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Micron-Patterned Deposition through Shadow Masks with High Precision Alignment for OLED and e-Paper Applications

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Abstract

Conventional shadow-mask alignment using mechanical pins or machine-vision techniques achieve 5 micron alignment accuracy. Here we introduce a novel alignment system-architecture based on coded apertures along with discrete photo detectors as the sensing elements. It allows submicron accuracy and repeatability making it highly suitable for display manufacturing applications.

Author Keywords

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1. Introduction

Display manufacturing is a complex and intricate process requiring precise alignment of micron size features for circuit fabrication as well as final pixel definition. Numerous processes using conventional photolithography and/or shadow masking are common practice for active matrix backplane fabrication and OLED deposition. Currently, backplanes are fabricated using state of the art photolithography and etch processes that were developed for Silicon-based CMOS technology manufacturing. Therefore, device fabrication requires sophisticated and expensive optical alignment equipment and environmentally unfriendly etch processing in a cleanroom setting.

At Advantech US, we offer a different approach to backplane fabrication by a low cost alternative solution using an evaporation printing method [1,2] that combines thermal and e-beam evaporation of materials through a fine metal mask or shadow mask. Shadow masking is an old fabrication art in which thin metal foils having well-defined small apertures on the micron size scale allow evaporated material to be deposited onto a substrate in discrete shapes to create device features necessary for electrical circuit fabrication. Furthermore this technology can also be easily extended for use in OLED deposition to define specific RGB pixel size and layout.

The key to the success of our technology is the shadow mask to mask alignment and registration to the substrate [3]. In the last ten years, Advantech has improved on the existing shadow mask technology by developing proprietary shadow mask design, mounting and management in process using multiple shadow masks of different apertures in combination with a novel alignment system. These technical advances provide the proper registry to fabricate circuits containing transistors and capacitors that can be easily fabricated on any type of rigid or flexible substrate without the need for conventional lithography.

In this work we describe our novel alignment system using an in-situ vacuum deposition alignment stage in which motion can be controlled in sub micron increments together with a detection system of coded apertures and discrete photo detectors as the sensing elements. Our alignment registry and repeatability between shadow mask and substrate of less than 1 micron accuracy has been achieved with our ultimate goal to attain alignment and deposition TAC time around 5 minutes per processing step. Currently, we have incorporated 4 alignment stages into 4 interconnected vacuum deposition chambers to fabricate active matrix backplanes and other circuits using this simple inline approach.

2. Alignment System

The basic design of our alignment system is as follows. Our shadow mask is rigidly mounted to the top plate of our alignment stage. The stage can be manipulated along the Z direction (mask to substrate distance) while keeping the shadow mask surface and substrate parallel to each other. Motion of the shadow mask is controlled along the X and Y axes as well as the in-plane rotation angle T (theta). Our detection scheme involves a set of 4 coded apertures strategically arranged at the 4 corners of Pre-Patterned Substrate (PPS) and Shadow Mask (SM). (See Figure 1) The 4 apertures on PPS are simple Ronchi gratings of identical pitch and 50% duty. The one in the first quadrant is oriented in 45 degrees so that gratings are nominally in radial orientation but not tangential. The other three apertures are placed such that positions and the orientations hold horizontal and vertical symmetry in the global geometry (See Figure 1a). The coded apertures on the SM are arranged in a similar manor except that they are phase shifted. (See Figure 1b) In the first quadrant the phase is advanced by quarter pitch from the apertures on the PPS. The apertures in other three quadrants are also phase shifted a similar amount in the orientation to hold horizontal and vertical symmetry.

Figure 1 a) Coded apertures on substrate. b) Coded apertures on shadow mask.

When the SM is placed over the PPS, the joint transmissivity values are measured at 4 locations. The apertures are illuminated by LEDs and the amount of light transmitted through overlapped apertures is measured by discrete photo diodes. When apertures are aligned, the gratings are overlapped by a quarter pitch in each quadrant and light transmissions are exactly half the value compared to the PPS alone. In this case, the 4 detectors show the same value indicating a perfect alignment. If detectors show unequal values, then the differences tell how much misalignment exists and in which axis. Examples are illustrated graphically. (See Figure 2) They demonstrate how the transmissivity in the four apertures are affected by displacement in X, Y and T (theta) axis. When the PPS is shifted in positive X direction (Figure 2a) then the positive side channels 1 and 4 experience less overlap between the gratings resulting in more transmission while the negative side channels 2 and 3 results in less transmission. Essentially, the east side becomes brighter than west side.

