Precision Photolithography on Flexible Substrates

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As the design and performance of flat panel displays (FPDs) have evolved, development has focused on producing displays that are thin and lightweight. This, in turn, has led to an interest in flexible substrates for backplanes and to such emerging technologies as OLEDs (organic light emitting diodes), PLEDs (polymeric light emitting diodes), and flex LCDs (liquid crystal displays)[1]. Polymer substrates offer the additional advantages of lower cost, less chance of damage due to breakage, and the ability to create ultra-large displays for advertising and large-scale information panels.

In producing flexible substrates for backplanes, the ultimate objective is to achieve roll-to-roll (R2R) manufacturing in which the circuitry is "layered" on the flexible substrate through photolithography. However, producing circuitry on flexible substrates presents a unique challenge for a photolithography system. To date, glass has been used for backplanes because the material is dimensionally stable. Though some expansion can occur due to increases in temperature, advanced step-and-repeat photolithography systems (aka, steppers) have the ability to compensate for the slight changes.

Flexible substrates are another matter, as they are neither dimensionally nor thermally stable. On the surface, such a limitation would seem to suggest the impossibility of ensuring precision in: a) stepping images from one circuit to the next, and b) layer-to-layer registration. Some materials are better than others. While PET (polythylene terephthalate) has historically been more commonly used for flex circuits, polymers such as PEN (polyethylene naphihalate) and

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[1] A flex LCD is simply an LCD on flex material. Most flat panel displays incorporate active matrix (AM) LCDs with amorphous-silicon thin film transistors. AMLCDs, in fact, represent more than 75% of the displays being manufactured today, with photolithography being used to form the thin-film transistors (TFTs), color filters, and scanning electrodes on high temperature glass.

polyamide-based Kapton[2] offer improved mechanical properties, including stability. Undoubtedly, these films, and others, will ultimately replace PET as the material of choice for flex circuit substrates. While films as thin as 50 µm may be used, the material thickness for polymer backplanes in FPDs is likely to run from 100 to 200 µm.

Meeting the Challenge

The challenge of applying a photoresist and circuitry on flexible substrates such that precision is ensured, both during the photolithography process across an individual layer and during the registration of subsequent layers, is being met by a step-and-repeat technology that incorporates an active compensation architecture. That is, intrinsic and process-induced distortion effects have been pre-measured and are accommodated for during stitching and overlay procedures. In addition to the advanced software with N-point alignment algorithms that enable alignment compensation, accuracy is achieved through a highly precise X-Y platform, a reticle mechanism that enables six degrees of freedom in adjustment, and high resolution optics optimized for flexible substrate imaging.

For a technician running the system, the steps to create circuitry on flexible substrates using photolithography are the same as they are for glass: a) deposit an ITO (indium tin oxide) layer, b) apply the photoresist material, c) expose the photoresist to light through a mask, or reticle, and d) clean the unexposed material off the surface of the substrate down to the ITO, leaving an “etched” circuit for that particular layer. With a stepper, the imaged area represents a portion of the entire circuit for a given layer; the system then “steps” to a contiguous portion of the circuit to expose the next image.

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[2] Kapton is a registered trademark of Dupont Teijin Films. There are different types of Kapton, the selection depending on temperatures encountered during manufacturing.

For the operator, running a stepper for flexible substrates is essentially the same as for glass because the alignment calculations have already been programmed in to one system. The difference between the two systems from a procedural standpoint is in the machine setup and programming of the software.

Ensuring Precision in Flexible Substrates

As suggested, there are two aspects to imaging flexible substrates: the initial layer and subsequent layers for completing the circuit. In setting up a machine with ACA (active compensation architecture) for the first layer, male and female verniers (known as cells) are imaged onto the test substrate for the first step position, which encompasses a circuit area of 50 mm x 50 mm. The platform is then stepped to the next position and is precisely adjusted such that the male verniers for that particular image fit precisely on top of the female verniers for the previous step position. The position is automatically recorded in the software. The platform is then stepped to the next position, and the process is repeated. In this way, the entire substrate is stitched with the exact position for each step and each portion of the circuit for that layer.

For subsequent layers, the software incorporates an advanced N-point alignment (NPA) capability, which ensures highly precise alignment of multiple points on one layer over corresponding points on the previous layer for near-perfect global registration. The process, known as the "least squares" method, employs algorithms to calculate the minimum total square distance between all corresponding points. Advanced NPA is an enhancement over existing N-point alignment systems in that the positioning information is gathered using the patented "six-degrees of freedom" platform, mentioned above, for positioning substrates. With as few as three alignment points, data can be recorded in terms of X, Y, θX, θY, and magnification in X and Y. The equations resulting from this data provide the positioning information.

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For registration of layers, the key to machine setup is the positioning grid, which enables global calculation of alignment points across the substrate for the completed circuit. The grid is thus representative of the re-positioning required for the cross hair measurement points. The actual positioning data is recorded by the software program in microns to two decimal points.

The positioning data represents both the global and the non-global offset results. Both must be calculated and accommodated for. If, for example, the second circle in the top row is off to the right (along the X axis) by a half micron and the deviation is consistent for the other circles in the same row, then the deviation is “global” and can be easily accommodated by the software program for that layer. Thus, when imaging the layer, the system automatically compensates for the global distortion by shifting the platform 0.5 μm to the right before the process begins.

A non-global deviation means that adjustment by the software must occur as the stepper reaches a particular measurement point. Such data is programmed in, and the adjustment occurs as the layer is being imaged. Alignment data is recorded for each measurement point and each reticle required to completely image a flexible substrate. In this way, layer-to-layer deviations are corrected alignment point by alignment point to ensure precise registration of the circuitry.

The Future of R2R

Currently, a technology has been developed by Azores Corp that achieves the reticle-to-reticle alignment and layer-to-layer registration precision required for imaging circuits on flexible substrates. The company has incorporated a number of advancements from its existing photolithography technology, developed for flat panel display substrates. As such, the new technology features a state-of-the art X-Y platform controlled by laser interferometry, a high

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fidelity lens and illumination system, automated reticle handling and storage, and a sophisticated suite of metrology sensors. The sensors, incorporated to calibrate and optimize system performance, include transmission alignment (TAS) to detect positioning of the lens grid; modulation transfer function (MTF) to detect lens focus; illumination intensity to detect illumination uniformity; and reflective alignment (RAS) to detect the position of the alignment system relative to the center of the lens.

Added to existing technology are automated substrate alignment architecture, attendant programming software, and a handling system for flexible substrates. The system successfully etches circuitry on PET, PEN, Kapton and other polymer materials, with an image field stitching error of less than ±0.3 µm.

The flexible substrate technology developed by Azores is designed for imaging 16” x 18” (406.4 mm x 457.2 mm) sheets of polymer material with thicknesses from 100 to 200 µm. The sheets are subjected to both tension and vacuum to ensure flatness and uniformity across the surface of the substrate.

Under contract with the U. S. Display Consortium (USDC), Azores is developing a system for roll-to-roll (web-based) imaging of circuitry for flat panel display applications with the R2R capability built-in. The system will be able to accommodate rolls with a width of 200 mm to 600 mm and with a length of 300 mm.

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