Application Note | Case Study | Technology Primer | White Paper

Line Scan Cameras Enable High Speed Inspection of Color Filters within Flat-Panel Display

The market of flat-panel displays (FPD) is a nearly $100 billion business that needs efficient automated optical inspection (AOI) to meet rising demand and remain cost effective. The color filters within the display represent a major inspection task, demanding both precision and speed. Inspection systems using high-speed, high-resolution line scan cameras have proven themselves both equal to the present need and able to support panel technology's evolution.

Demand for color flat-panel displays has driven significant growth and created a revenue growth of 20% in 2010. Three factors are driving this growth in demand. One is an increase in the penetration of color FPDs in applications such as computer monitors, high-definition television (HDTV), smartphones, and tablets. A second factor driving growth is the advent of new display functionalities, such as touchscreen , 3D capabilities and Wi-Fi connectivity, that are opening new applications for FPDs. Rising demand from emerging markets such as Brazil, Russia, India, and China are a third factor driving growth in the color FPD market.

FPDs Need Automated Inspection

To serve this growing market, FPD manufacturers must increase production capacity while keeping production cost low. The most cost-effective approach of inspection to achieving these goals is inline processing capability.

AOI is needed in FPD production in part because of the industry's zero-defect policy. With the high-definition image quality to which consumers have become accustomed, flaws in even a single pixel are noticeable. To maintain customer satisfaction, then, finished panels released to market must not have any defects. This requires that manufacturers inspect every pixel in their displays.

Such exhaustive inspection is complicated by the large number of structures that must be examined. Today's HDTVs display an array of 1920x1080 – more than 2 million – pixels, and each pixel is composed of three sub-pixels for the red, green, and blue primary colors (Figure 1). An extensive repetitive structure like this quickly exhausts the human vision system during inspection, allowing flaws to escape detection. The structure is ideal for automated inspection, however, which can quickly identify every flaw in a panel.

How and where in the production floor to inspect the panel depends on the fabrication process. Currently, the TFT-LCD (thin film transistor liquid crystal display) process dominates the market with between 80% and 90% market share. Inspection of the color filters used in this type of display, then, provides an excellent example of AOI in FPD production.

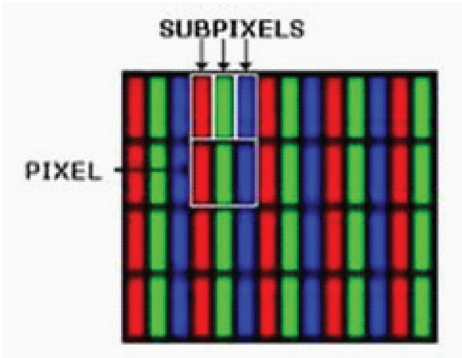

***Figure 1* - Flat panel display pixels comprise three sub-pixels in primary colors.**

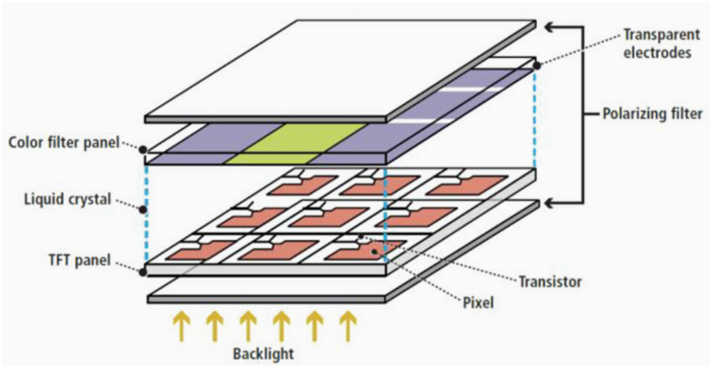

***Figure 2* - A color liquid crystal display typically has the color filter on one of two panels encapsulating liquid crystal material.**

The basic structure of a color TFT-LCD FPD, shown in Figure 2, is a sandwich of two panels with liquid crystal material between. One panel has an array of thin film transistors that controls the polarization of the liquid crystal and therefore the light intensity. The other panel carries the color filter array that filters out the spectrum of each primary color.

Fabricating the color filter array requires four cycles of film deposition, coating with resist, exposing and etching, and then cleaning. These cycles first form onto the glass panel a matrix of spaces outlined in black matrix then fill in alternate spaces with red, green, or blue filter material.

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Finding Repairable Flaws Boosts Yield

The entire surface of the filter panel will receive a transparent indium tin oxide (ITO) coating that serves as a return electrode for the transistors on the other panel. Before the ITO coating is applied, however, the filter panel requires inspection. Performing the inspection at this stage preserves the option of reworking the panel to correct errors in the filter matrix and thus improve yield. Once the coating is in place any flaws found must be worked around when cutting the panel into pieces for assembly into displays, creating waste.

