromacity Strengthens Position during Pandemic

Edinburgh-based laser company Chromacity announced new appointments to its commercial team as it adapts to Covid-19 travel restrictions by rolling out a new remote installation capability.

Bertrand Frossard joined as international business development manager, bringing more than twenty years' commercial experience in disruptive technologies and gaining market share for multinational organizations. The company also welcomed former laser systems engineer, Lawrence Titley, as its new sales associate.

Having recently secured funding from Kelvin Capital, EOS and the Scottish Investment Bank, the company is well-positioned for its next phase of expansion into international and industrial markets. Shahida Imani, CEO, Chromacity said: "It was great to receive strong support from our existing investors during these turbulent times – not to weather the storm, but to expand our commercial operations. We're now fully focused on accelerating our business over the next few months, to build upon our success to date and maintain our competitive edge."


Source: Chromacity

Bertrand Frossard

Despite the challenges placed on laser manufacturers by Covid-19, the company has continued to acquire new customers in Asia, Europe and North America by introducing a remote installation model for its optical parametric oscillators.

www.chromacitylasers.com

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GD Optics Sets Itself up for the Future

With effect from 1 January 2021, Winfried Czilwa is appointed sole managing director of GD Optics. He replaces the duo consisting

Source: GD Optics

Juliane Wolz and Ullrich Blöcher (right) hand over the management to Winfried Czilwa

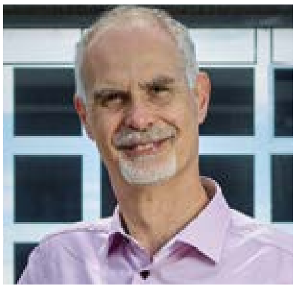
of Juliane Wolz and Ullrich Blöcher, who continue to support him. Due to the increasing international demand and the unique technological competence, the company wants to reposition itself strategically in order to further expand its market position. To this end, the previous management, consisting of Juliane Wolz and Ullrich Blöcher, decided to place the responsibility in the hands of an experienced manager.

Winfried Czilwa, a graduate engineer, brings with him extensive expertise in the areas of business development, strategy and brand development, product management and internationalization, which he has demonstrated in various companies, most recently since 2014 as CEO and chairman of the management board at the tool manufacturer Stahlwille in Wuppertal. "I am looking forward to the new task in a technologically demanding industry and a company with huge potential," says Czilwa.

"We are very pleased that we were able to win Winfried Czilwa for our family-owned company," explains Juliane Wolz.

www.gdoptics.de

Successor for El-Khoury as CEO of CSEM



Source: CSEM

Mario El-Khoury

Source: CSEM

Alexandre Pauchard

CSEM is opening a new chapter. After eleven years at the helm of the center, Mario El-Khoury, 57, is leaving his position as the head of CSEM to devote himself to personal projects. He is to be replaced by Alexandre Pauchard, who currently works for Bobst.

Arriving at CSEM in 1994, El-Khoury, a Lebanese-Swiss engineer, held multiple leadership and executive positions before being appointed to the role of CEO in 2009. Through his direction, he successfully managed to position CSEM as a key player in the development and transfer of cutting-edge technologies to benefit Swiss companies.

Alexandre Pauchard, 49, head of group R&D at the Swiss company Bobst, will take over the reins of the center on the 18 January 2021. He will jointly manage CSEM alongside El-Khoury until El-Khoury's departure on 28 February 2021. Pauchard has lived in both California and Zurich, graduated with a degree in physics from ETH Zürich, holds a doctorate in microengineering from EPFL and brings managerial experience with him.

www.csem.ch

Jean Gehrig Dies Age 79

Jean Gehrig, founder of SCL International, a cleaning and hard coating machine manufacturer based in France, passed away in November 2020.

"For all who met Jean, they will remember a gentleman, a professional, a real entrepreneur," write his colleagues from Swiss company Satisloh AG.

He was an electrical engineer who founded two companies before SCL International was formed in 1993, producing dip coating technology.

Jean's last initiative was joining Essilor and the Satisloh group, ensuring the future of the success story he built before retiring in 2017 and his son Denis assuming leadership of the company. (Source: Satisloh)

Jean Gehrig, founder of SCL International (Source: Satisloh)

https://scl-intl.com

Rauscher Mourns Death of its Founder

Ernst Rauscher, founder, shareholder and managing director of Rauscher GmbH, died on 5 November at the age of 74 after months of serious illness.

Ernst Rauscher founded the company in 1984 and has continuously expanded it over the past four decades. With his innovative strength, his tireless personal commitment and his secure sense of technology and markets, he was not only one of the pioneers of the industry, he also shaped Rauscher into a highly successful technology provider in image processing.

Ernst Rauscher was not only a successful businessman, he was a lively and always optimistic person, for whom respect and teamwork were important qualities.

With his death, image processing loses one of its pioneers, who was respected and highly valued by all employees, business partners and the entire industry because of his achievements and personality.

Source: Rauscher

Ernst Rauscher

Despite the personal loss, and in the spirit of Ernst Rauscher, Rauscher GmbH will continue to be a strong and reliable partner for customers and business partners in the future.

Thomas Miller, who has been with the company since 2006, and Raoul Kimmelmann, who has been with the company since 1999 and managing director of Rauscher GmbH since 2013, will continue to run the company together. With Thomas Miller, the nephew of Ernst Rauscher, the family succession is thus secured in the spirit of the deceased.

www.rauscher.de

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Innovative customized Fiber Laser Systems

Manufacturer: TOPTICA.
Supply: Innovative and custom-tailored fiber laser systems of the "FemtoFiber" series for applications in ultrafast optics. The laser systems enable cutting-edge research in the field of quantum technology, biophotonics and solid-state physics.
Features: The range of laser systems extends from synchronized multi-arm configurations for pump-probe spectroscopy to two-color laser solutions for CARS microscopy (Coherent Anti-Stokes Raman Spectroscopy) to highly advanced laser systems that emit phase-stable few-cycle light pulses for controlling individual electrons in solids.
The manufacturer offers more than 15 years of experience in femtosecond fiber laser technology and fiber laser design. In order to meet the diverse requirements, the fiber laser technology was developed with maximum flexibility and compatibility. Thus there are simple, compact and turnkey laser solutions that serve highly complex applications and are fully adapted to the needs of the customers. A team of application and technology specialists advises and supports the planning of each custom-tailored laser solution to unlock its full potential for the specific application and provide the customers with innovative laser systems that advance their research. More information on www.toptica.com/customized.

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EXO Camera Family

Manufacturer: SVS-Vistek.
Supply: New cameras "exo540" and "exo541" for industrial use with Sony's 4th generation "Pregius" sensors and C-mount adapters. *SVS-Vistek* is one of the first camera manufacturers worldwide to offer cameras with these sensors in batch production.
Features: The *Sony* sensors offer excellent image quality with global shutter, high resolution with 2.74 µm × 2.74 µm small, very light-sensitive pixels and exceptional speed with approximately 70 dB dynamic range. Thanks to their illuminated backlight technology, the sensors have very good light sensitivity and significantly improved quantum efficiency, which, in combination with the pixel density, enables a compact camera design with high resolutions and smaller, cheaper lenses.
The cameras offer resolutions of 24.5 and 20.3 megapixels with GigE Vision or USB3 interface. In order to make the best possible use of the outstanding sensor properties and at the same time allow economical lenses, they are equipped with a C-mount connector. All cameras of the "exo" series have a milled unibody, which is an essential part of the sophisticated temperature management and enables the cameras to be specified for operating temperatures up to 65 °C. They have a galvanically isolated input as well as a 4-channel power output with a maximum of 3 A. All functions are controlled via GenICam and can also be controlled via the GenTL driver of the camera. Another highlight is the smooth interaction with controllable Canon "EF" lenses via the SVS EF adapter: the camera controls the aperture and focus of the lens directly in the GenICam tree, which allows the lens to be controlled without special software.

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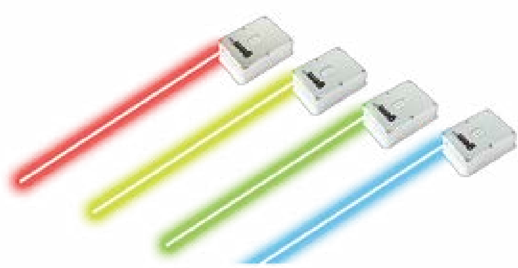
Powerful and narrow-band 640 nm DPSS laser

Manufacturer: Laser Quantum.
Supply: Diode pumped solid state (DPSS) laser "gem 640" of the "gem" series offering multiple wavelengths (473, 532, 561, 640 nm). With power levels more than 500 mW, the new laser reaches a power range not accessible for diode lasers previously available at this wavelength.
Features: The laser has excellent beam quality with a M^2 of < 1.2. The TEM_{00} beam for a perfectly round beam will help produce reliable, repeatable results. These qualities enable the laser light to be coupled into single-mode fibers with high coupling efficiency. The new model complements the "gem" series with an intense red. In addition to the three older lasers (red/green/blue, 640 nm/532 nm/473 m), the "gem" series is also available at 561 nm, 660 nm and 671 nm with at least 750 mW each. They demonstrate excellent beam quality and are characterized by a power stability of < 1.0 % RMS.
Applications: The laser series is ideally suited for high resolution microscopy. Especially single molecule localization microscopy (PALM/STORM) as a wide field technique benefits from the high output powers and the wavelengths tuned specifically for the available dyes due to fluorophore specificity. The "gem" family also exhibits excellent wall plug efficiency; power is not lost as heat creating a lower requirement for the customer to employ complex cooling systems.



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Goniometer Extension for Grinded Prisms

Manufacturer: Möller-Wedel Optical.
Supply: New innovative extension for ground prisms for the "GONIOMAT M5/M10" goniometers (patent-pending) allowing time and cost savings in the production process of prisms.

Features: For the first time, the new extension enables a goniometer to measure prism angles of fine ground prisms with a roughness R_q = 1.0 µm or smaller and a maximum measurement uncertainty of 10 arc seconds.The achievable accuracy and measurability of the test specimen depends on the size and roughness of the prism surfaces.
For the production of precise optical prisms, an appropriate basic angular accuracy of the prism must be achieved even during fine grinding, because the material removal during subsequent polishing is considerably lower. During the polishing process, only the fine correction of the prism angles is carried out. If the required basic angle accuracy is not achieved during fine grinding, this is usually only visible after polishing the measuring surfaces. In this case either sufficient material reserves are still available to finish the prism according to the drawing with further fine grinding, angle correction and subsequent polishing, or the prism must be written off as production scrap. Therefore, the extension for grinded surfaces has a high potential for time and cost savings in the production process. In addition, the system can help to optimize the fine grinding process and thus improve quality.

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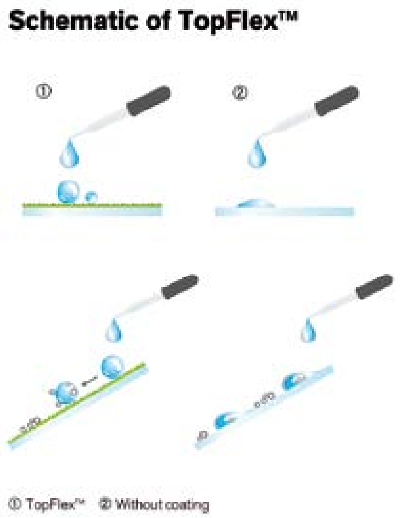
New Easy-to-clean Coatings

Manufacturer: Optics Balzers.
Supply: Two new hydrophobic "TopFlex" coatings ("TopFlex A" and "TopFlex B"). Both are chemically resistant to water, oil and grease and allow the easy cleaning of the protective windows of cameras and sensors.
Features: The new coatings are largely insensitive to the most diverse cleaning processes and form an optimal, dirt-repellent and easy-to-clean top coating. They can be easily deposited on any combination of optical coatings. This results in a wide range of applications from the automotive industry, to heating windows, sensors, optical systems, endoscopy, diagnostics and research.
The coatings have a high environmental stability and can therefore be used in harsh environments. In combination with mirrors or other optical coatings, their corrosion resistance can be significantly improved .Depending on the combination of substrate and coating, temperature resistance up to 250 °C can be ensured. The coatings tolerate even salt mist, cleaning agents and 500 temperature shocks of –40 °C/+85 °C. "TopFlex A" withstands the cheesecloth test with up to 50,000 cycles and "TopFlex UV" has a UV resistance of 500 hours.



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High-resolution Image Processing With 51 MP

Manufacturer: SVS-Vistek.
Supply: New "hr51" camera with a resolution of 51 megapixels and powerful interfaces for numerous demanding image processing applications.
Features: The camera offers a high resolution of 8,424 × 6,032 pixels (51 megapixels) in Gpixel's "GMAX4651" CMOS global shutter sensor (pixel size 4,6 × 4,6 µm) and a dynamic range of up to 65 dB. This pixel size is also ideally suited for a large selection of M58 lenses that already exist on the market. The basis for the outstanding homogeneity of the images with this sensor is a shading correction that can be selected for entocentric and telecentric lenses. For this sensor with its special micro lens structure this is optimized and unique on the market.
The camera is available with the interfaces CoaXPress (25 fps) and 10 GigE (10 fps). These two interfaces have established themselves as future-proof standards for the coming years and cover the most diverse requirement profiles. Industrial features such as dust-free housing cooling, an integrated 4-channel flash controller and operation via the GenICam GenTL interface make integration easy and inexpensive. The camera also allows easy replacement in existing applications using cameras with the "KAI-29050" sensor, which is no longer available and extremely popular in the industry, since the sensor dimensions, the pixel size and the dynamic range of the camera are comparable with this sensor.

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Telecentric F-Theta Lenses

Manufacturer: Sill Optics.
Supply: Extension of the existing series of telecentric F-Theta lenses with a focal length of 48 mm to meet the ever increasing laser pulse power in micro processing.
Features: The lenses can withstand even the highest fluences and are free from critical back reflections. The designs are optimized for scanners with 7 mm to 15 mm apertures and can be easily installed using an adapter ring. With the lenses, smallest spot diameters of 6 µm at 1064 nm wavelength, 3 µm at 532 nm and 2 µm at 355 nm can be achieved.

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Cages for Anti-Friction Linear Guides

Manufacturer: PM.
Supply: Variety of cages for use in the precision linear guides. With the choice between ball- and crossed roller cages, the anti-friction linear guides are popular for many high-end systems. These cages are the product of choice for use in microscopy, manipulator and medical image-scanners where repeatability and smooth motion are critical.
Features: With the ball cages "JJ" (brass) and "KKLK" types (plastic) and for crossed roller cages "KZR" (plastic), "AA" (steel), and "AL" (aluminum) types, the manufacturer offers the widest range of cages, meeting all the demands for these industries. The cages are supplied with retained rolling elements for easier handling. Main function of the cage is to separate the rolling elements at a fixed distance and to prevent that they contact each other which affect the running performance resulting in pulsations.
Roller cages are the product of choice for medium-high load carry applications offering stiffness and precision. Ball cages are used in low to medium load applications offering very low friction resistance. They are applicable in dust-contaminated environments as they swipe the particles away from the point of contact.
Precision linear guides are available as a standard set which include 4 rails, 2 cages and endpieces, but the components are also available as single piece. In this way, the engineer is free to design his own linear guide set and is not forced to use standard sets. The portfolio also includes cages on customized non-standard lengths.
The smallest rolling elements used in the cage are 1.5 mm in diameter and are superfinished for highest accuracy demands and running performance.
The linear guide rails start with a length of 20 mm ("RSD-1520") up to 1400 mm ("RSD-91400") in one piece. For longer lengths, multi-section pieces are available which are grind together. For cleanroom and vacuum applications there are also many stainless steel solutions available.
As an option the anti-friction guides can be cleaned and bagged for vacuum or cleanroom use.

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Green and Red Laser with High Power and Long Lifetimes

Manufacturer: Laser Quantum.
Supply: Air cooled, customized "axiom" lasers with a wavelength of 532 nm and 660 nm offering high powers up to 12 W.
Features: The laser has an M^2 close to unity to support tightly focused beams. The high output increases speed and resolution, making the "axiom" 532 nm laser an ideal solutions for metrology. In addition to high output to increase speed and resolution, the new laser has ultralow noise (<0.02 % RMS) and exceptional power stability (<0.05 % RMS) to achieve accurate, reliable readings. With both 532 m and 660 nm wavelengths available and power up to 12 W, the laser delivers high continuous wave power whilst incorporating all of the active optics within the laser head. This design lends itself to easy integration into equipment, without the complexities associated with fiber delivery of the pump light. The design features an innovative stress-free cavity architecture. Along with the ultra-compact power supply unit, the lasers both form small-scale laser systems ideal for metrology applications to deliver high power on a sample for high throughput, whilst minimizing any downtime.
Applications: The laser is an ideal laser solution for line scanning processes in battery manufacturing and research. This process uses a Raman spectroscopy in-line system that boosts productivity, enabling super-fast scanning and utilizing 10 times the normal laser power for Raman.

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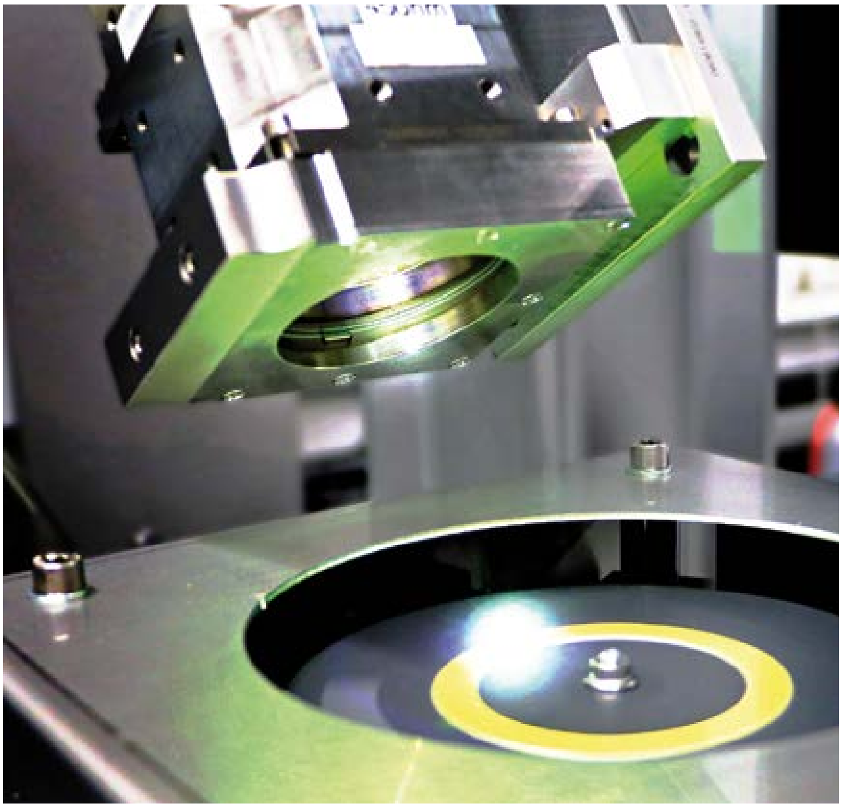
Blue Skies for High Power White Light by Blue Diode Lasers

LDMblue diode lasers and rotating phosphor converters revolutionize white light generation

The generation of high-power white light with more than 100,000 lumens has so far encountered technological limits as soon as small light sources with high luminance were required. The high-pressure discharge lamps used for a long time offered small light source sizes, but were short-lived and had only limited color rendering quality. The lack of sustainability due to the contained hazmat and handling threats due to high internal pressure provide additional limitations to their use. In a revolutionary step, white light LEDs, in which blue LED light was converted into broadband white light with the aid of a cerium-doped YAG phosphor – commonly referred to as a phosphor converter – were introduced to the market in 1995.The new approach was convincing with its high energy efficiency, long service life, as well as a constant and flexibly scalable luminous flux, even in the long term. However, since numerous individual LEDs, each with an output power of around 3 to 5 watts, had to be placed next to each other for very high luminous fluxes, the maximum luminance and thus also the contrast effect remained limited.



The blue high-power diode laser illuminates the rotating phosphor wheel. (Source: Laserline)

A new converter excitation solution now combines very high luminous fluxes effectively and robustly with high luminance levels. The approach is based on the phosphor conversion of blue LED light, but uses a Laserline LDM-blue diode laser with a wavelength of 450 nm instead of individual emitters. The laser provides up to 2,000 watts of output power in continuous wave operation. Due to its compact 19" design, it can be conveniently integrated into a wide variety of application configurations. A phosphor wheel is used to distribute the high energy input of this blue laser over a larger area to maximize its output power. The rotation of the wheel enables optimized thermal management in the conversion process when irradiating laser spots of about 15 to 20 mm^2 in size. Irradiating the phosphor wheel with blue laser light leads to an efficient conversion into a broadband light spectrum. The result is white light with a wavelength spectrum of about 450 to 750 nm and high contrast. Since the laser spot touches each spot of the fast rotating phosphor wheel only very briefly, a high laser power can be introduced without overheating the converter and accordingly a very high light output can be generated.

Potential for more than 200,000 lumens

The demonstration with around 630 watts of laser output power already clearly shows the potential of the new solution. In continuous operation, 150,000 lumens were achieved, and even 270,000 lumens for a short time at laser powers above 1 kW. The resulting luminance levels exceed 1,500 cd/mm^2. Since the optical conversion efficiency of the process is 230 to 300 lumens per watt of laser power and the current power spectrum of the blue Laserline diode lasers has not even been exhausted by half, these values – determined by 180° full-angle measurement – by no means reflect the end point of development. Through future improved thermal packaging, optimized phosphor wheels and optimized energy inputs, more than 200,000 lumens in continuous operation are considered realistic. Such light outputs and luminance levels are of interest, for example, for testing solar cells and photovoltaic systems (solar simulation), as well as for metrological applications in which the selective extraction of wavelengths is used. The process even offers new possibilities for conventional event technology, especially for the generation of spectacular lighting effects in the context of outdoor events. The generated white light can be easily focused with the help of compact optics, it can be scanned and thus also used for dynamic exposures. The size of the light source can be flexibly adjusted, the use of collimating optics ensures low divergence, and the emitted wavelength spectrum can be modified according to application requirements by selecting the appropriate phosphor converter.

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Meta Installs World's First C-Wave GTR Tunable Laser

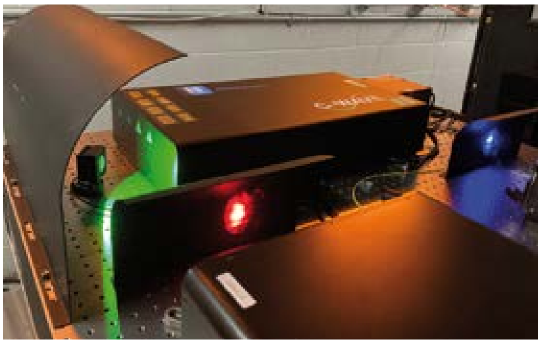
Full coverage of visible spectrum accelerates holographic development capabilities

Metamaterial Inc, a developer of high-performance functional materials and nanocomposites, has installed the world's first C-Wave GTR / NIR (green-to-red / near-infrared) tunable laser from Hübner Photonics. Laser light sources are core to holography, and the new system covers a significant gap in the green region, which would be costly and complex to address with alternative narrow bandwidth lasers. Together with two other tunable sources, Meta now has the ability to record holograms at any desired wavelength across the entire visible spectrum, which will accelerate holographic product development. This new, full-spectrum capability will be a crucial enabler for the crafting of full-color RGB holograms for optical combiners in augmented reality and head up display applications.

Meta has invented meter-scale and roll-to-roll capable proprietary holographic direct-write tools and products, working closely with its strategic suppliers to achieve better outcomes. "Hübner Photonics answered one of our major challenges, to invent a new light source that would be tunable from red to green. Thanks to their ingenuity and our feedback, they developed and delivered a first-of-a-kind tunable laser system, the C-Wave GTR / NIR," said George Palikaras, president and CEO at Meta.

Precise control of the recording wavelength is critical in holographic product development. Designers must compensate for wavelength shifts that result from material shrinkage and the effects of post processing, which cause the replay wavelength to differ from that used for recording. The new laser is fully tunable across the visible GTR region (500 to 750 nm), as well as NIR (1,000 to 1,500 nm).

"The green region is a particularly important range of wavelengths for our customers, and up to now we have lacked wavelength flexibility within that band.



The blue and red light in the foreground comes from two C-Waves. Meta's new GTR in the background supplies tunable green light in a wavelength range that was previously inaccessible. (Source: Metamaterial)

With the C-Wave GTR / NIR, Meta is now able to record RGB (red, green, blue) holograms at any combination of wavelengths our customers may require," said Dr Andrew Mark, manager of optical engineering and metamaterial design at Meta.

https://metamaterial.com
https://hubner-photonics.com

The Lightest Light Source

An ultrathin organic LED could revolutionize the future of mobile technologies

A team of scientists from the University of St Andrews has developed a new way of making the most durable, lightweight and thinnest light source available so far, which could revolutionize the future of mobile technologies and pave the way for new advances in brain science.

Using a combination of organic electroluminescent molecules, metal oxide and biocompatible polymer protection layers, the scientists created organic LEDs that are as thin and flexible as the everyday cling film we use at home. The new light sources developed will have future implications for digital displays and can be used to make lighter and thinner displays for phones and tablets; displays that are big when we look at them, but that can be folded or rolled up when not in use. In the longer term, these new LEDs could also see use in treatments for neurological diseases in which light-gated proteins are deployed to modulate brain activity in patients.

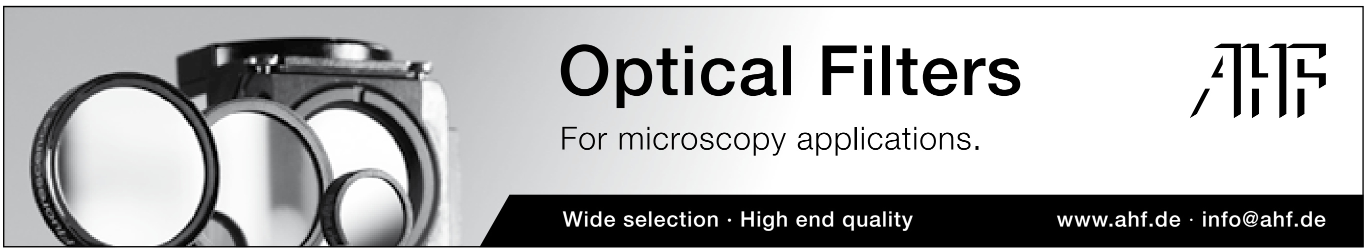
In addition to contributing to future development of mobile displays, and opening new avenues for basic research, the technologies developed in these studies could ultimately be used to improve clinical treatments by creating optical interfaces that send information directly to the brain of human patients who suffer from a loss of vision, hearing or sense of touch.

www.st-andrews.ac.uk/~osc

Source: U St Andrews

Flexible, ultra-lightweight and highly durable organic LEDs promise new forms of wearable displays.

References: *C. Keum* et al., Nat. Commun. **11**, 6250 (2020); DOI: 10.1038/s41467-020-20016-3 • *C. Murawski* et al., Nat. Commun. **11**, 6248 (2020); DOI: 10.1038/s41467-020-20013-6



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A Flash of Light to Identify Tumors

Results of the VIBRA project of Politecnico di Milano

The VIBRA project, 'Very fast Imaging by Broadband coherent Raman', has just ended at the Politecnico di Milano. Funded by the European Research Council over five years, it led to the development of a new type of optical microscope for biological and biomedical applications.

"Today, the identification of tumors and other diseases is largely based on the subjective judgment of a pathologist who visually inspects the tissue under a microscope. Our optical microscope, based on coherent Raman spectroscopy, is able to quickly visualize the chemical content of a biological sample to identify diseased cells in human biopsy – an accurate, reliable and non-invasive tool that can guide the surgeon's work in real time," explains Dario Polli, professor of physics at the Politecnico di Milano and scientific director of the project (see also article p. 45 ff.).

Optical microscope (Source: Politecnico di Milano)

By exploiting sophisticated laser techniques that generate ultrashort light pulses, it was possible to record the fingerprint of the molecules that make up matter. Each molecule, in fact, is recognizable by the 'sound' it emits when it vibrates. Hence the name of the project. The laser pulses have the double function of hitting molecules like a hammer to make them vibrate and then recording their vibration.

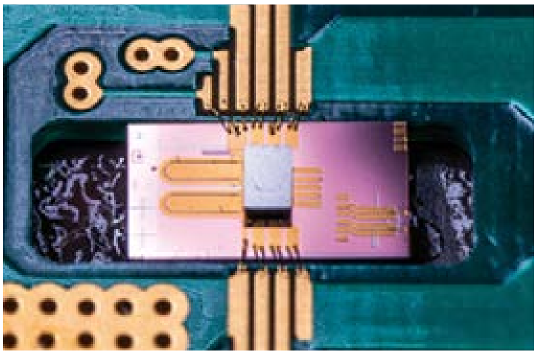
All this in a non-invasive way, that is, without adding any contrast agent or destroying or disturbing the sample. It was therefore possible to map the concentration of the various constituents of matter and create detailed three-dimensional maps of cells and tissues. "The results obtained will have a great impact in biology and medicine. In the future, they will allow researchers to visualize the properties of organic samples with great bio-chemical specificity. The aim will be to study the cellular mechanisms underlying various pathologies and to automatically identify tumors in biopsies, with a degree of accuracy and reproducibility better than we can do today", comments professor Polli.

www.vibra.polimi.it

First All-Silicon Optical Transmitter at 100 Gbps

Modulator fabricated through Southampton's Cornerstone research fabrication foundry service

Silicon photonics researchers from the Optoelectronics Research Centre (ORC) at the University of Southampton have demonstrated the first all-silicon optical transmitter at 100 Gbps and beyond without the use of digital signal processing. The optical modulator almost doubles the maximum data rate of current state-of-the-art devices, demonstrating the potential for low power, low cost, all-silicon solutions that avoid complicating fabrication processes with new materials that are not CMOS compatible.



The first all-silicon optical transmitter at 100 Gbps and beyond. (Source: ORC, U. Southampton)

The optical modulator is a critical component in systems serving modern information and communication technologies, not only in traditional data communication links but also in microwave photonics or chip-scale computing networks.

Ke Li, lead inventor on the technology's associated patents, says: "In contrast to previous work in the field, we have introduced a new design philosophy where photonics and electronics must be considered as a single integrated system in order to tackle the demanding technical challenges of this field." Graham Reed, deputy director of the ORC, says: "Our results are based upon a fully integrated electronic-photonic system, not a laboratory probed standalone silicon modulator. In all other work to date that does not rely on digital signal processing to recover signal integrity, integration of the electronics and photonics has resulted in an inferior system performance as compared to the performance of the individual components, resulting in a maximum data rate of approximately 56 Gbps."

The silicon modulator was in Southampton and integrated with bespoke modulator drivers that are designed in-house and fabricated at the TSMC electronics foundry in Taiwan. Fabrication and integration work is carried out at the University of Southampton's Mountbatten cleanroom complex.

Reference: *K. Li* et al.: Electronic–photonic convergence for silicon photonics transmitters beyond 100 Gbps on–off keying, Optica 7, 1514 (2020); DOI: 10.1364/optica.411122

www.orc.soton.ac.uk

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Trumpf, Sick Develop First Industrial Quantum Sensor

Experts estimate total market for quantum sensors at about € 1.1 B by 2023

The wholly-owned Trumpf subsidiary Q.ant and sensor specialist Sick will in future work together on the development of quantum optical sensors. Representatives of the two high-tech companies signed a cooperation agreement today to make quantum technology for sensors available for industrial use.

Quantum sensors enable measurements with unprecedented accuracy. The signing was preceded by a successful functional test of the world's first quantum optical sensor for serial production. "Sick is expanding its position as a worldwide technology leader in the sensor sector by embarking on the production of quantum sensors. Quantum sensors are a key technology for the future of industry," says Robert Bauer, chairman of the executive board of Sick AG.

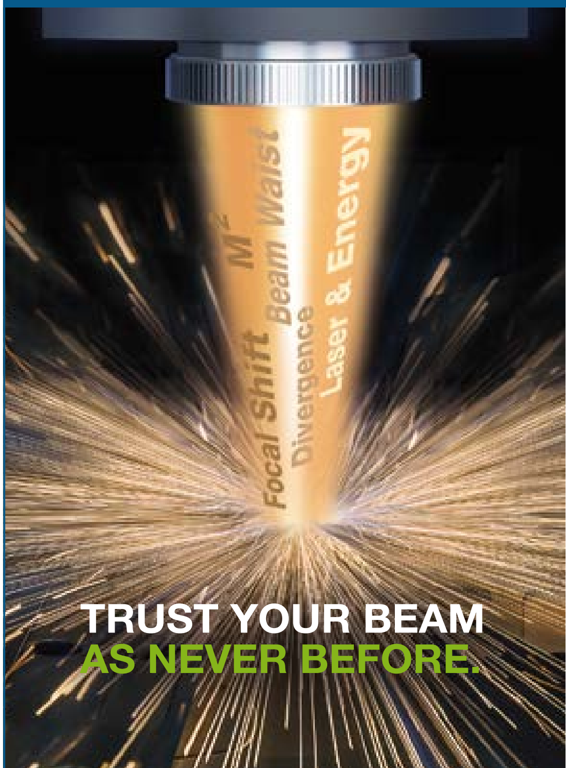
As a market and technology leader for industrial sensors, Sick will be responsible for application development and sales of the product. As a specialist in quantum technology, the Trumpf subsidiary Q.ant takes on production of the measurement technology – and thus the sensor's core technology.

Quantum sensors have hitherto mainly been used in research. For the first time, Q.ant and Sick have now successfully completed functional tests for an industrial application. "Quantum technology enables, for example, ultra-fast measurements of the movement and size distribution of particles. With the industrialization of these sensors, not just us but Germany – as a high-tech location – takes a major step towards the commercialization of quantum technology," says Michael Förtsch, CEO of Q.ant. Using laser light, quantum sensors permit highly efficient measurements that would be impossible with conventional processes.

"Quantum technology is the next level for sensors because it shifts hitherto firmly established technical limits. Using quantum effects, additional details can be perceived from signal noise where, up to now, no specific signals would have been measurable. This enables the measurement of particles that are about two hundred times smaller than the width of a human hair," says Niels Syassen, senior vice president R&D at Sick and responsible for the project there. The quantum sensors will initially be used for analyzing substances in air.

Testing the optical signal of the new quantum sensor from Q.ant and Sick. (Source: Trumpf)

www.sick.com
https://qant.de



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A New Efficient, Pure-Blue OLED

Novel approach shows promise for overcoming the bottleneck of blue emission in displays

Using a new combination of emitter molecules, researchers in Japan have demonstrated the promise of a novel approach to finally overcome a major challenge facing displays using organic light-emitting diodes: a blue light source matching the excellent performance of the red and green ones. By splitting energy conversion and emission processes between two molecules, the researchers achieved devices that produce pure-blue emission with high efficiency, maintain brightness for relatively long times, and lack any expensive metal atoms – a set of properties that has so far been difficult to obtain simultaneously.

Highly efficient, pure-blue organic light-emitting diodes are tested to measure their lifetime. (Source: Kyushu U.)

Acclaimed for their vibrant colors and ability to form thin and even flexible devices, organic light-emitting diodes, or OLEDs for short, use carbon-containing molecules to convert electricity into light. Unlike LCD technologies employing liquid crystals to selectively block emission from a filtered backlight covering many pixels, the separate red, green, and blue emitting pixels of an OLED display can be completely turned on and off individually, producing deeper blacks and reducing power consumption. However, blue OLEDs in particular have been a bottleneck in terms of efficiency and stability.

"A growing number of options exist for red and green OLEDs with excellent performance, but devices emitting high-energy blue light are more of a challenge, with tradeoffs almost always occurring among efficiency, color purity, cost, and lifetime," says Chin-Yiu Chan, a researcher at Kyushu University's Center for Organic Photonics and Electronics Research (OPERA). While stable blue emitters based on a process known as fluorescence are often used in commercial displays, they suffer from a low maximum efficiency. Phosphorescent emitters can achieve an ideal quantum efficiency of 100 %, but they generally exhibit shorter operational lifetimes and require an expensive metal such as iridium or platinum.

As an alternative, OPERA researchers have been developing molecules that emit light based on the process of thermally-activated, delayed fluorescence, commonly abbreviated as TADF. This can achieve excellent efficiency without the metal atom but often exhibits emission containing a wider range of colors. Takuji Hatakeyama's group at Kwansei Gakuin University recently reported a promising path to overcome the purity issue based on a unique molecular design for a highly efficient, pure-blue TADF emitter. However, the molecule, named ν-DABNA, quickly degrades under operation. The researchers have now found that lifetime can be greatly improved while still obtaining narrow emission by combining ν-DABNA with an additional TADF molecule developed at OPERA as an intermediate, high-speed energy converter.

