Passive Matrix MicrocupÒ Electrophoretic Displays

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ABSTRACT

Ultra-thin, plastic passive matrix electrophoretic displays (PMEPDs) have been prepared by a format flexible, roll-to-roll manufacturing process based on novel Microcup® and sealing technologies. High switching rate Microcup® PMEPDs having threshold voltages ranging from 5 to 50V with a sharp electro-optical transition ("gamma") have been demonstrated.

INTRODUCTION

A PMEPD using the traditional column and row electrode pattern has been a major technical challenge because of the lack of inherent threshold characteristics to suppress or eliminate the undesirable cross-talk or cross-bias among adjacent pixels during matrix driving. Several attempts have been made to address the threshold issue: An additional conductive layer[(1)] or grid electrode[(2,3)] has been employed to suppress the undesirable particle movement in non-addressing pixels. PMEPDs were demonstrated but the manufacturing cost for such multilayer electrode structures is very high. Alternatively, magnetic particles and a magnetic electrode have been proposed to provide the required threshold[(4)], also at the expense of manufacturing cost. An electrophoretic fluid having inherent threshold characteristics has been reported[(5)] with tradeoffs in for examples, response time, operation voltage, brightness, image uniformity, and display longevity.

A novel Microcup® PMEPD manufactured by the SiPix roll-to-roll format flexible manufacturing process[(6-8)] is described in this paper. Extremely stable electrophoretic fluids with optimized particle-particle and particle-electrode interactions have been developed. High contrast ratio, bi-stable PMEPDs with t_{on}= 30~250msec, and Vs (threshold voltage) = 5~20V for operation voltages from 15 to 60V have been demonstrated with traditional column/row electrodes.

ELECTROPHORETIC FLUID AND THE MICROCUP® STRUCTURE

The proprietary fluid comprises narrowly distributed charged pigment-containing microparticles which are submicron in size and density-matched very closely to the dielectric solvent. Excellent dispersion stability has been observed even after the fluid was centrifuged at 1000G for more than 30 minutes. The fluid was filled into a Microcup® array on a patterned electrode, sealed, and laminated onto a second patterned electrode[(6-8)]. A schematic drawing of a typical Microcup EPD is shown in Figure 1. Depending on the application, typical dimension of the Microcups may vary in the range of 60-180µm (w or l) x 15-40µm (h) x 5-30µm (ww).

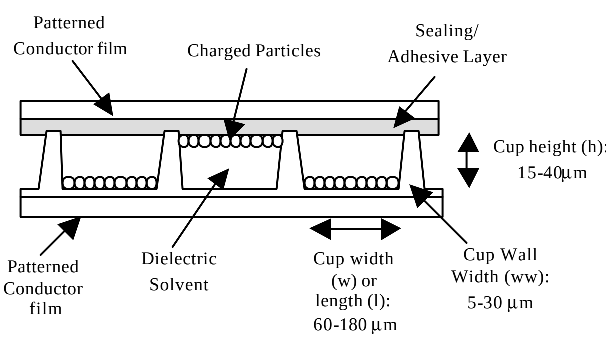

Figure 1 Schematic drawing of a typical Microcup® PMEPD.

The Microcup® walls or partitions provide excellent mechanical support throughout the whole display and result in outstanding physico-mechanical properties such as scratch, impact and flexure resistances. They also enable color separation by effectively isolating fluids of different properties such as colors and/or switching rate in each individual cup. With the novel continuous filling and sealing technologies developed at SiPix[6], format flexible Microcup®

EPDs may be manufactured roll-to-roll at a high speed with an extremely low cost.

THRESHOLD CHARATERISTICS OF THE MICROCUP[Ò] PMEPDs

The performances of the Microcup® EPD were evaluated by the electro-optic test setup shown in Figure 2. The optical response was recorded at 90^o angle normal to the EPD surface with the incoming light source illuminating at 45^o angle.