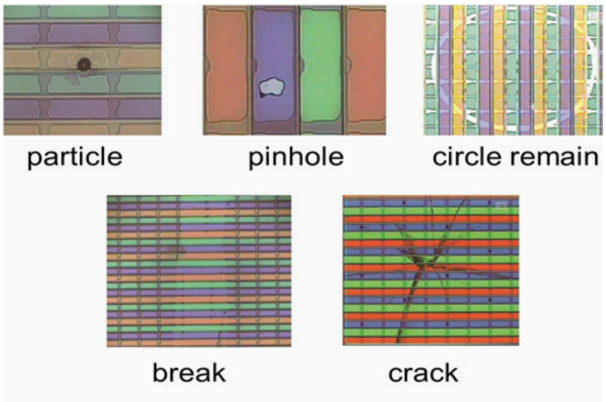

***Figure 3** - Inspection can identify and determine the position of both repairable and non-repairable defects.*

The color filter inspection step seeks to identify and determine the position of two defect types. One type is the repairable defect, including such flaws as opaque particles in the filter area, bubbles or holes in the filter coating, and non-uniformity in the filter color density (Figure 3). Any such defects the inspection system locates can be reworked in an attempt to correct the problem and restore the usability of that panel area.

The second type of flaw that inspection can find is the non-repairable defect. This includes cracks and large area breaks in the glass, which are either impossible or too time-intensive to repair. The inspection system simply provides the location of such defects to the production line operator. This information allows a later stage in the line to cut usable pieces from the panel in a way that avoids the defects.

In order to keep production throughput as high as possible, the AOI systems for FPDs must have several key attributes. One of the most important is that the inspection system operates in-line with the production flow. The glass on which the color filters are fabricated is relatively thin (0.5~0.7mm) and easily cracked or broken during handling. An off-line inspection station would require removal of the glass from the fabrication equipment and temporarily storing it before inspection as well as after while awaiting reinsertion into the production line. Such additional handling and storage greatly increases the risk of damage to the panel.

High Speed In-Line inspection

In-line inspection systems eliminate such handling and the resulting damage, helping to increase production yield. In order to avoid becoming a bottleneck in the production line, however, an in-line inspection system must have an additional attribute: it is fast. Ideally, inspection is as fast as or faster than the tact time of the line so that its operation does not affect throughput.

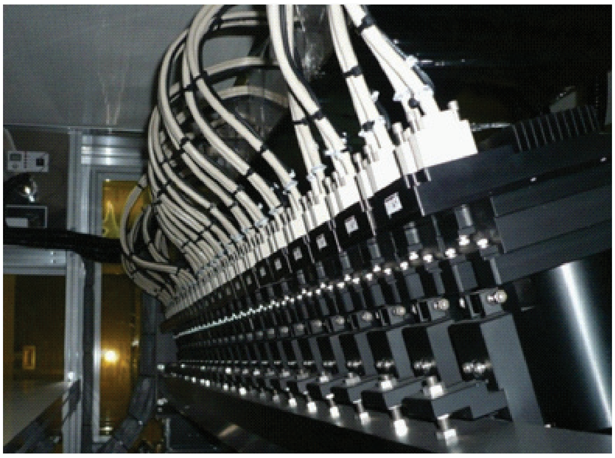

***Figure 4** - Handling panels as large as G8.5, the Cobra AOI system from Utechzone is representative of in-line AOI for flat panel production*

The Cobra flat panel inspection system from Utechzone is an example of such an in-line inspection system (Figure 4). The Cobra system is able to inspect many different aspects of color filter panels, including the black matrix, the color sub-pixels, the ITO coating, multi-dimension vertical alignment of the pixel structures, and the photo spacers that maintain separation of the filter and TFT panels after assembly. It handles glass panels are large as 2500x2200 mm (G8.5 size).

The system contains an array of 25 high-resolution P3-12k line scan cameras from Teledyne DALSA, each attached to its own PC to provide image processing using a proprietary neighbor-comparison algorithm. It uses a combination of

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front- and back-side illumination as needed to maximize the visibility of various surface and body defect types (Figure 5). The Teledyne DALSA cameras are a core component of the Cobra system and critical to its performance characteristics. The system uses 25x P3-80-12k40 line scan cameras to capture images of the entire panel as it moves past. Unlike the more familiar area cameras with a fixed rectangular image area captured all at once, line scan cameras form an image one stripe at a time as an object passes through the camera's field of view. Line scan cameras are thus able to form a full-length image of the panel while it is moving along the production line, whatever its length. By building the image while the panel is moving, the line scan camera eliminates any need to either stop the panel in order to take a picture or use high-intensity lighting to support rapid shuttering.