Reference: *C.-Y. Chan* et al.: Stable pure-blue hyperfluorescence organic light-emitting diodes with high-efficiency and narrow emission, Nat. Phot., online 4 January 2021; DOI: 10.1038/s41566-020-00745-z

https://hyoka.ofc.kyushu-u.ac.jp

Ultracompact Metalens Microscopy

Wide-field, high-resolution microscope imaging is achieved via flat metalens array

The pursuit of ever-higher imaging resolution in microscopy is coupled with growing demands for portability and high throughput. In pursuit of a compact integrated microscope system, a team at Nanjing University mounted a metalens on a CMOS image sensor to create a prototype of a coin-sized imaging device. Their metalens-integrated imaging device (MIID) exhibits an ultracompact architecture with a working imaging distance in the hundreds of micrometers. Using a simple image-stitching process, they are able to obtain large-FOV microscope imaging with high resolution. The prototype involves a millimeter-sized silicon metalens in a well-designed 6 × 6 array. Despite the integration of multiple lenses, imaging distance remains relatively small (~500 µm) because each single lens is sized about 200 µm. It can be extended to centimeter scale to cover the whole CMOS sensor.


Illustration of a metalens-integrated imaging device. (Source: B. Xu et al., Nanjing U.)

The MIID has two phase profiles corresponding to two circular light polarizations, which ensures the elimination of blind areas. The scientists hope that the prototype heralds a new era of the pocket microscope system. The imaging performance still needs improvement, e.g. through approaches such as adopting low-loss materials like GaN and SiN. (Source: SPIE)

Reference: *B. Xu* et al., : Metalens-integrated compact imaging devices for wide-field microscopy, Adv. Phot. **2**, 066004 (2020); DOI: 10.1117/1.ap.2.6.066004

www.nju.edu.cn

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THE LARGEST PHOTONICS INDUSTRY ASSOCIATION IN THE WORLD

By dedicating ourselves to serving the photonics industry, we have become the largest photonics industry association in the world.

Thank you to all our members for making this happen.

EPIC
European Photonics Industry Consortium

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Successful Project Kick-off

New open network for hyperspectral technologies

More than fifty participants took the opportunity to define common focus topics around hyperspectral technologies: on 9 December, the virtual kick-off workshop for the 'Innovation Forum Hyperspectral Technologies – HyperInno' took place.

With this federally-funded project, Photonics BW, the innovation network for photonics and quantum technologies in the German state of Baden-Württemberg aims to stimulate and promote applications of hyperspectral technology in medicine and biotechnology as well as in industrial manufacturing and other fields. Small and medium-sized enterprises (SMEs) in particular are to be supported in opening up new markets and fields of application.

Preceeding the disussion of challenges and possible solutions, keynote speakers introduced the topic of hyperspectral technologies. (Source: Photonics BW)

After a welcome and short project presentation by Photonics BW managing director Dr Andreas Ehrhardt and project manager Eva Kerwien, two exciting keynote speeches introduced the topic. Dr Karl Stock from the Institute for Laser Technologies in Medicine and Metrology introduced the basics of hyperspectral imaging and medical applications. Dr Jan Makowski from LuxFlux GmbH then demonstrated hyperspectral systems in process analytics.

Afterwards, the participants discussed current challenges and possible solutions. The following main topics were summarised for further work in the project:

- Technology – hyperspectral systems from illumination to evaluation
- Process technology – applications, opportunities and challenges
- Medical technology – applications, opportunities and challenges

Based on these key topics, Photonics BW is planning three workshops, which will took place at the beginning of February.

The results will be presented at the Innovation Forum on 20 May, and cooperation and cooperation and technology transfer will be encouraged through interactive offers.

All parties interested in joining the workshops or the Innovation Forum either as speaker or as guest are welcome to contact Eva Kerwien via kerwien@photonicsbw.de.

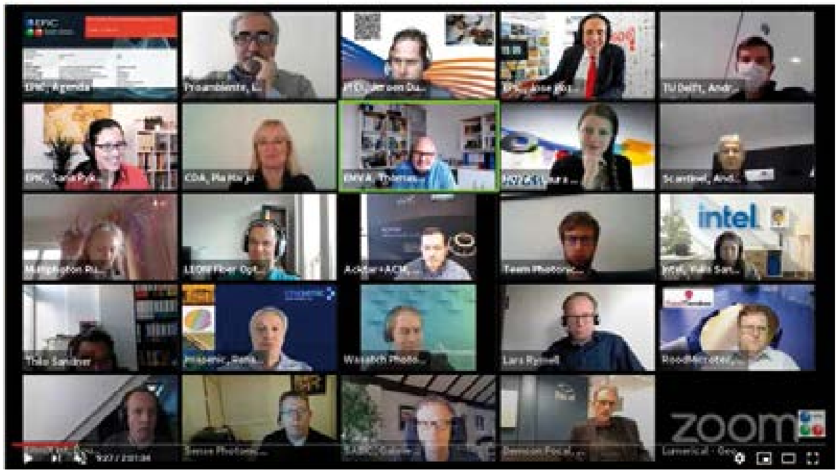
www.photonicsbw.de

EMVA and EPIC Sign MOU

Collaboration to strengthen the photonics and machine vision industries

The European Machine Vision Association (EMVA) and the European Photonics Industry Consortium (EPIC) signed a collaboration agreement in the last week of November 2020, bringing together members and knowledge to better serve and strengthen the photonics and machine vision industries.

The memorandum of understanding signature was publicly announced during the EPIC Online Technology Meeting on 3D Sensing on 23 November 2020. The collaboration between EMVA and EPIC is focused on cooperative activities involving continued industry endorsement of standards and supporting the development of an efficient and sustainable industry.



Thomas Lübkemeier (green frame), general manager at EMVA during the EPIC Online Meeting on November 23 next to other participants (Source: EPIC)

The partnership will encourage cooperation between the members, including participation at events, collaboration on information exchange and promotion, and advisory mandates to develop an efficient and sustainable industry. Dr Jose Pozo, CTO of EPIC, said: "Having EMVA on board as a partner brings the opportunity to EPIC members to build potential collaborations and partnerships with the key players of the machine vision industry. The main goal of this cooperation is to facilitate the communication between different parts of the value chain towards building a common voice for the interests of companies using machine vision technologies."

"The collaboration with EPIC supports our members and the wider machine vision industry by strengthening links across a broad value chain and increasing opportunities for collaboration" said Thomas Lübkemeier, general manager at EMVA. "At the same time, worldwide standards provide an important basis for industry growth, and we look forward to working with the extensive network of EPIC to support this topic."

www.emva.org – www.epic-assoc.com

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New Pan-European Photonics Digital Innovation Hub

PhotonHub Europe has been awarded € 19 M EU Horizon 2020 investment

PhotonHub Europe – a new pan-European photonics digital innovation hub – has been awarded a 19 million euro investment from the EU's Horizon 2020 programme. "Photonics is essential to the functioning of new applications that are powering the new industrial wave – Industry 4.0 – and which are also critical to our ability to fundamentally address the enormous global societal and environmental challenges of our times," said Prof Hugo Thienpont, director of Brussels Photonics (B-Phot) at the Vrije Universiteit Brussel and overall coordinator of PhotonHub Europe.

"European industry needs to be at the forefront in innovating with photonics, making the most of our combined strengths across all parts of the innovation value chain, and working collaboratively across all member states, to support European business innovation and growth. This is the motivation behind the establishment of PhotonHub, which is directly building on top of over fifteen years of previous European projects and collaborative efforts by all of the organizations involved in developing and integrating the infrastructure necessary for such a major undertaking," added Thienpont.

In order to accelerate the uptake and deployment of photonics technologies by European industry, PhotonHub will establish a single photonics innovation hub that integrates all of the best-in-class photonics technologies, facilities, expertise and experience of 53 top competence centers across Europe. These will be under one roof as a one-stop-shop solution with open access for any company anywhere in Europe that wants to innovate with photonics.

As a result, PhotonHub will provide European companies, in particular 'non-photonics' SMEs and mid-caps that are first users and early adopters of photonics, with open access and guided orienteering through the PhotonHub front office in Brussels. It will provide a broad range of services and capabilities covering training and upskilling support, 'test before invest' innovation support, and support to find investment.

Training and upskilling supports to companies will cover both technology and application-specific learning in photonics using lecture-based tutorials, hands-on lab-based training and 'Train-the-Trainer' programs within the hub's forty Demo Centres and ten Experience Centres throughout Europe. This will all be coordinated for consistent standards of excellence under the umbrella of PhotonHub's European Photonics Innovation Academy.

PhotonHub will establish a single photonics innovation hub which integrates all of the best-in-class photonics technologies, facilities, expertise and experience of 53 top competence centers across Europe under one roof. (Source: VUB / EPIC)

PhotonHub will uniquely support cross-border innovation activities of European companies, whilst simultaneously working closely with local photonics hubs representing 18 European regions as additional partners in the consortium to further boost photonics innovation amongst SMEs at a localized level all over Europe.

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Quality for Instruments and Images in Light Microscopy

'Quality Assessment and Reproducibility for Instruments & Images in Light Microscopy' (QUAREP-LiMi) is a group of enthusiastic light microscopists from Academia and Industry all interested in improving quality assessment (QA) and quality control (QC) in light microscopy. They came together in a first Web meeting on 28th of April, 2020 with about fifty attendees.

By November 2020 the group had grown to 166 people from twenty countries all over the world. They have members from national microscopy communities, companies involved in the microscopy business and organizations or institutions related to standardization on a national or international level. In a second Web meeting on 9th of July, ten working groups were established to bring the common aims quickly forward. The webpages give a short overview about QUAREP-LiMi. They also provide access to a cloud server with more information and as a common repository and exchange point for the group's work.

QUAREP-LiMi is absolutely open for new members and welcomes contact by email. If you want to join QUAREP-LiMI send an email info@quarep.org or fill out the contact form on the Web site:

https://quarep.org

EPIC Hires Tracey Vanik as Head of Market Research

The European Photonics Industry Consortium is growing fast and is now the largest industry association in the world. To better serve its members, EPIC wants to publish more tailored market reports. For this purpose, it hired Tracey Vanik as head of market research.

Tracy Vanik (Source: EPIC)

Tracey has over thirty years experience in analysing and introducing new technologies to markets. Her experience ranges from biomed systems to optical and semiconductor components, and includes network and communication equipment. By evaluating emerging technical applications vs. incumbent solutions, her component forecasts factor in system adoption dependencies and time frames.

www.epic-assoc.com

The Largest Photonics Industry Association in the World

How adapting to changes can make the difference

In this first issue of 2021 we look back at 2020; the year in which Covid-19 seriously impacted the world; the year in which traveling was restricted and face-to-face meetings became nearly impossible. But also the year in which EPIC celebrated becoming the largest photonics industry association in the world. So what drove this success during such a challenging period?

When Covid-19 put the world on lock-down in early March last year, EPIC knew that it had to make some serious changes. Networking to establish business opportunities between its members is one of its core activities and the restrictions on traveling and meetings was seriously impacting our events calendar. Forced to postpone or cancel most of our physical events for 2020, EPIC soon realized that the only way to network was online. And so we did. We organized no less than eighty online events, starting on 23 March 2020 with the EPIC Members Online Meeting on Coronavirus Impact & Possible Concerted Actions and closing the year on 16 December 2020 with the EPIC Online Technology Meeting on Photonics for the Food and Beverage Industry.

Meetings included online networking parties, meetings on the impact of Covid-19, EPIC member product releases, online company tours and of course our famous online technology meetings. Roy McBride, managing director at Power Photonic said: “It’s great to see how innovative and effective EPIC has been in rising to the challenge of Covid-19. I’m proud to be a member of EPIC!” And he is not alone. EPIC has received praise throughout the industry, with many new members joining month after month. And in October of this year we were able to announce: EPIC is now officially the largest photonics industry association in the world. Thank you to all our members for making this happen.

But being the largest photonics industry association in the world was never a target. Our mission is to serve the photonics community and to serve our members. And so we continue to expand our services. Last year we introduced the EPIC Online Technology Meetings, the EPIC Member New Product Release and the EPIC Online Virtual Company Tour, EPIC Online Tech Watch, and many more online meeting formats. But we also launched www.mentors-in-photonics.com, a website where EPIC members can find some inspiring leaders in photonics that are willing to share their expertise and knowledge with colleagues in the industry who are exploring new applications or want to expand their territories. It is a unique platform to connect and learn from the industry experts.

We also continued to connect our members with end-users and potential partners by signing memorandums of understanding (MoU) with other relevant industry associations and networks. This year we signed six more MoUs with the Optical Internetworking Forum OIF, International Ultraviolet Association IUVA, International Association of Horticultural Producers AIPH, Driving Vision News DVN, Clean Rivers HUB, and European Machine Vision Association EMVA. We released almost twenty market reports and held almost forty C-level interviews.

For 2021, you can expect nothing less. Quite the opposite ... watch us as there will be more. So keep an eye on our website www.epic-assoc.com and if you are not a member, be sure to join the photonics revolution and send an email to info@epic-assoc.com

www.epic-assoc.com

Upcoming EPIC events:

- 22 February 2021, 15:00 CET
EPIC Online Technology Meeting on The Role of Photonic Sensors and Lighting in Advanced Agriphotonics
- 26 February 2021, 15:00 CET
EPIC Online Quantum Technology Meeting on Essential Key Strategies for Tomorrow’s Security and Defence Sectors
- 1 March 2021, 15:00 CET
EPIC Online Technology Meeting on Photonics Impact on Green Energy Generation: Photovoltaics, Wind, Wave, Hydrogen
- 3 March 2021, 15:00 CET
EPIC Online Technology Meeting on Roadmap 2021 for Co-packaged Optics (in cooperation with COBO)
- 12 March, 15:00 CET
EPIC Online Quantum Technology Meeting on Quantum is Key to More Effective, Affordable, Personalised (tele)Medicine
- 15 March 2021, 15:00 CET
EPIC Online Technology Meeting on Lidar 2.1 Applications for 2021
- 17 March 2021, 15:00 CET
EPIC Online Technology Meeting on Next Steps Fast Growing Freeform Optics Applications
- 22 March 2021, 15:00 CET
EPIC Online Technology Meeting on Photonics Sensors for Safer and Intelligent Oil & Gas Producers
- 24 March 2021, 15:00 CET
EPIC Online Technology Meeting on Impact of Photonics on Sustainable Textiles, Wearables, Fashion and Design
- 25 March 2021, 15:00 CET
EPIC Online Technology Meeting on Mini/Micro LED (in cooperation with ISA & PIDA)
- 26 March 2021, 15:00 CET
EPIC Online Quantum Technology Meeting on Next-Generation Transport and eMobility
- 29 March 2021, 15:00 CEST
EPIC Online Technology Meeting on New Medical Devices Making the Impossible Possible
- 31 March 2021, 15:00 CEST
EPIC Online Technology Meeting on Quarterly Briefing on New Space Communications and Monitoring
- 9 April 2021, 15:00 CEST
EPIC Online Technology Meeting ‘Quantum Technology Meeting on Implementing Secure Strategies for Past, Present & Future’

www.epic-assoc.com/epic-events

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"We Are Going to Enable a New Wave of Safe Connectivity"

Portrait of Carlos Abellan, CEO of Quside

Jose Pozo

Source all images: Quside

Jose Pozo, EPIC's director of technology, explores the history of Quside, one of the first companies in Europe to provide a quantum random number generator based on photonic phase-diffusion technology.

Initially interested in audio, Carlos developed a passion for cryptography and quantum physics while studying a first degree in Telecommunication Engineering at the Polytechnic University of Catalonia. On graduating in 2012, he began a Master's in Photonics, which involved working as an MSc Research Intern at the Institute of Photonic Sciences in Barcelona (ICFO). His work at ICFO focused on quantum cryptography and experiments with quantum random number generation schemes and quantum key distribution systems for space applications. Following the success of a prototype device for generating quantum random numbers, he continued his research at ICFO as a PhD researcher working on quantum randomness generation technologies for use in cryptography, super-computation, quantum cryptography and fundamental physics experiments.

The random number problem

As Carlos explains, his research at ICFO was essentially focused on the development of a practical technology for producing unpredictable random numbers. The generation of high-quality random numbers is of fundamental importance in the field of cryptography and computation, among others. In order to send a secure message between two parties, we use standard encryption algorithms, which convert a message into a stream of meaningless characters (encryption algorithm) and then back to the original message (decryption algorithm).

As we all use the same algorithms as basic means to communicate to each other, we all know how to encrypt and decrypt data, so this piece alone is not enough to secure a message. To avoid this trap, we use random numbers every time we encrypt a message. In this way, every application of an encryption algorithm is sort of unique (randomized) and can only be decrypted if we know what random numbers have been used. If someone knows what random numbers are used, then there is no security in our communication. For this reason, the generation of unpredictable random numbers is key.

After producing random numbers and encrypting a message, there is a third important element to establish a secure communication. The different parties exchanging a message need a mechanism to share, in a secure way, those random numbers, so that the recipient of the stream of meaningless characters can decrypt the message.

These are the three key building blocks of a cryptosystem: the encryption part, the key generation part (random number generation) and the key distribution part (randomness distribution technology).

*) Distributed Denial-of-Service, such attacks flood Web services and prevent them from working.

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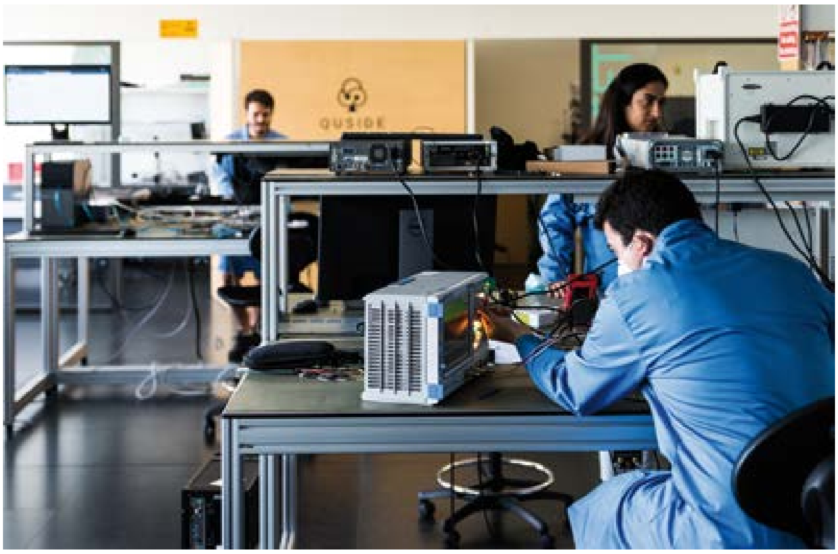

Quside's lab space in Castelldefels, Barcelona

Carlos explains that producing good random numbers is a hard engineering and scientific challenge and emphasizes that the challenge multiples when we want to do it at fast rates.

How to overcome the limitations

The motivation of the ICFO team Carlos was part of was to design prototype quantum systems that could overcome the limitations and lead to cheap, compact, and quick quantum generators for the mass market – devices that could be installed in mobile phones, laptops or anything else needing secure communication.

Their approach was based on oscillating a distributed feedback laser diode above and below its threshold level, i.e. the energy level at which the stimulated emission of photons starts. Each time the laser exceeds its threshold level, the laser emits photons with a random phase, which become the basis for the random numbers used to generate a cryptographic key. Building the prototype in those early days was a joint effort involving significant input from the research team, various engineering teams, and the KTT team (Knowledge and Technology Transfer) at ICFO. As Carlos recalls: "It was an exciting time as I was able to use my engineering skills to build a prototype that could actually be used, and we had the opportunity to test it with a partner in a real environment."

Initially, the devices used fiber optic cables and were the size of a shoebox. But then, in collaboration with Photonics Research Labs at the Universitat Politècnica de Valencia, they used standard chip-fabrication techniques to integrate the components onto an indium phosphide PICs measuring less than 6×2 mm² that could potentially be installed directly into a phone or an IoT sensor. For the team, this was a big milestone as they were one of the first research groups to use a multi wafer run to test a prototype for a potentially commercial project.

The birth of Quside

By 2017, after six years of intense R&D effort at ICFO, the founding team of Quside, where Carlos was part of, decided the time was right to establish Quside and continue the commercial development of the random number generators based on their proprietary phase-diffusion technology. They set themselves two milestones: first, to prove that their PIC technology was scalable at the right cost and quality for the volumes required, and second, to produce a device that would exactly match their customers' requirements.

In 2020, after advancing the technology and testing it with their partners, they launched their first commercial product, the Quside FMC 400, a random number generator providing 400 Mb/s of raw random numbers based on their proprietary phase-diffusion technology. The Quside FMC 400 has been specifically designed to target FPGA engineers to allow a facile and versatile integration for high-performance applications.

Since 2017, the company's workforce has grown to 23 people. For Carlos, building the right team has been crucial. In the beginning the core team consisted of people from ICFO who were already familiar with the technology. But soon more talents were needed, particularly for engineering positions, and this step required more clarity about communicating the technology and the development effort and maintaining engagement and alignment towards the company's goals. This has presented new challenges but also opportunities to grow as a company and move forward.

When looking at those past three years, one of Carlos' learnings is that as a cofounder of a deep tech company, it is important to not just think about the technology but also about the products that will be marketed. This perspective needs to start early on. At the same time, Carlos is convinced that we should always be aware that it takes time and a lot of investment to convert deep tech prototypes into commercial products, and that a continued investment on technology is important to remain competitive in a rapidly changing landscape.

Among their other achievements, Quside has been elected to join EU quantum flagship projects, has been invited to talk at NATO's 70th anniversary in London and in 2018, Carlos

Company

Quside

Quside builds quantum technologies for safer connectivity and more powerful computation. A spin-off of ICFO – The Institute of Photonic Sciences – in Barcelona, Spain, Quside is commercializing innovative hardware solutions for all connected devices. Quside is part of the European Quantum Flagship, collaborating in this ambitious initiative as an industry partner of the quantum communication projects CiViQ and QRANGE.

www.quside.com

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Quside FMC 400 – Europe's first fast quantum randomness module based on phase-diffusion technology

was awarded as one of the innovators in MIT's 35 under 35 European list.

The Future

As regards products, Quside is about to release their next range of products with all components integrated on a single chip. Carlos envisages a future where most forms of data communications will interact with random numbers generated by a Quside chip. As he says: "With our high-speed QRNG chips, we're going to enable a new wave of safe connectivity everywhere and for everyone to address the emerging security challenges in technologies such as 5G and AI."

He goes on: "Right now, we're hitting computational limits: we can't protect information enough and neither can we digest the quantity of information we're generating. I strongly believe that quantum technologies will help us overcome these limits in connectivity and computation."

To achieve growth, Quside is working together with manufacturing partners and system integrators to adopt their technology. According to Carlos, working across the full value chain will be crucial, including dissemination of the technology benefits with end users like e.g. banks, to assess the advantages of quantum technologies in their businesses. This has become even more obvious lately, partly because of the increase in well publicised company data breaches but also because of the increase in employees accessing sensitive company data from their laptops at home due to coronavirus.

In this context it is also very helpful and essential to collaborate within the quantum ecosystems such as the quantum industry consortium and quantum community network in Europe and other international efforts.

As regards the Quside team, Carlos couldn't be prouder with the development of the last three years. "Seeing the team grow to more than twenty people working on our quantum and photonic technologies is something very reassuring that we are on the right track. But my main message when thinking about the journey of the last years, is that building a company needs a lot of effort and hard work. Without perseverance and passion, it's hard to make it through the ups and downs that come with the job. Building a company and building a team can be difficult, but the rewards are incredible."

[1] *C. Abellan* and *V. Pruneri:* The Future of Cybersecurity Is the Quantum Random Number Generator, IEEE Spectrum (2018)

Author

Jose Pozo is director of technology and innovation at EPIC, and as such he represents more than five hundred leading corporate members active in the field of photonics. His work consists of actively engaging with them and providing them with the tools to strengthen their position in the supply chain. He has twenty years' background in photonics technology, market knowledge, and a large network within the industrial and academic photonics landscape. Jose holds a PhD in electrical engineering from the University of Bristol, UK, and an MSc and a BEng in telecom engineering from Spain and Belgium.

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"Invest in Photonics Now to Fight Infectious Diseases!"

Strong investment will help prevent the death of an unimaginable number of people and prepare us against future pandemics

Dr Jürgen Popp, Leibniz Institute of Photonic Technology, Jena, Germany

"By harnessing photonics – technologies that are based on light – we are producing solutions in fields as varied as next-generation farming, the environment, transport, industry and healthcare.

Light technologies are recognized as revolutionary and beneficial to a number of sectors: industrial applications with driverless cars, 5G, health care with faster diagnostics and green technologies, farming, environment are all made possible by the generation, detection, manipulation, emission, transmission, modulation, processing, switching, amplification, and sensing of light.

The threat of infectious diseases and antimicrobial resistance is just one case to illustrate that now is the time to commit to strong investment in photonics.

Fast, clean and precise, photonics can build advanced diagnostics, pervasive monitoring and innovative e-health applications that can detect body signals, symptoms and diseases at very early stages.

Detecting with light

Covid-19 has shown us that we, as a species in many regions of the world have been unprepared for a dangerous pandemic. Nations all over the world have lacked the necessary capacities to test for infectious diseases, meaning responses have been delayed and adequate measures not taken at appropriate times.

It is in this critical time period – the testing and initial response – that determines our ability to control or respond adequately to a threat. And it is in this crucial phase where photonics can provide unique solutions like no other technology owing to its speed and the rapid time it can deliver information.

Photonics can deliver instantaneous information about the health status of a patient to determine whether they are suffering from a condition that is

Source all images: Photonics21

caused by a virus or a bacterium. Indeed, one of the unique selling points of light technologies is that results can be determined on-site, in-situ without having to send samples to a laboratory and await analysis – all of which can take days or sometimes weeks.

Infectious diseases

Infectious diseases can have a number of causes, including bacteria, viruses – like SARS-CoV-2 –, fungi, or even parasites, and can be transmitted from person-to-person, or animal-to-person.

There are many infectious diseases that pose a danger to our species, like Influenza, AIDS / HIV, Malaria, Tuberculosis, SARS, Ebola or Zika. This serious threat requires drastic, urgent solutions and has been highlighted by Covid-19 this year. With the global pandemic of 2020 caused by SARS-CoV-2, Covid-19 will be added to the three infectious diseases that account for the top ten leading causes of death worldwide.

Even before Covid-19, according to the World Health Organization, the situation was worse in low-income countries, with five infectious diseases being a leading cause of death among the top ten.

Photonics projects tackling infectious diseases

At the time of writing, in Europe, the Photonics Public Private Partnership is funding many research projects to develop tools and techniques for infection diagnostics. The CoNVat consortium, for example, is developing an ultrasensitive laser sensor that detects coronavirus at the earliest point of infection from a saliva or nasal swab in minutes.

Originally developed to look for bacterial infections or cancer biomarkers, the new ultrasensitive detector uses photonics to detect infections in patients with a small amount of the virus and will diagnose in real-time with high specificity from a low concentration sample.

Looking at tiny molecules, the new point-of-care detector examines virus RNA using miniaturized chips – or 'nanophotonic biosensors' – from a simple nasal or saliva swab.

Similarly, the RAIS consortium was making a bold bid to reduce the mortality rate from sepsis by more than 70 % with their new detector using photonics to identify *E. coli* bacteria from a tiny drop of blood, producing a while-you-wait diagnosis in less than thirty minutes. Programmed to detect

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micro-ribonucleic acids (microRNAs), interleukins and other specific proteins associated to sepsis, the detector then uses light to look for those specific biomarkers (the tell-tale signs or an indicator of a disease) that are as small as few nanometers in size. A small blood sample taken from a thumb or forefinger is sufficient for this rapid 'microarray' detector. The patient's blood sample is then separated in a centrifuge so that a clinician can examine the plasma, the part of the blood sample where all the proteins are contained.

Spectroscopy and imaging to advance diagnoses

Photonic methods hold a high potential for the diagnosis of infections. In the following, a few recent collaborative projects are presented where the Leibniz-IPHT was/is involved either as coordinator or a partner.

A powerful method for diagnosis of infection and sepsis has been researched within the EU-funded project 'HemoSpec'. From a small amount of blood from the patient, the photonic- based algorithm can differentiate patients with sterile inflammation, infection and sepsis with high accuracy. The algorithm is based on valuable information of the leukocyte's activation state that can be extracted in a non-destructive and label-free manner using Raman spectroscopy. The technology is currently in translation together with the industry.

> The EU only commits 100 million euros on photonics every year – a tenth of the China equivalent
>
> Jürgen Popp

In order to provide the basis for a future decentralized application of biophotonic technologies such as Raman spectroscopy as a novel diagnostic tool in hospitals and doctor's offices, the EU COST action 'Raman4Clinics' brought spectroscopists, clinicians and device manufacturer from all over Europe together to perform a large scale cross-laboratory study. This study assessed the comparability of configurations of 35 Raman spectroscopic devices with different configurations in 15 institutes within seven European countries. Statistical data analysis played an important role in achieving comparability.

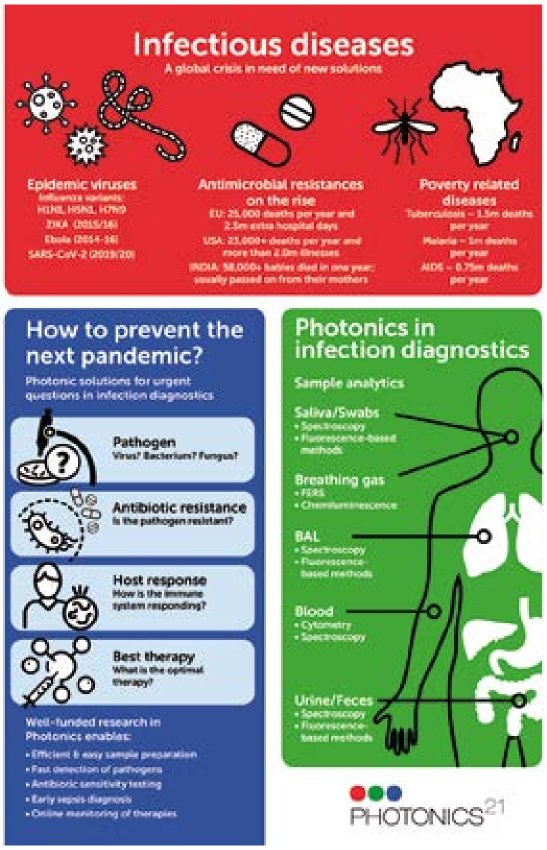
The European Union is currently funding the Innovative Training Network 'IMAGE-IN: Imaging Infections' within the Marie Skłodowska-Curie Actions to educate the next generation of scientists who can actively advance imaging technology for medical applications.

In further national funded projects, spectroscopists advance in close collaboration with physicians and live science researchers optical-spectroscopic methods for fast antibiotic susceptibility testing (AST). The aim is to reveal the infection-causing bacterial pathogen and its antibiogram within three hours directly from a minimal amount of the patient's sample. Ideally, the patient sample is easily accessible, such as a patient's urine or blood.

The joint research project 'ReHwIN' of academic (Jena University Hospital, Leibniz IPHT) and industrial partners (Jenoptik, Grintech, BiFlow, Biophotonics Diagnostics) focusses on nosocomial urinary tract infections that account for up to 30 % of all nosocomial infections in Germany. The final photonic analysis system will combine microfluidic processing of a urine sample with a miniaturized and sensitive Raman spectroscopic readout platform and data analysis with artificial intelligence. The collaborative project 'InfectoXplore' is part of the BMBF-funded InfectoGnostics research campus, a public-private partnership breaking new ground in the diagnosis of infections. The team made of industrial (mibic GmbH, Biophotonics Diagnostics) and academic (University of Applied Sciences Jena EAH, University Hospital Jena, and Leibniz-IPHT) partners tackles bloodstream infections which are associated with high morbidity and mortality rates and require rapid therapy; otherwise, they can lead to sepsis. Within InfectoXplore, positive blood cultures will be analyzed and a targeted and personalized photonics-based diagnostic algorithm will be developed that enables a tailored antibiotic therapy as quickly as possible.

Step up funding

While Europe has a wealth of researchers working on cutting edge photonics techniques, we cannot simply rest on our laurels. We need to ensure we are



prepared against the next pandemic with a collective commitment to fund photonics, a global industry predicted to be worth a staggering € 696 ($ 829) billion by 2025. In parts of the world, photonics is recognized as having enormous potential and leverage. The Chinese government increased its investment in photonics every year by 40 %, to reach € 1 B in 2020 while the South Korea government spending in photonics increased to € 2.8 B per year. While these figures sound impressive, we must recognize that the EU only commits 100 million on photonics every year – a tenth of the China equivalent. The German government took the initiative and is now investing > € 120 M in the Leibniz Center for Photonics in Infection Research (LPI) in Jena, to force the introduction of photonic technologies and platforms in infection diagnostics and therapy, which may revolutionize the diagnosis and treatment of infectious diseases e.g. in the context of difficult-to-treat infections and growing antimicrobial resistance.

For the sake of defending ourselves against future pandemics, now is the time for Europe to commit to a programme of strong investment in photonics.

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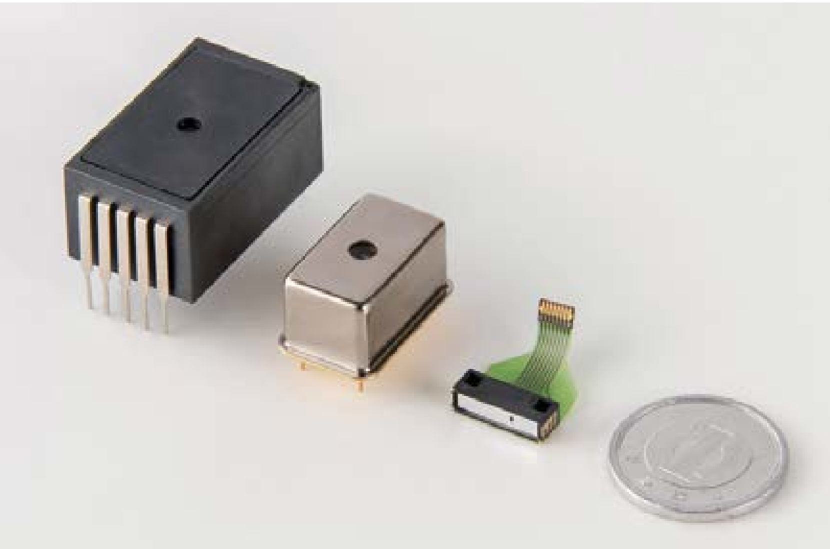
Compact Spectrometers: Technologies, Market Trends and Needs

Disruptive chip-size technologies will play the dominant role for miniature, micro and chip-sized devices

Jacek Kulakowski and Benoît d'Humières



Miniaturization of Hamamatsu spectrometers (Source: Hamamatsu Photonics)

A breakthrough moment for spectral analysis is coming: while miniature and micro spectrometers achieve steady growth and are well established on the market, the disruptive chip-size technologies are emerging and elevating the role of spectroscopy to an entirely new level. Now spectrometers can be available to everyone.

In the last few years, optical spectroscopy has become more popular due to the increasing need for in-line, in-the-field and point-of-use measurements. The interest was confirmed by the high growth of the compact spectrometer systems market, which went from 655 million US dollars to 922 million in just three years between 2016 and 2019. Emerging chip-size spectrometers are going to fuel this growth even more.

New type spectrometers can be as small as semiconductor wafers. Their ultra-compact size (<1 cm^3) allows the integration of spectral analyzers into smartphones and wearable devices. The fastest growing applications will therefore be biomedical and consumer. The use of chip-size spectral sensors should reach more than three hundred million pieces per year in 2024, with a CAGR of up to 111 % (2020 to 2024) for some applications.

A new 2020 Tematys report on this subject provides a comprehensive view of the process of spectroscopy popularization [1]. It describes the compact spectrometer market in detail, including breakdowns into applications and segments. It also reaffirms and extends the predictions of the previous Tematys report from 2016.

Company

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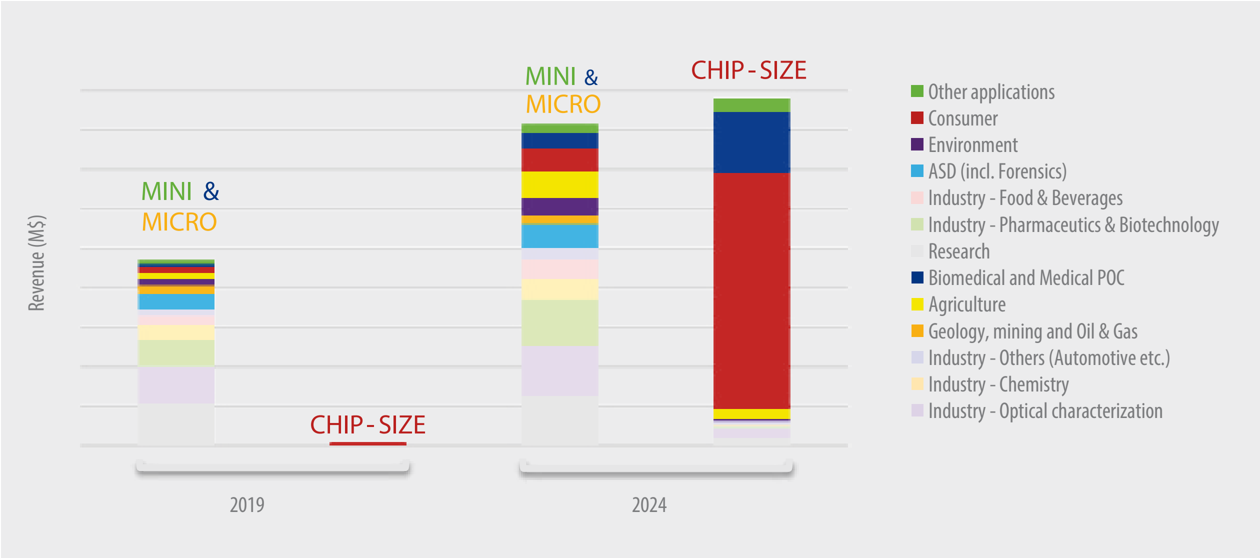

Fig. 1 Forecasts for spectrometer modules of various sizes (Source: Tematys)

Disruptive chip-size technologies will play the dominant role

The first aim of the development of compact spectrometers was to bring the lab measurements to the field or into the process line. This has been accomplished in many industrial applications – optical characterization, pharmaceutics and biotechnology, chemistry etc. – by maintaining the required performance level. It was at this time when miniature spectrometers emerged (size <10,000 cm^3).