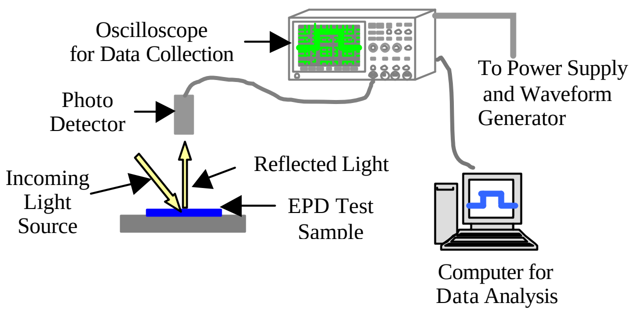

Figure 2 Experimental setup for electro-optical response measurements

Figure 3 shows a series of electro-optical response curves of a typical Microcup® PMEPD sample driven at 5~45 volts. A fully saturated optical density was obtained when the EPD was driven with $\geq$30 volt electrical pulses. In contrast, no optical signal was detected when the display was driven at $\leq$15 volts. Figure 4 shows the contrast ratio (defined as the ratio of %reflectance of the bright state to that of the dark state) as a function of the driving voltage of the same Microcup® PMEPD sample. A nonlinear characteristic curve with a high gamma (or slope) and an inherent threshold voltage of $\geq$15 volts was obtained. Since the threshold voltage is well above 1/3 of the driving voltage needed to achieve saturate contrast ratio, passive matrix EPDs free of crosstalk or cross-bias may be first-time realized with only row and column electrodes on a plastic film. By optimizing the compositions of the electrophoretic fluid, the Microcup® structure, high performance Microcup® PMEPDs having threshold voltages ranging from 5 to 50V with high gamma and excellent fluid stability and image uniformity were obtained.

IMAGE BISTABILITY AND EDGE SHARPNESS

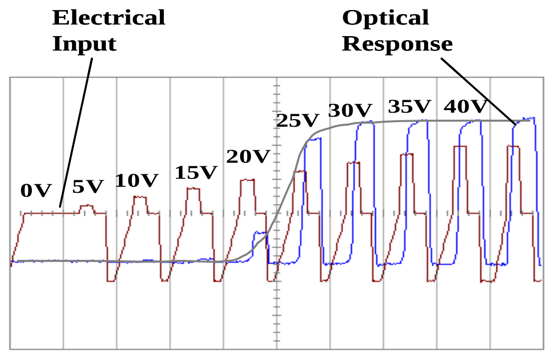

Figure 3 Electro-optic response curve of the 1st generation of Microcup® EPD.

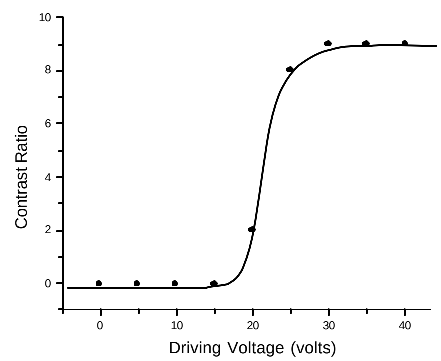

Figure 4 Contrast ratio vs. driving voltage curve of the 1st generation of Microcup® PMEPD.

The Microcup® PMEPDs have also shown extremely good image bistability. No observable deterioration of contrast ratio was found after the display was turned off for more than 30 days. As a result, significant power saving is possible since power is needed only for updating the information. Image edge sharpness of a typical Microcup®PMEPD is illustrated in Figure 5 where a 300 dpi (about 80µm x 80µm) Microcup® array was driven by a row electrode of about 400µm width. Sub-Microcup® addressing with extremely sharp edge can be clearly seen in the picture. Similar to other types of EPDs, the resolution of a Microcup® EPD is mainly defined by the resolution of the electrode rather than by the size of the Microcups®, although the latter has a major impact on the degree of graininess or image uniformity.

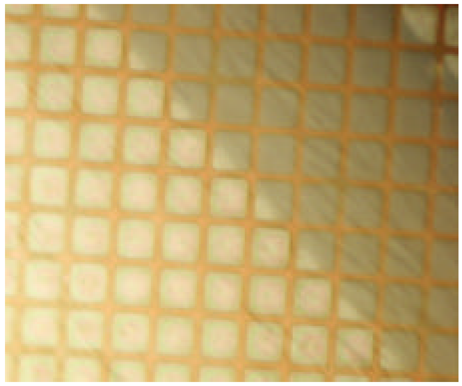

Figure 5 Optical photograph of a Microcup® EPD showing sub-Microcups® addressing along a 400 ? m electrode line.

CONVERTING OF THE MICROCUP® EPD FILMS

Another important feature of the Microcup® EPDs is its excellent format flexibility. Since each Microcup® is isolated and individually sealed seamlessly, the Microcup® may be cut into different sizes and shapes without the risk of losing fluid in the active area. Two types of Microcup® EPD films have been manufactured by the SiPix roll-to-roll process: (1) pre-laminated EPD rolls sandwiched between row and column electrodes, and (2) ready-to-laminate EPD rolls sandwiched between a release liner and an electrode film. The latter may be laminated to a second patterned electrode film by the customer after the release liner is removed.

