Novel Method for Fabricating Flexible Active Matrix Organic Light Emitting Diode (AMOLED) Displays

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Keyword(s):

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Abstract:

Recently, significant progress has been made toward application of organic (small molecule/polymer) lightemitting diodes (OLEDs) in full color flat panel displays and other devices. However, current technologies for OLEDs in the market are still very limited, especially in terms of cost, size and flexibility. We believe fabricating OLED displays using roll-to-roll (R2R) manufacturing on plastic is the way to achieve low cost, light weight and flexibility. One of big challenges for fabricating flexible OLED displays is alignment on large area flexible substrates. We discuss here a proof-of-concept HP proprietary solution to fabricate flexible active matrix OLED displays, which involves a process in which a welldefined micro OLEDs (μOLEDs) frontplane is directly laminated with our R2R processed active matrix flexible backplane built via self-aligned imprint lithography (SAIL) without any in-between alignment. A proof-of-concept AMOLED device has been built, which contains a flexible μOLEDs frontplane with OLED sizes of 50 μm on PET and active matrix backplane on polyimide with pixel pitches of 1 mm. Such alignment-free method offers great possibility to create large area interactive displays such as wall-paper type of displays with very low cost that no other technology today can achieve.

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ABSTRACT

Recently, significant progress has been made toward application of organic (small molecule/polymer) light-emitting diodes (OLEDs) in full color flat panel displays and other devices. However, current technologies for OLEDs in the market are still very limited, especially in terms of cost, size and flexibility. We believe fabricating OLED displays using roll-to-roll (R2R) manufacturing on plastic is the way to achieve low cost, light weight and flexibility. One of big challenges for fabricating flexible OLED displays is alignment on large area flexible substrates. We discuss here a proof-of-concept HP proprietary solution to fabricate flexible active matrix OLED displays, which involves a process in which a well-defined micro OLEDs (µOLEDs) frontplane is directly laminated with our R2R processed active matrix flexible backplane built via self-aligned imprint lithography (SAIL) without any in-between alignment. A proof-of-concept AMOLED device has been built, which contains a flexible µOLEDs frontplane with OLED sizes of 50 µm on PET and active matrix backplane on polyimide with pixel pitches of 1 mm. Such alignment-free method offers great possibility to create large area interactive displays such as wall-paper type of displays with very low cost that no other technology today can achieve.

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INTRODUCTION

Tremendous progress has been made toward application of organic (small molecule/polymer) light-emitting diodes (OLEDs) in full color flat panel displays and other devices. Especially, active matrix OLED displays (AMOLEDs) are a highly promising information display technology since they are more efficient than passive matrix (PM) OLEDs and are not limited in size or resolution. However, current technologies for AMOLEDs in the market are still very limited, especially in terms of cost, size and flexibility. Our goal is to create AMOLEDs that are light-weight, flexible, extremely low cost, and with brilliant color. We believe fabricating OLED displays using roll-to-roll (R2R) manufacturing on plastic is the key to enabling this goal. As commonly known, making AMOLEDs is currently not easy or simple, and it involves several stages – taking the substrate, cleaning it, making the backplane, depositing and patterning the organic layers and finally encapsulating the whole display. With such complicated processing, it is even more difficult to fabricate AMOLEDs on flexible substrates. Patterning and re-alignment on large area flexible substrate is extremely challenging due to the nature of the flexible substrate. The substrate has varying distortion during different process steps. This makes it impossible to re-align the mask to pre-patterned substrate. Bonding and de-bonding flexible substrate on a rigid substrate has been used to solve the instability problem. For large size displays, it requires a modified flat panel manufacturing line which has extremely high cost. Therefore, developing alignment-free or self-aligned processes for fabricating AMOLEDs is essential. In this paper we discuss a proof-of-concept HP proprietary solution to fabricate flexible AMOLEDs. It involves a process in which a flexible AM backplane and a flexible OLED front plane are fabricated separately. Our R2R processed AM flexible TFT backplanes built via self-aligned imprint lithography (SAIL) is directly integrated with a well-defined micro OLEDs (µOLEDs) frontplane by anisotropic conductive bonding without any in-between alignment.