A few years later, the same spectrometers also opened up new applications where spectroscopy had not been used before: precision farming, recycling, process control, etc. The range of potential applications became vast. The market started to be split into a wide variety of niche adoptions, each having its own requirements (performance, costs, design, operating conditions, …). This forced the development of products specific to each segment.

At the same time, microspectrometers were first presented (size between 10,000 cm^3 and 100 cm^3), offering a similar performance to miniature devices but in a handheld, portable design. They enabled the launch of new systems for professional users.

At the moment, it is still research and industrial optical characterization that possess the biggest shares within the compact spectrometer market. However, the better knowledge of end-users needs results in improving medium series applications (agriculture, environment) and also in developing further solutions for professionals (hair analyzers, textile identifiers, cannabis testers etc.).

A turning point for the market is coming. It is the arrival of global leaders, both in the role of manufacturers (AMS Technologies, Osram, Viavi Solutions) and end users (Huawei, Samsung, Bosch, Henkel). Big players will drive the market toward consumer and biomedical applications (image enhancement, personal monitoring etc.). This is possible due to the emergence of chip size spectral sensors (<1 cm^3).

The question is: to what extent will this technology be exploited? The report answers this question by providing a market forecast from 2020 to 2024. The study also provides a detailed analysis of the most promising applications and describes the end users' needs for the widespread adoption of compact spectrometers.

Are the acquisitions going to consolidate the market?

Consolidation is now a more evident trend in the spectrometers market.

Due to the transactions made by the Nynomic Group (acquisitions of Avantes and tec5 before 2016, Spectral Engines in 2018), Metrohm (B&W Tek

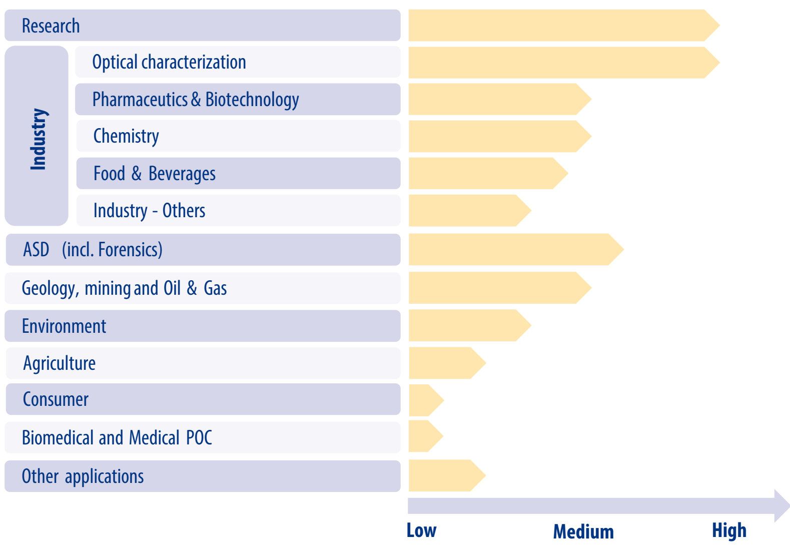

Fig. 2 Market penetration rates for compact spectrometers 2019

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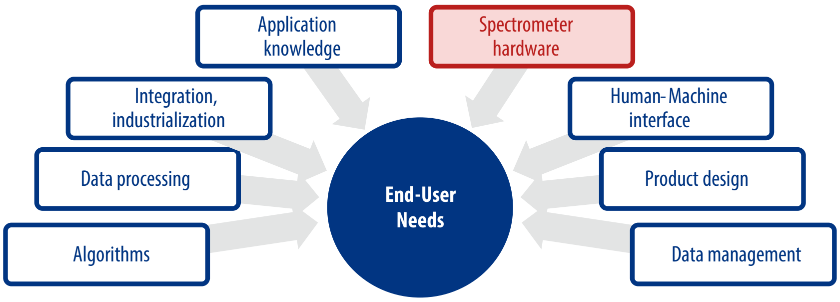

Fig. 3 Essential components of a compact spectrometer system

in 2018, Snowy Range Instrument in 2016, earlier IPS) and Halma (owner of Ocean Insight since 2004), these three companies alone accounted for a third of the total market revenue (2019).

If other, mainly vertically integrated large companies were added, (Bruker, Carl Zeiss, Hamamatsu, Horiba, Thermo Fisher), the eight key players of the market accounted for 80 % of revenue (2019).

The gap between the biggest entities and their small competitors is widening, and it is also harder to enter the market. Older companies are trusted, can provide many references and offer mature products.

It is still an open question as to which of the main players is going to catch the value in the current compact spectrometer sub-systems market. The report analyzes key elements for the successful adoption of a spectroscopy product.

Innovative solutions

Technological breakthrough is necessary to reach new applications. That is why the miniaturization of spectrometers exploits new designs and novel ideas.

Recent progress in the development of compact spectrometers is following this path and taking advantage of microtechnologies such as MEMS and MOEMS. This reduces the cost and offers large production capabilities while maintaining high performance.

With regard to new, chip size spectrometers, the dominant technologies are ultrasmall gratings, multispectral filters, plasmonic filters, photonic crystals and organic semiconductors.

This study consists of a detailed description of all key technologies of the compact spectrometer market with examples of manufacturers. The advantages and trade-offs for each technology have been also discussed.

Key importance of modern algorithms

Data analysis is becoming crucial for developing new applications in spectral analysis, especially those based on ultra-small spectrometers.

The global IT environment is helping progress – the development of cloud solutions, big data, machine learning and artificial intelligence is very extensive all around the world. There is massive funding for machine learning companies ($ 16.5 B in 2019 globally, driven by 695 deals).

Modern algorithms have become the key element of the spectroscopic system – even if there is a lot of stray light in the spectrometer, one can correct it with proper data processing. Algorithms allow the reduction of the cost of extracting useful information from the spectra. This helps to bring spectroscopy out of the lab.

The report helps to understand the role of modern algorithms in compact spectroscopy.

[1] 2020 Tematys Report on "Miniature, Micro and Chip-size Spectrometers: Technologies, Market Trends and Customers' Needs", www.tematys.com

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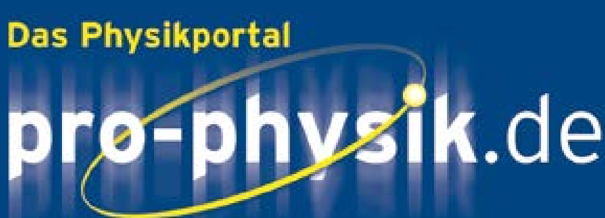

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Photonic Technologies are 'Invading' Food Industry

Spectroscopy revolutionizes quality, safety, integrity and taste of food

Elena Beletkaia

Fig.1 Mobile NIR spectroscopy solutions (Courtesy of Trinamix)

The history of spectroscopy starts in the 17th century. A lot of technological changes have taken place since then, but the main idea stayed: light brings a lot of information, whether we see it or don't see it. Advances in optics, gratings, filters, coatings, lasers, and detectors have made it possible to extend the observations from the visible part of the spectrum to the UV, NIR, MIR and IR.

Spectroscopy has always played a continuous and significant role in chemistry, physics, and astronomy and it is still gaining stronger positions in nearly every other industry. For the past couple of decades, spectroscopic methods have been increasingly 'invading' the food industry. Spectroscopy technologies enable characterization of the ripeness of fruits, crops and vegetables; the detection of raw material and water quality; the control of the processing steps. They make it possible to conduct the inspection for foreign objects in a contactless and non-destructive way. When a few spectral imaging techniques are combined with other imaging modalities and are empowered by AI, applications such as digital sorting also become possible directly within the production line.

Why new technology is needed today more than before

Food is complex. Often there are multiple components mixed together: water, fat, proteins, carbohydrates, salts, sometimes special bacteria or yeast and numerous minor components. The amounts, molecular structure and interactions within food define the characteristics of food products. Undesired microbial growth or chemical and enzymatic modifications make most food products naturally perishable. The alterations lead to the modification of the sensory and nutritional quality of most foods. It is estimated that about 25 to 30 percent of food is lost due to microbial spoilage. So one or more preservation and/or processing techniques are often applied to maintain the quality and extend the shelf-life of the products.

The quality of a food product can be rated by its appearance, color, flavor and texture as well as chemical, biological and microbial factors, like instability. Food quality and safety is an area of increasing concern both for the general public and for the food producing and processing industries. The change in eating habits and overall consumer behavior is leading to the development of such devices as hand-held spectrometers. Companies like Trinamix [1] and Bayspec already offer a number of solutions to characterize various products (Fig. 1). Technology development and miniaturization will very soon make it possible to integrate these further into a smartphone for example, allowing con-

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Fig. 2 Test your beer with IR-fiber spectroscopy. (Courtesy of Art Photonics)

sumers to test the properties of food on the market or at home.

The globalization of the supply chain along with the increasing population has caused increased demand for food, which is resulting in a rise in food fraud. Food fraud includes any deliberate action altering, substituting, mislabeling, tampering or misrepresenting any food product at any point along the supply chain to gain undue advantage. Fraud can occur at different stages: raw material, ingredient, final product or food packaging. Food fraud is considered to be the second most significant black-market activity in the EU. So to meet the high expectations of the consumer in general food quality, food fraud has to be prevented.

Spectroscopy for the food industry

Inspection of food and its ingredients is carried out along the whole farm-to-fork supply chain: precision agriculture, manufacturing (raw material inspection, sorting, process control, machine vision, final product inspection), laboratory analysis, product development, and the regulatory and supply chain validation. Traditionally food quality and quality changes caused by preservatives are evaluated using sensory and microbiological analysis or physicochemical measurements. While these methods are reliable, they are destructive and time-consuming, and cannot be applied for online assessment. At an industrial scale, there is an increasing demand for in-line and on-line quality control and food safety, including decontamination, inspection of cleanliness on production line surfaces, in pipes etc., detection of pathogens, allergens and mycotoxins.

Also, there is a need for foreign body detection, whether metal or low-density materials such as plastic, wood, egg shell, nut shell, fruit stones, or glass fragments.

Spectroscopic methods bring quick, accurate, and reliable solutions. Molecular spectroscopy and ultraviolet-visible (UV-vis) are among of the most commonly used spectroscopic techniques in food testing or when dealing with food adulteration issues. Infrared (IR) and near-infrared (NIR) spectroscopy are fast, easy-to-use techniques with a history of being used for food applications. Fourier transform infrared (FTIR) spectroscopy is also routinely used in cases of suspected food fraud.

IR technologies are most known in the food industry

Infrared technologies can yield both qualitative and quantitative information. They can be used for the investigation of the chemical composition and food ingredients. IR spectroscopy is very commonly used in the dairy industry. Wide-spectrum NIR spectroscopy using a discrete filter-based NIR analyzer can be used for process monitoring of the production of various cheeses. Fiber-optic NIR sensors, such as those developed by Art Photonics can provide the information from product bulk, and therefore applied to monitor processes such as yoghurt incubation.

NIR technology used with a diode array can deliver the results in seconds rather than several hours as with many traditional chemical analysis methods. Such time reduction enables the collection of a large number of spectra and still performs a multicomponent analysis in seconds. Moisens developed by Art Photonics combines specific wavelength LED-sensors with individual IP-addresses in a fiber probe, enabling data collection in the iCloud and process optimization in real time (Fig. 2).

NIR spectroscopy also has a huge potential for meat quality assessment due to its non-invasive analytical advantages. NIR spectroscopy can rapidly detect freshness, protein and fat content, predict sodium content in commercially processed meat and in vacuum-dried ham slices. It is also widely used for grains and flours, chocolate

Organization

EPIC – European Photonics Industry Consortium

EPIC is the world-leading photonics industry association representing more than 660 members across 33 countries. EPIC promotes the sustainable development of organizations working in the field of photonics, EPIC fosters a vibrant photonics ecosystem by maintaining a strong network and acting as a catalyst and facilitator for technological and commercial advancement. EPIC publishes market and technology reports, organizes technical workshops and B2B roundtables, supports EU funding proposals, advocacy and lobbying, education and training activities, standards and roadmaps, pavilions at exhibitions.

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and syrups, herbs and spices, coffee, tea, mineral water and many other foodstuffs.

Mid-infrared (MIR) spectroscopy is a valuable technique for food-related research and quality control purposes in the food industry. FTIR is used the most often, being a likely candidate for a rapid, non-destructive and reliable technique for authentication analysis. For example, an FTIR spectrophotometer could detect adulteration in honey using glucose/fructose solutions with 95 % recognition accuracy. FTIR spectra are also often used to authenticate fats and oils, for instance. It is important, however, to use chemometrics as analytical data treatment to transform the information from FTIR spectra into understandable data.

Raman and fluorescent spectroscopy

Conventional Raman spectroscopy exhibits small scattering cross section of many materials. Nevertheless, the advances in electronics, lasers, optics, and nanotechnology have made Raman spectroscopy suitable in many areas of application. A Raman spectrometer can be used for monitoring and quality control in industrial food processing, food safety in agricultural plant production as well as inspections through different types of packing. Like IR spectroscopy, Raman allows quantification and characterization of the lipid components of food systems. It also gives quantitative analysis of the degree of unsaturation and the content of cis and trans isomers. Furthermore, it enables the characterization of polymorphism and chain packing, and the monitoring of interactions with other food components or changes induced by processing or storage, such as auto-oxidation or isomerization.

Fluorescence spectroscopy is another extremely sensitive spectroscopic approach. It can be used for the identification, classification, quantification, and optimization of different parameters during food handling, processing, and storage. However, the technique alone is not usually used in the food industry and most of the time it is linked with liquid chromatography. Such a combination is advantageous for detecting extremely low concentrations of contaminants such as toxins (mycotoxins), pathogenic microbes (bacterial species: salmonella, escherichia coli), antibiotics (e.g. penicillin, tetracycline, oxytetracycline), and food additives (e.g. aspartame, salicylates). Other important applications of fluorescence in food are the identification and quantification of components, contaminants and additives.

While the spectroscopy techniques described and others can bring clear advantages to many processes in the food industry, the diversity of techniques and parameters makes it challenging to implement them. In some cases, a complex and comprehensive software solution is required to combine information from different measuring methods. In other cases, the required solutions can be very customer dependent. There is no unique standard to make a comprehensive characterization of food parameters.

[1] *F. Schmidt, N. Christiansen, and R. Lovrincic:* The Laboratory at Hand: Plastic Sorting Made Easy – A next-generation mobile near-infrared spectroscopy solution, PhotonicsViews **17** (2020) 5, 56, Oktober; DOI: 10.1002/phvs.202000036

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IR-Spectroscopy Shows Quality of Natural Gas

An infrared spectrometer detects the percentages of several different hydrocarbon chains

The quality of natural gas is subject to strong fluctuations. Not only different natural gas deposits are responsible for this, but increasingly also the feed-in of hydrogen from power-to-gas plants. For fuel gas analysis, Fraunhofer IPM has developed an optical measuring system, which now recognizes the hydrogen content in the gas in addition to the hydrocarbons contained.

The calorific value also fluctuates with the composition of the gas. The gas composition is an important factor for consumers because the price of the gas is determined on the basis of the volume supplied and the calorific value. In industry, there is another aspect: the gas composition influences the combustion process. If, for example, the proportion of hydrogen in the gas mixture increases, the calorific value decreases. If the gas flow is not adjusted, for example in an oven, its temperature decreases. Such fluctuations can lead to quality problems, such as in the case of glass melting. Today, natural gas quality is usually determined using gas chromatographs at distribution points in the gas network or directly at large consumer's premises.

The spectrometer and the hydrogen sensor installed on a natural gas bypass. (Source: Fh.-IPM)

The new EcoSpectro fuel gas measuring system, which Fraunhofer IPM developed on behalf of RMA Mess- und Regeltechnik, determines the main components of natural gas spectroscopically: an infrared spectrometer detects the percentages of methane, ethane, propane, butane and longer hydrocarbon chains. Compared to gas chromatography, spectroscopy has several advantages: gas chromatographs are expensive, comparatively slow and laborious to operate. The IR-spectrometer, on the other hand, measures at subminute intervals, works without recalibration over a period of several months and does not require rinsing gases.

The spectra are analyzed using chemometric methods. In this way, gas concentrations of more than 70 % can be determined down to the 100 ppm range. The system is therefore particularly suitable as a fast-reacting measuring system for power-to-gas systems or for consumers behind a hydrogen feed-in point.

www.ipm.fraunhofer.de

An Optical Test for Cancer

Sensitive spectroscopy approach detects formaldehyde at a level of just one part per million

Researchers have developed an extremely sensitive, yet simple optical method to detect formaldehyde in a person's breath. Because formaldehyde is being studied as a potential biomarker for lung and breast cancer, the new method could one day lead to an inexpensive and fast way to screen for cancer. "Measuring biomarkers in exhaled breath is noninvasive, painless and fast and could be used to screen for cancer even at very early disease stages, which is crucial for successful treatment," said research team leader Mateusz Winkowski from the University of Warsaw in Poland. "The optical method we developed could make this type of measurement more practical and inexpensive."

Winkowski and Tadeusz Stacewicz show that their new optical sensing method based on multipass spectroscopy can detect the presence of 1 ppm, even in the presence of gasses that can interfere with optical measurements. "Our dream is to one day build a tabletop device that would be inexpensive and could be used for cancer screening in any medical consulting room," said Winkowski. "During a basic medical examination, the patient could blow into the device, and within a minute the doctor would know if the patient might need additional conventional examinations."

An extremely sensitive, yet simple optical method for detecting formaldehyde: the approach is based on multipass spectroscopy, which introduces a laser through a small hole in a mirror. The laser light then bounces back and forth between mirrors, creating interaction lengths with the sample that are tens or hundreds of times the length of the cell. (Source: M. Winkowski, U. Warsaw)

The spectroscopy approach known as multipass is useful for detecting low concentrations of gas molecules because it increases the extent to which the light interacts with the sample. This setup uses an experimental cell with a mirror on each end. A laser introduced through a small hole in one mirror then bounces back and forth in the cell, creating interaction lengths tens or hundreds of times the length of the cell.

When trying to detect extremely low concentrations, noise can be a problem with multipass spectroscopy. This is because the multiple laser beams create a type of optical interference called fringe interference that decreases sensitivity and makes it impossible to precisely determine the biomarker concentration. To reduce this optical interference, the researchers developed and used a method called optical fringe quenching. (Source: OSA)

Reference: *M. Winkowski & T. Stacewicz:* Optical detection of formaldehyde in air in the 3.6 µm range, Biomed. Opt. Exp. **11** (2020) 7019; DOI: 10.1364/BOE.405384

http://optyka.uw.edu.pl

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World's Smallest Broadband IR LED for Spectroscopy

Osram presents new phosphor technology for handheld quality control

Does the apple in the supermarket only look delicious, or is it spoiled and vitamin deficient? Is the shirt on the shelf really made of 100 % cotton? A closer look at the molecular structure provides the answers to these questions. Near-infrared spectroscopy makes that possible. For many years, Osram Opto Semiconductors has been a leader in the development of compact and particularly powerful broadband infrared emitters for spectroscopy. This product aims to soon make mobile spectroscopy solutions a reality.

The most important aspect of infrared light sources for NIR spectroscopy is to cover as broad a wavelength range of emitted light as possible. The larger this range, the more objects that can be analyzed. In order to determine ingredients or water content, the target object is illuminated with infrared light of a wide wavelength range (usually 650 – 1050 nm). Parts of this light are reflected, others are absorbed. This ratio varies from object to object, resulting in a unique molecular fingerprint for each item.

NIR spectroscopy determines an object's molecular fingerprint. This makes it possible to determine not only a food's ingredients, but also its freshness. (Source: Osram)

With its dimensions of just 1.6 × 1.6 × 0.9 mm, the P1616 SFH 4737 is the world's smallest NIR LED (NIRED) for spectroscopy applications available in the market – and is only half the size of the previous smallest product in the Osram portfolio. It is not only its compact design that makes this NIRED ideal for use in smartphones, but also its output of 74 mW at 350 mA – about three times the peak values of earlier products.

Carola Diez, product manager in the sensing division at Osram OS explains: "Used in mobile spectroscopy applications, our NIREDs not only help determine the freshness of food, but also identify counterfeit medicines and banknotes. And in agriculture, they are a key tool in determining the ideal time to harvest."

www.osram.com/os

Spectral Sensing for Rapid SARS-CoV-2 Testing

AMS technology chosen by optical metrology specialist Eldim

High performance sensor solutions provider AMS makes its latest sensor technology available to Eldim, a France-based maker of optical metrology soft and hardware. This supports the development of a point of care detection solution for Covid-19 using molecular biology and yielding results in professional healthcare environments in only forty minutes – instead of the previous several hours or days. A specifically developed sensor system based on the AMS AS7341L spectral sensor solution allows spectrally resolved read out of amplified RNA of the virus particles, reinforcing AMS' position in delivering high-quality professional health diagnostics.

A team from Normandy, France, – Loop Dee Science, a biotech startup focused on point-of-care testing; LRX Technologies, a miniaturized and connected photonic sensors design company; Eldim, an industrial producer of readers; as well as the University Hospital of Caen, which is providing scientific input and clinical supervision – has been actively working on the project for several months. The resulting solution is the LoopXplore Covid-19 analytical kit and the LoopX, a portable and autonomous professional diagnostics device.

Miniaturization of PCR testing

Polymerase chain reaction (PCR) testing is fundamental to much of the genetic testing underway today and is currently the most frequently used test for SARS-CoV-2. However, the equipment and expertise needed to use and interpret the data is highly specialized, can be expensive, and is found only in centralized laboratories. In contrast, this new kind of testing from Eldim and its partners uses isothermal amplification technology to detect the virus itself without bulky equipment. This has the advantage that patients get virtually instantaneous and highly accurate feedback on their health status, which can avoid the spreading of the virus.

Rapid test results will be available in 40 minutes with the LoopXplore and not only limited to a professional healthcare environment. (Source: AMS)

"In this important project, we are overseeing the sensor and analytical side of the LoopX solution. Our proven experience in high-end, mass-production processes and manufacturing capabilities will provide healh authorities and future users the best possible quality and reliability," says Thierry Leroux, president and CEO, Eldim.

https://eldim.biz – https://ams.com

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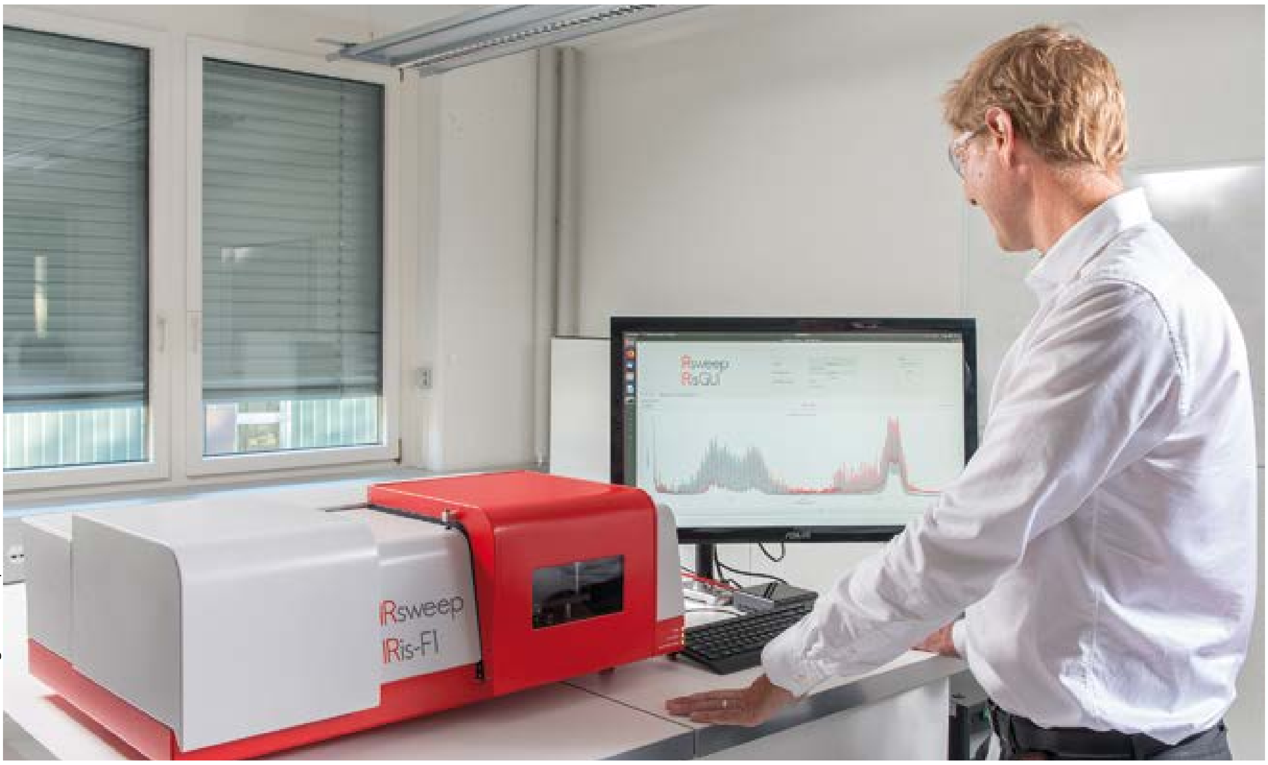
QCL Dual-Comb Spectroscopy Matures for Applications

What reaction monitoring and process analytics can gain from integrated QCL mid-IR dual-comb spectrometers

Markus Geiser, Raphael Horvath, and Jakob Hayden



Source all images: IRsweep

Dual-comb spectroscopy is a powerful direct absorption spectroscopy technique and has attracted considerable attention, with high precision spectroscopy applications being the most prominent since the invention of the frequency comb was awarded the 2005 Nobel Prize in physics. The application range is continuously broadening and here we review recent advances achieved with quantum cascade laser frequency comb spectrometers in process monitoring and reaction kinetics applications.

Infrared absorption spectroscopy is widely used in applications from quality control to studying the dynamics of proteins. Much of its success is based on the versatility of the Fourier-transform infrared spectroscopy (FTIR) spectrometer, an interferometer-based instrument, usually driven by a thermal light source. While such light sources provide enormous spectral coverage, the power spectral density – the number of photons per wavelength – is limited. For fast or low optical throughput applications, the signal to noise ratio (SNR) of FTIR measurements suffers.

Laser sources with their orders of magnitude higher power spectral density and coherent and narrowband emission are therefore used for an increasing number of applications, from gas sensing to tissue imaging. In the past fifteen years, broadband frequency comb lasers have become especially popular and powerful tools for spectroscopy. The spectral elements of a frequency comb are equidistant, and this enables one to use a second, slightly detuned frequency comb laser as a dispersive element, resolving the comb lines on a detector in a heterodyne manner. This method is called dual-comb spectroscopy. Initially, the properties of dual-comb spectroscopy were exploited for highest precision frequency metrology work, but as devices mature and dual-comb spectroscopy becomes available as an out-of-the box technique, a much broader range of applications becomes available.

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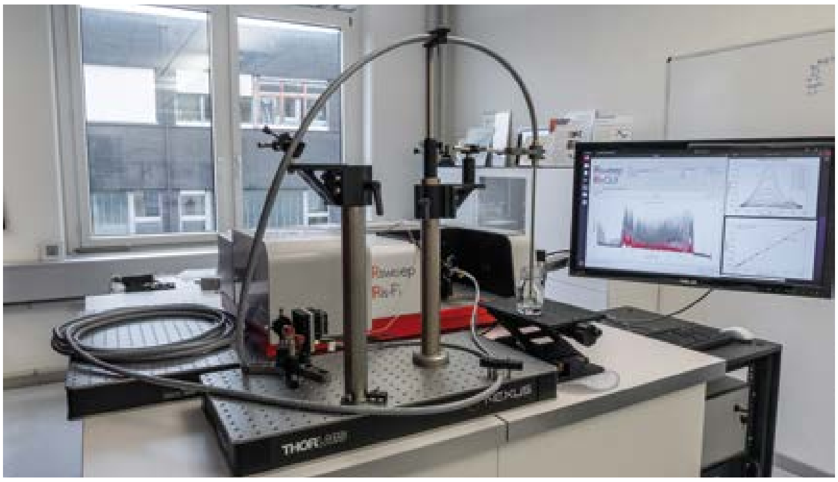

Fig. 1 IRis-F1 dual-comb spectrometer coupled to a 10 m mid-IR fiber probe.

Frequency combs have been realized in many different laser systems, but the spectroscopically interesting mid-infrared range – loosely defined as covering wavelengths from 3 to 30 µm – has been a challenge [1]. Quantum cascade laser (QCL)-based frequency combs have emerged as a simple chip-scale high power comb source in that spectral region [2, 3]. Interband cascade lasers (ICLs) are a related development that have shown promise at higher energies and can also be operated as frequency combs. In contrast to many fiber-based combs, QCL frequency combs are not octave-spanning but cover a spectral range of up to 100 cm^{-1}, which is sufficient for many applications since the spectral band to be observed is often well defined. The short cavities of QCLs result in large mode spacings and less dense spectral sampling (typically 0.3 cm^{-1}). However, the large mode spacing and comparably low number of spectral lines enables very high temporal resolution down to 4 µs and results in a very high power per mode (> 2 mW in some cases) and consequently a high signal to noise ratio for each line at short integration time. Also, a spectral resolution of <0.001 cm^{-1} can be achieved [4].

The chip-scale mid-IR frequency combs have simplified integration [5, 6] into dual-comb spectrometers for applications beyond physics laboratories and as laboratory spectrometers. Here, we will review some applications that have been developed for IRsweep's IRis-F1 QCL dual-comb spectrometer (**Fig. 1**) with three examples: Stopped flow reaction monitoring, process analytics with ten meter long fiber probes and time-resolved reaction kinetics studies. Different spectral regions within the mid-IR will be observed in these applications.

Stopped flow reaction monitoring

Following kinetics with mid infrared spectroscopy allows protein chemists to better understand how proteins fold and to obtain information about secondary structure changes involved in the folding process. Stopped-flow is a popular technique for these studies where reagents are rapidly mixed and the consequent reactions can be studied with a mixing-limited time resolution of a few milliseconds. Traditionally, the stopped-flow instrument is coupled to a FTIR spectrometer. For these measurements, FTIR has two major limitations, namely speed and optical power. The speed is limited by how fast the mirror scan can be completed. Even with rapid-scan instruments, the fastest acquisition speed is often in the 30 to 50 ms range, which is much longer than the few milliseconds dead time of a stopped-flow apparatus. At the same time, the low optical power sources of FTIRs mean that the signal to noise ratio suffers at short acquisitions. Thus, it can be necessary to average over many stopped-flow shots to improve the signal quality to acceptable levels, which is problematic for concentrated and precious samples.

The IRis-F1 spectrometer from IRsweep is a dual comb spectrometer specifically designed for rapid measurements that allows the recording of mid-IR spectra at 4 µs time resolution in a single stopped-flow shot. We studied the fast transition from β-sheet to α-helix in β-lactoglobulin secondary structure that has been described by Gerwert et al. [7]. The transition in secondary structure is initiated as described in detail elsewhere [8]. For the experiments, 100 µL of the sample were mixed with a denaturing agent with a 5 ms dead time. The measurement was triggered electronically from the stopped flow instrument (BioLogic SFM4000), ensuring synchronization with the injection process.

Spectra were continuously acquired every 4 µs for 130 ms and spectral sampling was 0.3 cm^{-1}. Pre-trigger spectra, corresponding to the initial state of the reaction, were used as the background for absorbance spectra. In post-processing, spectra were co-averaged over 1 ms and spectral averaging over 3 cm^{-1} was performed. Four stopped-flow experiments were co-averaged and baseline drifts were corrected by subtracting the absorbance at 1623 cm^{-1}.

Fig. 1 shows the evolution of the IR spectra measured during the first 10 ms after mixing. The lactoglobulin initially contains a significant amount of β-sheet. The positive band at 1660 cm^{-1} can be attributed to the formation of α-helix structures, while the negative band at 1634 cm^{-1} corresponds to the consumed β-sheet. At timescales below 3 ms, a small positive band at ~1637 cm^{-1} can be observed that has been attributed to an intermediate species by Gerwert and co-workers. For later times, above 7 ms, this small positive band is masked by the negative β-sheet band.

Company

IRsweep

IRsweep introduced the first commercial QCL dual-comb spectrometer IRis-F1 and focuses on the development of applications in mid-IR absorption spectroscopy for academic and industrial applications. The company was founded in 2014 as a spin-off of ETH Zurich, Switzerland, and has since installed systems in Europe, North America, and Asia.

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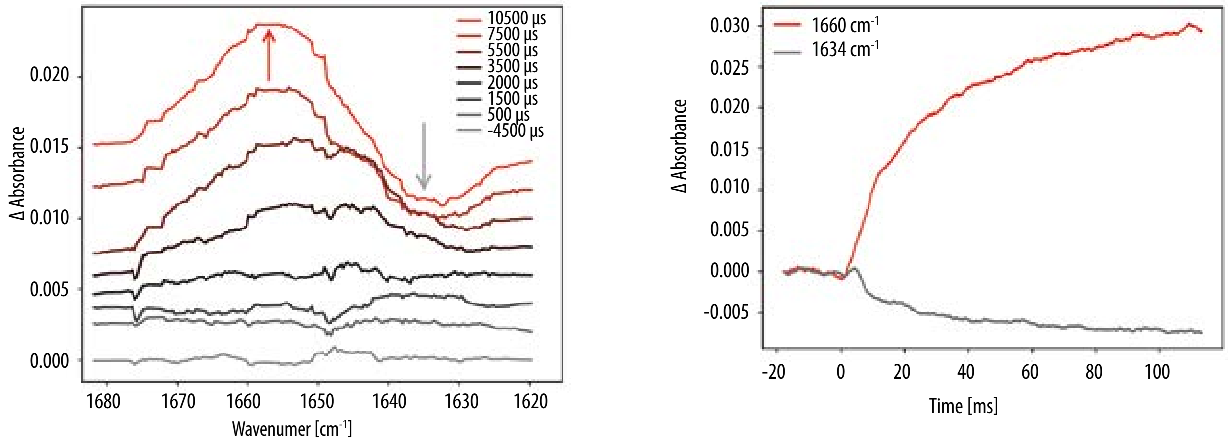

Fig. 2 Spectral signatures of secondary structure change in b-lactoglobulin. Left: spectra recorded during first 10 ms, consecutive offset for visualization purposes. Right: evolution of absorbance at 1660 cm^{-1} and 1635 cm^{-1}.

Mid-IR PAT with 10 m long fiber probes

Fiber optics are often used in combination with infrared spectroscopy for industrial reaction monitoring purposes. While fibers in the visible and near-IR spectral regions can span many tens or even hundreds of meters, mid-IR fiber probes typically don't exceed two to four meters, as the attenuation at longer distances is simply too great for them to be used with commercial FTIR spectrometers. Due to the short fiber probes, spectrometers have to be placed close to the sampling point, which is often a restricted area with non-spectrometer-friendly conditions (e.g. explosion safety relevant).

A solution to this limitation is to increase the power of the spectroscopic light source by using QCL frequency combs, enabling the use of 10 m fiber probes [9]. The fiber is a custom-made 10-m unit from Art Photonics (Berlin, Germany) with a two-bounce diamond ATR probe. A good test sample that is also relevant to process analytics is acetone in toluene, and we measured several concentrations in the spectral range of 1200 – 1290 cm^{-1} to determine the limit of quantification. Each measurement consisted of fifteen samples, corresponding to an acquisition time of approximately 250 ms and a processing time of <1 minute.

The spectra of a range of concentrations of acetone in toluene are shown in Fig. 3. A clear band is seen at 1215 cm^{-1}, corresponding to the asymmetric C-C stretch of acetone. Gaussian wavenumber averaging has been performed, resulting in a full-width at half maximum spectral resolution of 3.5 cm^{-1}. A linear baseline correction was done with two points on either side of the analyte peak to isolate the feature of interest.

It is evident that this acetone band is visible until a concentration of approximately 0.1 %. This is similar to FTIR measurements but at a far greater fiber length, which is only possible with a high-power source. At lower concentrations, baseline fluctuations are at similar intensities to the acetone band.

A simple linear regression analysis is performed to determine the limit of detection of better than 0.1 % of acetone in toluene. The right panel shows a linear fit of the point at 1215 cm^{-1} over the entire tested concentration range. Although this method can already be used to quantify low concentrations of analyte with low errors, more sophisticated processing that takes multiple spectral points into account is expected to produce even more robust results for future experiments.

