Microcup® Electronic Paper and the Converting Processes

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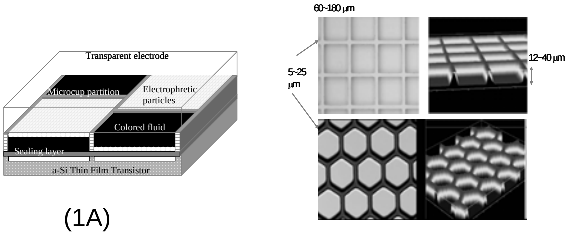
ABSTRACT

High performance Electronic Paper based on bistable, charged electrophoretic microparticles has been prepared by the SiPix roll-to-roll manufacturing processes using novel Microcup® and top-filling/sealing technologies. Two types of format flexible EPD rolls have been produced: (A) a sandwich roll of release liner/filled and sealed Microcup®/non-patterned conductor film for active matrix (AM) EPD and direct drive applications, and (B) a sandwich roll of row conductor film/filled and sealed Microcup®/column conductor film for passive matrix (PM) EPD applications. Simple post converting processes have been developed to convert the EPD rolls into display modules or products.

Keywords: Microcup® EPD, post converting, active matrix, passive matrix

INTRUDUCTION

Ultra thin, ultra light-weight, flexible electronic paper/displays have been prepared by SiPix's roll-to-roll EPD manufacturing process at very high throughput and low cost[1-8].



(1A)

(1B)

Figure 1 (A) Schematic illustration of the Microcup® AMEPD, and (B) Photoprofilometry of two Microcup® arrays

Figure 1A shows the schematic illustration of a typical Microcup® active matrix EPD. From top (the viewing side) to bottom are the transparent first electrode, Microcup® array filled with a colored electrophoretic fluid, sealing/adhesive layer, and a TFT back-plane. The Microcup® array may be prepared by, for example, photolithography or microembossing a UV curable resin on a conductor (ITO) film on a continuous plastic web. The Microcups® confine the electrophoretic fluid in small, isolated compartments to avoid crosstalk of fluids and undesirable particle movements. The unique structure also provides the format flexibility, structural integrity and mechanical stability of the resultant displays. The physical shape and dimensions of the Microcup® may be optimized to meet special needs of various applications. Figure 1(B) shows the photoprofilometry of two typical Microcup® arrays.

By optimizing the particle-particle, particle-sealing, particle-Microcup® interactions, paper-like 64x240 lines Microcup® PMEPDs with a response time of $\leq$ 30msec/line and a contrast ratio of $\geq$ 10 at 30 volts have been demonstrated recently. Microcup® AMEPDs and direct drive EPDs with a contrast of $\geq$ 10 at low driving voltage of $\leq$ 10 volts have also been developed.

SEAMLESS TOP-SEALING LAYER

SiPix's unique top-sealing processes allow a very durable barrier material to deposit at high speed and form a seamless sealing layer on the filled Microcup® array[1-5]. The top-sealed Microcup® is then laminated with a second substrate or conductor film to form the display panel and subsequently converted to a display module/product. To manufacture AMEPDs and direct drive EPDs, Microcups® were formed roll-to-roll on a non-patterned conductor film, filled with an electrophoretic fluid, top-sealed and laminated onto a release liner optionally with an adhesive to form a sandwich roll. The sandwich roll is then shipped to customers for converting to display modules or finish products. The ability of the as-sealed Microcup® to retain a low viscosity dielectric solvent during transportation and storage before the subsequent lamination step by various customers is critical to enable such a user-friendly converting concept.