SELF-ALIGNED IMPRINT LITHOGRAPHY (SAIL)

Hewlett-Packard Laboratories and PowerFilm Solar are building AM displays on polymer substrates using roll-to-roll (R2R) processes exclusively. The approach developed in HP Labs is named Self-Aligned Imprinted Lithography (SAIL) [1] and is the first demonstration of low-cost fabrication of an amorphous silicon TFT backplane with sub-micron resolution and high aspect ratio in a fully R2R process. The process combines plasma deposition, imprint lithography, and wet and dry etching as shown in Figure 1.

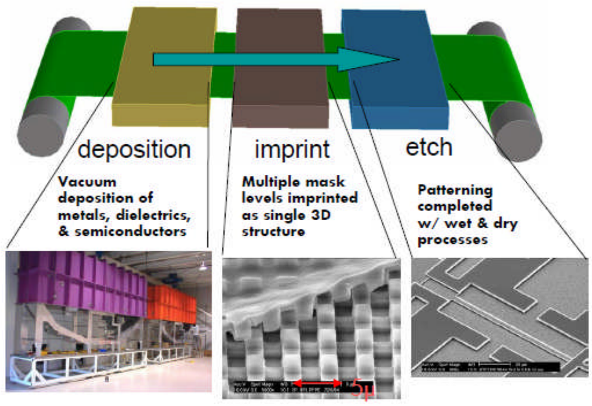

Figure 1. SAIL Process Flow

Unlike a conventional panel based process in which a number of deposition, alignment and patterning steps are involved sequentially, the SAIL process solves the challenge of patterning and aligning submicron features on meter-scale substrates by encoding the geometry for all of the patterning steps into discrete heights of a 3-dimensional (3D) masking structure shown in Figure 2. The 3D mask is imprinted on the film stack in advance of patterning and maintains alignment regardless of process induced substrate distortion. Figure 2(b) is an SEM image showing the 4 discrete heights in the mask used to produce bottom gate a-Si TFTs. In the SAIL process, all of the deposition steps for the complete thin film transistor (TFT) stack are completed before any of the patterning steps. The multiple patterns required to create the backplane are encoded in the different heights of a 3D masking structure that is molded on top of the thin film stack before any of the etching steps. By alternately etching the masking structure and the thin film stack the multiple patterns required for the backplane are transferred to the device layers. Because the mask distorts with the substrate perfect alignment is maintained regardless of process induced distortion.

(a)

(b)

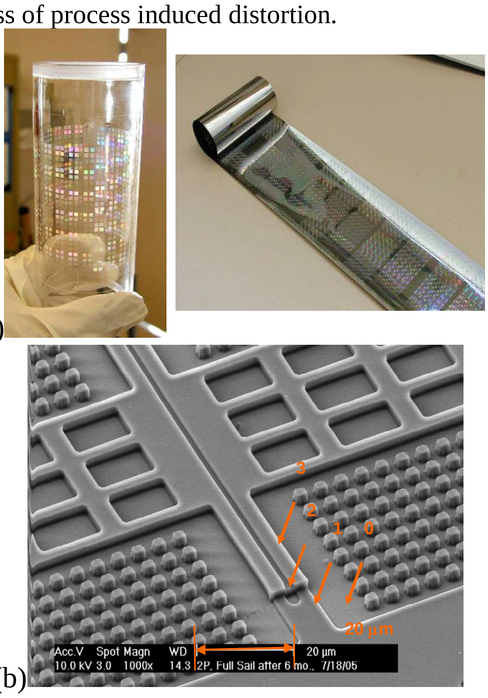

Figure 2. (a) Quartz Roller with a 3D masking structure (left) and Imprinted web (right); (b) SEM image of 4-level imprinted mask for AM backplane

SAIL has been used to fabricate both electrophoretic and OLED displays and amorphous silicon and metal oxide based backplanes have been demonstrated with the process [2-4]. Our backplanes are fabricated on 50 µm thick 1/3 m wide polyimide films. All equipment has been built in-house or externally to our specifications. The full TFT stack is deposited using vacuum deposition equipment. The imprint polymer is coated and embossed on a coater/imprinter. The subsequent etch process which transfers the imprint mask into the TFT geometries are performed by in a R2R tank etch and RIE (Reactive Ion Etch). The backplane arrays are then singulated, tested, and some simple defects such as shorts are repaired before laminating them with OLED frontplane. Figure 3 shows TFT circuit of finished AM backplane through R2R based SAIL process.