Fast reaction kinetics

Dual-comb spectroscopy is still a form of Fourier-transform spectroscopy, but in contrast to common FTIRs, the interferogram is generated by the beatings of pairs of lasing modes. The time to record one interferogram is given by the time required to resolve these individual beatings, being $1 / (f_{rep1} - f_{rep2})$, where f_{rep1} and f_{rep2} are the repetition rates of the two frequency combs. With typical parameters for QCL frequency combs, this time is of the order

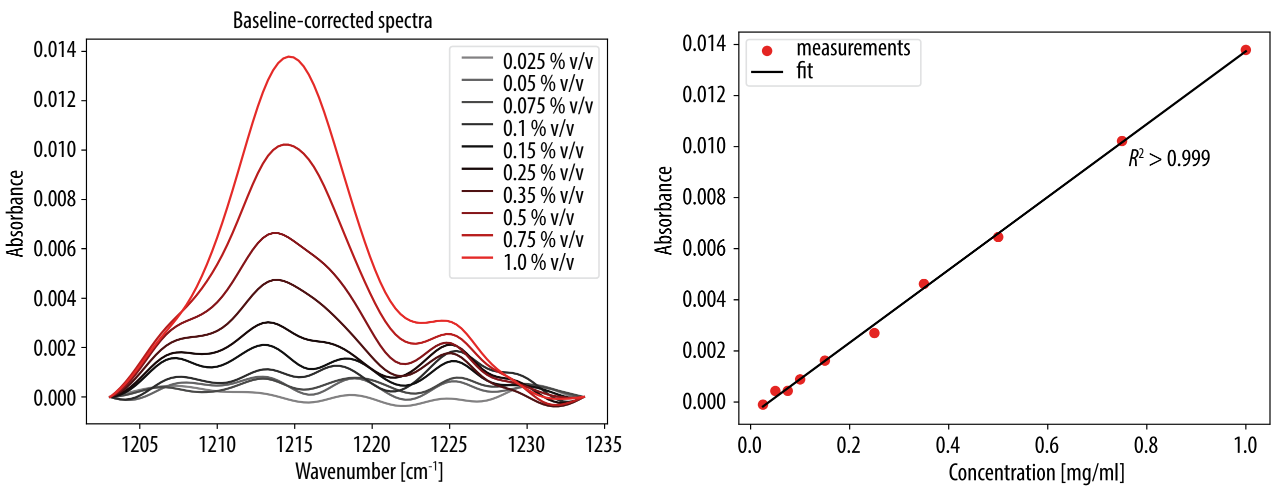

Fig. 3 Absorption spectra (left panel) and regression (right panel) of acetone in toluene through a 10-m long fiber probe with a two bounce ATR crystal

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of 1 µs. This opens up the possibility of fast reaction kinetics studies, where repeatability of reactions is limited and high signal-to-noise ratio, broad spectral coverage and high temporal resolution are required simultaneously. Typical examples are protein dynamics and combustion diagnostics studies.

For protein dynamics, step-scan FTIR is often the method of choice for repeatable reactions, but numerous experiment repetitions are required for that approach. This is a challenge when protein samples are expensive and available in low volume, and also when samples age or the sample aging during the measurement is not known. Dual-comb spectroscopy can offer rapid spectrum acquisition to access µs time scales without experiment repetition. Single shot difference spectroscopy of bacteriorhodopsin [10] shows the way to study such non-repeatable proteins, such as vertebrae rhodopsins. The high power of the dual-comb source also allows increasing sample interaction length, boosting signal strength. Typical spectral regions of interest for proteins are the amide bands, where secondary structure can be studied.

Combustion diagnostics has different challenges because widely used shock-tube model systems have typical test times of the order of a millisecond, experiments are not exactly repeatable and thermal emission from oxidizing fuel has to be separated from the light used for absorption spectroscopy. Due to these complications, laser-based diagnostics are often used in combustion applications and the added spectral bandwidth at short timescales that dual-comb spectroscopy offers has recently been used to study formation and decomposition time constants [11] and as a means of validating kinetic models [12].

Conclusion

QCL and ICL-based chip-scale frequency comb systems have developed in a different direction than the widely used fiber-based stabilized frequency comb systems since their first demonstration in 2012. The chip scale comb specs are lower in terms of spectral sampling, frequency stability and spectral coverage but, on the other hand, their simplicity and compactness have allowed integration into field-deployable commercial systems relatively quickly after discovery. They also offer advantages in terms of detection speed, sensitivity and optical power in the spectroscopically interesting mid-IR spectral range. These features enable applications ranging from fast (bio)chemical reactions in fundamental research to low optical throughput scenarios in process analytics, as outlined in this article. Considering the rapid advancement of those chip-scale comb sources, we expect further integration in industrial and research applications and an increase in available spectral coverage to make dual-comb spectroscopy available to an ever broader range of users.

*

We acknowledge support by the European Union's Horizon 2020 research and innovation program under grant agreements No. 871529 ("Hydroptics") and No. 820419 ("Qombs").

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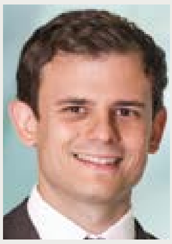
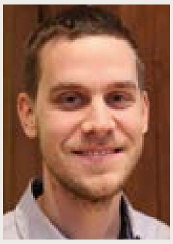


Markus Geiser studied physics at TU Munich, Germany, and holds a PhD from ETH Zurich, Switzerland, during which he focused on strong coupling of 2D electron gases in microcavities in the group of Jérôme Faist. He co-founded IRsweep in 2014, where he is managing director.

Raphael Horvath has a PhD from the University of Otago, New Zealand. In 2012 he became a research fellow at the University of Nottingham, UK, where he worked on time-resolved infrared characterization of materials relevant in catalysis and biology. In 2018 he joined IRsweep as an application engineer.



Jakob Hayden received his PhD from TU Vienna, Austria, where he studied cavity enhanced spectroscopy for trace gas sensing applications in the group of Bernhard Lendl. He joined IRsweep in 2020 as a sales and application engineer.

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MIR Spectroscopy for Continuous Control and Monitoring of Metabolites

Tackling inefficient bioprocesses, one – continuous – step at a time

Géraldine Baekelandt and Anja Müller

Source all images: Irubis

A new measurement system, which is based on mid-infrared spectroscopy, allows to monitor multiple bioprocesses online at the same time. Applications of the instrument are foreseen in upstream bioprocessing, in metabolite monitoring and control, as well as in downstream bioprocessing to aid in aggregation studies, contaminant detection or the monitoring of target proteins and excipients.

Bioprocessing is the term used to describe the whole process that occurs from the initial stages of cell harvesting (i.e. extracting cells) to the production of the biopharmaceutical. The most commonly used types of cells are mammalian cells.

Mammalian cells are extensively used in cell biology studies, for model systems of human pathologies or as a source of biopharmaceuticals. The cells themselves, or specific proteins within them, are the raw material for biological drugs. As such, it is vitally important to develop monitoring methods for these cells. Monitoring and control of these cells should give crucial information about the quality, stability, and growth patterns [1].

To go from cells to useful pharmaceutical products is a long, specific, and highly controlled process. Due to the precise nature of this process, batch-to-batch variation, as well as contamination and impurities are major causes of decreased product yield and the need to have more automated processes [2]. Fig. 1 shows the variety of parameters that need to be kept constant and monitored throughout the bioprocess, from cell parameters to product impurities and downstream parameters. As can be seen in Fig. 1, there are many areas of control and validation necessary to optimize processes in the industry.

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QUALITY ATTRIBUTES			PROCESS PARAMETERS AND OUTPUTS	
Product-related and process-related impurities	Safety	Others	Cell Culture Control	Downstream Control
Aggregation	Microbial safety (bioburden)	Bulk DS concentration	IgG titer	UV
Fragmentation	Endotoxin	Cell-based potency assay	Cell viability	Conductivity
Charge Profile	Virus safety	Antigen binding	Viable cell density	pH
Deamidation		FcgR, C1q and FcRn binding	Yeast proteins	Pressure
Oxidation		Density	Insulin	Flow
Glycosylation profile		Appearance (color)	Glucose	Turbidity
Glycation		Visible and sub-visible particles	Amino acids	Product concentration/mass
Non-glycosylated heavy chain			Galactose	
Host cell proteins (HCPs)			Glutamate	
Host DNA			Glutamine	
Leached protein A			Lactate	
			Ammonia	
			Other nutrients and metabolites	
			Exit gas composition	
			pH	
			Metals (Cu, Mn, etc)	
			Gas concentrations	

Fig. 1 Process parameters and quality attributes needed to be monitored within the bioprocess. Many critical attributes need to be controlled and monitored in order to adhere to strict standards. (Adapted from [3])

It is relevant to acquire information about the conventional critical variables (such as cell growth, consumption of nutrients, production, and consumption of by-products and the bioproduct production), and the cell metabolism towards a better understanding of the culture process and consequently for more efficient optimization and control procedures. To optimize and consistently achieve high quality products, specific frameworks have been put in place, such as quality by design and process analytical technology (PAT) initiatives.

Quality by design (QbD) is defined as "a systematic approach to development that begins with predefined objectives and emphasizes product and process understanding and process control, based on sound science and quality risk management" [4]. The need for QbD is evident; in order to have consistently high-quality products, systematic approaches need to be defined and controlled. Part of this type of approach encompasses tools such as PAT, which is defined as "a system for designing, analyzing, and controlling manufacturing through timely measurements (i.e., during processing) of critical quality and performance attributes of raw and in-process materials and processes, with the goal of ensuring final product quality" [5]. PAT has been implemented as a pillar of process control for many parts of bioprocessing. The aim is to monitor and analyze processes in real time, enhancing prior understanding and establishing a control strategy to improve both the quality and quantity of produced product in the biopharmaceutical industry. To some extent, large leaps have been made within the last decade, especially with regard to obtaining quality attributes and more consistent monitoring of processes [6]. However, utilizing data, as well as data collection and control of processes, is still lagging. So to fully integrate PAT into bioprocessing, new solutions for data collection and the control of bioprocesses are ultimately necessary for higher product quality and yields. By looking into improved PAT processes, we also must first talk about the two main areas of bioprocessing, upstream and downstream, and how this area of monitoring and continual processing can aid both succinct parts of biopharmaceutical production [7].

Upstream bioprocessing describes all processes from the first steps of cell isolation, to cell cultivation. Cell cultivation, which is crucial, is the process of keeping the cells alive for further steps. This also includes scaling up the process from cell flasks to larger vessels, which are called bioreactors. Bioreactors are vessels in which living cells produce proteins, in a large and highly controlled environment, where factors such as pH levels and oxygen levels are kept consistent [8]. Very large volumes of proteins can then be harvested in these bioreactors. As previously mentioned, the process from cell isolation to biopharmaceutical product is long, tedious, and fraught with many possible failures in both product quality and quantity. Once we have isolated the relevant protein from the cell, the next steps are taken to purify the product. These processes are referred to as downstream processes, involve another array of steps such as filtration (amongst others) so that a stable formulation can be produced. These steps involve different types of chromatography, from size exclusion chromatography to ion exchange and affinity chromatography [9]. Chromatography is slow, expensive, and difficult to automate. Some of the most difficult hurdles of PAT can be found here; scaling up chromatography in downstream processing and more continuous process monitoring and control in upstream processing.

Company

IRUBIS

The Munich start-up was founded in 2017. It is specialized in mid-infrared spectroscopy. IRUBIS has designed an instrument – Monipa – specifically for bioprocess monitoring and control. The hardware consists of a mid-infrared spectrometer, a single-use flow cell and user-friendly software. Applications of the instrument are foreseen in both upstream bioprocessing as well as in downstream bioprocessing.

irubis.com

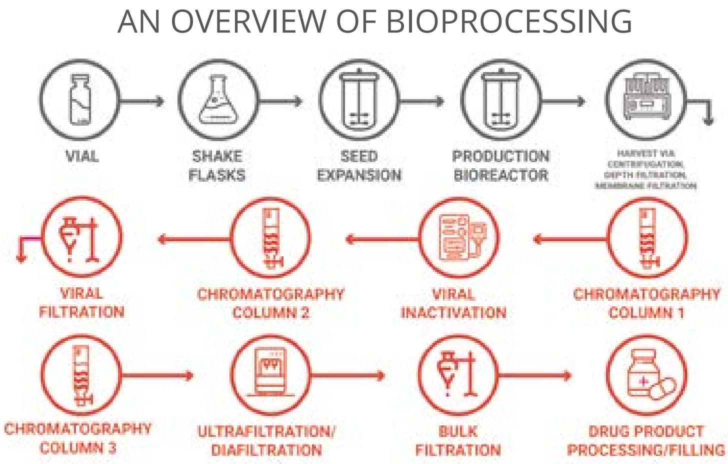

Fig. 2 The overall biopharmaceutical process, both upstream (grey) and downstream (orange); from cell isolation to the production of the biopharmaceutical. (Adapted from [10])

In order to visualize the many steps that are part of bioprocessing, Fig. 2 shows the overall life cycle of biopharmaceutical processes, from cell isolation to eventual biopharmaceutical product.

The eventual goal in PAT for biopharmaceutical production is to have upstream and downstream processes that involve real-time and continuous monitoring and control. Data can then be analyzed on the fly, and problems can be fixed as soon as they occur. Through this, product quality not only increases, but batch-to-batch variation also decreases and hence product yield sees a steady increase. However, in order to do this, the instrument has to be able to take continuous data. This is a difficult task, and there are few instruments that are robust, can provide monitoring for continuous processing and produce useful data to aid in the monitoring and control of such difficult processes.

Our solution

Spectroscopy is a powerful tool to monitor bioprocesses. Molecular spectroscopy describes the interaction between electromagnetic waves and molecules. For bioprocesses, typical wavelengths range from UV to mid-infrared. Spectroscopy enables real-time monitoring of several parameters in parallel. For example, in upstream processing it is possible to monitor glucose, lactate, ammonium, glutamate and glutamine all at the same time. Bioprocesses can be monitored inline, online, atline or offline. These terms are described using the example of the analyzer used for bioreactors. Inline means the analyzer is directly inside the bioreactor, for example a Raman or MIR probe. For online methods, the analyzer is not in the bioreactor but directly connected to it, for example via a loop. Inline and online measurement methods enable continuous real-time monitoring. For atline (nearest to the bioreactor) and offline (may be further apart from the bioreactor) methods the operator needs to take a sample to a separate device.

Today, the established and most used technology to monitor nutrients, and metabolites in upstream processes are offline systems, such as the Cedex Bioanalyzer or Nova Bioprofile. These measurement instruments work offline, which means they are separate and not connected to the bioreactor. Therefore the device cannot provide a real-time and continuous monitoring as with inline or online methods. The samples are taken manually. Manual sample taking is not ideal in the industry, foremost because it increases contamination risk as well as giving poor monitoring and control of metabolites which is only done once a day.

The most important energy source for the cell is glucose that is fed daily to the bioreactor. The glucose concentration has been shown to have an influence on antibody production, cell growth and

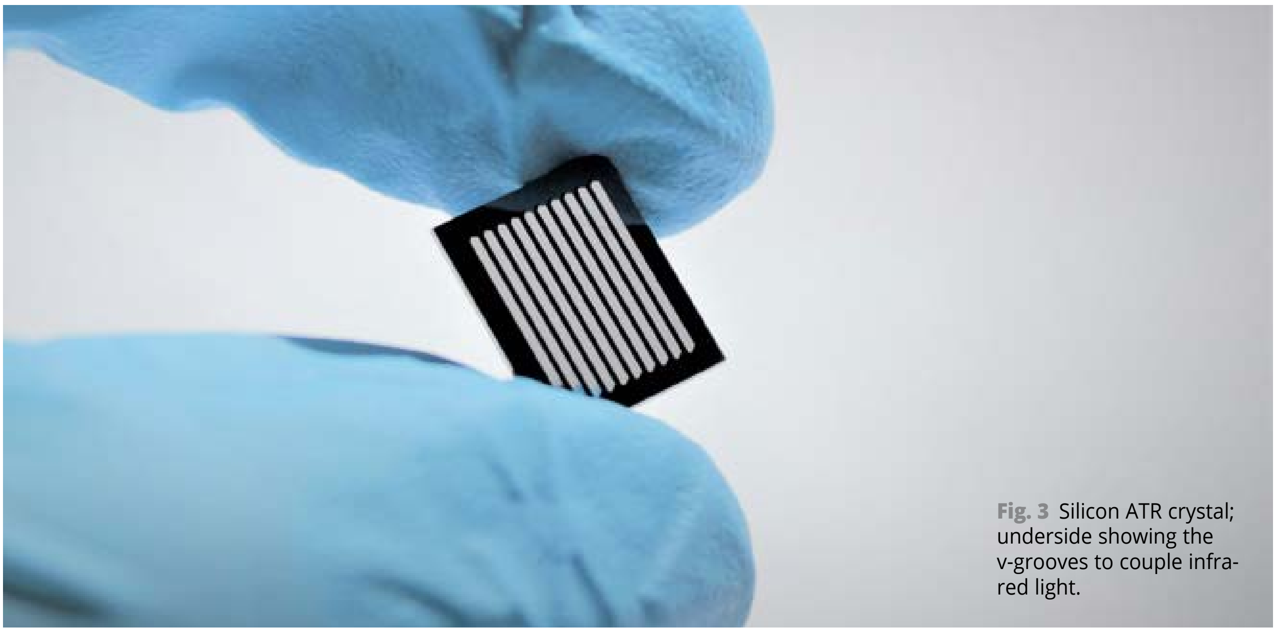

Fig. 3 Silicon ATR crystal; underside showing the v-grooves to couple infrared light.

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glycosylation [11]. Improved glucose control is therefore crucially important for an increase in production of the factors mentioned above, and to avoid large fluctuations.

It has been shown by Sandor et al. [12] that infrared spectroscopy provides high sensitivity in monitoring metabolites such as lactate and nutrients, e.g glucose. For the continuous monitoring and control of bioprocesses in the industry, a single-use sensor and plug-and-play device would be the ideal solution.

So we have developed an instrument specified to the customer's need called 'Monipa'. The core element is a cost-effective ATR crystal as the sample interface. ATR is the abbreviation of attenuated total reflection. This established infrared spectroscopy method does not need any sample preparation and is independent of the sample thickness. Transmission methods are limited in relation to the maximum sample thickness, otherwise the absorption of the light is too high. So our device relies on the measurement principle of ATR spectroscopy: the light passes through the ATR crystal under a certain angle, and is totally reflected at the interface between the sample and the ATR crystal. A small part of the beam interacts with the sample, which is called the evanescent wave. One important factor is the material of the ATR crystal, as the angle of total reflection also depends on the refractive index. Therefore only materials with a high refractive index can be used, such as diamond, zinc selenide, etc. However, these materials are expensive and therefore not suitable for single-use application in bioprocess monitoring. Irubis optimized the ATR crystal (Fig. 3) published by Schumacher et al. [13] to enhance the light throughput. By using silicon material and well-known semiconductor manufacturing processes, large quantities of ATR crystals can be fabricated, reducing the price. This makes them suitable for single-use application. This ATR crystal is integrated into a single-use flow cell that can be attached to our MIR system Monipa. The flow-cell is easily connected via a loop to the bioreactor. As a demountable component, it is autoclavable and suitable as a disposable element. Alternatively, it can also be gamma sterilized if necessary. Compared to inline probes, the external flow-cell provides a constant measurement environment, without influences of gas bubbles or the stirrer in the bioreactor. Our MIR system Monipa evades problems with absorption from water vapor by background measurements. These are reference measurements which are used to correct the spectra for changes of the instrument or the environment.

Calibration model building is an important step for spectroscopy. The spectra depend on the molecules in the measured samples. Different cell lines, cell culture media, metabolite or nutrient concentration lead to changes in the spectra. Therefore, calibration models are built by online monitoring of the process, as well as reference samples by offline methods (e.g. a Cedex HT Bio). The spectroscopic measurements are correlated to the reference method building a calibration model. The additional bioreactor runs and offline measurements to build the calibration model are costly and time intensive. A new model is necessary for every change in the cell culture or media. This can, in theory, be solved by building a generic model. However, this creates even more work, with many more additional bioreactor runs and can lead to reduced accuracy. As well as the large cost and time, the compliance regulations of biopharma industries are not compatible with creating generic models based on the data of a large array of pharmaceutical companies.

To tackle this setback, Irubis created two options to reduce the effort of building a calibration model for our spectroscopy method. With our system, it is possible to measure the samples offline. Samples are taken and archived for almost every bioprocess run. These archived samples can be used to create a calibration model. So instead of measuring three to five bioreactor runs, which takes up to two to four months, our calibration model can be built in just one week. The second option is to keep the glucose concentration at a constant level. Irubis created a relative measurement to address both the control of the glucose concentration and to avoid extensive calibration model building. A known start value, such as 3 g/L is given for the relative measurement as the input to the Monipa system. The algorithm of the system then compares the actual spectrum to the spectrum with the known start value. If there is a change, the coupled pump adds glucose to the bioreactor system; see also Fig. 4. This

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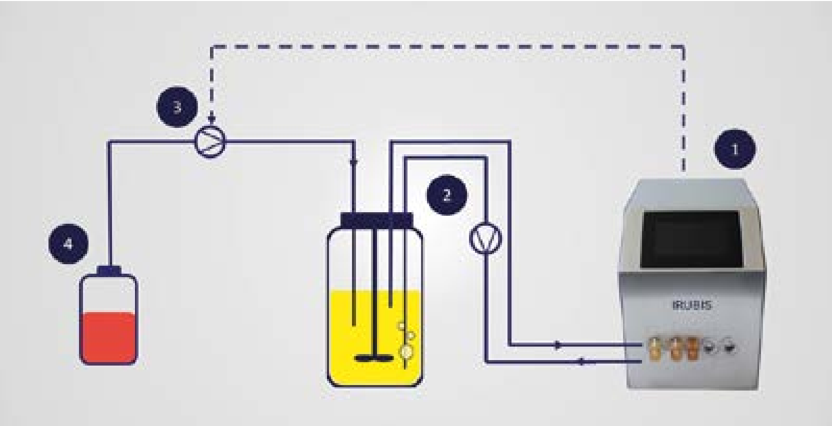

Fig. 4 Schematic of the setup to monitor and control glucose. The numbers indicate different parts of the setup, with number 1 being the MIR instrument Monipa. The instrument contains orange flow cells, which contain the ATR crystal. Number 2 refers to the bioreactor, which as can be seen by the schematic, is connected to the instrument through tubes. Number 3 references the control loop, which runs from the instrument to the feed to increase the amount of glucose in the bioreactor (dependent on measurements). Number 4 is the feed, which goes directly into the bioreactor.

created the first of its kind of spectroscopic mid-infrared system as a plug-and-play device for bioprocesses.

In the previous paragraphs, the methodology of the instrument was discussed for its application in glucose and metabolite control and monitoring in upstream bioprocessing. This is just one of the many applications of the instrument in the field. For downstream use, MIR has been shown to be used in aggregation and conjugation studies, as well as for determination of concentrations of antibodies and proteins [14, 15]. So the applicability of the system for bioprocessing is not limited to its use upstream.

The Monipa system tackles some of the many challenges faced in bioprocessing. Circling back to the introduction, obstacles faced by the industry to obtain high yields and quality products are vast. However, being able to continuously monitor and adapt concentrations of nutrients and metabolites in real time in the upstream processing steps is a huge advantage over older, conventional approaches.

Additionally, using MIR for downstream applications to monitor aggregation or the conjugation of antibodies or proteins would also be highly advantageous for the field of bioprocessing [16]. The opportunity for a fast acquisition time and little sample preparation is even more vital here than in upstream processing, because processes are faster as they do not require cell cultivation and growth.

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This project has received funding from the European Union's Horizon 2020 research and innovation program under the grant agreement No. 954732.

DOI: 10.1002/phvs.202100019

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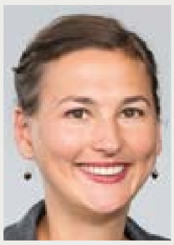
Anja Müller



holds a master's degree in physics from the Technical University of Berlin. Over the course of her studies, she acquired relevant knowledge and skills in the field of MIR spectroscopy. During her master's studies, she was awarded a scholarship for the Career Building Program at Femtec, where she acquired important management and leadership competencies. At Irubis she is responsible for funding and project management as co-founder and COO.

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A New 'Hera' in Hyperspectral Imaging

Low light applications come into range thanks to a novel camera system

Fabrizio Preda, Antonio Perri, and Dario Polli

Fig. 1 The Hera Iperspettrale hyperspectral camera

Source all images: Nireos

Hera Iperspettrale is a novel hyperspectral camera based on a patented Fourier-transform approach. The device can be employed in a large variety of applications, ranging from cultural heritage to biology, from material sorting and food inspection to remote sensing and vegetation studies. The exceptional throughput of the optical system ensures high-quality data even at the lowest light dose, making the camera very suitable for fluorescence hyperspectral imaging.

Hyperspectral imaging (HSI) is a novel analytical technique based on spectroscopy, with the aim of measuring the spectrum of the light coming from each point of a scene of interest. While the human eye has only three color receptors, for blue, green and red light, hyperspectral imaging measures the continuous spectrum of the light as a function of the wavelength λ for each pixel of the scene at coordinates (x, y) with fine spectral resolution, not only in the visible but also in the infrared range. The collected data form the so-called hyperspectral image: a three-dimensional data cube as a function of x, y and λ. These data contain an extensive amount of information. Therefore, many numerical methods and algorithms have been developed to enable the extraction of quantitative parameters related to the physicochemical properties of the imaged objects, as well as the clustering into different components, useful for the analysis of congested scenes. For this reason, HSI is an extremely powerful technique, which has been applied to a wide range of fundamental and applied studies in fields as diverse as remote sensing, medical and biological imaging [1], agriculture [2], coastal and geological prospecting, safety and security, military applications, archaeology and conservation science [3].

Approaches to hyperspectral imaging

HSI has been implemented in a wide variety of methods. The simpler approaches are constituted by snapshot HSI systems, which employ a matrix of bandpass filters on the surface of the detector, and spectral HSI systems, which use a tunable spectral filter in front of a monochrome imaging camera. These methods are quite straightforward, the drawback being the acquisition of a limited and discrete number

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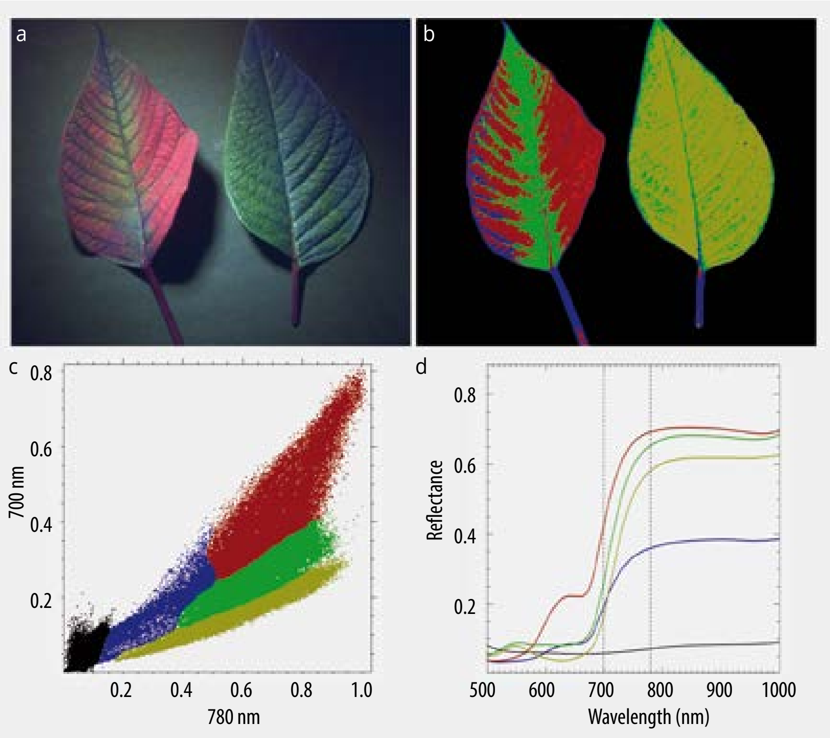

Fig. 2 Hyperspectral image of two leaves from a Poinsettia plant: RGB (a) and classified image (b); scatter plot in the 700 – 780 nm bands space, in which five different classes have been identified (c). Average reflectance spectra of the five classes (d)

of bands. To measure continuous spectra, another common approach is spatial scanning HSI, which combines a dispersive spectrometer with a raster-scanning approach, either in point-scanning (whisk-broom) or line-scanning (push-broom) modes. This technique is widely applied in industrial quality-control monitoring processes. However, the main limitation of these techniques is the high losses imposed by the entrance slit of the spectrometer, which leads to long acquisition times.

An alternative HSI method to measure continuous spectra combines a monochrome imaging sensor with an interferometer [4]. In this approach, known as Fourier transform (FT) spectroscopy, the light of interest is split into two collinear delayed replicas, whose interference pattern is measured by a detector as a function of their relative delay. The Fourier transform of the resulting interferogram yields the continuous-intensity spectrum of the light. The FT approach has prominent and well-known advantages over dispersive techniques:

- all the wavelengths are measured simultaneously, thus increasing the number of photons reaching the sensor and leading to a higher signal-to-noise ratio in a read-out-noise-dominated regime (multiplex or Fellgett's advantage),
- higher throughput, due to the absence of slits (the Jacquinot's or étendue advantage),
- high wavelength accuracy, thanks to the calibration of the device with a laser beam (the Connes' advantage),
- variable spectral resolution, which can be adjusted at will by varying the maximum scan delay of the interferometer via software, without affecting the throughput of the device,
- the spatial resolution can be adjusted independently of the spectral resolution.

Two essential conditions must be met by an FT-imager to provide high quality spectra:

- the relative delay of the two generated replicas of light must be controlled to within a fraction (1/100 or better) of the optical cycle and
- the bundle of rays that form the interferogram at a given pixel must preserve a high degree of coherence.

FT-based imaging is achieved using either a static or a temporal approach. In the static scheme, the interferometer has no moving parts, and a spatial interferogram is formed along one of the dimensions of the image. The acquisition is performed by moving the object with respect to the camera, making this method particularly suited to production lines where the object to be measured is moving on a conveyor belt, or for airborne remote sensing. In the temporal approach, the interferometer has a moving element, which is scanned to vary the delay of the replicas, with no need for relative movement between the object and the camera. This method is better suited to the imaging of stationary objects and is thus widely applied in applications such as biology or cultural heritage studies. FT-HSI systems have been built based on Michelson or Mach-Zehnder interferometers; however, since they are sensitive to vibrations, it is difficult to achieve the required interferometric stability without active stabilization or tracking. Alternatively, liquid crystal cells have been used to introduce a voltage-controlled delay between orthogonal polarizations. In the last few years, birefringent interferometers have attracted particular attention because of their compactness and insensitivity to vibrations, due to their common-path

Company

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NIREOS SRL is a fast-growing start-up and official spin-off company of Politecnico di Milano University, located in Milan (Italy). Incorporated in 2018, NIREOS is rapidly empowering its business and strategic market positioning thanks to the development of ground-breaking technologies in the spectroscopy and photonics sector. The solutions provided by NIREOS, such as spectrometers and hyperspectral cameras, are now unlocking new applications both in the industrial and in the scientific field.

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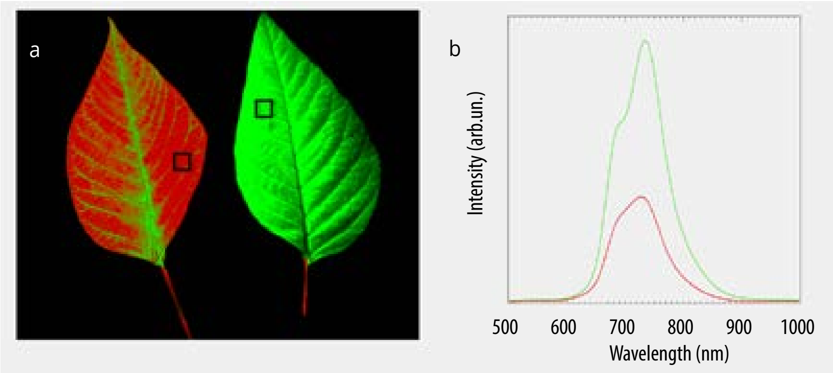

Fig. 3 Fluorescence hyperspectral image of two leaves from a Poinsettia plant: (a) Classified image in false color, showing the spatial distribution of the two main components in red and green. (b) Fluorescence spectra of the two components, corresponding to the selected squared areas in (a).

nature. They are mostly based on Wollaston or Savart prisms, or their variants. Because of the arrangement of their optical axes, they are characterized by a strong chromatic lateral displacement, which reduces the visibility of the interference fringes.

Hera Iperspettrale's working principle

Hera Iperspettrale (Fig. 1) is based on a Fourier transform (FT) approach and it employs a patented common-path birefringent interferometer (CPI) in combination with a bidimensional CMOS sensor. The CPI overcomes the limitations of the Wollaston and Savart prism-based imagers, providing negligible chromatic dispersion and small geometrical separation between the interfering replicas, leading to high degree of coherence at each pixel and a strong interference modulation. The three-dimensional datacube is acquired in the time-domain by serially stacking multiple images acquired at different positions of the CPI. The software then automatically computes an FT at each pixel of the image, thus providing the final hyperspectral data cube. As a result of an FT, the spectrum at each pixel is a continuous curve, so the number of bands is virtually unlimited, and it is not defined by the hardware. Hera Iperspettrale works in a broadband spectral region, from the UV to the near infrared (0.4 – 1 µm), and it features an exceptional throughput, a high spectral accuracy, and a wide versatility of use [5]. The spectral resolution, proportional to the wavelength as in any other FT techniques, corresponds to 3 nm at 600 nm. The objective has focal length $f = 25$ mm and maximum aperture $f/1.85$. The detector is a 1280 × 1024 monochrome silicon CMOS sensor and the total angular field of view of the imaging system is 16°.

Reflectance and fluorescence hyperspectral imaging

Thanks to the absence of aperture slits and gratings, and to its 10-mm clear aperture, Hera Iperspettrale is specifically designed to provide an extremely high light throughput, making it the ideal device for low light conditions or delicate samples.

As an example, Fig. 2 reports the results of a reflectance measurement performed on two different leaves of a poinsettia plant. The leaves were illuminated with a 50-W halogen lamp placed at 200 cm distance from the scene, to avoid heating or damaging of the sam-

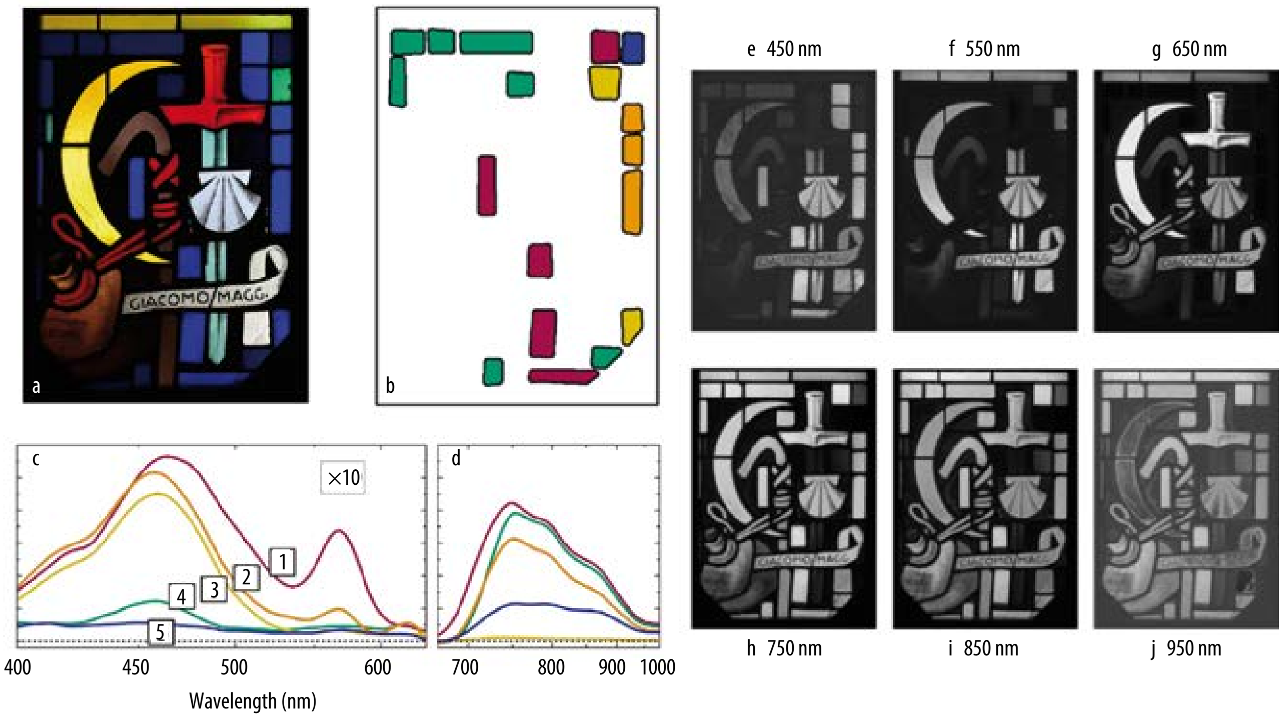

Fig. 4 Hyperspectral image of an artistic glass window (A. M. Nardi, 1969): RGB image synthesized from the spectral data (a); map (b) and corresponding transmitted spectra of the blue tiles, after automatic image segmentation (c, d); hyperspectral data at selected wavelengths (e-f).