To test the barrier property of the sealing layer, a low boiling-point solvent was top-sealed with a 2~3 um sealing layer. An increase of onset temperature of evaporation in a TGA thermograph from 33^{o}C to 180-220^{o}C and an activation energy of about 23~26 Kcal/mol for the solvent the diffuse through the sealing layer were observed[4]. A typical filled and top-sealed Microcup® array showed negligible weight loss of its electrophoretic fluid after 5 days storage in an 80^{o}C oven. The barrier properties of the top-sealing layer indicates that the electrophoretic fluid may be kept for a sufficiently long period of time in as-sealed Microcup® arrays under normal storage and transportation conditions. As expected, the solvent retention is further improved significantly by the release liner laminated on the top-sealed Microcups®.

FORMAT FLEXIBLE EPD ROLLS

Figure 2 illustrates two types of format flexible Microcup® EPD rolls: (A) sandwich of release liner/filled-sealed Microcup®/non-patterned conductor film (such as ITO/PET film) for direct drive and AMEPD applications; and (B) sandwich of column electrode film/filled-sealed Microcup®/row electrode film for PMEPD applications. In either case, the EPD rolls are of symmetrical and repeated structure and can be cut to desired size/shape for different applications. For AMEPD and direct drive application, the release liner of EPD sandwich (A) may be easily removed by customers and laminated onto a TFT back-plane or a patterned second electrode film.

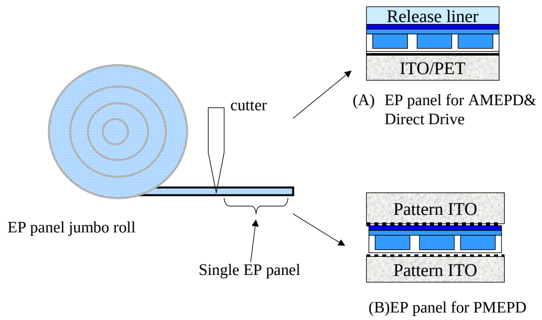


Figure 2 Schematic illustration of two types of format flexible EPD rolls.

POST CONVERTING PROCESS

A post converting process is required to expose the electrodes of Microcup$^{®}$ EPD panel for connection to display drivers. A typical converting process for direct drive and AMPEDs includes the following steps: (1) kiss-cutting the protective release liner or one of the conductor film on top of the electrical connection area; (2) removing the sealing/adhesive layer on the connection areas; (3) stripping off the Microcup$^{®}$ layer on the electrode; (4) applying conductive adhesive; (5) laminating the resultant Microcup$^{®}$ film onto a TFT back plane or a second electrode; and finally (6) bonding the display to drivers. The schematic process flow chart is shown in Figure 3.

THE CUTTING AND STRIPPING PROCESSES

The kiss-cutting removes the unwanted conductor film or the release liner to reveal the microcup structure for chemical stripping. It was found that a resolution better than 20 um could be achieved easily by commercially available precision kiss-cutter. No observable damage of the ITO layer on the opposite electrode was found.

The most critical step in the converting process is the removal of the Microcup$^{®}$ layer from the conductor (ITO) film. Since the adhesion between the Microcup$^{®}$ layer and the ITO layer is typically stronger than the adhesion between the ITO layer and the PET substrate, physically remove the Microcup$^{®}$ may damage the ITO on PET substrate. Proprietary stripping fluid was developed at SiPix to significantly weaken the adhesion between the Microcup$^{®}$ and the ITO surface and remove the Microcup$^{®}$ layer in unwanted areas without damaging the ITO conductor film. The stripping process has been proven very efficient and may be completed in less than 2 min at 70^{o}c as shown in Figure 4. The resistivity of the ITP/PET film remain unchanged after the stripping process (Figure 5).

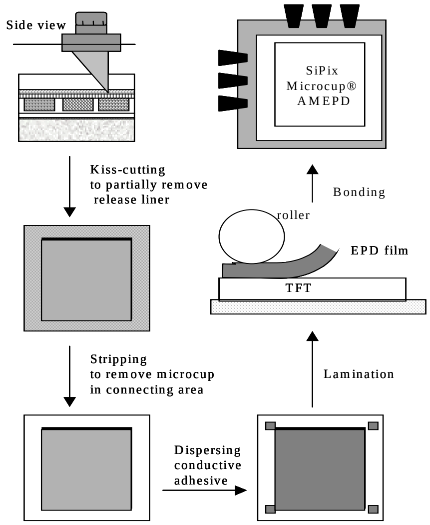


Figure 3 Post-converting process flow chart of AMEPDs.