Figure 6 shows the schematic process flow of converting a roll of Microcup® PMEPD film sandwiched between row and column electrode substrates to a PMEPD module. The roll of Microcup® PMEPD was may be cut to desired sizes and formats, followed by an asymmetrical cutting and stripping process to expose the electrodes for connection to outside circuitry. Figure 7 shows the schematic process flow of converting the second type of EPD rolls sandwiched between a release liner and an electrode film. After the film was cut to a desired size, the release film is removed and the EPD film is laminated with a patterned electrode substrate such as a TFT substrate and ready for circuitry connection. Either of the two post converting processes provides great flexibility in product designs for various applications.

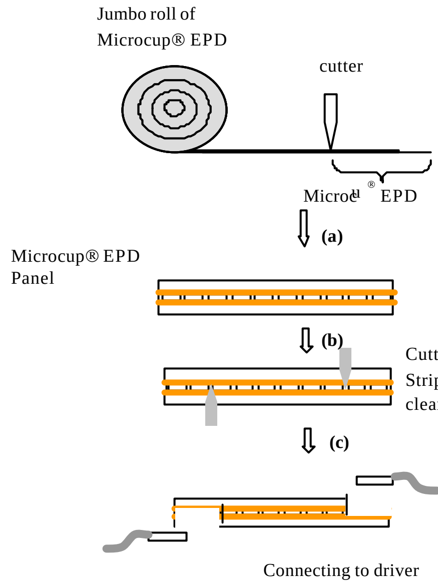

Figure 6 Schematic process flow of converting a Microcup® PMEPD roll; (a) cutting the roll of EPD film to individual pieces; (b) asymmetrical cutting and stripping one side of the electrode substrates to expose the electrodes on the other side; and (c) connecting the exposed electrode to driving circuitry.

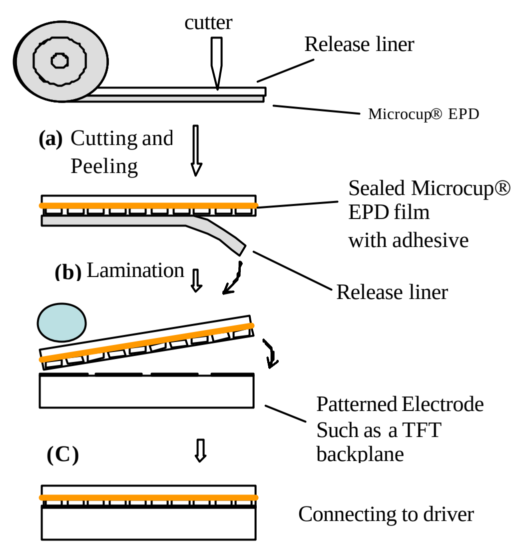

Figure 7 Schematic process flow of converting a roll of Microcup® EPD/release liner; (a) cutting the roll into individual pieces and removing the release liner from the sealed Microcup® EPD film, (b) laminating the Microcup® EPD film to the 2nd electrode substrate such as a TFT substrate and finally (c) connecting the assembled Microcup® EPD to driving circuitry.

Significant cost saving is possible because of the format flexibility of the Microcup® EPDs. Defects on the EPD film may be identified and cut off before the lamination step. Moreover, the entire area of a Microcup® EPD film may be utilized with minimum waste. Figure 8 illustrates the possibility of fully utilizing the same jumbo roll of the Microcup® EPD film for different applications such as cellular phone, PDA, and e-book.

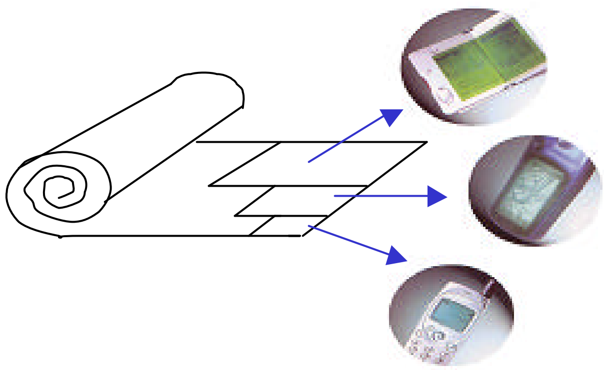

Figure 8 Schematic illustration of fully utilizing the same jumbo roll of Microcup® EPD film for various product applications.

CONCLUSIONS

High performance PMEPDs with excellent format flexibility and physico-mechanical properties have been prepared at high speed and extremely low cost by the roll-to-roll manufacturing process based on novel Microcup® and sealing technologies. Two types of jumbo roll structure and their converting processes were discussed. By optimizing the electrophoretic fluid and the Microcup® composition, threshold voltages ranging from 5 to 50V as well as a sharp gamma in the characteristic contrast ratio-voltage curves have been demonstrated. The high switching rate and the extraordinary non-linearity of the electro-optical characteristics have successfully enabled high resolution passive matrix driving without observable crosstalk or cross-bias.

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