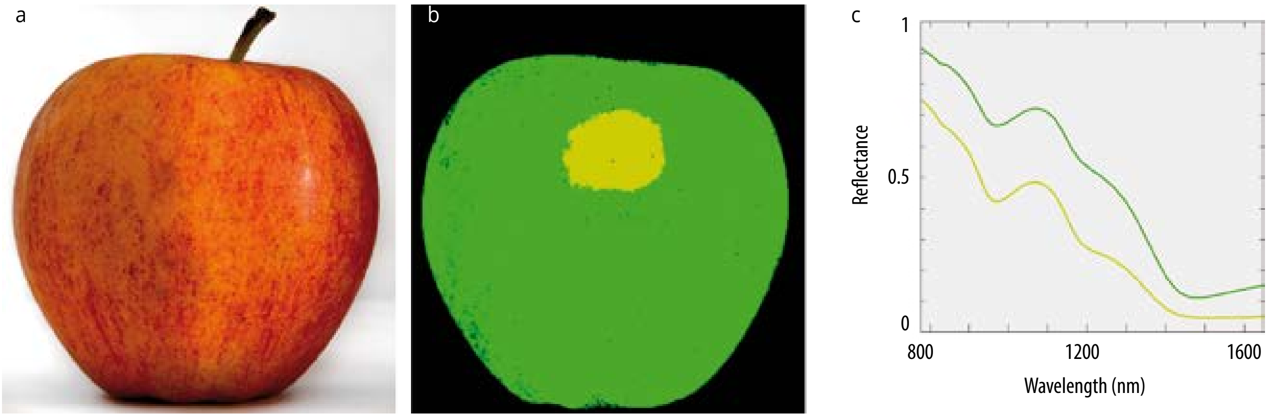

Fig. 5 Infrared hyperspectral image of a bruised apple: standard RGB picture of the sample (a) and classified image obtained from the infrared hyperspectral data. The yellow area shows the bruised portion of the apple (b). Infrared reflectance spectra of the bruised and healthy areas of the sample, in yellow and green lines, respectively (c).

ple. The absolute reflectance was calculated after spectral calibration with a white reflectance reference (not shown in the image) and correction for spatial and spectral non-uniformities of the illumination by imaging a white Lambertian surface at the object plane. The synthesized RGB color image obtained from the hyperspectral data is shown in Fig. 2a. We then applied a classification algorithm based on the scatter plot of Fig. 2c, which reports the distribution of the pixels in the 700 – 780 nm bands space. By analyzing the scatter plot, we identified five different classes, whose average reflectance spectra are shown in Fig. 2d. Fig. 2b reports the spatial distribution of the identified classes, clearly exhibiting the different structures of the two leaves with an excellent spatial resolution.

For a further analysis and demonstration of its excellent sensitivity, Hera Iperspettrale was also employed to measure the fluorescence hyperspectral image of the optical emission of the same leaves, upon excitation with a UV LED (760 mW @ 405 nm) placed at 20 cm distance from the scene. The weak fluorescence signal was collected using a long-pass filter at 500 nm wavelength to filter out the more intense excitation light. Despite the extremely weak signal, the quality of the data is excellent and in good agreement with the literature. A classification algorithm identified two main spectral components in the image, spatially distributed as represented in Fig. 3a. The average fluorescence spectra relative to the areas delimited by the black rectangles in Fig. 3a are shown in Fig. 3b. By analyzing the spectra, it is possible to clearly distinguish the two components, with the feature around 700 nm, probably due to re-absorption, that uniquely characterizes the spectrum represented in green.

Works of art

The great advantage of this FT-based hyperspectral device in terms of extremely high light throughput can also be exploited in the study of works of art and cultural heritage, where low-illuminance conditions are recommended in order not to damage the samples. In this field, Hera Iperspettrale has already been used to investigate the attribution and the dating of paintings [6], to monitor their state of conservation and to assess their authenticity [5].

As an example, we report here the analysis of a portion of an artistic stained-glass window located at the Santo Spirito Church in Milan, Italy, realized in 1969 by A. M. Nardi (1897 – 1973). Stained glasses typically exhibit unique spectral features due to strong absorption bands located at well-defined wavelengths. Since the manufacturing process of window glass has changed throughout time, its spectral characterization is a valuable method to determine its composition and coloring agents, therefore enabling the assessment of the authenticity of ancient windows. In this measurement, the window was back illuminated by natural sunlight, and the camera recorded the transmitted light. The synthesized RGB color image is shown in Fig. 4a. Due to the back-illumination configuration it was not possible to measure a reference image of a Lambertian source. Therefore, the RGB image shown in Fig. 4a is a colored representation rather than a projection in the RGB space. A selection of images corresponding to specific wavelengths are reported in Fig. 4e – j; as expected, each tile absorbs at specific spectral bands. An automatic image segmentation algorithm was performed to extract the different characteristics of the blue tiles. This algorithm is based on ‘k-means’ statistical analysis of the measurement. The blue colored tiles were assigned to five classes with different spectral transmission as shown in Fig. 4c – d. The spatial distribution of these classes is shown in Fig. 4b. Interestingly, despite very similar RGB colors, these classes show peculiar spectral differences. This is especially evident by looking at class number 3. Indeed, the tiles belonging to this class are strongly absorbing in the NIR spectral region. This is a very different behavior with respect to all the other classes. This might suggest that these tiles were added later to the artwork, maybe as a replacement for broken ones.

Towards the infrared

As the CPI employed in the Hera Iperspettrale works in a broad spectral range, from the ultraviolet to the short wavelength infrared (SWIR) region, the presented hyperspectral system can be straightforwardly extended to the infrared range using a suitable detector and objective. The Nireos team is already working on this development, and the first measured infrared hyperspectral image is presented in Fig. 5. The measurement was performed on a specially bruised apple, employing a monochrome SWIR camera as sensor. Fig. 5a shows a standard RGB picture of the sample, in which it is not possible to detect any sign of damage. The damage was also not detectable by analyzing

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the hyperspectral image obtained using the Hera Iperspettrale in the standard 400 – 1000 nm spectral region. However, the classified image obtained from the hyperspectral data in the 800 – 1700 nm range, reported in Fig. 5b, clearly distinguishes the damaged area (colored in yellow) from the healthy portion (colored in green). The average reflectance spectra of the two identified classes are shown in Fig. 5c.

The implementation of the infrared hyperspectral system will enable the exploitation of all the advantages of Hera Iperspettrale's Fourier transform approach, such as high light throughput, high signal-to-noise ratio, and the user-adjustable spectral resolution, also in the infrared spectral region. Consequently, this development will unlock a broad range of novel imaging and sensing applications in both the scientific and the industrial sectors.

DOI: 10.1002/phvs.202100020

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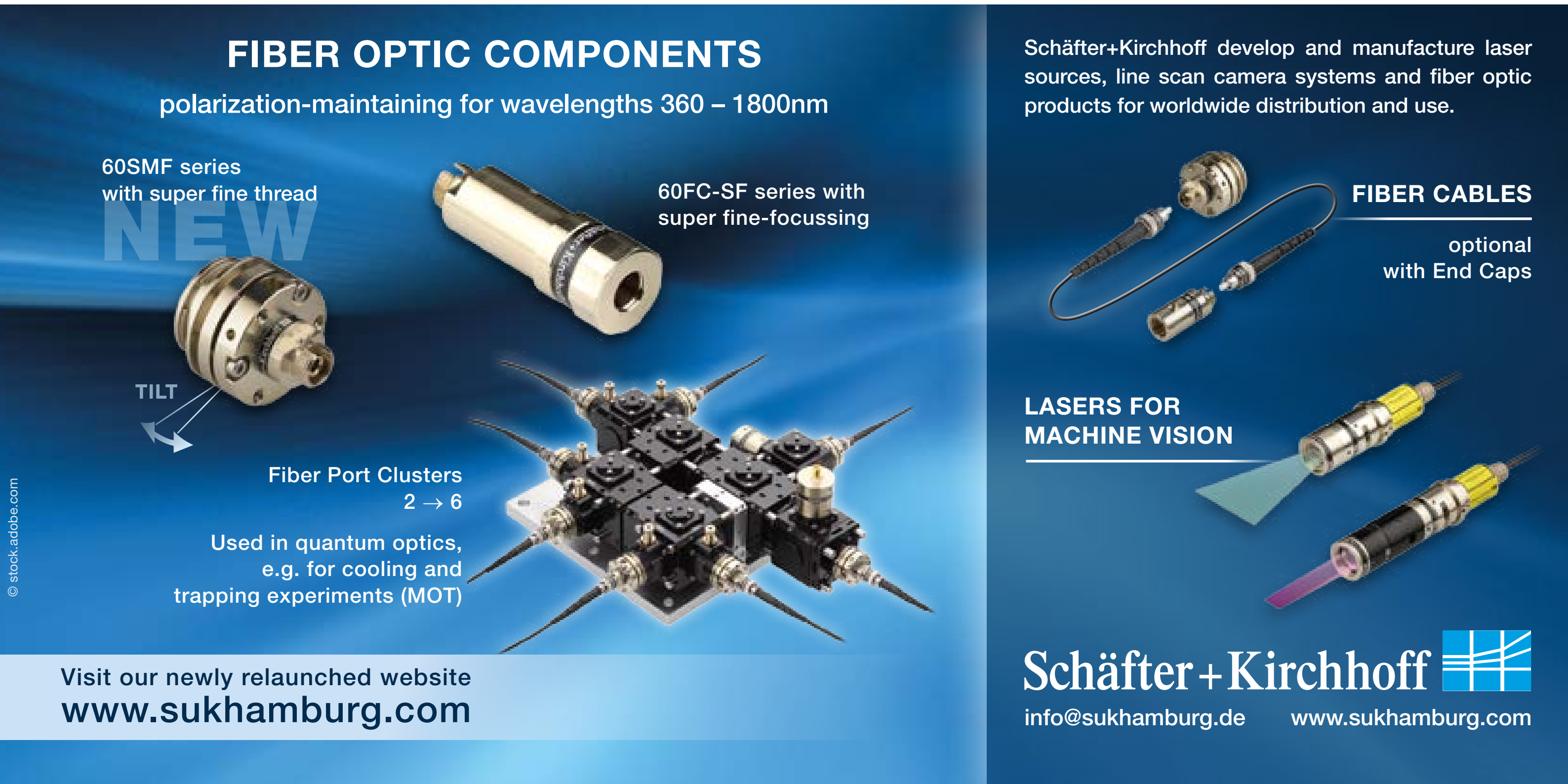

MIR Spectroscopy: The Medical Diagnosis Swiss Knife?

Accessing global information, useful for fast detection of various diseases

Hugues Tariel and Olivier Sire

Source all images: Diafir / Novosphere

For more than two decades, mid-infrared (MIR) spectroscopy appeared a promising method for fast medical diagnostics. However, some material limitations slowed down its development until the past five years. Now, the first CE-marked diagnosis solutions are coming onto the market and the future of this technology as a near-patient fast screening test looks bright.

Vibrational spectroscopy is the study of the interaction between molecular bonds and electromagnetic radiation. Mid-infrared (MIR) refers to the light spectrum of wavelengths between 2 and 25 µm. MIR is the area where bodies at room temperature radiate.

This is the reason why MIR cameras are also called 'thermal imagers', as they show warm bodies' light emission, or 'night vision cameras' as by using these bodies' emitted light they do not need ambient light to visualize objects.

The other interesting feature of MIR is that the fundamental (strongest) molecular absorptions of biological elements fall within this mid-infrared area.

As shown in Fig. 2 on the right, atomic bonds exhibit periodic oscillations within the molecule. Most carbon to oxygen, nitrogen and hydrogen bonds vibrate within the MIR area, so they generate strong absorption bands that can be observed and assigned by MIR spectroscopy. Hence, a MIR absorption spectrum reflects most of the organic elements present within a biologic sample. Any chemical or structural change within the said samples, caused for instance by a disease, affects the spectrum. These changes can then be detected and used as biomarkers of the disease that generated them.

MIR spectroscopy's major advantage is that a spectrum collects global information instead of distinct molecular targets, allowing access to a rich pool of information. It also requires minimal if no sample preparation for a measurement close to a patient. Last but not least, results are quickly provided, in an average of 15 minutes. It has however some limitations, such as a lack of sensitivity. An atomic bond may have several absorption bands, and common atomic bonds like C-H or C=0 are present in many organic molecules. Hence, MIR

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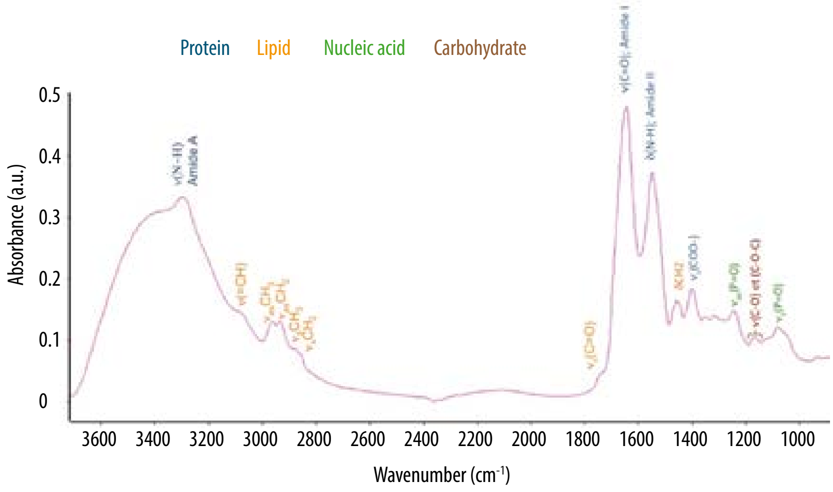

Fig. 1 Example of an MIR absorption spectrum from 3700 to 900 cm^{-1} (or 2.7 to 11 µm wavelength)

spectroscopy cannot identify a specific metabolite within complex biofluids but rather categories (cf. Fig. 1). Water also has strong absorbance around 3400 and 1700 cm^{-1} that may screen some information, so sample water content has to be minimal.

MIR spectra collect a comprehensive molecular signature from a biological sample. This global information is often seen as a metabolic fingerprint of the analyzed biofluid. It can provide a powerful biomarker of a specific disease or patient condition that alters the global metabolic status. Its simplicity and speed make it an ideal screening tool to select patients that may require further examination.

Tumors, bacteria and obviously metabolic diseases have an impact on metabolic status, and therefore significantly affect some biomarkers. Hence, potential applications are limitless and proof of concept systems are available for most cancers, chronic diseases and infections, diagnosis and prognosis. For instance, MIR spectroscopy has demonstrated its capability to quickly detect infection in most body fluids, such as synovial fluid (joints), cerebrospinal fluid (brain, spine), and ascites (abdomen). More than two hundred papers rely on MIR spectroscopy capabilities for cancer detection. However, MIR spectroscopy-based diagnosis is still very rare within hospitals. The first reason is the above-mentioned limitation of a lack of selectivity, so diagnosis development requires a significant number of patients for calibration, then again for validation (>300 patients). Although this may appear a small number compared to the thousands needed for drugs development, these are significant numbers for in vitro diagnosis, where development budgets are smaller and a smaller number of patients are used, if any.

Material

The second restraint to clinical development of MIR spectroscopy application has been tools' availability. MIR spectroscopy equipment has some internal limitation that prevented its use in routine clinical practice, especially for biofluids analysis. Initial dispersive spectrometers had limited power, which implied long measurement times and the use of thin samples to limit overall absorption. Fourier transform IR spectrometers were a first answer as they allowed more powerful signal capture from the samples. However, measurement implementation was still cumbersome as it had to use transmission measurement in order to get a proper signal. This meant preparing thin and thickness-controlled samples between two MIR transmitting materials. The alternative was the ATR (attenuated total reflection) sampling technique, where a sample was deposited onto an IR crystal waveguide. Part of the signal was absorbed by the sample, allowing the spectrum to be recorded. This method lacked sensitivity, and moreover, ATR plates are not single-use, implying a thorough cleaning process between two measurements to avoid cross contamination. Fiber evanescent wave spectroscopy (FEWS, Fig. 4) brought some interesting improvements, however, here again simple and sensitive tools were missing for biological analysis as the main fiber material on the market are silver halogenides that deteriorate in the presence of water, the main biolog-

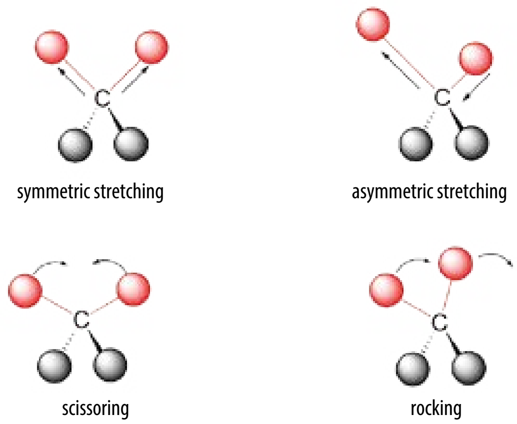

Fig. 2 Bond vibration types

Company

DIAFIR

DIAFIR was established in 2011 following twenty years of research by Rennes University laboratories. Using this unique knowledge in MIR optical material, it has developed the SPID™ platform, using patented single-use sensors, for fast near patient diagnosis. Its first applications are quick articular joint infection and NASH metabolic disease diagnoses for obese patients. Some applications are also appearing for the veterinary and agro-food industries.

www.diafir.com

Fig. 3 Spid compact platform, wasy to use near patient

ical compound element. Chalcogenide glass fiber was the next step; it made it possible to make thinner fibers, and thereby more sensitive sensors. And as a hydro-resistant and hydrophobic material, the chemical inertia of such fibers towards biologic samples is ensured.

Part of the light going through an optical fiber actually escapes from the fiber as it is reflected at the surface; it is named the evanescent wave. This part of the signal can be absorbed by a sample in contact with the fiber.

At the fiber exit, we get the initial signal minus the quanta absorbed by the medium; this yields the fingerprint.

Here again, the chalcogenide brittleness prevented their development. Encapsulated chalcogenide glass fiber sensors, coupled to an uncooled detector FTIR spectroscope solve this issue by providing a simple and affordable sampling method. They are disposable, and avoid any cleaning and cross contamination issues. Their sensitivity and reproducibility have been demonstrated over more than two thousand measurements.

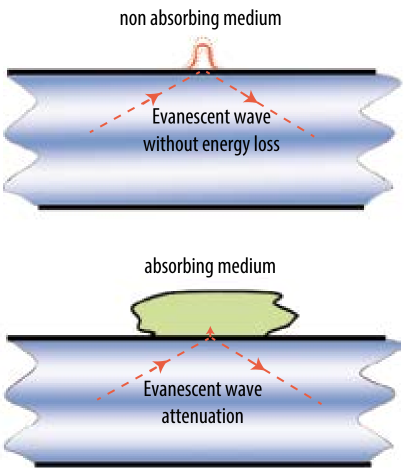

Fig. 4 Fiber evanescent wave spectroscopy (FEWS) principle

It is then possible to obtain a spectrum by simply placing a 7-µl drop onto the sensor. A dedicated, compact, touch-screen operated spectroscope has been developed to operate these sensors. It records an infrared spectrum within ten minutes after just a single one-hour training period, a process adapted to clinical practice.

To get diagnostic information out of the MIR spectrum, machine learning techniques will allow the detection of the metabolic fingerprint from a calibration subject. This requires a patient group with MIR measurements, associated to a diagnosis given by an approved method, usually the one considered as the gold standard. Algorithms such as partial least square regression, random forest, genetic ones, will then identify the metabolic fingerprint from correlated discriminant wavelengths.

To overcome the lack of sensitivity of the method, a robust group of several hundred patients is necessary. The model formula is as follows:

$$D = e^{\Sigma(\beta_i \lambda_i)} / (1 + e^{\Sigma(\beta_i \lambda_i)}) \times 100,$$

where:
D is the diagnostic score, when D is above a set threshold, the patient has a significant probability to exhibit the disease
λ_i are the significantly discriminant wavelengths selected during the learning phase
β_i are weights of the predictive model

The model gives a score from 0 (healthy) to 100 (disease). Several thresholds can be determined to help the practitioners to segregate different conditions (severely ill, probably ill, probably healthy, healthy …). The wavelengths used by the model are checked against known effects of the disease to confirm their biologic relevance. Then the model is validated against a second independent group of patients. This validation group has to be a minimum of half the size of the calibration group.

Fast detection of joint infection

Synovial fluid infection, or septic arthritis, is due to bacterial presence within the joint. It is a therapeutic emergency as it can evolve into septicemia leading to death, or at least create irreversible joint damage and motion loss. Unfortunately, current diagnosis by cell culture only delivers a result within about 48 hours. As a consequence, most patients with acute arthritis and fever, and hence at risk of septic arthritis, are treated with preventive antibiotic doses, delivered by an intravenous procedure. This has numerous drawbacks: for the patient, an annoying treatment, with a hospital stay, that prove useless when the cell culture result is negative. It also favors antibiotic resistance development, a long-term concern for public care. And for the community it generates unnecessary hospital and treatment costs. Here, MIR spectroscopy is a precious tool to exclude the non-septic patients within fifteen minutes with 98 % certainty, avoiding the burdens above. This demonstrates the full capability of the technique. The test is affordable, and possibly near patient thanks to the compact FTIR device, for an immediate decision. Avoiding unnecessary antibiotic treatment brings a three thousand euro saving per patient for the community and makes several days of hospital stay

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Fig. 5 Single-use mid-infrared medical sensor

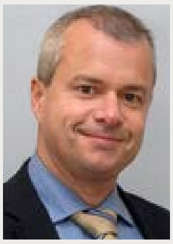
for the patient unnecessary. With more than 100,000 patients at risk yearly, the gain is obvious.

A promising future

MIR spectroscopy development will benefit from current technological evolution. Development of simpler IR spectrometers will increase the prevalence of the technology, from large hospitals to local care units. Furthermore, development of new diagnoses will allow wider use of each piece of equipment and further reduce individual test costs. And the improvement of machine learning techniques will help the search for biomarkers within metabolic profiles global information, without a priori, to develop new diagnoses.

DOI: 10.1002/phvs.202100022

Authors



Hugues Tariel, born in 1967, material science engineer (1991), MBA (1996), worked most of his international career within the special optics industry, serving the nuclear, defense and medical sectors. He founded Diafir in 2011 to produce mid infrared sensors for biological analysis and diagnosis applications. His is currently Diafir CEO.

Olivier Sire, born in 1954, PhD in fish reproduction physiology (1981), DSc in fundamental biochemistry for protein-membrane interactions (1986), senior researcher in biophysics at Université Bretagne Sud since 1996. His research interests are biopolymer self-organization and IR spectroscopy applications for health early diagnostics (hepatic, cancers). He is a former president of his university.

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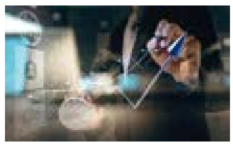

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Could Your Smartphone Analyze the Coronavirus on Surfaces?

Project Chipscope brings nano-level microscopy into the field

Koen Mortelmans

European researchers are developing a new generation of optical microscopes for mobile phones where LEDs and tiny detectors in the camera can detect very small structures. The ChipScope project is funded by the European Union's Research Programme Horizon 2020.

SMILE platform for structured micro-illumination to enhance resolution of optical microscopes (Source: QubeDot)

Optical microscopy is entering a new world. Future microscopes will be chip-sized and have superresolution capabilities. This means they will be available in everyday life, not just in specialist laboratories. And it might become possible to detect SARS-CoV-2 and other viruses using a smartphone.

"This use of chip-integrated nanoLEDs will revolutionise the way science and applications related to optical microscopy will be done in the future," says Angel Dieguez, professor at the University of Barcelona, Spain. "It can be used to investigate extremely small structures such as viruses, DNA or living cells, almost anywhere and in real time."

The resolution of conventional light microscopes – still standard equipment in laboratories – is limited by diffraction: they cannot resolve structural features smaller than about two hundred nanometers. Until now, all technologies for going beyond this limit rely on complex setups, with bulky components and advanced laboratory infrastructure. They are not suitable for mobile research devices used in field or in remote areas.

The University of Barcelona is a partner in ChipScope, a project supported by the EU-programme FET – Future and Emerging Technologies; now part of EIC Pathfinder – which is developing an array of nano light emitting diodes (nanoLEDs) with individual pixel operation [1]. LEDs smaller than the diffraction limit will be used

Source: private

Prof Dr Angel Dieguez
Departament d'Enginyeria Electrònica i Biomèdica, Universitat de Barcelona

as light sources for a microscope, which will be integrated on a chip. "This will lead to extreme miniaturization and simplicity for superresolution microscopy," Dieguez remarks.

The project's members are universities and research centres as well as small and medium sized enterprises. They intend to integrate the nanoLEDs into a real-time imaging device. Several European industry leaders in imaging and microscopy are represented on an advisory board.

Dieguez explains: "In conventional optical microscopy, the area that needs to be analyzed is illuminated simultaneously, collecting the light which is scattered from each point of the sample with the human eye or the sensor of a camera as a sensitive detector. Our idea, however, is based on a structured light source with tiny, individually addressable elements. The sample is put on top of this light source. Whenever single emitters are activated, the light propagation depends on the spatial structure of the sample."

"This is very similar to shadow imaging in the macroscopic world. To obtain an image, the overall amount of light which is transmitted through the sample region is sensed by a detector, activating one light element at a time and thereby scanning across the sample space."

The nanoLEDs, which are the first with individually addressable pixels in the submicrometer range to become available on a commercial scale, are

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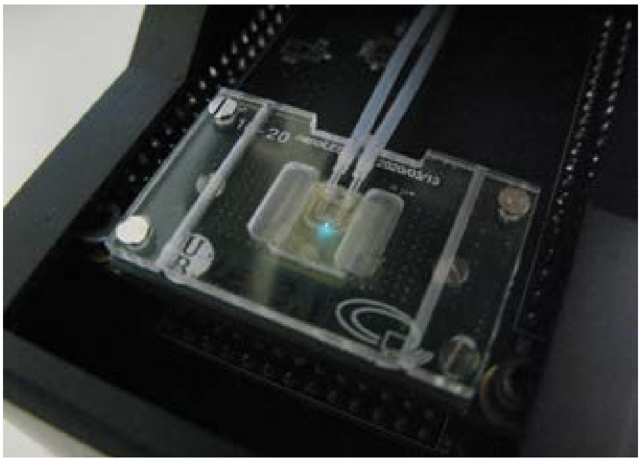
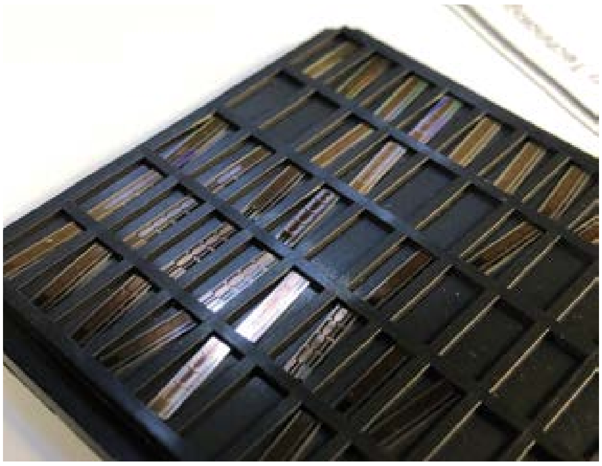


Source: ChipScope

Detail of the microfluidics over the nanoLED array with one LED switched on



Source: ChipScope

LED driver chips to control the nanoLED array

being developed at the Braunschweig University of Technology, Germany. "They are based on gallium nitride, a semiconductor commonly used for blue and white LEDs."

Dieguez' own team in Barcelona constructed the light detectors: "We now have a prototype device to conduct further experiments. Other projects will be tasked with making a marketable microscope. I don't have a time scale in mind, but I'm convinced that this will revolutionize the microscope market and the ways to do field research. With chips instead of lenses, the devices will be very mobile extremely cheap. They also can be integrated into existing tabletop systems."

Taking the approach even further

Joan Daniel Prades, also a professor at the University of Barcelona, coordinates the project 'Scalable Structured Micro-Illumination Light Engines', SMILE, which is using the outcomes of ChipScope. The researchers are developing microLED devices that can bring innovation in microscopy and other research fields such as DNA chip fabrication and optogenetics.

Particularly for optical microscopy, the researchers see possibilities to study the properties of large quantities of substances. "We try to combine holography and chip-based technology with microscopy to allow transparent cells to be visualized with classic cell culture plates. Today, we have a prototype that allows a resolution of 256 pixels per inch, which is available through our start-up partner QubeDot in Braunschweig, Germany. The project's goal is to obtain 2,000 pixels."

Another application is the fabrication of DNA biochips. Prades explains: "DNA chips or DNA microarrays are an important tool for gene expression analysis. These chips consist of a solid surface with a collection of single-stranded DNA fragments [which is the known sequence, ed. note]. The DNA samples that need to be analyzed [the unknown sequence, ed. note] are fluorescently labelled and fixed onto the chip." The complementary binding between the known and the unknown sequences is then analyzed.

Thanks to the microarray technology, the researchers can get information on thousands of genes simultaneously with just a single DNA chip. "A similar application already exists with lasers. However, these produce DNA samples point by point, whereas DNA chips will perform this task by blocks, which means they work much faster," Prades continues.

The project also aims at bringing innovation into optogenetics, the biological technique that uses light to activate of deactivate individual neurons or neuronal networks in the brain of living animals by shining light on them. Up to now, complex fiber-optic systems are used to do this. "The time to generate a pixel and switch to the next one will be less than ten nanoseconds, at a full frame rate of one megahertz. So, the planned systems will encompass relevant existing restrictions regarding the maximal frequency of activation, minimum spot size and maximal power output. In addition, conventional microscopy systems are very costly and not readily available, leading to restrictions in the number of experiments to be performed per time, which limits scientific progress."

Source: private

Dr Joan Daniel Prades
Departament d'Enginyeria Electrònica i Biomèdica, Universitat de Barcelona

Photolithography is another field of application: "Manipulation technologies enabled by large computing capacity allow high replication throughputs as demanded for in industrial micropatterning," Prades remarks.

The project is one of the EIC Transition to Innovation Activities, which aim at bringing innovative FET technologies to a level of development for business creation. "An end-user board, with experts from various branches – multinationals, SMEs and interdisciplinary research institutes – will perform tests and validations for quickly increasing markets with the prototypes we are going to make available in five pilot applications," Prades concludes.

*

Text: Koen Mortelmans, freelance journalist, Belgium, on behalf of FETFX (www.fetfx.eu).

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[1] "A New Approach to Optical Microscopy", PhotonicsViews **17** (2020) 3, 17, June / July

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Flow Cytometry for Immunology Research

New multiwavelength engines support medical applications

Ingo Waldeck and Matthias Schulze

Source all images unless otherwise noted: Coherent

The fight against the current Covid-19 pandemic highlights the need for, and benefits of 'personalized medicine'. This is driving a growing demand for more detailed analysis of disease pathology as well as patients' individual immune system characteristics and hence predicted disease progression and optimum treatment. One of the consequences is that clinical labs and research facilities are looking to increase performance and usage of multiparameter flow cytometry as a key tool to analyze the cellular components of the immune system. In response, Coherent is supporting faster instrument development and increasing the number of parameters in two ways – integrated multiwavelength OEM subsystems, and new laser wavelengths in the ultraviolet, all with output beam parameters optimized for common flow cytometry platforms.

Personalized medicine refers to medical treatment that is optimized to match the genetic/proteomic profile of both the patient and the disease strain. It is already widely used in oncology, where many new drugs are highly effective, but usually only for tumors with particular genetic characteristics and mutations. The ongoing pandemic has provided further impetus for personalized treatments; specifically there has never been a disease with such a wide and continuous spectrum of outcomes, in addition to the growing recognition of a broad set of long-term symptoms and complications.

Researchers and clinicians have already identified several correlators for enhanced risk of disease severity, including age and obesity. But it is clear that immune system genetics also plays a key role, where a twenty-something patient may die and yet a sixty-something patient may be asymptomatic. Considerable effort is being directed at identifying what genetic markers and immune system characteristics indicate who will likely progress to a serious illness and who will not. This would hopefully enable the appropriate treatments to be reserved and deployed for only those who need them and will benefit from them.

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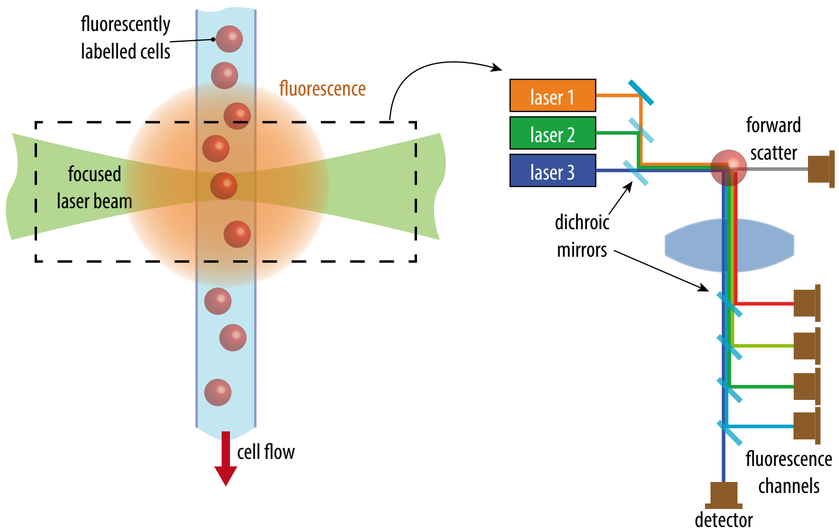

Fig. 1 The use of several lasers and fluorescence detection channels enables a single instrument run to analyze for multiple simultaneous parameters.

There are two parts to successfully addressing a disease like cancer or Covid-19 with a personalized medicine approach. First is the extensive research needed to identify what markers correlate with disease outcome. The second part will then be the targeted clinical analysis (pre-screening) of patients, presumably focusing on high-risk age groups and those with pre-existing complications. The frontline tools in both efforts will be DNA sequencing and flow cytometry. An excellent example of the value of flow cytometry was published early in the pandemic by researchers in Australia who repeatedly performed highly detailed blood analyses over the entire disease progression for a hospitalized patient with non-severe Covid-19 [1].

Flow cytometry background

Flow cytometry is a widely used method to analyze (count) and/or sort cells, sperm and other bio-entities according to one or more distinct parameters. This entails forcing the cells to pass in single file through an interaction zone, often using a flow conformation called hydrodynamic focusing. In this zone, the cells are then sequentially irradiated by one or more focused laser beams – see Fig 1. The resultant scatter and (Stokes-shifted) fluorescence is collected by optics and separated by cut-off and bandpass filters into discrete wavelength bands. Light in each band is then quantitatively measured using a photodetector such as an avalanche photodiode (APD). For example, in blood cell analysis applications in research and clinical laboratories, the cells are treated with fluorescent labels (fluorochromes) that are bonded to antibodies targeted at specific antigens on the outer membrane of the cells. For every cell that passes through the interaction zone, analysis of the relative intensities in the wavelength bands can be used to count the population as a function of different parameters, typically using multivariate parameter analysis. In addition, scatter at key angles can be measured to determine information about cell shape.

For some research applications such as oncology, immunology and drug discovery, flow cytometry can also be used to sort cells, i.e., to selectively collect a target type of cell while discarding all the others. In a sorting instrument, the flow passes through a nozzle prior to the interaction zone that ensures the cells are individually held in tiny droplets which pick up a small static charge from the nozzle. Electrostatic plate electrodes are then activated to create a field that deflects the charged droplets into a collection tube, according to the cell type registered by the instrument's computer.

New UV laser wavelengths support trends in research

Covid-19 is but one example of the need to maximize the number of parameters in order to obtained more detailed information in research applications. This need can be met by including more excitation wavelengths in the instruments, in tandem with new fluorochromes that match these wavelengths. However, the entire visible spectrum is now well covered with smart plug-and-play laser wavelengths such as the OBIS series from Coherent. As a result, both

Fig. 2 Two new UV laser wavelengths (349 nm and 360 nm) are now available as part of the OBIS family of compact lasers.

Company

Coherent

Founded in 1966, Coherent Inc. is one of the world's leading providers of lasers and laser-based technology for scientific, commercial, and industrial customers. With headquarters in the heart of Silicon Valley, California, and offices spanning the globe, Coherent offers a unique and distinct product portfolio and services that touches scientific research, instrumentation, microelectronics, and materials processing.

www.coherent.de
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Fig. 3 The use of several lasers in a single instrument involves numerous adjustable optomechanical components which must all be specified and aligned by the instrument builder (left; source ACEA Biosciences). A self-contained multiwavelength light engine with independent adjustment of each wavelength can replace all these standalone lasers and optomechanics (right).

instrument builders and laser manufacturers have identified that the only way to significantly increase the number of parameters is to extend the wavelength bandwidth – into the near-IR and, more importantly, into the ultraviolet.