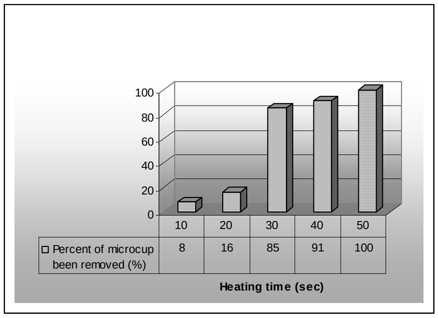


Figure 4 Time needed to remove the Microcu from an ITO surface. (Microcups$^{®}$ were su 70^{o}C with the present of stripping fluid).

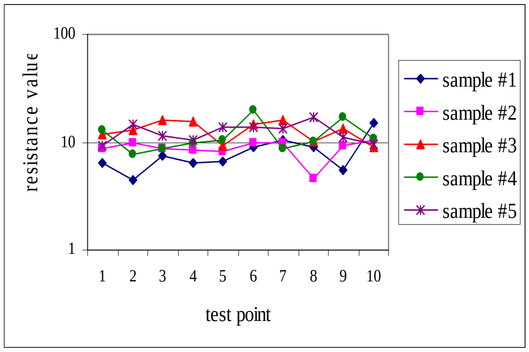


Figure 5 Resistivity of ITO film after stripping remains almost the same as that of the unprocessed ITO/PET film. Resistivity of 10 test points was measured for each of the five as-stripped samples.

It was also found that the Microcup® partition walls in fact help prevent the stripping solvent from spreading widely to active areas. High resolution stripping of insulating cup /adhesive materials from the electrical connection areas has been achieved without any difficulty even for AMEPD applications in which the connection area is typically less than 2mm^2 and in close proximity to the active area.

THE LAMINATION PROCESS

Most of the (A) type of Microcup® EPD films for AM and direct drive applications comprise a heat-activated adhesive layer to facilitate the lamination onto a back plane. Figure 6 shows the effect of lamination temperature on the rising time (t_{on}) at ±15V of a typical segment EPD. As it can be seen Figure 6 that the switching rate of the display decreases significantly as the lamination temperature was lower than the activation temperature (about 185^{o}F) of HA-1. Insufficient melt flow of the adhesive layer tends to result in a poor electrical contact and/or a thick adhesive layer. Both of which are detrimental to the EPD switching performance. The effects of lamination pressure and speed on display t_{on} are further illustrated in Figure 7 at a lamination temperature about 40^{o}C above the activation temperature. The display contrast ratio is about 10-12 at a driving voltage from ±10 to ±20V in all cases. The display t_{on} increases with increasing lamination speed (Figure 7A) and remain relatively insensitive to pressure except the sample laminated at ≤40 psi (Figure 7B).

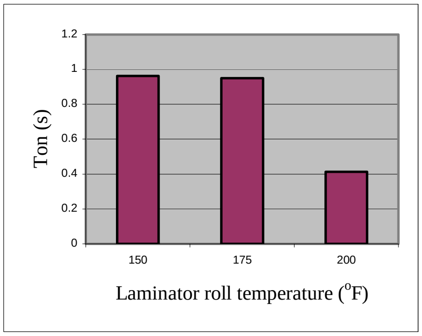


Figure 6. Effect of lamination temperature on t_{on} at a driving voltage of ± 15V.