(a)   (b)   (c)

Figure 2. Joint Transmissivity response to displacement between SM and PPS a) Horizontal displacement b) Vertical displacement c) Rotational displacement

The signal responses in the other axes are of similar nature. When PPS is shifted in positive Y direction the positive side channels 1 and 2 observe more transmission than negative channels 3 and 4. In this case, the north side becomes brighter than south side. In the rotational axis T, response to displacement verifies as well. (See Figure 2c) Positive rotation causes more transmission in the diagonal channels 1 and 3 while less transmission in the anti-diagonal channels 2 and 4. In general the amount of displacement in each axes delX, delY and delT can be expressed in terms of transmissivity measurement in the 4 quadrants f1, f2, f3 and f4 respectively such that

$$delX = A(f1 - f2 - f3 + f4) \qquad (1)$$

$$delY = A(f1 + f2 - f3 - f4) \qquad (2)$$

$$delT = A(f1 - f2 + f3 - f4) \qquad (3)$$

where A is a proportionality constant to the pitch of the gratings. Note the shorter the pitch, the finer the resolution can be achieved. Therefore the selection of fine gratings is advantageous to achieve fine alignment accuracy. The sensor output repeats itself due to the periodic nature of Ronchi grating that might cause a 2π ambiguity. Thus the grating pitch should be kept within the ambiguity of the starting position. The acquired displacement values are fed into a 3-axis servo system to achieve the desired alignment tolerances. A closed loop control system is used to minimize the displacements to achieve the desired alignment tolerances in the shortest time possible.

3.   Demonstration of Alignment

A trolley carries the substrate to the alignment stage and we begin the alignment process by adjusting the Z height to a distance of 500 um between mask and substrate. Capacitive sensors accurately measure the distance and verify final contact between mask and substrate. We begin our coarse alignment procedure and reduce the displacement in X and Y below 6 um and T below 0.003 degrees. Our fine alignment procedure begins and is achieved when the displacement in X and Y is below 2 um and T is below 0.001 degree. At this point the alignment stage is commanded to reduce the Z height from 500 um to 0 while minimizing X, Y and T displacement. A magnet is then activated to assist in potential mask sagging and the alignment procedure ends when the closed loop control is released. A graphic representation of a typical alignment is shown in Figure 3, where the displacements in X, Y and T are shown as a function of our alignment time stamp. In this example the substrate and shadow mask were over 50 um displaced in X and Y to begin with and after alignment the overall displacement was reduced to less than 2 um. Upon the "lock on" release the stage motors and magnet rigidly hold the substrate and mask sandwich together during film deposition.

Figure 3. Alignment output data showing the convergence of the measured displacement of X, Y and T as a function of alignment time in arbitrary units. The breaks in the curve indicate the beginning or ending of a particular part of the alignment process as shown with the arrows. Note the T value is multiplied by 2000 for scaling.

To further confirm the alignment system is working properly and can repeatedly align a shadow mask to substrate, we performed the following experiment. We first begin by aligning a shadow mask, with distinct rectangular features, to substrate and deposit a 50 nm thick CdSe film. The substrate is removed from the vacuum system and the features are inspected using an optical microscope. An image is recorded of a particular feature fabricated at a particular location during the 1st deposition as shown in Figure 4. The substrate is then replaced back into the vacuum system and the alignment is repeated for a second time along with a second 50 nm thick CdSe film deposition. The substrate is then removed from the system and re-inspected.

1st deposition   2nd deposition

Figure 4. Optical micrograph indicating overlay and repeatability capabilities of shadow mask alignment.

As shown in Figure 4, the second deposition feature nearly falls on top of the first feature. Specifically there is a small displacement between the first and second deposition features of less than 2 um along the X direction and less than 1 um along the Y direction. Furthermore the edges of both rectangular features are parallel to each other with a T displacement of less than 0.001 degree.

Finally we have used our inline deposition approach along with our novel alignment system to fabricate micro-circuits and active matrix backplanes. In Figure 5 we show a close up view of a 1T/1C pixel backplane circuit used for our e-paper Electronic Shelf Label display that was fabricated using 5 different shadow masks. An alignment tolerance of 2 um or less has been achieved in this circuit.

Figure 5. Optical micrograph of a single pixel (1T/1C) circuit fabricated using 5 separate shadow masks and multiple alignment stages at the Advantech US facility.

4.   Conclusion

In conclusion, Advantech US has developed a low cost shadow mask evaporative printing process to fabricate active matrix backplanes for OLED and e-Paper displays using a unique alignment system approach. Currently our novel system process can align a substrate to shadow mask within a 1 um tolerance accuracy within a minimal amount of time. We are developing an inline deposition approach to fabricate a complete backplane within 1 hour where each deposition step will have a TAC time around 5 minutes.

5.   References

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