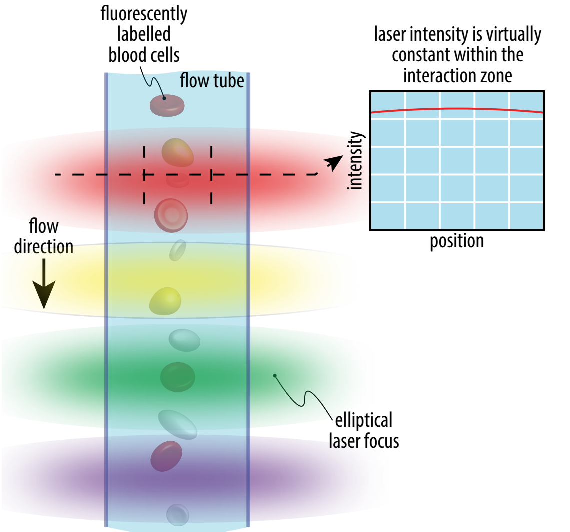
Research instruments typically require a few tens of milliwatts at each excitation wavelength. For integration into the confines of a multi-laser flow cytometry instrument, a compact laser package with low power and thermal budgets – i.e., high efficiency – is also highly desirable. Unfortunately, most UV lasers have been based on frequency tripling (to 355 nm) which limits their efficiency.

In response to the need for more efficient ultraviolet lasers, Coherent recently introduced two additional laser wavelengths to their family of compact plug-and-play lasers. These OBIS XT lasers feature 349 nm and 360 nm wavelengths with a choice of 20, 60, or 100 mW of output – see Fig. 2. They are diode-pumped solid-state (DPSS) lasers based on frequency-doubled praseodymium (Pr) technology. Previous attempts by the laser industry to commercialize this technology met with limited success, because Pr presents some unique laser challenges, particularly in the area of reliability. However, Coherent engineers have developed proprietary solutions that now overcome these limitations. Moreover, these UV lasers are electrically efficient with a correspondingly low thermal load, and can thus be produced in a compact OBIS-style laser package that supports simple integration as discrete lasers, or alternatively in turnkey multiwavelength OEM light engines – see below. Just as important, the lifetime and reliability is similar to existing OBIS laser wavelengths based on OPSLs and diode lasers, with the same low noise characteristics. And like other OBIS lasers, they provide the same electronic interface and have the same output beam characteristics: the standard 0.7 mm TEM_{00} circular beam long used in flow cytometry, as well as identical specifications for beam pointing, beam circularity, etc.

These new 349 nm and 360 nm lasers serve as direct replacements for 355 nm lasers, exciting a similar set of fluorochromes, but in a smaller package with lower heat generation, lower power consumption and lower output noise. In addition to these advantages, some early adopters are stating a preference for 349 nm because it may also excite short wavelength fluorochromes more efficiently than 355 nm. Other users indicate they are interested in the 360 nm wavelength since this offers the extra advantage of better transmission through BK7 glass than 355 nm.

New multiwavelength engines support multiparameter clinical instruments

Moving now to the clinical side of things, this push for personalized medicine is creating a demand for multiparameter flow cytometry instruments with high throughput and market sustainable costs. Coherent is supporting faster and more economical development by providing completely integrated multiwavelength light engines called the CellX series, which incorporates multiple OBIS lasers – see Fig. 3. Here all the lasers, electronics and beam shaping and focusing optics are housed in a single module to streamline the development of multiparameter instruments. These off-the-shelf, standard engines are currently supplied with the four wave-



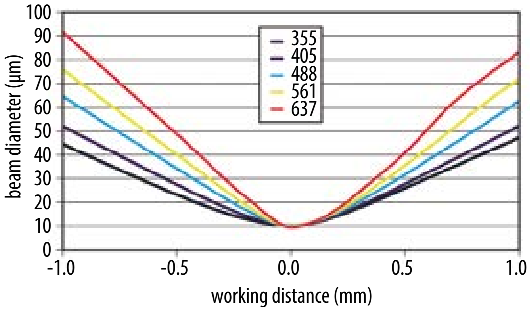


Fig. 4 Integrated light engines include the lasers and optics required to produce up to four focused beams, with the focal distance, shape and location of each beam independently set by the instrument builder. The optics are optimized for both visible and UV wavelengths.

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lengths most commonly used in multiparameter instruments: 405, 488, 561, and 637 nm. (Importantly, all the optics are already compatible with the new UV laser wavelengths, in anticipation of future market demand.) Instruments typically use the laser beams as a series of elliptical foci – see Fig. 3 – where the short axis maximizes the instrument's time resolution and the broad lateral axis minimizes sensitivity to changes in cell positions as the cells traverse the interrogation points.

These integrated light engines are designed to offer highly flexible output to support different instrument designs. Removing the cover provides access to simple, precise, independent adjustment of each of the four beams, and enables the separation between the staggered beam spots (see Fig. 4) to be varied from zero (i.e., co-aligned) to ±250 µm. The x and y ellipse dimensions can also be independently adjusted for each wavelength. Thus, the shape, size and position of each of the four focused laser beams can be adjusted to exactly match the geometry of a specific instrument. In addition, each of the four lasers is independently addressable and controlled through a standard USB connection.

There are several advantages to this new type of module. First, by outsourcing the beam conditioning and laser integration, the instrument builder cuts development costs and shortens the time to market while also minimizing performance risk. And second, this integration provides cost-reduction through consolidation of hardware and electronics – for instance by using a single laser controller board, common power supply and single I/O connector. Moreover, outsourcing the photonics technology allows the instrument builders to focus on fluorochrome chemistry and other key differentiators, such as novel data analysis and other features.

Summary

Lasers and flow cytometry have always involved close and synergistic co-development. Although flow cytometry has a history spanning decades, in the form of multiparameter instruments, it is currently a remarkably dynamic field in both immunological research and clinical applications, driven to a large part by the push for 'personalized medicine'. This is supported by laser manufacturers with new ultraviolet wavelengths and streamlined multiwavelength products designed to improve the performance of instruments, accelerate their development, and contain their costs.

DOI: 10.1002/phvs.202100002

[1] I. Thevarajan, T. H. O. Nguyen, M. Koutsakos et al.: Breadth of concomitant immune responses prior to patient recovery: a case report of non-severe COVID-19, Nature Medicine **26** (2020) 453–455; DOI: 10.1038/s41591-020-0819-2

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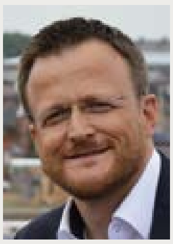

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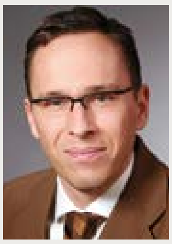

Matthias Schulze is director marketing OEM components & instrumentation for Coherent Inc. He joined Coherent in 1995 as a sales engineer in Germany and subsequently was holding various positions in marketing; first in Luebeck and later in companywide responsibilities. He holds a PhD in physics from the Technical University in Berlin, Germany.

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The Hybrid Autocollimator

Upgrading a century-old instrument technology to lead the way for modern intricate laser & optical measurements

Oren Aharon and Itai Vishnia

Source: Artem Oleshko / 123RF.com

The concept of autocollimation as an optical instrument was conceived about a century ago for accurate, non-contact measurements of angles. Since it was invented, it has developed a long history of being used in alignment of angles and optical elements. Recent novel photonics development has created a need for alignment and measurement of optics and lasers – the new hybrid technology does exactly that.

For better understanding of the technology, an optical schematic illustration of the classical autocollimator is shown in Fig. 1. The system has a light source followed by a projection reticle. The light source is an LED (usually 670 nm, IR versions were recently introduced), and after passing through the beam splitter, it enters the objective lens where it is collimated prior to exiting the instrument. Collimation means that the projected reticle is exactly one focal length away from the main surface of the objective lens. The projected collimated light is back reflected by a mirror, or other high-quality reflective surface, and is captured by the objective lens. The returned image appears in sharp focus on the high-quality CCD detector. Due to the high sensitivity of the detector, even a very faint back reflection will be captured and displayed.

Deviation of the mirror by an amount a causes deviation from the original line of sight by an amount of $2a$. Assuming the amount of deviation of the reflective surface and the focal length is denoted by f, then the mirrors' deviation is determined by the relationship: $a = x / 2f$.

From this equation it is apparent that measuring mirror angular deviation is independent of the distance between the instrument and the reflecting surface.

Deviations in azimuth and elevation can then be electronically determined and calculated by a computer. Furthermore, the results are then clearly displayed on its screen. Resolution down to 0.01 arcsec is achievable.

As a rule of thumb: the higher the f, the higher the resolution. As a result, the field of view is smaller and thus it is more difficult to acquire the reflected signal.

The electronic method offers the advantage of complete objectivity in data recording as well as a computer interface, unlike optical autocollima-

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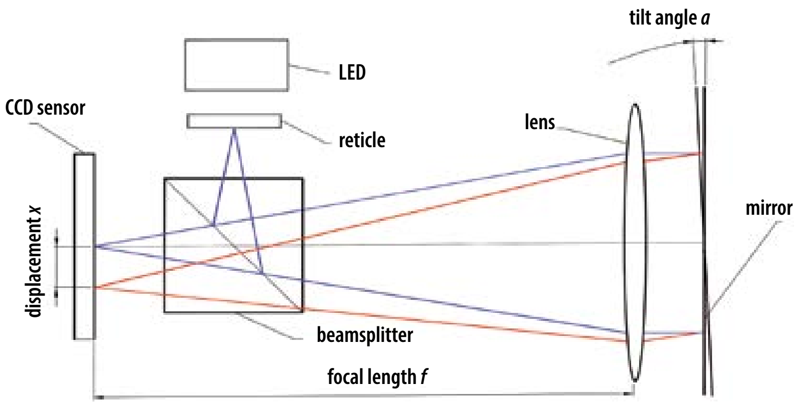

Fig. 1 Optical schematic illustration of classical autocollimator and telescope into one instrument (Source: Duma Optronics)

tors which are bulkier and less accurate.

In a telescopic application, where the telescope is calibrated to infinity, the angle of movement is $a = x / f$.

Novel hybrid electronic autocollimator

Recent technologies require many new measurements that could be performed by upgrading the fundamentals of autocollimation. This upgrade will expand the usability of the newly introduced hybrid autocollimator throughout the photonics industry. Measurements such as laser measurements, laser alignment, silicon wafer alignment, multi-laser measurements in parallel, VCSEL and inter-alignment between laser, optical axis and mechanical datum plane will be feasible. This is achieved by fusing the autocollimation concept with laser beam profiling and accurate mechanics. Measurements such as laser angle measurements, positioning, parallel characterization of multiple lasers and relative deviation between mechanical datum to laser systems are feasible. So implementing leading-edge technology into the autocollimation concept can add functionality and revive this century-old technology. Duma Optronics did just that, fusing together some exciting technologies into the existing electronic autocollimator. Features such as motorized focusing, built-in laser beam profiling, multiple laser beam characterization in parallel, multiple illumination wavelengths for crosshair and fast processing up to 1,000 fps have culminated in a totally new instrument. This instrument will serve new applications in laser production, alignment, car lidar, MEMS mirrors, optical fibers, measurement and characterization of VCSEL arrays (used for 3D face recognition) and many more.

A novel autofocusing electronic autocollimator was developed that is capable of repeatable motorized focusing at different distances. Progress in laser analyzing instrumentation development allows implementation of this technology into electronic autocollimation. Until recently, measurements of mirrors or the mechanical datum plane relative to a laser beam was a daunting task. The focusing feature with accurate line-of-sight retention allows angle and position measurements of mirrors as well as laser beams and laser beam collimation. Multiple new applications will be demonstrated such as the centering of wafers using lasers, the alignment and centering of mirrors, the alignment and centering of VCSEL laser arrays, etc.

Autocollimator technological improvement fundamentals

The concept of autocollimator improvement is based on several building blocks such as multisource illumination, an automatic focusing knob, a fast CMOS sensor, and a software upgrade to provide modern high-tech laser optical and mechanical application.

The use of multisensors integrated into one advanced autocollimator as an alternative to conventional usage of several measuring instruments to perform an intricate alignment or measurement solves many problems in day-to-day applications. The major upgrade is the unique combination of a laser beam profiler integrated into the autocollimator measuring capability.

Company

Duma Optronics

Duma Optronics specializes in photonics-related instrumentation, with a lineup of several categories:
- Beam analysis systems (beam profilers, M^2 meters, and divergence meters)
- Optical beam positioning
- Alignment measurement systems
- Electronic autocollimators
- High power laser beam profiling

We combine a vision of innovation, a wide spectrum of technical disciplines, and custom-made capabilities. Everything can be done!

www.dumaoptronics.com

Company

PLX Innovative Optical Systems

For the past 60 years, PLX has been at the forefront of developing high-quality monolithic optics that can withstand and perform under the harshest environmental conditions and maintain their accuracy over time. PLX assemblies can be found in applications throughout the world. PLX's proprietary, monolithic optical structure technology (MOST™), integrates complex optical elements into compact monolithic structures, achieving exceptional accuracy and stability. PLX instruments are applied in boresighting, beam alignment and delivery systems, laser tracking, military fire control, environmental monitoring, and satellite ranging. To meet the demands of a new generation of optical requirements, PLX is now offering total subsystem and system integration.

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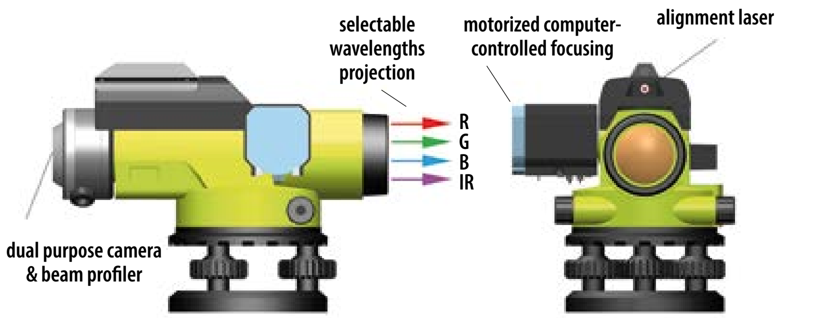

Fig. 2 Schematic illustration of hybrid technology including RGB+IR illumination and built-in motorized focusing (Source: Duma Optronics)

This is complemented by the unique motorized focusing of the autocollimator, which in turn forms a multi-wavelength autocollimator from visible to NIR and beyond. All the optical elements including multiwavelength sources are precision mounted and the entire instrument is rugged and stable, providing very accurate beam pointing and robustness for various applications. By maintaining the alignment of the beam profiling device with the autocollimator's line of sight, a new application field is available for integrating and aligning lasers with optical elements and telescopic sights. Moreover, by integrating multiple independent beam profiling measurements from one sensor, a leap forward is achieved for performing measurements of VCSEL arrays and their alignment to specific optical assemblies.

At first glance, the multitask autocollimator looks similar to its predecessor, but its sensory system has been greatly upgraded as follows:

- A dual-purpose camera sensitive from deep UV to NIR is used as an autocollimator sensor, as well as a beam profiler
- Multisource illumination will project a cross line with different colors to create multiple crosses, adaptable to specific needs
- The motorized, computer-controlled focusing will automatically adapt itself to compensate for the difference created by the projection of different wavelengths
- By flipping the software application, the autocollimator will transform itself into a beam profiling telescope, accepting various laser beams to be analyzed for direction and divergence
- Yet another functionality created by the software will enable accurate measurements of a laser's M^2 numbers
- The motorized focusing will allow the autocollimator to focus at pre-calibrated distances, controlled by software
- A built-in alignment laser will point the line of sight's direction in a clearly observable way, facilitating fast and accurate alignment.

In practice – hybrid electronic autocollimator

The range of applications for laser beams in conjunction with optical elements is extremely diverse in such areas as medical technology, semiconductors, the automotive industry, manufacturing equipment, mechanical alignment, face recognition, autonomous driving and more. The flexibility that this new hybrid automatic autocollimator offers will solve challenging development hurdles in an exceptionally wide range of applications. A list of typical applications is discussed below. However, new approaches are created where efficient and flexible implementations take advantage of the hybrid autocollimator.

The latest flagship cellphone devices will probably implement 3D sensing modules for face recognition. One of the most promising technologies, already incorporated in iPhones, is based on VCSEL technology, where multiple laser beams are directed at the user's face and picked up by a second camera to create a 3D recognition pattern (image p. 60).

Others, such as Samsung, Huawei and Sony, will also implement similar technologies. Some will go an additional step further by equipping both cameras – front and back. Moreover, the structured light and time of flight are great candidates to determine depths and 3D patterns with extreme precision for autonomous driving. From the measurement point of view, there is a need to check alignment between mechanical mounting surfaces or the lasing chip surface in each laser direction. This hybrid technology can fulfill this purpose, for example by measuring mechanical surfaces with the autocollimator features, and a laser's direction with the same instru-

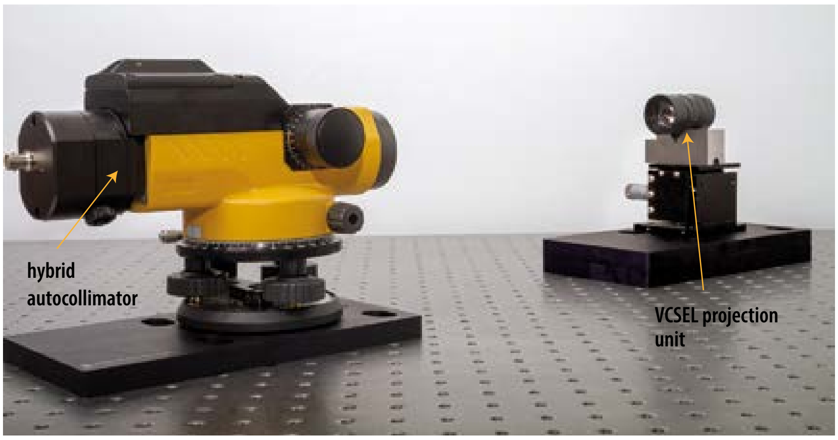

Fig. 3 Photographic layout of measuring application of collimated VCSEL array performance (Source: Duma Optronics)

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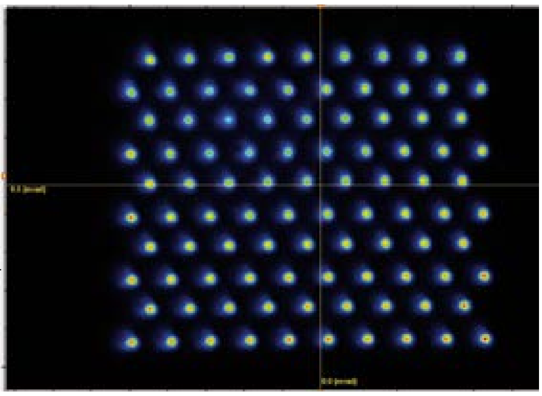
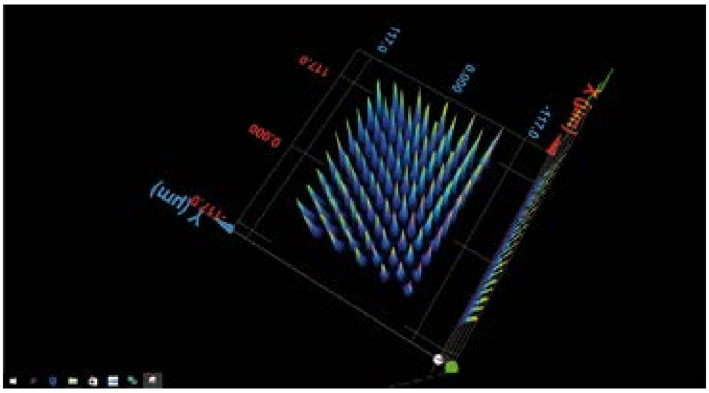


Source: Duma Optronics

Fig. 4 A typical representation of a VCSEL array from the autocollimator software



Source: Duma Optronics

Fig. 5 3D screenshot from the hybrid autocollimator analyzing software representing the VCSEL and their relative power levels

ment in the appropriate measuring mode. Those relative measurements can be compared to each other and used in the QC of the system.

Traditional applications of autocollimators can also benefit from this new technology by combining laser technology in parallel with the autocollimation function – such as for centering, alignment and straightness measurements. The implementation of special technologies, such as PLX's lateral transfer hollow periscope LTHP, could also be used for boresighting and multiple line of sight alignment in conjunction with the autocollimator's hybrid technology.

Establishing multiple lines of sight

A modern test case will be to establish the accuracy of a VCSEL multi laser direction in space, along with establishing the reference mechanical line of sight. A setup performing this measurement is shown in Fig. 3.

Here we see the hybrid autocollimator where the optical VCSEL unit is positioned in such a way that lasers are projected towards the autocollimator input aperture. In this arrangement, we would like to perform two main measurements:

- To align the projector mechanical axis to the autocollimator's axis.
- To measure the relative position of the lasers to the mechanical axis and in between.

One can adjust the autocollimator to the mechanical axis by placing a mirror on top of the mechanical axis. Secondly, by using the hybrid autocollimator in the beam profiling mode, the VCSEL array position relative to mechanical axis can be determined, as well as the projection angles of each laser in the array.

In the following screenshots, the cross represents the mechanical axis as recorded by the autocollimator mode, with the VCSEL lasers projected to infinity by the optical element. We can clearly see the separation between various VCSEL sources, and measurements such as the beam size of each laser, its location, and relative power are available from a special software package. This will enable automatic assessment of the system's performance.

To guarantee eye safety, 3D reconstruction capability and the reliability of VCSEL (or other collimated) laser arrays, a lab measurement is essential and should be performed with high precision. A one-shot solution is offered by using the hybrid autocollimator technology, obsoleting such devices as optical goniometers and power meters. The profile of each laser on the array is easily examined, and comparative measurements of power and beam profile size are observable and can be analyzed. A spatial characterization of the VCSEL system is achieved by using this hybrid technology. The spatial regimes of a collimated VCSEL assembly, including emission patterns in the far field, are defined. This very accurate method rivals and surpasses goniometric measurements which are very tedious and time consuming. This is therefore an alternative to goniometric measurements and offers a solution suitable for mass production. However, for a specific application, it is advisable to precalibrate the measurement system for consistent and accurate results.

Conclusion

Hybrid technologies have the potential of satisfying the requirements of several technologies, such as alignment, the spatial characterization of lasers and beam profiling of multiple single emitters. This analysis process provides the angle-dependent spatial resolution patterns of light sources in respect to a mechanical datum plane, an adequate solution for the accurate and fast testing of VCSEL lasers. This specific application is given as an example due to the growth of VCSEL arrays applications, but many other intricate measurements involving lasers, mechanics, optical alignment and other technologies will become more generally available and relevant using this new technology.

DOI: 10.1002/phvs.202100001

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Oren Aharon has several decades of experience in the electro-optical field, including start-up initiations based on his patents. He founded Duma Optronics 25 years ago to offer advanced enabling technologies to industry. He owns thirty patents and graduated from Technion with a BSc in nuclear engineering and an MSc in industrial engineering. He has written numerous articles and served as a technical assistant to the Israeli Minister of Energy.

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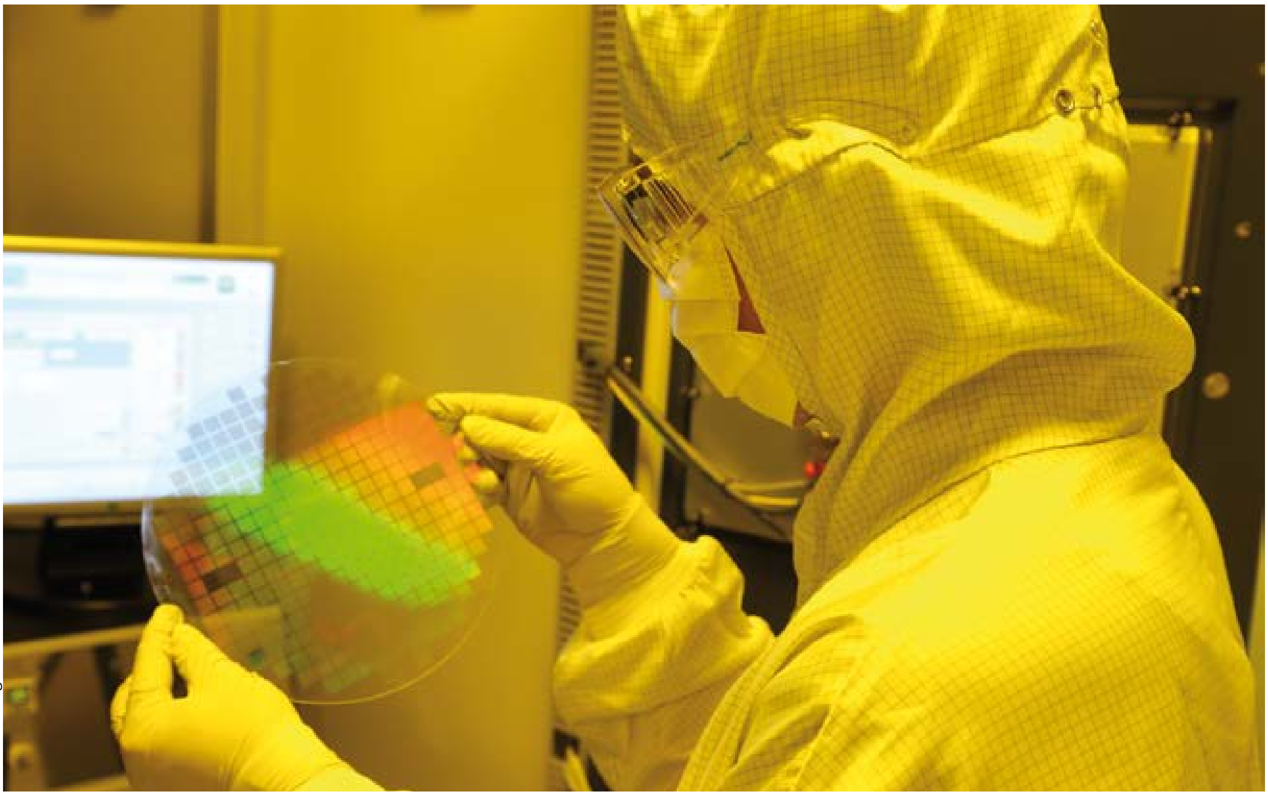
Essential Materials and Processes for Nano-Imprinted Optics

High refractive index resins for diffractive optics

Jukka Perento, Robert Roozeman, Mikko Poutanen, Janne Kylmä, and Juha Rantala



Source all images: Inkron

Optical 3D sensors and augmented reality (AR) glasses are prime application examples of the rapidly growing interest in photonics-based devices. Mobile devices are being equipped with 3D sensors for fingerprint and face recognition as well as with lidar, which is also utilized to help the navigation of autonomous vehicles. In addition, immersive AR glasses have been developed for augmented reality applications. These applications benefit from diffractive optics, whereas nanoimprint lithography (NIL) provides an affordable and reliable means to mass produce the same. The NIL-compatible optical materials with a high refractive index presented here are proven to be pivotal in enabling the commercial breakthrough of these applications.

The increasing applicability of 3D sensors and augmented reality devices coincides with the need for high refractive index (hereafter: RI or *n*), NIL-processable optical materials. This has both technical and commercial reasons. One of the dominating technologies for AR glasses uses diffractive waveguides with surface relief gratings as the in and out-coupling elements of the lenses. Waveguides are critical optical components in AR glasses that transfer the projected image from the projector at the edge of the lens to the eye of the user. Diffractive optical elements (DOEs), i.e., surface relief gratings, handle the required turns on this optical path.

For optimal performance, materials with a high refractive index are required for DOEs: a higher refractive index enables a wider field-of-view (FoV), which enhances the 'immersiveness' of the image, thus improving the user experience and thereby the commercial attractiveness of the product. Optical components made from a material with a higher RI are more effective at 'bending' or diffracting the light. Consequently, high RI components can be thinner (and therefore also lighter) than similarly performing components with a lower RI. In the case of 3D sensors

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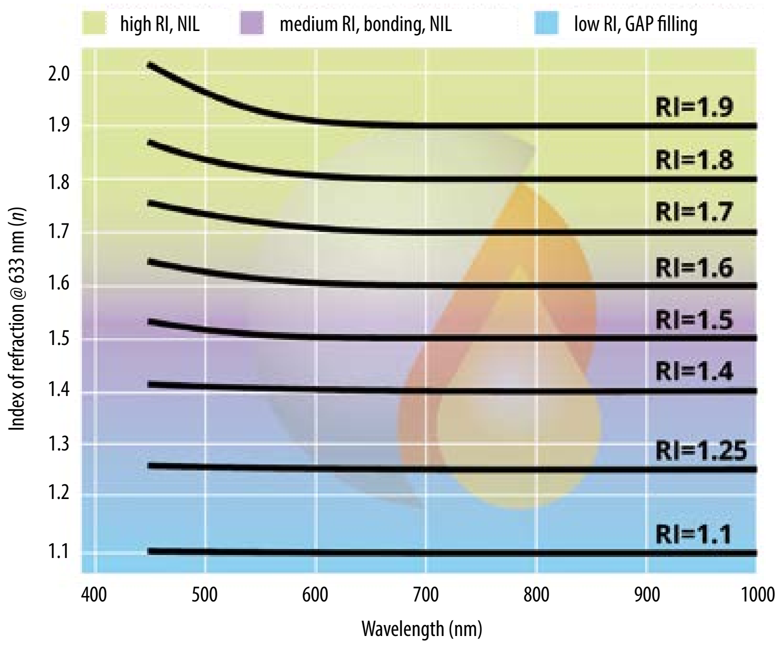

Fig. 1 Index of refraction range of Inkron optical coatings cover n = 1.1 – 1.9 at visible and NIR wavelengths.

where space is often limited (e.g., sensors of mobile devices, and in automotive applications), a higher RI material enables critical volume reductions, optionally providing a larger detection field.

NIL materials development and challenges

Responding to the demand for these kinds of optical properties, a new class of siloxane-based coating materials with a high refractive index has been introduced. The core technology is based on silane precursors and siloxane polymers designed and synthesized in-house by Inkron [1]. Siloxane polymers are a good starting point for optical applications: they can be manufactured to be optically clear, highly transparent, and unaffected by high temperatures and environmental influences. Designing and synthesizing *in-house* enables specific customer requirements to be met, already in this early phase of production. This ensures that the resin optimally fulfils the needs of the target application. Components of the polymer are modified according to the targeted need, including the monomers and the side groups used. This level of control allows fine-tuning of the molecular structure, and physical parameters like viscosity, modulus, and RI according to each given application and process.

To arrive at the final blend, resin development is complemented with specific formulation. Starting from the siloxane polymer, the final properties are determined by the additives added in the formulation stage. Functionalities typically adjusted here include curing mechanisms, adhesion, surface properties and flowability of the coating. Unfilled resin fulfils very tight optical requirements and can reach a refractive index of up to 1.6 at 589 nm (for reference: all refractive indices reported in this article are indicated at 589 nm wavelength range). To achieve higher RI values, nanoparticles with a high RI must be added to the resin. Typical examples are zirconia and titanium oxide nanoparticles. The functionalization of these nanoparticles is one of the core targets of the development process. These, together with the siloxane polymer development and formulation form the three cornerstones of the in-house development process.

The addition of nanoparticles can negatively affect various optical and physical properties of these coating materials. Parameters such as haze, scattering, and absorption tend to increase with the increasing nanoparticle loading. These effects have a negative impact on the diffraction efficiency, resulting in increased absorption and undesired attenuation of the waveguide. The haze and scatter are related to the nanoparticle size and to the particle's compatibility with the overall resin system. Larger nanoparticles, i.e. >1/20 of the optical wavelength in question, cause undesired optical scattering and haze.

Poor compatibility of nanoparticles with the resin system may introduce particle agglomeration. This can lead to similar optically undesirable effects as above as well as difficulties in mold filling and flowability within the NIL process. To minimize these effects, the nanoparticles must be carefully optimized. This means the synthesis of sufficiently small (preferably <20 nm) nanoparticles with a narrow size distribution and the selection of a correct surface functionalization that ensures a well-dispersed, uniform mixture of the particles and the polymer matrix. The surface functionalization, basically a surface-active material, must adhere well to the nanoparticle and keep the nanoparticles from agglomerating while promoting the dispersion of the nanoparticles in the resin.

In addition to the above considerations there are also process-related topics such as adhesion, flowability and thickness of the residual layer. There is a multitude of substrates with widely varying surface properties that can all affect the resin/substrate adhesion. Matching

Company

Inkron

Inkron Oy, a Nagase Group Company, develops and manufactures advanced siloxane-based polymer products for optical devices, optoelectronics packaging and printed electronics. Inkron's core technology is centered around in-house designed and synthesized siloxane polymers production combined with advanced formulation skills. Inkron has its primary development and manufacturing operation in Espoo, Finland.

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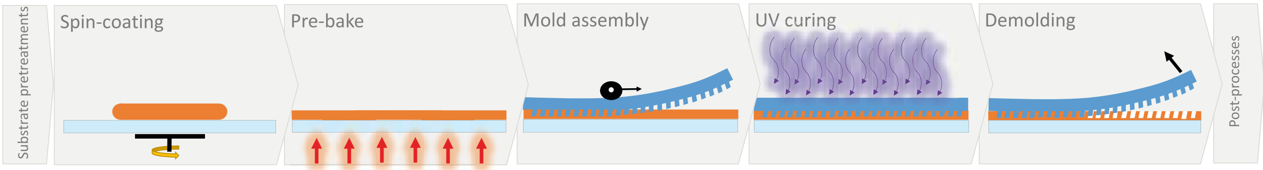

Fig. 2 Flow chart of a typical nano-imprint process.

adhesion promoters can be added to optimize the adhesion for a specific substrate. Decreased flowability can be improved not only by optimizing the resin and additive combo used, but also by optimizing the NIL process parameters. The residual layer remaining on the substrate after the NIL process is often undesired as it may reduce the efficiency of the waveguide. Apart from the mold filling properties, flowability also relates to residual layer thickness: ideally – with optimum process and flowability of the resin – all material between substrate and working stamp is used to completely fill the structures, leaving no residual layer.

A final critical parameter is shrinkage, which facilitates master design and shrinkage compensation. Shrinkage should not exceed 2 – 3 %. This all set, the product must still pass reliability tests that include exposure to high temperatures, thermal cycling, and 85 °C / 85 % RH tests, to name a few.

Optical coatings product range

Inkron has developed a range of optical coatings with refractive indices at visible and near-infrared (NIR) wavelengths as indicated in Fig. 1. Formulations addressing $n = 1.5$ and higher are compatible with nanoimprint lithography. These siloxane resin-based formulations currently reach $n = 1.9$ with good NIL processability. An NIL-processable material with $n = 2.0$ is the next development target.

The complementary, low refractive index polymers in the blue and purple areas in Fig. 1 ($n = 1.1 – 1.4$) are filler-free coatings. In the absence of filler particles, the optical properties are excellent, with good gap-filling performance on NIL-patterned high RI optical structures.

The nanoimprint lithography process

Performance of the formulations is assessed at Inkron's state-of-the-art nanoimprint lithography facility, with equipment including an EVG Smart NIL tool, coating equipment as well as a range of surface corrugation and optical characterization instruments.

Fig. 2 elucidates a typical nanoimprint process. First the optical coating is applied onto the wafer, traditionally by spin-coating. The targeted thickness is application-dependent while the total thickness variation (TTV) should be minimized. Alternatively, inkjet or

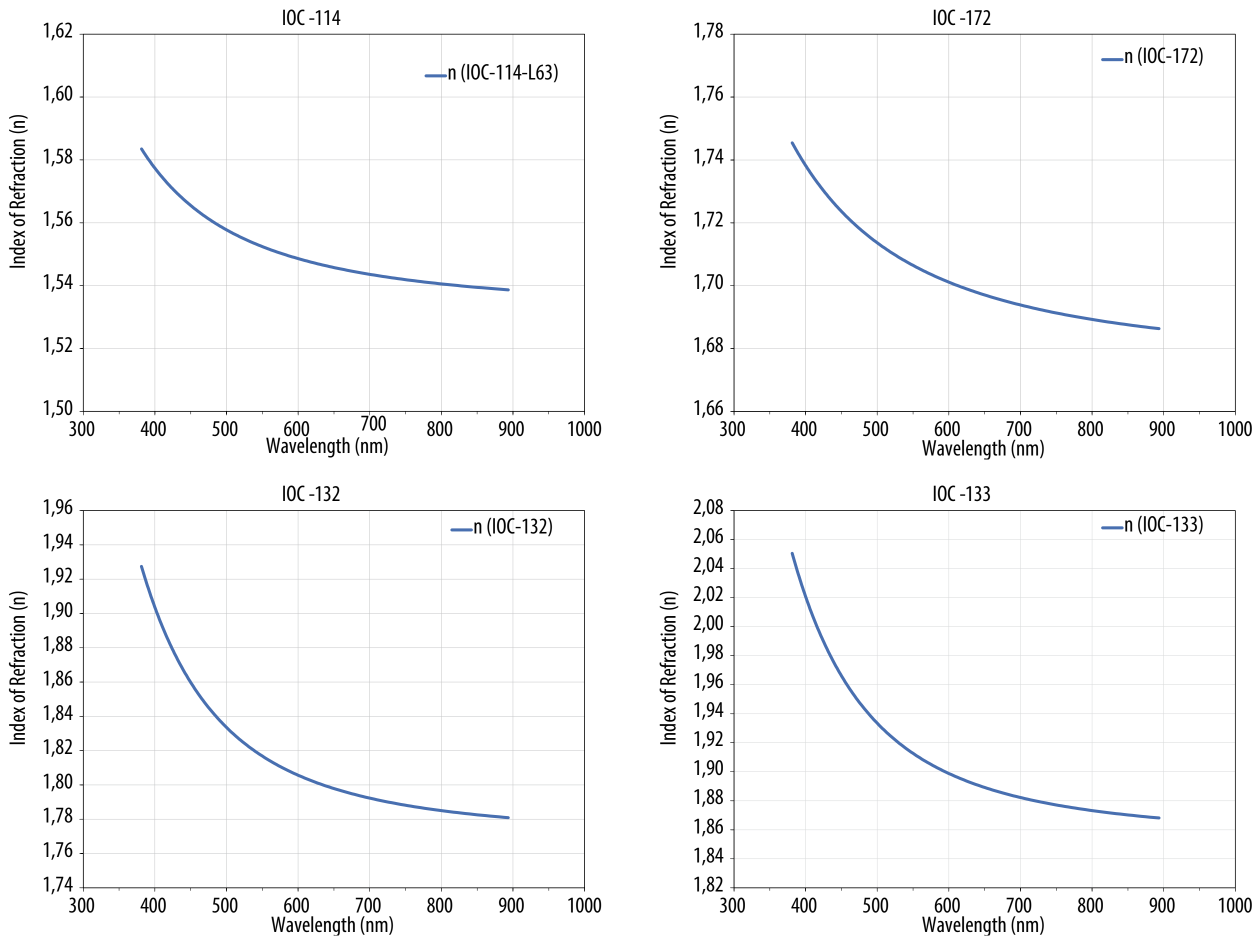

Fig. 3 Four imprintable resins and their RI measured with a Woollam ellipsometer. At 589 nm, $n = 1.55 – 1.9$.