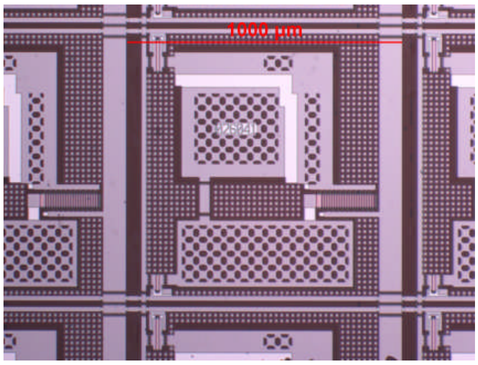

Figure 3. Pixel of our AMOLED backplane

INTEGRATED AMOLED DISPLAY

To be compatible with our highly flexible R2R processed AM backplanes, solution-processing is very attractive for fabrication of the OLED frontplane due to its simplicity and highly reduced equipment costs relative to vacuum deposition. Even more importantly, it is essential to achieve alignment-free integration between AM backplane and OLED. Our approach is to fabricate well-defined OLEDs with a cathode size of tens of micrometers that are much smaller than the pixel electrodes on AM backplane so that the light-emitting area is totally defined by the backplane. We called them micro OLEDs, referred as µOLEDs below. The design of integration between µOLEDs and AM backplane is shown in Figure 4. After bonding with the backplane using anisotropic adhesive only those µOLEDs that overlay the backplane pixel region will be turned on, such as those ones in the dashed circle in the Figure4.

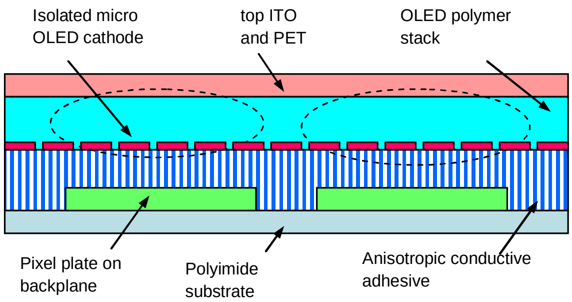

Figure 4. µOLEDs frontplane laminated with backplane by anisotropic bonding adhesive

In our on-going experiment, µOLED based frontplanes with white emission are fabricated through solution processing for organic stacks and thermal evaporation for micro electrodes on ITO coated PET substrates. The µOLED frontplane has a simple structure of ITO-PET/DuPond Buffer® (DB, used as hole injection layer)/organic emissive material/Ca/Al for concept demonstration. Our blue-emitting material and three-color based organic white-emitting materials are formulated in-house using commercially available emissive conjugated polymers including poly(9.9-dioctylfluorenyl-2,7-diyl) (PFO), poly[2-methoxy-5-(-ethylhexyloxy)-phenylene-vinylene] (MEH-PPV), poly[9-dioctyl-fluorene-co-benzothiadiazole)] (F8BT) following procedures reported previously [5]. Both DB and emissive layer were spin-coated. The cathode electrode including layers of Ca and Al was thermally evaporated in a vacuum chamber under a pressure of 8 x10^{-6} Torr using shadow masks. Figure 5 shows a finished μOLED array with approximately 75 μm pitch sizes.