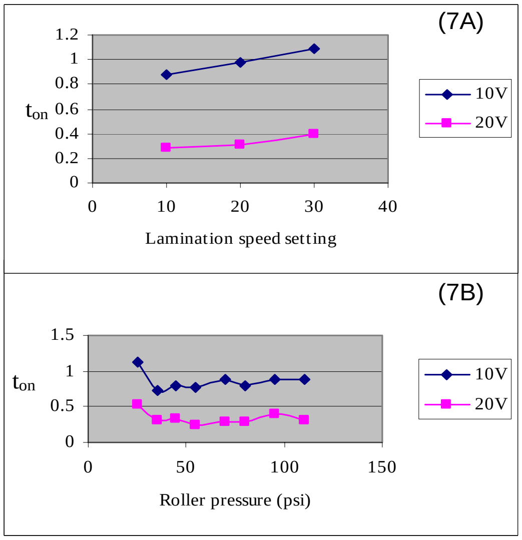


Figure 7 Effect of lamination speed (7A) and roller pressure (7B) on display t_{on} at ±10 and ±20 V.

Similarly, the type (B) prelaminated EPD rolls may be easily converted by the same kiss-cut and stripping processes for variety of PMEPD applications. Two laminated displays are shown Figure 8 to illustrate the super-flexibility of the Microcup® EPDs. No creeping of the laminated sample (2inch^2 of size)was observed at all with 5 Kg hanging weight on one side of the laminated display at 60^{o}C for overnight.

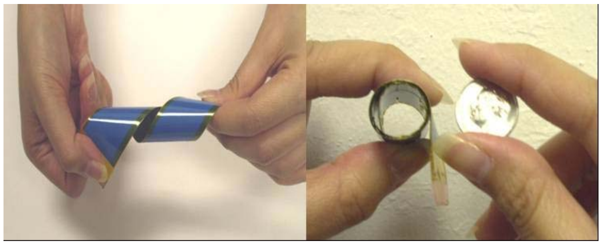
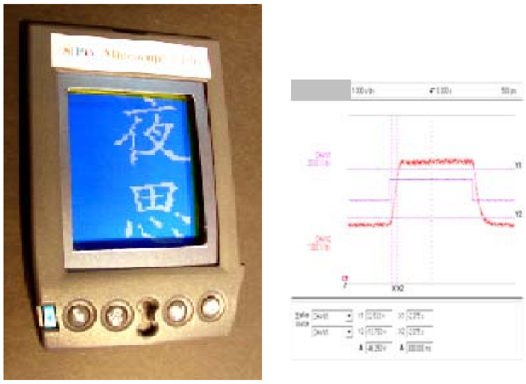


Figure 8 Pictures of Microcup® EPDs showing the super-flexibility.

Microcup® AMEPDs and Direct Drive EPDS

Figure 9A shows a Microcup$^®$ AMEPD equipped with an 3.5" reflective color a-Si TFT back-plane of 320x240x3 QVGA resolution. To simplify the driving, all three R,G, B sub-pixels were connected together to form 223.5 um x 223.5 um monochrome pixels. A conventional STN LCD driver IC was used for the source driving, a TFT gate driver IC was used for gate driving, and a FPGA was used to provide the timing control for both binary and grayscale modes. The electro-optical response curves are shown in Figure 9(B). The Microcup® AMEPD shows a contrast ratio of 8 and switching rate of 0.3 sec at a ≤ ±10.



(8A) (8B)

Figure 9 (A) SiPix proto type AMEPD (B) Electro-optical response of the AMEPD sample: CR = 8:1 at +/- 10V with a frame rate of 300ms.

SiPix format flexible EPD may also be laminated onto various types of back electrodes for direct drive applications, such as price tag, smart card, and E-sign. A smart card equipped with a Microcup$^®$ EPD is shown in Figure 10.

Figure10 Smart card integrated with SiPix

CONCLUSION

Simple and efficient post converting processes have been developed for SiPix's format flexible Microcup® EPD rolls to minimize the material waste and maximize the throughput of module assembly. This customer friendly process has been proven a cost effective way towards the commercialization of Microcup® EPD products.

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