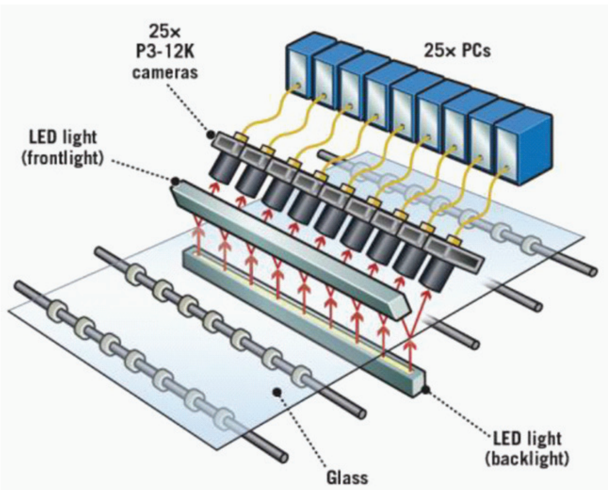

***Figure 5** - LED illumination from both the front and back sides of the panel under inspection allows the Cobra system's cameras to detect a wide variety of defects in the glass and filter array.*

Each camera in the Cobra system captures 12,288 pixel-wide line images with a pixel size of 5 microns at a line rate of 21 kHz, so scanning an entire G8.5 panel requires only 15 seconds. The system's defect detection, identification, and location logging processes, working with a collective 6.5 Gbytes/second of image data, are fast enough to yield a tact time of 27 seconds for the entire inspection stage. This corresponds to a production throughput of nearly 150 G8.5 color filter panels per hour, each of which will yield multiple FPDs.

The cameras provide image resolution down to 7.5 microns. Pixels in an HDTV can be as small as 80-90 microns, which makes sub-pixels as narrow as 30 microns. With a resolution of 7.5 microns, then, the Cobra system is able to provide at least 3~4 pixels across the width of a color filter sub-pixel segment, more than adequate for image processing to provide a thorough inspection of every filter on the panel.

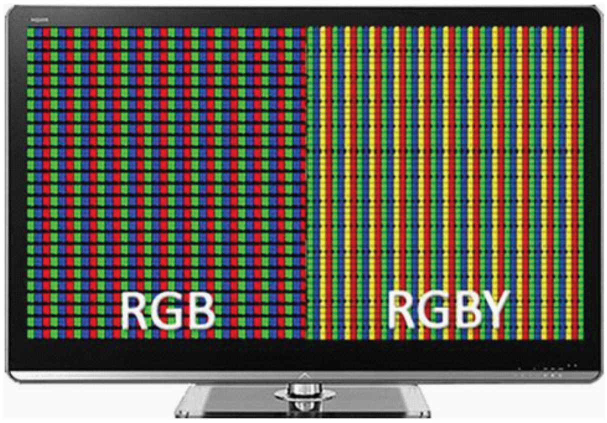

***Figure 6** - Adding a yellow filter to the traditional red-green-blue display yields a brighter, more colorful picture at the cost of reduced sub-pixel size.*

AOI Tracks FPD Technology Evolution

The Utechzone Cobra AOI system readily hands today's FPD inspection requirements, but display technology does not stand still. One recently-introduced innovation, for example, is Sharp's Quattron display that uses four primary colors per pixel instead of three (Figure 6). By adding yellow to the traditional red, green, and blue filters on a TFT-LCD display, Sharp was able to improve the panel's light transmission as much as 20% and increase the range of colors the panel could produce from 16 million to over 4 billion.

AOI systems can handle the expanded color palate with relatively straightforward software changes. A more significant impact of the additional filter, however, is that its presence means that the sub-pixels must shrink by more than 30% to fit with the same pixel spacing. This reduction increases the AOI system's resolution requirement. The rising market for tablets and other handheld media devices needing high pixel density (e.g. 400ppi), hence smaller pixels, is also increasing resolution requirements. Inspections systems such as the Cobra are readily adapted

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to handle smaller sub-pixel sizes, however, through camera sensor replacement. Teledyne DALSA offers a 16k/3.5μm-pixel version of its line scan camera upgradeable from the P3-80-12k40 that provides the needed resolution improvements. And as resolution requirements continue to increase, enhancements to Teledyne DALSA camera sensors will keep pace and allow AOI systems to match evolving resolution requirements through camera upgrades without requiring any other system hardware changes.

There are other emerging FPD technologies, however, that may require new AOI system designs. One such technology is the color filters fabricated on the same panel as the thin-film transistors. Placing both filter and transistor on the same panel reduces the materials, reducing cost. Tests also indicate that the color-filter-on-array (COA) approach improves light transmission through the LCD panel as much as 20%, providing a brighter image with less power.

The glass panel of a COA display is more complex than traditional panels and will require more complicated image processing. Early results also suggest that the light used to illuminate the panel during inspection may need to employ different wavelengths than the white LEDs used in current systems. But these are not insurmountable obstacles to AOI. Teledyne DALSA offers a wide range of camera and sensor technologies that work at a variety of wavelengths providing both the high resolution and high speed that AOI systems for FPDs require. In addition, the company has significant expertise in image processing and vision system design that can help developers address complex inspection needs such as COA inspection.

Automated Optical Inspection will thus continue to play a critical role in flat-panel display manufacturing. AOI serves as an enabler for the cost-effective manufacture of the high-performance panels needed in HD display products by helping increase yield without compromising production throughput. Further, AOI technology provides a clear upgrade path for handling current needs as well as emerging requirements such as smaller filter structures. And as display technology continues to evolve, companies such as Teledyne DALSA have the products and expertise that allow AOI to keep pace.

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