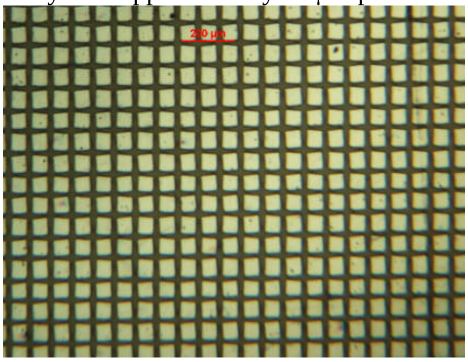

Figure 5. Microscope image (Al-side) of μOLED array

One of challenges for this alignment-free direct lamination between μOLED and AM backplane is the bonding method since both pieces are fairly delicate, especially the μOLEDs which are sensitive to many environment elements such as moisture, oxygen, chemicals, high temperature and pressure as all OLEDs are. A common anisotropic adhesive coated on the backplane for integration would cause the OLEDs to fail after the bonding process because it normally introduces high temperature and pressure during the bonding. One big problem is that the contact materials in the adhesive can easily penetrate through the OLED stack under pressure or even high temperature resulting in shrinkage of adhesive materials and cause shorts in devices. A special anisotropic conductive adhesive is used in which the conductive beads in UV curable adhesive matrix can be aligned under a magnetic field before curing (Figure 6). The backplane is coated with this adhesive by stencil or screen printing and a μOLED based frontplane is placed on top of the adhesive layer. When the magnetic field is applied those beads can form isolated columns and create vertical conductive paths. UV irradiation is then applied to cure the adhesive. This type of adhesive minimizes the negative impact to OLEDs due to high temperature and pressure. μOLED based frontplanes are bonded with a mock backplane which was created on polyimide substrate and a segmented backplane using such adhesive to prove the concept. The devices were operated in air without further packaging shown in Figure 7. No alignment is required in the bonding process. The μOLED area that has turned on shows that the anisotropic conductive columns are well formed with a high connection yield and the pattern is totally defined by the backplane pixel shape.

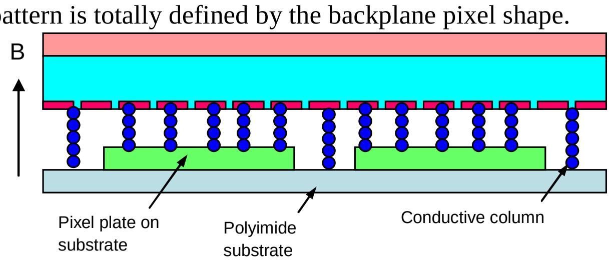

Figure 6. Cartoon image of magnetic conductive adhesive laminating layer in-between μOLEDs and AM backplane

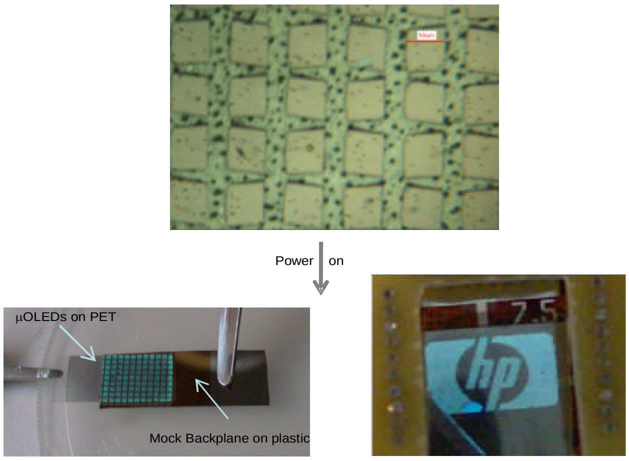

Figure 7. Microscope image (top) viewing from μOLEDs substrate PET side (note: the black spots in streets of Al electrode are magnetic particles), an operating array (bottom left) of integrated device containing flexible μOLEDs frontplane and a mock backplane array, and a segmented display device (bottom right)

With the success of the proof-of-concept devices shown above, we have built an AMOLED demonstrator using this alignment-free direct lamination method (Figure 8). This is a 30x10 array, which includes a μOLED frontplane with bottom emission of white color and a fully R2R SAIL processed AM a-Si TFT backplane. The device was operated at 12 V in air without further packaging and protection. Improvement for a better yield and performance is currently underway.

Figure 8. AMOLED demonstrator using alignment-free lamination process

CONCLUSION

In summary, a novel method has been demonstrated to fabricate flexible AMOLED displays by integrating a flexible AM backplane with a μOLED based frontplane using an alignment-free direct lamination method. The AM backplane is fabricated using R2R SAIL processing on a flexible polyimide substrate with a thickness of 50 μm. The bonding process has been developed and shows great compatibility with both the frontplane and the backplane. Although our first AMOLED demonstrator built with such a method requires further optimization, the feasibility to fabricate low-cost AMOLED displays in a simple way has been proven.

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