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slot-die printing can be used to apply the resin. The coated substrate is pre-baked to remove excess solvent prior to the imprint step, typically circa sixty seconds at 80 – 120 °C. Following the pre-bake, the soft working stamp is carefully brought into contact with the resist by a roller. When the resist has filled the stamp structures, it is UV-cured with 365 nm wavelength LED irradiation. The selection of the working stamp material is based on the master design and the resin system used. Various types of working stamp materials are used. For example, soft stamp materials are beneficial when imprinting slanted gratings. After curing, the stamp is carefully released from the imprinted structure and the imprinted wafer is ready for the next process step.

High RI resin specifications

The main product families discussed here, and their nominal refractive indices, are (product name/RI at 589 nm): IOC-114/1.55, IOC-172/1.70, IOC-132/1.80 and IOC-133/1.90. It should be noted that the given refractive index is nominal and can be adjusted according to application needs. Fig. 3 presents the RI of all four products, measured with an ellipsometer.

The Abbe numbers of the same products are 38.5 (n = 1.5), 35.7 (n = 1.7), 18.8 (n = 1.8) and 16.9 (n = 1.9). Although the refractive index of the high RI products is adjusted by using fillers with a high refractive index, the optical properties of these optimized coatings, like haze and transmittance, remain at a very good level. The transmittance of blanket films of each coating system is shown in Fig. 4.

The transmittance is over 98 % (at 450 nm) and the haze value for each grade is below 0.1.

Replication

Flawless pattern quality and fidelity must be preserved throughout the whole NIL process chain, as defects caused by unfilled or collapsed structures, bad adhesion and excess shrinkage for example can cause the performance of the DOE to deteriorate. The imprintability evaluation of these resins has been performed using several master designs that include slanted gratings, pillar structures and binary structures of various kinds.

IOC-133 (n = 1.9) was evaluated with pillar structures, with pillar sizes varying from 48 nm to 300 nm, a pitch of 140 – 500 nm and an average height of 115 nm. The tests were performed on a Schott high-RI glass substrate without adhesion promoter. AFM imaging revealed excellent pattern fidelity (Fig. 5).

The maximum print depth reached so far approaches 500 nm while the maximum achievable aspect ratio depends on the design, with an aspect ratio of 3.5 having been achieved for some designs.

Test runs with the n = 1.7, 1.8 and 1.9 resins were performed using a basic test master with binary structures of varying dimensions. Evaluation was done with standard metrology tools including ellipsometry, spectrophotometry, and microscopy (optical, SEM and AFM). Table 1 shows the dimensions of the standard test working stamp. In a typical process, the wafer was cleaned, spin-coated at 1000 rpm followed by a thirty-second pre-bake (80 °C) and twenty joules UV curing dose (365 nm). The structure 'C' on the master (Table 1) pro-

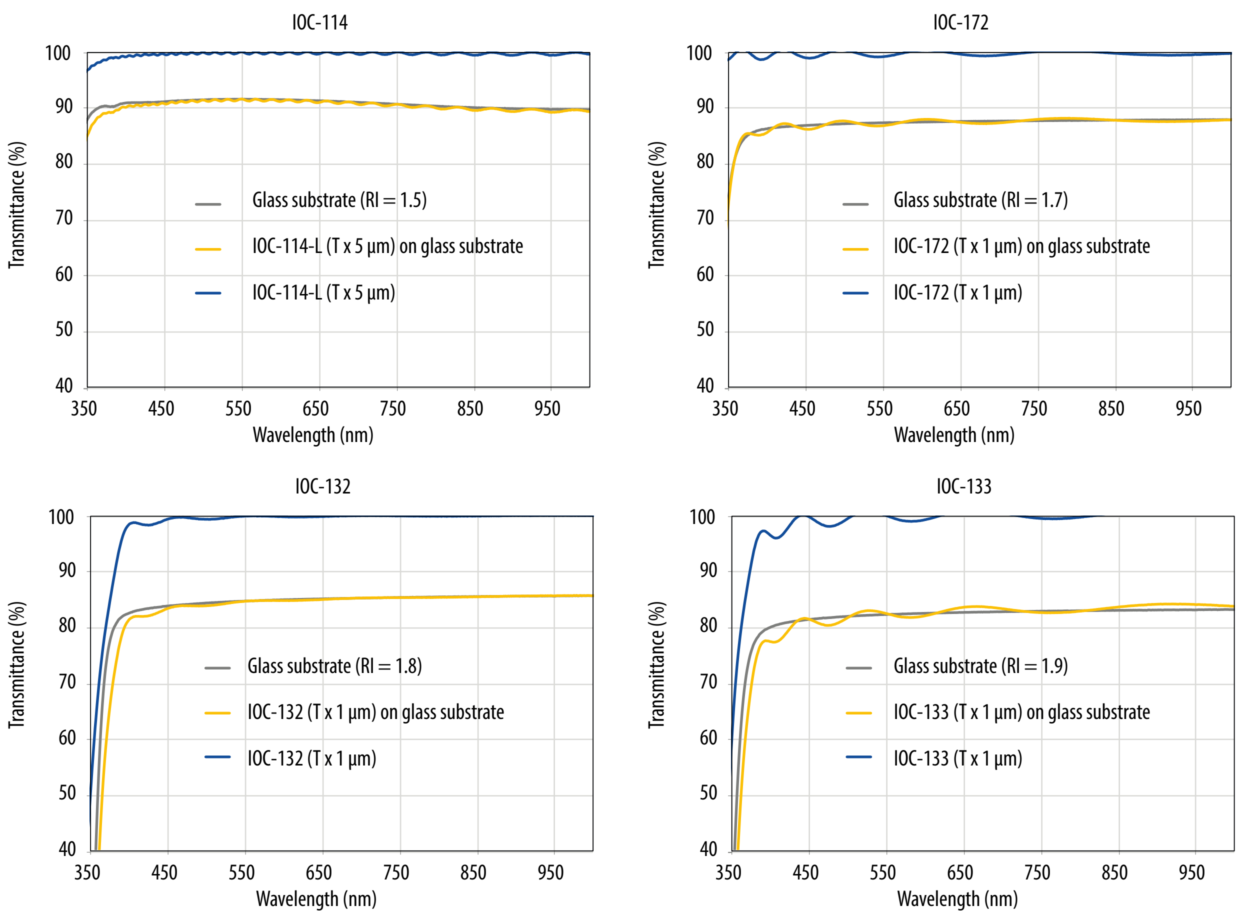

Fig. 4 Transmittance of blanket films of the four resins. The yellow line shows the transmittance of the glass substrate with the coated resin, the blue line the transmittance of the coating only. Film thickness is 5 µm for IOC-114 (RI 1.55), 1 µm for the others.

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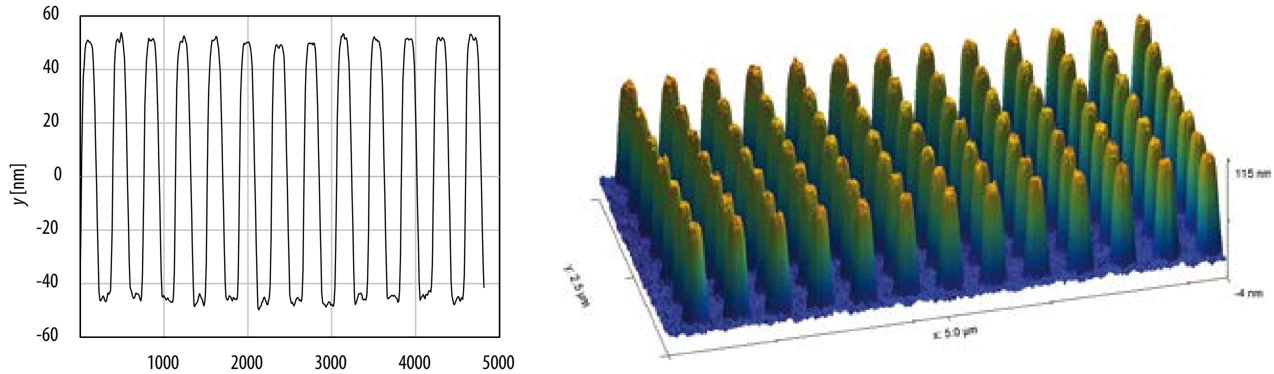


Fig. 5 Imprinted pillar (binary) structures with a 1.9 RI resin

Master mold			
Structure	Period (nm)	Line width (nm)	Depth (nm)
A	304	161	256
B	405	205	285
C	500	193	349
D	589	282	359

Table 1 Test mold dimensions and actual imprint of structure C. Resin's refractive index: 1.9

duced a sample with a 510 nm period, 189 nm linewidth and 337 nm depth, indicating a replication variation within a 2 – 3.4 % range.

A thin residual layer is often desired as it improves the device performance. Residual layer thickness correlates with the overall film thickness after spin-coating and the structure dimensions: a thinner film gives a thinner residual layer. Minimizing the residual layer is challenging, as it may lead to from suboptimal mold filling, especially at grating edges, but also to increased mechanical stresses in the stamp detachment step leading to possible breakage of the structures. With proper process parameters, residual layers of 80 nm and less have been demonstrated.

Reliability

The high RI resins have been tested both as blanket films and as imprinted structures to determine the pattern resistance to environmental impact.

Pattern fidelity at high temperatures was tested with 200 nm and 400 nm high gratings. A 30-minute heating ramp was followed by a 30-minute stay at the target temperature followed by a 30-minute cooling ramp. This cycle was then repeated by increasing the temperatures incrementally after each test cycle. Pattern fidelity was found to stay within 2 % at 200 °C for both IOC-172 (n = 1.7) and IOC-133 (n = 1.9). IOC-132 (n = 1.8) is slightly more sensitive to the high temperature. All three grades endure the time/temperature combination required by the reflow process. The transmission is unaffected by temperatures of even over 200 °C and decreases to 90 % only after prolonged heating at 250 °C, with IOC-172 performing somewhat better than the other two. In similar test sequences it was shown that the refractive indeces of all three resin systems remained unaltered at temperatures up to 300 °C.

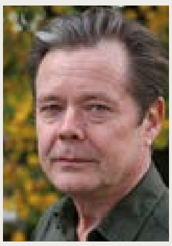
Reliability testing included 85 °C / 85 % RH tests of nanoimprinted films. Samples were prepared using the standard procedure as described above. Typically, the cured resins retain their performance after 500 hours in an 85 °C / 85 % RH climate chamber. None of the samples show defects and they all retain their transmittance values. Slight changes in refractive index and thickness are observed. For example, IOC-172 showed a fully stable RI and thickness, while IOC-133 showed a small 0.01 increase of the RI together with a 5 % decrease in film thickness. Generally, the reliability testing of the end product is significantly milder for the resin when the fragile grating structures are covered by other layers, which also provide protection from the environment.

Conclusions

The key to optically clear, nanoimprint-processable materials for diffractive optics elements lays in carefully balanced formulations that include a polymer, nanoparticles, and additives. These key elements must be correctly selected and be fully compatible to achieve a successful, functional solution. It has been shown here that imprintable resins for nanoimprint lithography are available with a refractive index range from 1.5 to over 1.9. A NIL-processable resin with n = 2.0 is on the development roadmap for the near future. These resins are commercially available and are ideal candidates for new diffractive optics applications such as waveguides for AR glasses and 3D sensor components.

DOI: 10.1002/phvs.202100021

Authors



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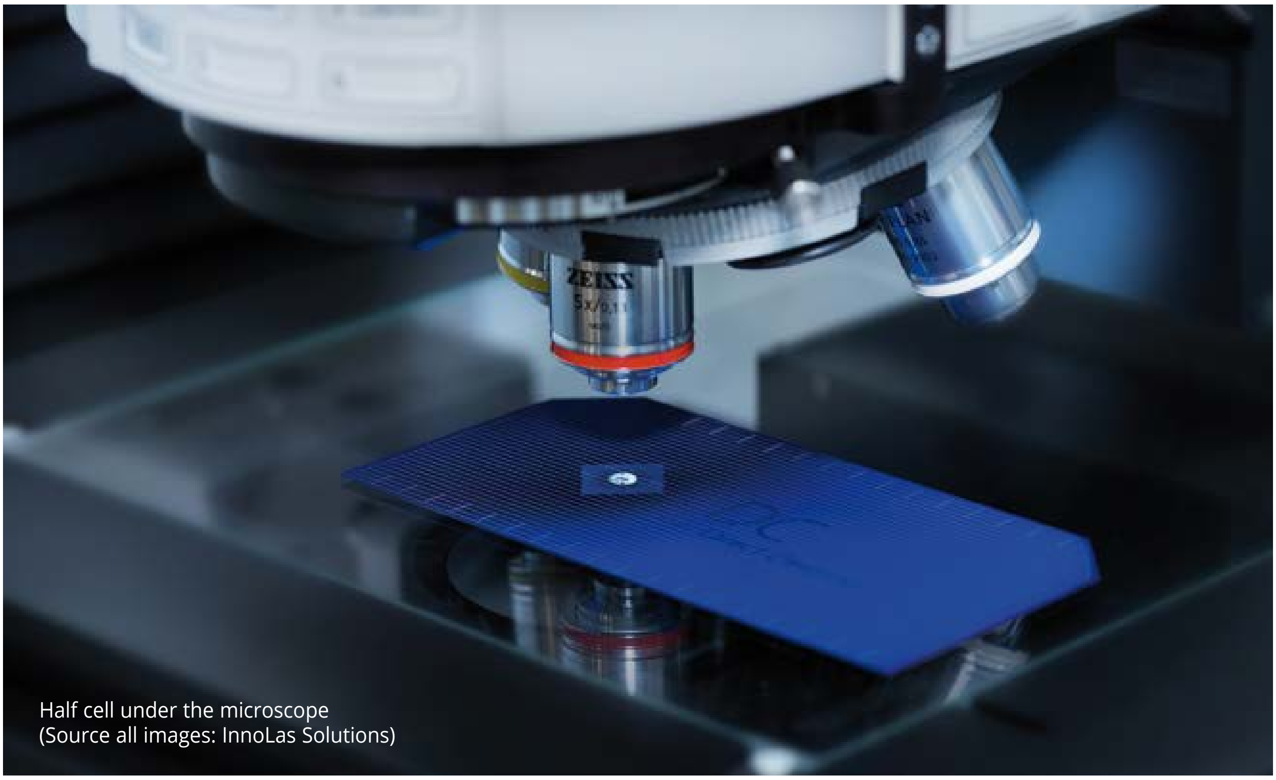
And… Cut!

Innovative laser cutting technologies in photovoltaics

Eckhard Schäfer



Half cell under the microscope
(Source all images: InnoLas Solutions)

Along with wind energy, photovoltaics is one of the major building blocks of the energy transition. But it is also regarded as one of the greatest social challenges of our time. Twenty years ago, the production of crystalline silicon solar cells and thin-film modules was still in its infancy. Much has changed since then as manufacturing in small batches has long since given way to mass production.

The laser industry has also seen a similar rapid development since the 1970s. Although Albert Einstein laid the foundation for modern laser technology with his principle of stimulated emission in 1917, it was US physicist Theodore Harold Maiman who developed the first laser in 1960, which would prove to be one of the defining inventions of the 20th century. In the same decade, the laser-assisted metal cutting process was developed and also integrated into industrial use. For the first time, individual cuts could be carried out automatically. Laser technology finally became the industry standard in the 1970s. To this day, laser separation boasts greater flexibility, controllability and above all unparalleled quality in comparison to mechanical processes.

PV laser processing over the years

The photovoltaic (PV) industry may still be a relatively new one, but laser processing has already experienced a number of ups and down. A look back at the past shows that the laser process has historically played a number of roles in the manufacture of crystalline silicon solar cells. Various applications have appeared on the scene over the years which then disappeared again shortly afterwards. These include laser drilling for metal / emitter wrap-through (MWT/EWT) solar cells and laser edge isolation (LEI).

While the MWT/EWT process was never able to become a leading technology due to a limited market volume, laser edge isolation shaped the photovoltaic market for several years before it was replaced by a one-sided wet chemical etching process that guaranteed greater cell efficiency. In around 2010, another process became the subject of a great deal of buzz: the laser-doped selective emitter (LDSE) process. However, this was also short-lived and it was replaced by an optimized printing technology that made the advantages of a selective emitter superfluous.

Thanks to laser contact opening (LCO) however, laser processing has finally established itself as the primary technology in the PV industry when it comes to the industrial manufacturing of standard silicon solar cells. The method of structuring the rear cell passivation layer has developed into a key step in the modern manufacturing of

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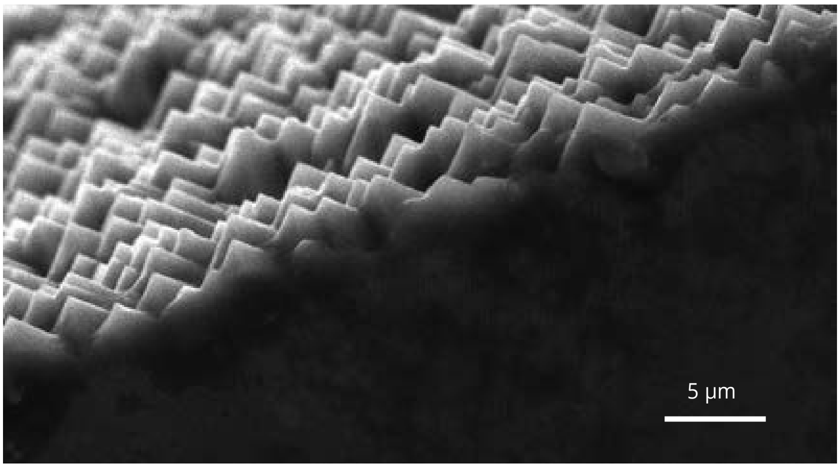

Microscope image of the cell edge after laser processing

passivated emitter and rear cells (PERC) and is now a vital part of the whole process. The rear cell passivation of solar cells sees a dielectric layer applied to the rear of the cell and perforated by a laser. PERC is now considered the technological standard for leading solar cell technologies and brings the advantage of increasing the efficiency of the solar cell, thanks to its special design. As PERC technology has developed, the selective emitter process has also come back to the fore due to the fact that the efficiency of the cells can be significantly increased once more.

Increasing module output by using highly efficient solar cells is the market's top priority. Another application that is currently garnering more and more interest in the industry, thanks to its ability to increase performance, is using a laser to cut a solar cell into two half cells.

Half-cut cell technology – 'scribe and break'

Crystalline silicon solar cells are typically cut with a laser these days because of the low process costs and the high degree of precision. Although there are different approaches to cutting a cell into two – or more – parts, the most common way is by scribing and breaking.

The 'scribe and break' technology sees the rear of the cell first scribed by a laser to a depth of about one third of its thickness. In the next step, the scribed solar cell is broken by applying mechanical force along this scribed line. Breaking the cell exactly along the cutting edge therefore requires an additional action step.

Despite this conventional technology's level of sophistication, there is still a risk of microcracks forming on the cell edge during the scribing process. These cracks are not visible to the naked eye and only become visible through electroluminescence. This sort of damage to the half-cell can influence and reduce the performance of a solar module in the long term. In addition to crack formation, cell cutting processes also involve the risk of damaging the extremely sensitive passivation layers of the cell. This can lead to tension losses.

On top of this, the formation of dust during the scribing process, and thus the probability of the cell being contaminated by the high number of particles, is a significant problem with the 'scribe and break' process. The heat created by the laser process should also not be underestimated, as this can lead the cell edges melting and material from the front of the cell reaching the inside as a result. The mechanical separation step also requires the process to be automated.

Nevertheless, half-cut cell technology has quickly established itself as a comparatively reliable and relatively simple method for manufacturers to get greater performance out of their solar modules and to satisfy the growing demand from customers for high-performance products. However, in light of the growing demand for half-cut cells, the market is continuously searching for innovative alternatives to the scribing and breaking process to prevent cell damage.

Laser direct cleaving – a cutting process without ablation

New separation processes for crystalline silicon solar cells are constantly finding their way into the PV market. One example of this is the innovative laser direct cleaving (LDC) cell-cutting technology. InnoLas Solutions' patented thermal separation process is guided by a laser beam and is a direct separation process. In specific terms, this means that, unlike the 'scribe and break' process in which the cell is scribed completely, the laser only scribes the cell for the process. The scanner-based process involves first inducing a precisely defined microcrack at the cell edge, which can then be guided along an almost freely definable line to the opposite edge by the local heat of the laser. The laser beam is moved using galvanometer mirrors, which allow a high travel speed on the workpiece. The solar cell is split purely by the tension generated by the laser. Not only is this particularly gentle on the material, but it also means that no additional process gases or coolants are required.

Company

Photonics Systems Group

Photonics Systems Group is a market leader in laser systems for micromaterial processing. The Group, comprising the InnoLas Solutions, LS Laser Systems and EPP Electronic Production Partners companies, develops, produces and distributes customized machines and process solutions for high-precision laser applications in the photovoltaic, electronics and semiconductor industry. Photonics Systems Group has over 120 employees working at its Group headquarters in Krailling, Germany, as well as in the US and at several sites in Asia.

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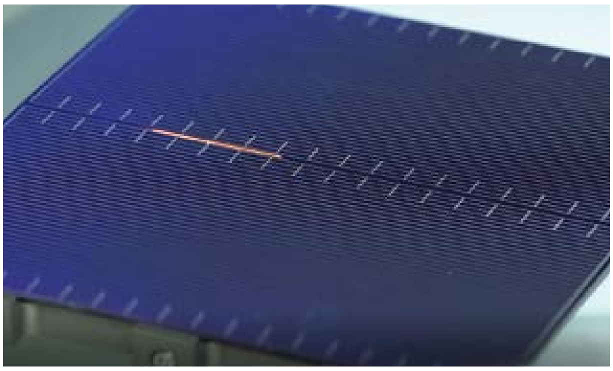
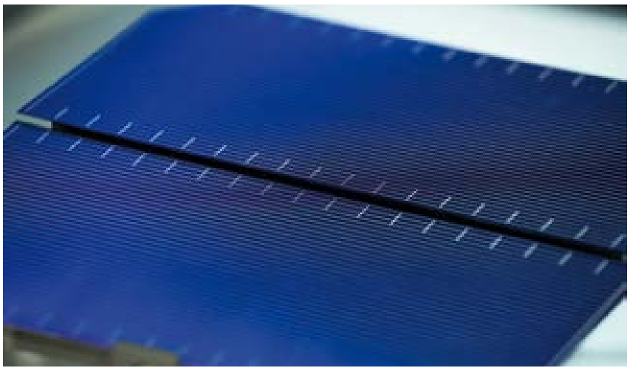

The laser direct cleaving process in action


Silicon solar cells after laser separation

Since laser direct cleaving is a thermal separation process that only makes one pass, it is characterized by two main points: speed and particle-free operation. The fact that LDC does not require material to be removed from the cell surface, unlike the conventional scribing and breaking process, is the biggest advantage of this state-of-the-art process: the ablation-free process both completely eliminates filtration and dust separation costs and prevents the risk of microcracks forming and damage being caused to the passivation layer. After separation, the edges of the silicon solar cells have neither damaged nor melted areas, which guarantees a much higher mechanical strength and results in a lower breakage rate.

As with the traditional 'scribe and break' process, laser direct cleaving produces two separate workpieces as the final result, with the difference being that no second step is required after the laser process to finally separate the two half cells. The fact that automation is no longer required for the mechanical separation saves both costs – which is another hallmark of this process – and time. The fully automated LDC cell cutting solution neatly combines a laser scribing process with integrated soft break and handling automation.

A look ahead

Recent developments in the PV industry have focused on the need for effective and low-damage cell cutting techniques to handle the processing of solar cells into half-cut or even smaller formats. However, it can be assumed that differences in quality resulting from the various innovative cutting processes will only become apparent over time once half-cells have established themselves on the market as a common format for solar modules. Due to the introduction of shingling technology into the market, separating cells using 'scribe and break' will struggle to establish itself in the long term as a result of the difficulties outlined above. With shingling, the cell is cut several times to achieve even higher degrees of efficiency in the module through high packing densities.

Progress in the size of the separable cells is also expected in addition to the continued development of half-cut technologies for crystalline solar cells. Currently, wafers with a size of 158.75 mm, 161.7 mm, or 166 mm present even greater challenges for conventional scribing and breaking processes. The reasons for this can be found in the additional scribing that takes place during multiple passes and the associated risk of increased dust and microcracking. The higher time factor is also key here. This is not the case when using the laser direct cleaving process to separate cells, which in principle enables wafers of up to 210 mm in size to be processed.

In recent years, the market development in photovoltaics has repeatedly come up with innovative surprises, so it remains an exciting one to watch. A look into the future also suggests that we are far from having seen or discovered everything that the laser has to offer. In fact, research efforts are hoping to gain further insights into processes within atoms, for example. At the same time, a wide range of new technologies in the field of crystalline solar cells continue to promise great leaps in terms of development. Examples of these include TOPCon (tunnel oxide passivated contact) technology and IBC (interdigitated back contact) solar cells. All ablation processes, which often require wet-chemical technologies, will continue to be scrutinized in the future and attempts will be made to replace them with highly efficient and above all cleaner laser processes accordingly.

Once you also take into account environmental factors, laser technology will always be superior to other ablation processes. New developments will also require new processes in which lasers will always play a role. The same applies to the further development of laser technology in itself, which also provides fertile ground for finding new processes and optimizing existing ones.

DOI: 10.1002/phvs.202000049

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The First Coupling of a Laser Beam to a Water Jet

How a miniature dental hand tool started a revolution in cool laser machining

Nitin Shankar

Fig. 1 Water jet guided laser sawing a rough diamond

Source: diamcad. Source all other images: Synova

Assigned to a project for designing a laser-based dental hand tool, Bernold Richerzhagen visualized combining a water jet and a laser for tooth ablation. His dental tool envisioned a laser within a low-pressure hair-thin water jet that guided the beam by means of total internal reflection in a manner like an optical fiber. Eventually, this fusion of light and water resulted in a new technology capable of machining hard materials with high precision. Starting with a dental tool developed in a Swiss laboratory in 1993, this invention has fostered high-precision laser machining in the aviation, diamond and semiconductor industries amongst others.

Back in 1986, Bernold Richerzhagen decided to focus on bio-medical sciences at RWTH University Aachen. He obtained his master's degree in mechanical engineering with a thesis on artificial heart design. A year later, he joined a research project at the Applied Optics Laboratory of the Federal Institute of Technology, Lausanne, EPFL, to develop a laser-based dental tool. The goal was to develop a laser energy transmission system for dental applications such as the removal of caries.

Cool laser for tooth ablation

During the design stage, Richerzhagen was asked to try a new approach to transmit the laser energy to the target and to cool the tooth during laser drilling. The theory was to guide the laser beam by total reflection within a water jet in the manner of an optical fiber. The laser would provide the heat for ablation while the water would cool the tooth. It was a radical and yet unrealized concept.

In fact, the feasibility of guiding light in a water jet had already been proven: Professor Colladon from Geneva University had shown in 1840 that a stable water jet can be used to guide light [1]. Although nobody had succeeded in combining a laser beam with a water jet, Richerzhagen decided to pursue this option. For one thing, the water jet guided laser offered the advantage of a parallel laser beam. For another, the water jet guiding the laser offers simultaneous cooling with virtually no resulting heat damage to the tooth. This was important since the nerf in the

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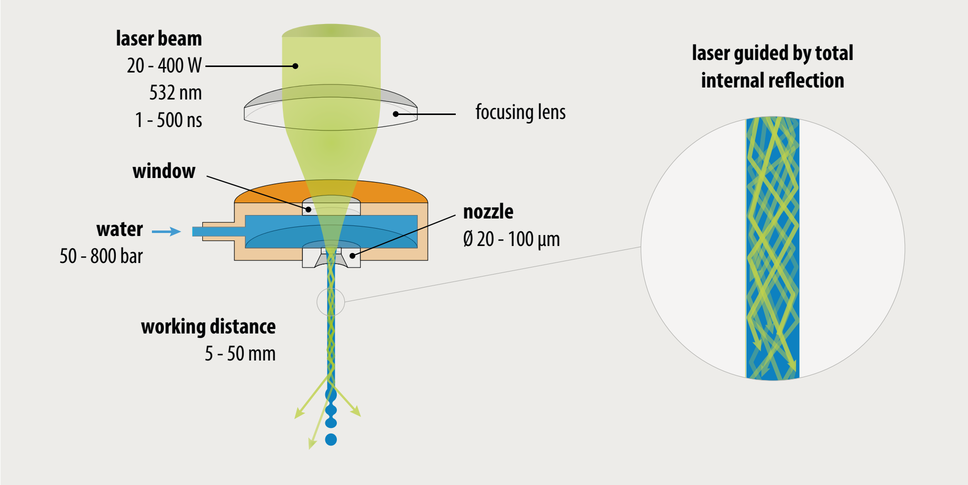

Fig. 2 Concept of a water jet laser beam

tooth is overly sensitive to temperature changes.

In theory, Richerzhagen's concept was based on passing a laser beam through a pressurized water chamber and then focusing it into a nozzle (Fig. 2). His calculations showed that it was possible to focus a laser beam into a water jet nozzle without losses other than the natural absorption in water. The low-pressure water jet emitted from the nozzle would guide the laser beam by means of total internal reflection. This parallel water guided laser would operate on the tooth.

The coupling dilemma

In practice, Richerzhagen faced two challenges. The first, rather easier, was to transfer energy from a laser source to the dentist's handheld tool. The second, more demanding, was to develop a coupling unit that would merge the laser beam in a water jet.

Using lasers available at the EPFL lab, Richerzhagen constructed his first prototype with other components such as a water pump and a water jet nozzle. After several experiments, Richerzhagen determined that a 300-micron optical fiber connected from the laser source to the dental tool resulted in minimal power losses. To obtain the needed power density, he developed a system with a mirror and multiple lenses to focus the 300-micron beam down to 100 µm.

Richerzhagen's first coupling unit consisted of an enclosed water chamber with a window on one side and a nozzle on the other side. The laser beam would pass through the window and water and be focused on the entry of the nozzle. It would then exit as a laser beam in a water jet (Fig. 3). Richerzhagen's coupling unit had mixed results. Though his calculations and simulations showed that the laser beam should pass through the nozzle, even low energy pulses damaged the nozzle bores. The beam was apparently getting defocused, hitting the nozzle edge and damaging it (Fig. 4).

Richerzhagen was faced with a serious problem of low transmission and quickly damaged nozzles. The laser beam should be reflecting internally within the water jet. Such total internal reflection results from refraction, a phenomenon that causes the laser beam passing from water into air to bend toward the surface. If the beam hits the water surface below a 'critical' angle, it reflects within the water like an

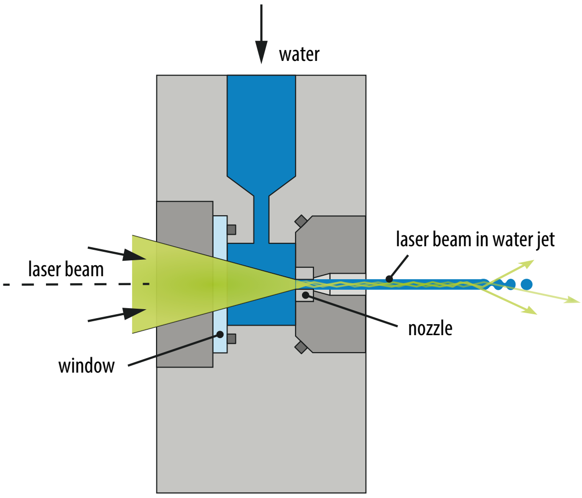

Fig. 3 Coupling unit

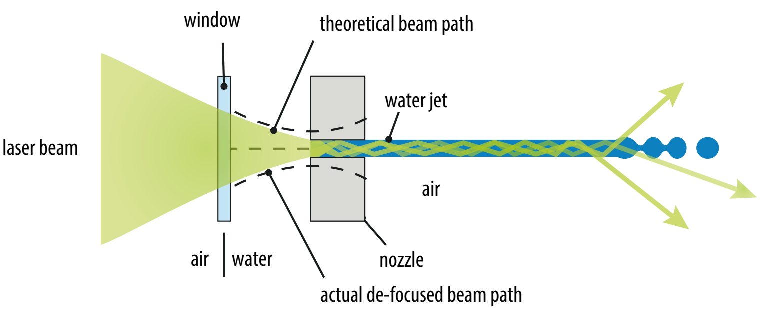

Fig. 4 Theoretical versus actual defocused beam path

Company

Synova

Synova SA, based in Duillier (Switzerland), develops and manufactures 5-axis laser machining systems based on its proprietary Laser Microjet technology. This hybrid method of machining combines a laser with a 'hair-thin' water jet that precisely guides the laser beam by means of total internal reflection. The company has supplied over 350 machines designed for applications such as drilling coolant holes in turbine blades, faceting raw diamond stones and dicing semiconductor wafers.

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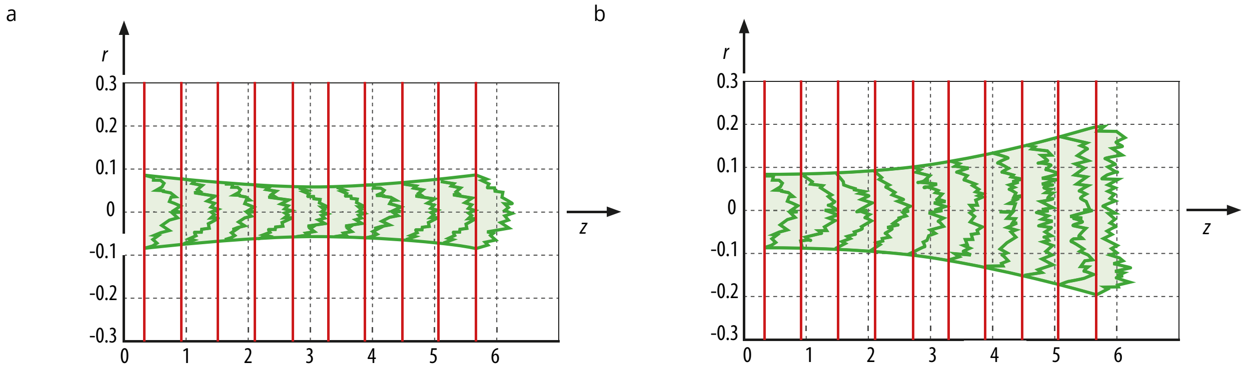

Fig. 5 Beam waist at the start of pulse in water (a), and at the end (b; from [4])

optical fiber. The priority was to identify the external factors preventing the laser beam from focusing within the nozzle. The investigation to solve this problem would last a couple of years and result in several interesting discoveries.

Proof of thermal defocusing

His first experiment was designed to study what takes place when a transparent chamber containing water absorbs energy from a laser pulse. This experimental set-up used two laser sources, a ND:YAG laser with a 200-microsecond pulse width and a second continuous low-power helium-neon laser. A photo diode registered that the helium-neon signal experienced a loss in power intensity during the 200-microsecond pulse. This led to the conclusion that a rise in water temperature resulted in a weakening of the helium-neon signal.

This was clear proof that during each 200-micron pulse, the water absorbed a small part of the laser energy. This energy was converted to heat. The increase in water temperature resulted in a change in the refractive index, which is a measure of the bending of the beam when it passes through media with different indices of refraction. A certain time after the laser pulse, the water cools down due to heat exchange processes such as convection and conduction. As a result, the refractive index returns to its original level. This 'thermal-induced' lens loses its effect. This phenomenon is known as thermal blooming or thermal defocusing.

So defocusing caused the beam to widen and the position of the focal point to shift, Richerzhagen assumed. Thus, a significant part of the energy was outside the theoretical focal point. This energy struck the front surface of the nozzle and damaged it. This process took place during the laser pulse and clear traces of the laser radiation were found on the damaged nozzles.

The next step was to measure the impact of thermal defocusing on the laser beam profile.

Fattened laser beam waist

Richerzhagen designed an experimental set-up with imaging optics and a high-speed camera to capture the change in laser beam waist at the start and end of a 200-microsecond pulse as it passed through a water chamber. The entire set-up was automated. The 200-microsecond laser beam pulse passed through a water vessel with two glass windows. Its focal point was on the output window. Imaging optics magnified the beam waist to a resolution of 2.2 microns while the camera operated with adjustable shutter speeds down to 1 microsecond. The camera recorded ten frames at different axial points from the start till the end of the 200-microsecond laser pulse.

The images were startling. They showed that the laser beam waist diameter which was less than 0.2 millimeters at the start of the pulse doubled to 0.4 millimeters at the end of the laser pulse (**Figs. 5a, b**). It was clear proof that thermal defocusing was altering the profile of the laser beam.

The problem now shifted to the domain of optics because, as a PhD student, Richerzhagen wanted to confirm his observations by theoretical calculations. For this purpose, there was a need to measure the change in refractive index of water as a function of its temperature. This would eventually enable him to take the measures needed to eliminate the thermal defocusing effect.

Water temperature and refractive index

He found that the existing quantitative data on the relationship between water temperature and the change in refractive index at 1064 nm did not serve his purpose. For this reason, he needed to measure the refractive index as a func-

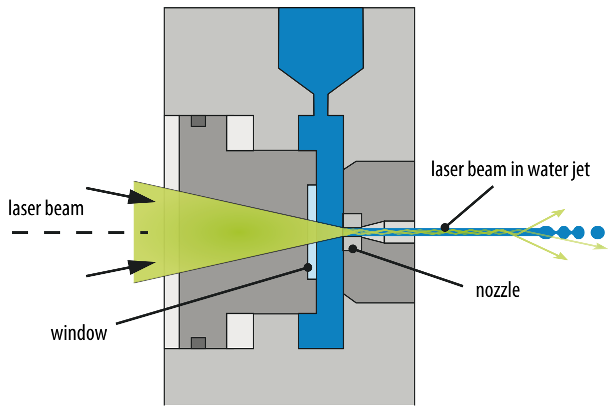

Fig. 6 Modified coupling unit

Fig. 7 Coupling unit prototype

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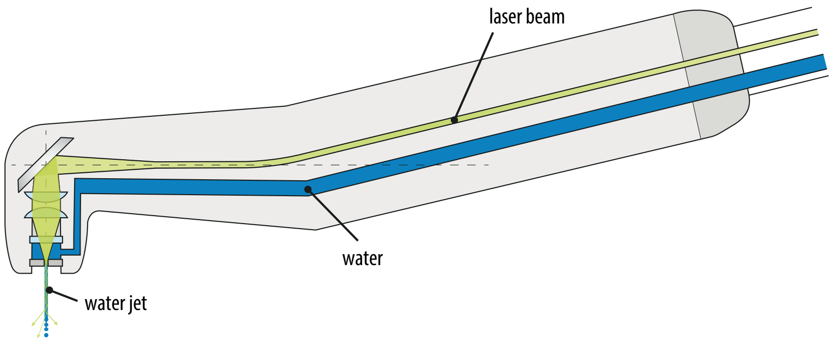

Fig. 8 Schematic of water-cooled dental tool

tion of water temperature in a controlled laboratory environment. The laser wavelength was set at precisely 1064 nm. The goal was to have accurate data that could be supported by a theoretical simulation.

Richerzhagen designed a set-up based on a modified Michelson interferometer, a configuration used for optical interferometry. The laser source was coupled to a monochromator, to ensure that the laser wavelength was within a very tight wavelength spectrum to assure a strong interference effect. The lenses and aperture corrected any astigmatism caused by the monochromator. The glass vessel was thermally insulated, so that the water temperature remained constant during the one-minute measuring process. An external circuit keeps the water heated.

The measurement cycle was long. After heating the water in the glass vessel to a specific temperature, there was an hour wait for the water temperature to stabilize. The measuring process consisted of moving the mirror in the water a specific length and measuring the interference signal. Measurements were carried out for water temperatures from 20 – 60 °C to record the refractive index for each temperature. The results were significant enough to be published in the journal Applied Optics in 1996 [2] and to become part of the Handbook of Chemistry and Physics.

Theoretical simulation

Having found the most accurate method of establishing the relationship between the refractive index and the water temperature, Richerzhagen went a step further. He decided to confirm the hypothesis of thermal defocusing and reproduce his experimental measurements of beam profiles under thermal defocusing through numerical simulation. In the process, he metamorphosed from engineer to scientist, using a methodology based on combining finite element analysis with raytracing. In a simplified form, his simulation was based on a laser beam passing through a grid of finite elements and its path being influenced by different refractive indices axially and radially.

The simulation results were extremely close to those obtained in his earlier practical experiments, without any fitting factor. The findings were of such significance to be published in Applied Optics [3] and Optical Engineering [4], in 1996. The agreement between measurement and theory enabled him to make reliable theoretical predictions of the thermal defocusing effect. Although his research was trail blazing, he did not lose track of his primary goal: developing a coupling unit that did not damage nozzles.

Improved coupling unit

In his goal was to stabilize the water temperature in the chamber when a laser pulse passed through it, he had to resort to a solution based on fluid dynamics. After much experimentation, he established that any stagnation of the water in the area where the laser beam passes through must be avoided. The conflict was that the literature says that a quasi-stationary state is necessary to achieve a stable and laminar flow towards the water jet. Laminar flow is smooth. It occurs at lower velocities. At such velocities, water flows without lateral mixing. Adjacent layers slide past one another like playing cards. The velocity depends on the viscosity and density of the fluid and dimensions of the nozzle aperture.

To ensure a laminar flow based on these fluid dynamics, he redesigned the water chamber. It simultaneously allowed a homogenous flow as well as high speed in the area of the laser path. This key milestone was achieved by transferring the features of flow laminarization to the nozzle itself. This design change resulted in a very thin chamber stabilizing the temperature of the water when the laser pulse passed through it. It achieved a constant, homogeneous acceleration of the water from the chamber until it passed through the nozzle without any turbulences. Everything was compact. The laser passed through the window and water chamber, focusing directly into the nozzle. It coupled with the water jet that was ejected from the nozzle. The process worked.

The improved coupling unit design (Fig. 6) and prototype (Fig. 7) was the first system to guide a high-power laser beam in a water jet to ablate material. With this invention, Richerzhagen had demonstrated the feasibility of a water jet guided laser capable of ablating material for the first time in history in 1993.

Fig. 9 Bernold Richerzhagen with a laser system for turbine blade machining

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Integration of water-guided laser in a dental tool

After more than two years of research on thermal defocusing and experimenting with coupling unit designs, Richerzhagen produced a water jet guided hand tool for dental applications (Fig. 8). The integration of this new process in a handheld tool for dental drilling showed its superiority in many ways. The laser energy for tooth ablation was available at a length of more than four centimeters. The water jet ensured a constant cooling of the tissue. As a result, the dentist has a greater working distance between the hand piece and the tooth which enabled deeper cavities in the tooth.

The successful execution of the dental laser hand tool project provided the basis for Richerzhagen to complete his doctoral thesis by May 1994. While working on his PhD project, he submitted his first patent application (FR 2 676 913, May 1991) in the name of the project sponsors. This application described a water jet guided system based on the initial concept of having a large chamber for quasi-stationary flow of water that has not led to success. He later registered first a German patent in 1994 and then a European patent (EP7629481) in his own name in 1995, supported by the EPFL.

Richerzhagen deserves credit for his multidisciplinary approach in resolving the coupling problem. His hard work paid off; he was eventually able to apply the water guided jet laser principle in other industrial sectors. Starting from the dental hand tool and coupling unit design, he founded a company, Synova, in 1997 to manufacture laser cutting machines using water jet coupled lasers.

Extension of water jet guided laser technology in industry

Since its inception, Synova has supplied more than 350 machines worldwide in industry sectors ranging from automotive and aviation to diamonds and semiconductors (Fig. 9). However, the results of the fundamental research carried out on the coupling unit are still valid. To ensure the successful coupling of any laser in liquid jets, a thin, disc-type water chamber is needed to control the thermal effects. The work done on the dental hand tool is still paying dividends today.

Richerzhagen has laid the basics for a machining technology that is being increasingly applied in many industry sectors to process various materials, often high-tech materials such as ceramic matrix composites or CVD tools requiring a high quality of surface finish. Leading research institutes globally have taken interest in the technology and its potential applications. The future looks bright for the evolution of this technology.

DOI: 10.1002/phvs.202100014

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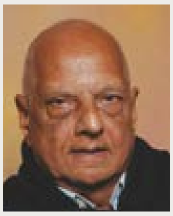
Author



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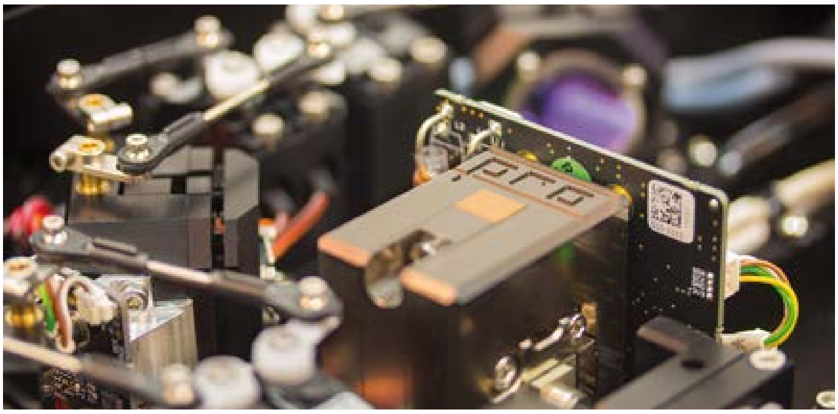
Full articles in PhotonicsViews issue 2/2021 April/May

From Quantum Mechanics to Quantum Technologies

How fundamental physics turned into one of the hottest technologies today



Lasers are based on quantum effects and enable many novel quantum technologies. The photo shows a semiconductor optical amplifier in Toptica's high-power, frequency-doubled diode laser DLC TA-SHG pro. (Source: Toptica)

Quantum physics is often considered weird, counterintuitive, and irrelevant at macroscopic scales – a topic just for physicists. And yet, more and more people talk about quantum technologies, including politicians like Canadian prime minister Justin Trudeau and German chancellor Angela Merkel. Why now? Quantum effects facilitate many devices that have been around for decades. What has happened?

Scientists have continued to work hard, to be curious, and to push boundaries. The resulting scientific breakthroughs, each individual one typically too small and too specific to be noticed by the general public, have added up. Experimental physicists have learned to isolate, control, and manipulate individual quantum systems like atoms and photons with unprecedented precision – they have become quantum engineers. Theorists have asked questions that initially seemed bizarre. Their answers, however, have led to spectacular new insights like a completely new computing paradigm. These ideas and the aforementioned capabilities combined are revolutionary. This article will give a glimpse of the resulting technologies: quantum computing, quantum simulation, quantum sensing, quantum metrology, and quantum communication.

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Principles of Laser Scanning Microscopes

How the Olympus LEXT OLS5100 can perform fast, nondestructive submicron sample analyses

One of the factors that contributes to the recent considerable reduction in the size and high integration of electronics and other devices is miniaturization of the electronic components that make them up. In addition, new fine functional materials have been developed and widely used in industrial fields including the automobile, aviation, metal, and chemical industries. As a result, higher accuracy and resolving power are required for minute three-dimensional measurement of these components and materials. Although a variety of devices are available to satisfy these requirements, the confocal microscope is gathering attention as the device of choice for easy three-dimensional, non-contact surface profile measurements in air.

In this article, I discuss the basic principles of and the features and applications of Olympus industrial laser scanning microscopes, with primary focus on the reflection-type confocal laser scanning microscope (referred to as the laser scanning microscope), which is aimed at high-resolution detection.

A confocal optical system only obtains information in the direction of the optical axis. Therefore, some kind of two-dimensional scanner system orthogonal to the optical axis is required to convert data into images. Since this two-dimensional scanner system uses raster scanning to create an image, the accuracy of this scanning system directly determines imaging performance. Accurate two-dimensional scanning is one of the most important technologies used in laser scanning microscopes.

Comparing non-confocal (left) and confocal (right) imaging. (Source: Olympus)

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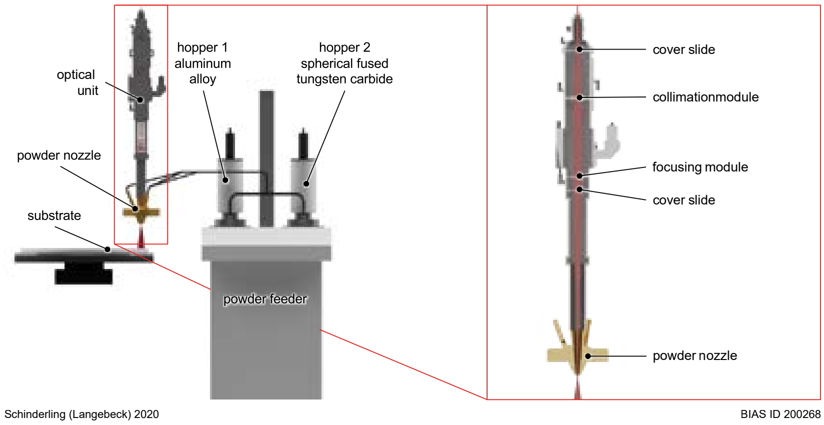
Directed Energy Deposition with Aluminum Alloy

Directed energy deposition of high-strength aluminum alloy with local hard particle reinforcement

Anika Langebeck

Directed energy deposition (DED) is an open space process of additive manufacturing (AM) technologies. Due to its high deposition rates, DED processes are well suited to produce large components in small quantities or for customer-specific individual production. During the manufacturing process the laser is used to create a melting pool on the substrate and to melt the added powder as well. Welding tracks are manufactured from which the large AM component is built.

As powder material steel powders like 316L or aluminum alloys from the 4xxx series with a good weldability are used. The use of high-strength 7xxx aluminum alloys in particular meet the increasing demands for energy-efficient lightweight construction of components. However, 7xxx alloys have a poor weldability, which makes their processing by DED a challenge. In addition to the use of a single powder material in DED-based additive manufacturing, process setup also allows the tailored use of powder mixtures. These material combinations include MMC materials (metal matrix composite), in which a metallic matrix material is reinforced with hard particles. This is done, among other things, for wear protection purposes.



Sketch of experimental setup directed energy deposition of large components made of a high-strength aluminum alloy with a local hard particle reinforcement. The optical unit used is shown enlarged on the right (Source: A. Schinderling, BIAS)

DOI: 10.1002/phvs.202100004

Closed-loop Control of Penetration Depth in Wire-based Laser Cladding

Dieter Tyralla and Thomas Seefeld

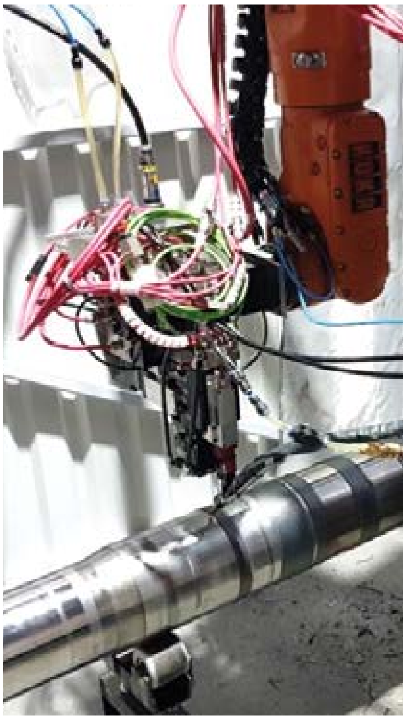
Up to now, powder based cladding processes are used to produce high-quality coatings with low dilution. However, the productivity of the process is limited and is accompanied by complex handling and the health hazards of powder materials. In comparison, the wire-based cladding process allows higher deposition rates, and the wire-shaped filler material is much cheaper compared to powder. However, the dilution and the geometrical shape of the layer usually fail to comply higher quality standards.

Laser cladding is a well-established production technique for the generation of functional layers on a parts surface and for the reconditing of worn work pieces. The process uses the energy of a laser beam to create a melt pool on the surface of the substrate. The filler material is fed into the melt pool, where it melts and mixes with the substrate. The additional material forms a welding bead on the surface by the relative movement between processing head and the workpiece. If several welding beads are placed side-by-side, a consistent layer is formed.

In most applications, the layer should provide the properties of the filler material and thus, as little substrate material as possible must be melted and mixed to achieve a high purity of the layer. However, enough must be melted to create a metallurgical bond. The relation of substrate and filler material is called dilution which is one of the most important quality features in laser cladding.

In the AiF project “Kontrolliertes Laser-Heißdrahtbeschichten” a new variant of wire cladding processes was developed that provides low dilution and high deposition rate in once. For this purpose, a laser hot-wire cladding (LHWC) setup is used where the wire is fed at a 45° angle in a trailing arrangement. In addition, a laser beam oscillator is used to distribute the laser energy over the process zone.

DOI: 10.1002/phvs.202100006



Experimental setup at project partner LaserCladding Germany GmbH

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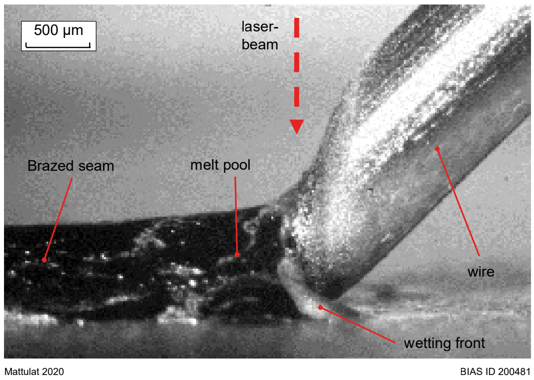
Laser Brazing with Wire Oscillation

A new approach for increasing the optical seam edge quality

Thorsten Mattulat and Peer Woizeschke

The technology of laser brazing is frequently used to produce seams with the highest optical requirements, making them good enough to remain visible in in areas accessible to the customer. To increase these optical qualities, external wire oscillation was imposed on a conventional constant wire feed, offering a feasible method for homogenizing the wetting process and increasing the straightness of the seam edges. The technology is easy to integrate into existing systems, thereby increasing the quality of laser brazed seams also on an industrial scale. The following presents an in-depth insight into the effects of external wire oscillation.

In laser brazing in automotive production, a laser beam melts a filler wire that is continuously fed into the process zone. Hereby, beam diameters greater than the wire diameter are used to simultaneously preheat the substrate. Seams are created through the relative movement between the processing optics and the substrate. The process is predominantly used to connect zinc-coated car body parts in areas visible to the customer using seams made of a copper-based filler material. As these seams are often not reworked before painting, high optical seam qualities are required in addition to the requirements of strength and tightness.



High-speed process recording during laser brazing to visualize the wetting progression.

DOI: 10.1002/phvs.202100012

Increased Laser Polishing Rates of LPBF Components

High path overlaps to reduce surface features at laser polishing of LPBF-components with high process speeds

Lucas-H Beste, Florian Schadewald, Tim Radel, Brodan Richter, Patrick J. Faue, Frank E. Pfefferkorn, and Frank Vollertsen

The production of components using Laser powder bed fusion (LPBF) offers a wide range of applications. The selective local energy input and layer-by-layer melting of powder particles allows high design flexibility and a wide range of component geometries. It is often necessary to apply post-processing steps in the process chain to meet the design requirements. Besides metallurgical reasons, which may, for example, require a heat treatment, a subsequent treatment may be necessary due to the surface topography. During the LPBF process, partially-melted powder particles often remain on the surfaces. Additionally, the layer-by-layer melting of the powder particles can contribute to the waviness of the surface. Therefore, LPBF components usually have a process chain with post-processes such as machining, grinding, mechanical polishing, shot peening and similar techniques. Laser polishing is an alternative that allows complex surfaces to be polished contact-free and non-abrasively without tool wear. Thus, it is not only possible to smooth the surfaces by remelting, but also to reduce the porosity close to the surface. Typical polishing rates are in the range of a few mm^2/s. The melt pool dynamics and the associated waviness limit the melt pool size and processing speed and therefore the achievable polishing rates. Nevertheless, an increase of the polishing rate is desirable.

DOI: 10.1002/phvs.202100009

PhotonicsViews Special Issue S1/2021

Read fifteen conference contributions of the Laser Application Forum 'laf 2020' – which should have been taking place in Bremen, Germany, in Novmber 2020 but had to be canceled on short notice – in this special online issue S1/2021 as PDF or e-paper through our brand new portal, Wiley Industry News, WIN:

www.wileyindustrynews.com/en/photonicsviews

laf 2020


Source: BIAS


Source: CIOE

new / next date

February 17 – 18, 2021
EPIC PHOTONICS+ Virtual Exhibition and Conference
online
https://photonicsplus.com/

February 24 – 25, 2021 → **April 27 – 28, 2021**
W3+ Fair Wetzlar
Wetzlar, Germany
https://w3-messe.de

March 02 (online) / September 13 – 15, 2021
QuApps 2021
onine / Duesseldorf, Germany
https://quapps-conference.com

March 03 – 05, 2021
Asiamold – SIAF
Guangzhou, China
www.asiamold-china.com – www.spsinchina.com

March 06 – 11, 2021
SPIE Photonics West
online
https://spie.org/pw

March 09 – 12, 2021 → **2022**
EuroBLECH
Hanover, Germany
www.euroblech.com

March 15 – May 20, 2021
LEF Bricks
online
www.lef.info

new / next date

March 17 – 19, 2021
SEMICON China
Shanghai, China
www.semiconchina.org

April 19 – 20, 2021
ICULTA 2021
online
www.iculta.com

May 04 – 06, 2021 → **June 22 – 23, 2021**
Rapid.Tech 3D
Erfurt, Germany
www.rapidtech-3d.de

May 04 – 06, 2021
Sensor+Test
Nuremberg, Germany
www.sensor-test.de

May 04 – 06, 2021 → **June 8 – 10, 2021**
T4M – Technology for Medical Devices
Stuttgart, Germany
www.t4m-expo.com

May 04 – 07, 2021
Control
online
www.control-messe.de/en/control-virtual/

May 11, 2021

Photonics Online Meeting #3
online
www.photonics-france.org

WIN NEWS **Read event previews and reviews on www.wileyindustrynews.com/en/events**

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International Exchange on Laser Polishing

Review: 4th Conference on Laser Polishing – LaP 2020", 16 & 17 September 2020, online

Around 70 experts logged in for the final touches: participants from the USA, Canada, China, Europe and other parts of the world attended the 'LaP 2020', which took place virtually for the first time. The event, organized by the Fraunhofer Institute for Laser Technology (ILT) in Aachen, focused on laser-based deburring and polishing – an exciting journey to, among other things, wobbling lasers, high-speed monitoring with AI support and nine-axis simultaneous processing.

In 2014, Fraunhofer ILT launched the first 'LaP' conference to exchange research results in an international setting. Under Dr Edgar Willenborg, head of Fraunhofer ILT's research team for laser-based polishing and deburring, the conference has since developed into a well-attended English-speaking location for laser polishing experts from all over the world to meet.

Initiator and moderator Willenborg was satisfied with the outcome: "The LaP conference number four had to be virtual, but this premiere worked out perfectly. I look forward to seeing the international laser polishing community again at the fifth LaP, which will hopefully take place live in Aachen again in 2022." *Nikolaus Fecht*

Source: Fh. ILT

Part of the LaP team in action: Alina Bauer, Katharina Schulte, Manuel Jung, and Dr Edgar Willenborg.

www.ilt.fraunhofer.de

"The Digital Heart of the AM Industry"

Review: Formnext Connect, 10 – 12 November 2020, online

Formnext Connect demonstrated its ambitions to be the international, digital hub of the additive manufacturing world, highlighting, even in challenging times, the continuing importance of the world's leading exhibition for the AM industry and the next generation of industrial production.

It attracted 203 exhibitors with about 2,200 representatives, and showcased 1,412 products. 8,541 active participants from more than one hundred nations (one third from Germany, two thirds international) made great use of the intelligent and modern matchmaking function, which managed to generate more than 450,000 recommendations for products and other participants. Further, 23,311 new contacts and 4,733 business meetings in the form of video calls were enabled. The 221 lectures and presentations of stage events and sessions were watched by 45,000 spectators. Experts from all over the world discussed current and future trends, developments and applications in various webinars and discussion panels.

With international product launches, amongst them numerous new materials, an SLM machine with twelve lasers as well as post-processing solutions for finishing, de-powdering and curing and exciting new developments on show, Formnext Connect demonstrated that the AM industry remains highly innovative. Even in this year of corona, it urgently needs an international platform for business opportunities and networking. A number of partner organizations were also on hand to share their in-depth knowledge.

Formnext 2021 is scheduled to return live to Frankfurt am Main from 16 – 19 November 2021.

Source: Mesago

An ever-present accompaniment to Formnext Connect was the varied program from the Additive Manufacturing Capital Studio with its guests.

www.formnext.com

"Digital Exchange Platform a Resounding Success"

Review: SPS Connect, 24 – 26 November 2020, online

With high participant numbers and an impressive interaction rate, the SPS Connect illustrated the continuing importance of a professional exchange between suppliers and users, and clearly demonstrated that technological progress in the automation industry cannot be stopped even in the midst of a pandemic. For organizer Mesago, the event has been a resounding success.

SPS Connect saw a total of 239 exhibitors and their 4329 employees showcase more than 2,500 products. 9,008 active participants, including 27 % from outside of Germany, accessed the virtual platform over the three-day event to discover the latest trends and innovations, and extend their professional network. The platform remained active until the end 2020 to give interested parties the opportunity to connect with others and consume video content on-demand.

With the subject of digital twins as an integral part in the realization of Industry 4.0, Patrick Bruder, business development manager automation at Lenze held a talk entitled: "On the way to Industry 4.0 with the digital twin". The talk included insights, especially designed for machine builders and end-users, into the standards that need to be followed as well as what concrete steps have to be taken to remain competitive.

SPS is scheduled to return to Nuremberg from 23 – 25 November 2021.

http://sps-exhibition.com

Successful 2nd Edition with 250+ Participants

Review: Photonics Online Meetings #2, 3 December 2020, online

Photonics Online Meetings #2, December 3, 2020 (Source: Photonics France)

On December 3rd, the 2nd edition of Photonics Online Meetings took place. Marked by its 100% digital form, these Photonics Online Meetings #2, supported by eleven European partners, gathered a total of 255 effective participants (25% international) including 71 congress attendees and a total of 650 conference participations.

The program of this day of business meetings between principals and suppliers of the photonics industry included: more than 450 B2B meetings (90 % of realizations), three high-level conferences presented by Jean-Luc Beylat and Jan-Erik Källhammer on behalf of Photonics21 and photonics, a key technology for European sovereignty, and on photonics in mobility. There were also a Business France presentation on current events, trends and prospects of the semiconductor/optics/photonics market in China and nine product webinars organized by Hamamatsu Photonics France, Horiba Scientific, Le Verre Fluoré, IDIL Fibres Optiques, Photon Lines, Polytec France, Silios Technologies, Sphere Ultrafast Photonics and Iberoptics.

To summarize, POM #2 provided an opportunity to meet with actors from the photonics industry, R&D and innovation to identify skills and technological solutions, the present projects and converse with clients and partners, to develop one's business network, to target funders (public or private), and to meet virtually.

With an 83 % satisfaction rate on the quality of the meetings, a third edition is already scheduled for May 11th (cf. p. 84); booking is open.

www.photonics-france.org

SpectroNet 'Photonics and Machine Vision' Web Pitches

13 January – 10 February 2021, online

Dr Jan Makowski of Luxflux Web Pitch on 2D True Color Measurement with Hyperspectral Imaging (Source: SpectroNet)

The next series of Photonics & Machine Vision Web Pitches started on January 13th, 2021. This format is free and open to companies and research institutes in photonics and machine vision. The presentations focus on technology and applications. Companies from these fields are welcome to contact the organizers to give a presentation with insights into their business and practical solutions.

The weekly event series started after the holiday break with Dr Jan Makowski of Luxflux outlining '2D True Color Measurement with Hyperspectral Imaging'.

The next weeks saw talks by Benedict Diederich of Leibniz IPHT Jena, by Acktar's Alexander Telle, by Prof Thomas Längle of Fraunhofer IOSB., and by Dr. Christoph Garbe.

SpectroNet was able to start the new year with good news. It received the Cluster Management Excellence Label Silver – Dedicated to Cluster Excellence, in recognition of continuous improvements.

www.spectronet.de/web-pitches

Preview: Asiamold, SIAF Gear Up for the 2021 Edition

3 – 5 March 2021, Guangzhou, China

Asiamold – Guangzhou International Mould & Die Exhibition is scheduled to take place from 3 – 5 March 2021 at the China Import and Export Fair Complex in Guangzhou, China. Held concurrently with the 12th edition of the SPS Industrial Automation Fair (SIAF), Asiamold will feature the latest mould making, 3D printing and die casting technologies presented by leading domestic and international brands. Apart from the exhibition, the fair also offers unparalleled sourcing and networking opportunities in education, information and technology exchange across the manufacturing industry.

Asiamold and SIAF are two of the leading industry events in South China to kick off the 2021 sourcing year. Buyers can expect to source the most appropriate items to meet the surging need for smart manufacturing solutions in the region by discovering both events' diverse selection of exhibitors. Together, Asiamold and SIAF 2021 expect to welcome over 55,000 visitors and host more than 660 exhibitors across 50,000 sqm of exhibition space.

In addition to being a wide-ranging trading platform, Asiamold also offers unique opportunities for fairgoers to exchange professional insights and discover different market perspectives. A comprehensive fringe programme will be held alongside the exhibition to help industry players navigate emerging trends and new business realities.

www.asiamold-china.com
www.spsinchina.com

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Preview: First 2021 SPIE Events Online Only

6 – 11 March 2021, ff., online

SPIE Photonics West, which normally convenes in San Francisco, will be held as an interactive, virtual conference 6 – 11 March 2021. North America's largest optics and photonics technology event – with its popular Bios, Lase, and Opto conferences – also includes two digital exhibitions and the industry-focused Quantum West. Registration for SPIE Photonics West will open 5 January.

In addition to Photonics West, the following SPIE 2021 conferences will also be held via the organization's digital-forum platform: Advanced Lithography, Medical Imaging, AR/VR/MR, and Smart Structures + Nondestructive Evaluation. "The SPIE Digital Forum platform was developed to help people share results and make connections during the pandemic, and we've continued to fine-tune our virtual platform and digital offerings throughout this year," says SPIE CEO Kent Rochford.

"We'll be implementing the latest improvements during Photonics West and are excited to release them to our attendees, presenters, and exhibitors. These forums, as always, ensure the professional discussion, innovation sharing, and networking opportunities that the SPIE community values and relies on to advance its research, product development, and engineering collaborations," he continued.

SPIE uses its digital forum platform to organize the first five meetings of 2021 (Source: SPIE)

https://spie.org

Preview: International Conference ICULTA 2021

19 & 20 April 2021, online

Three years after the first successful 'International Conference on UV LED Technologies & Applications – ICULTA', the follow-up event will be held from April 19 to 20, 2021. Due to the Corona pandemic, the conference takes place one year later than originally planned and as a virtual event. Once more, it will bring together pioneers, leaders, and experts from science and industry to discuss the latest progress and innovations in the development of UV LEDs and their broad spectrum of applications.

Current global developments have increased awareness of topics like disinfection and sterilization in medical environments with UV radiation, especially in the context of Covid-19 and UVC LEDs. These compact-sized, eco-friendly, and flexible light sources open up new applications that cannot be achieved by using conventional UV lamps. UV LEDs with their emission wavelength adjustable over the entire ultraviolet spectral range are a highly attractive tool for controlling biological and chemical processes. Applications range from the disinfection of water, air, and surfaces to medical diagnostics, plant growth lighting, and the curing of materials.

ICULTA 2021 offers an international platform for experts in UV LED technology and applications. Talks by internationally recognized speakers have already been confirmed.

For two days, ICULTA 2021 will feature oral and poster presentations as well as many networking opportunities. The German consortium 'Advanced UV for Life' and the International Ultraviolet Association IUVA invite all those who are interested in being part of the conference as attendee, exhibitor, and/or sponsor.

www.iculta.com

Preview: Sensor+Test 2021

4 – 6 May 2021, Nuremberg, Germany, hybrid

"Although the experts were not allowed to meet for a concentrated exchange at the worldwide most important industrial trade fair for sensor and measurement technologies in 2020, the Sensor+Test event is still an important date on the calendar of this branch of industry," says Holger Bödeker, the managing director of AMA Service. His team is already planning the next event to take place from 4 – 6 May 2021 for exhibitors and visitors at the Nuremberg Exhibition Center. Sensor+Test will also feature hybrid configurations and a novel Digital Area.

The program is going to be packed again: so, the special topic planned for 2020, Sensor and Measuring Technology for Condition Monitoring, will be held in 2021 instead. The organizer and the exhibitors' committee approved this change because the special forum was received with great interest in 2020 and booked out early.

The second highlight is the presence and digital premiere of the SMSI – Sensor and Measurement Science International Conference – which is to open its doors on May 3rd and will include the presentation of the AMA Innovation Award.

"This event is going to be of high quality, even if we as the organizers have to expect a somewhat more compact presence trade fair due to corona," stated Holger Bödeker. Whether international visitors are allowed in Germany in May 2021 needs to be seen. "We will adapt Sensor+Test to whatever conditions exist, while ensuring that both exhibitors and visitors can look back with satisfaction on the three days of the fair."

www.sensor-test.com

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Preview: Photonics Online Meeting #3

11 May 2021, online

After the success of our first two editions (cf. p. 82) with more than 250 participants each time (including 25 % international) and more than 80 % satisfaction with the quality of appointments, Photonics Online Meetings #3, is ante portas! With even greater international participation, this 3rd edition will provide the opportunity for even more important networking with the support of many associations such as Photonics Austria, Photonics Netherlands, Photonics Sweden, Optonics, Litek, Spectaris, and others.

Photonics Online Meetings are day of business meetings on a European scale, between buyers and suppliers in the photonics industry, complemented by product webinars and services.

From your office you can expect: an average of ten one-on-one virtual meetings of around twenty minutes between principals and technology and service providers; appointments with R&D/production service providers throughout the day; live demonstrations, experiments, showrooms and software demonstrations; virtual conferences on an intuitive and easy to access platform. The event enables virtual meetings to provide a solution to the challenge of attending events in person.

Buyers have the opportunity to find solutions to the sourcing problems that they face, while business-related questions can be raised with suppliers of this technology and they can make recent developments and trends in the photonics industry more widely known.

www.photonics-france.org

Postponed: RapidTech 3D

22 & 23 June 2021, Erfurt, Germany

RapidTech 3D, which was scheduled to take place at the beginning of May in Erfurt, will be postponed to 22 and 23 June 2021 and held as a conference event with an accompanying exhibition. The decision to postpone was made jointly by Messe Erfurt and the advisory board. “The current infection rate and its expected continuation are making it difficult to prepare properly for the event over the coming weeks and to ensure the usual high standard of quality. In particular, it is difficult for exhibitors to commit to the event in the current situation. To take this into account, we have decided to focus on maintaining the exceptional calibre of the specialist conference and the accompanying exhibition, and to postpone the event until the early summer,” explains Michael Kynast, CEO of Messe Erfurt GmbH.

www.rapidtech-3d.com

Postponed: T4M – Technology for Medical Devices

8 – 10 June 2021, Stuttgart, Germany

Consultations with the trade fair’s supporters and partners, such as the VDMA Working Group Medical Technology, Swiss Medtech and MedicalMountains Cluster Tuttlingen, and feedback from the medtech sector indicate that an in-person trade fair in the first half of the year is still desired. Through this early postponement, Messe Stuttgart is increasing the likelihood of the event taking place and is contributing to more planning certainty for exhibitors and visitors.

A concept to protect the health of all exhibitors, visitors and employees developed to ensure controlled and safe implementation of the trade fair.

The new trade fair date promises the medical technology sector exciting synergies through the parallel in-house events Moulding Expo, International Trade Fair for Tool, Pattern and Mould Making, and CastForge, trade fair for castings and forgings with processing.

www.t4m-expo.com

Postponed: QuApps 2021 Conference

13 – 15 September 2021, Düsseldorf, Germany / hybrid

The QuApps conference deals with the state of the art and the development of quantum technology. The international event was originally to take place at Düsseldorf Airport from March 1 – 3, 2021. As the corona pandemic continues and still leads to severe restrictions worldwide, the organizers are postponing it until September.

The participants will gain deep insights into current research progress and expected milestones. The conference focuses on the exchange with renowned experts in quantum technology, e.g. from IBM Research, Volkswagen, Bosch, the University of Stuttgart or FZ Jülich. Technologies and applications in the fields of telecommunications, healthcare, security, automotive and others discussed during more than thirty lectures. An accompanying exhibition will show examples of possible applications. The event is aimed at quantum engineers and researchers, business development strategists and trend scouts in industry, at investors and the interested public.

https://quapps-conference.com

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Our buyers' guide can be found in each issue of PhotonicsViews.

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Mirros, UV

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Wiley-VCH GmbH
Boschstraße 12, 69469 Weinheim, Germany
ISSN 2626-1294

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Valid advertising price list: 01.10.2020

Banking account:
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Account number: 6161517443
BLZ: 50110800
BIC: CHASDEFX
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Production and Layout:
Marita Beyer, Anja Hauck

Printed in Germany by westermann DRUCK I pva

Per media partnership, members of the European Photonics Industry Consortium EPIC receive PhotonicsViews with currently six issues per year.

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