Multicolor Polymer Disperse Microencapsulated Liquid Crystal Displays

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***Abstract*—This work develops a new technology to fabricate polymer-dispersed microencapsulated liquid crystal (PDMLC) devices using screen-printing, which is a low temperature procedure (about 90 °C) for application on a soft plastic substrate. This research demonstrates numerically and in Mandarin, a 4.5-in multicolor PDMLC (MPDMLC) device with high color contrast, low electric consumption and flexible bending mechanical property. The current work coats three different color pastes (red, blue and black) on a single substrate. Their turn-on voltages are all as low as 5 V and saturation voltages are 20, 30, and 30 V for red, blue, and black colors, respectively.**

***Index Terms*—multicolor polymer-dispersed liquid crystal (MPDMLC), polymer-dispersed microencapsulated liquid crystal (PDMLC).**

I. Introduction

RESEARCHERS have investigated and developed polymer-dispersed liquid crystal (PDLC) since 1985 [1]–[3].The PDLC are made by dispersing micro-drops of liquid crystal materials in the polymer content. The recent application field includes two main manufacture methods: the phase separation method [4], [5] and the emulsion method [6], [7]. The phase separation method does not easily distribute liquid crystals uniformly in the polymer content, especially for a large area application. This study adopts the emulsion method. In related studies [8]–[10], a PDLC device can only present monochrome performance without auxiliary modules of back lighting units and polarization plates.

This work develops a multicolor polymer-dispersed liquid crystal (MPDMLC) device, fabricated by packing both liquid crystals and dichroic dyes into microcapsules for multicolor performance. Dichroic dye molecules inside the microcapsules rotate by following liquid crystal rotating behaviors under interaction force effects. When applying external electric field, liquid crystals are switched to become visibly transparent and diechroic dyes are responsible for making colorful visions. This study applies the low temperature, low cost, screen- printing technology to coat three different color pastes on a single substrate.

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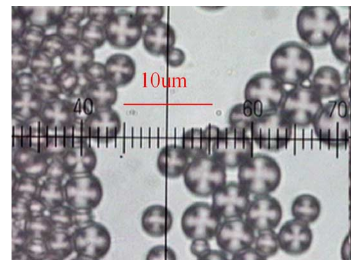

Fig. 1. Optical microscope observation of dispersed microcapsules (diameter sizes ranges from 4 to 10 microns).

II. Experiments

Fabricating MPDMLC devices can be mainly divided into three steps: MPDMLC material synthesis, screen-printing, and packaging, described as follows.

A. MPDMLC Material Synthesis

This work mixes a surfactant agent, such as polyisocynate, with liquid crystals and dye molecules under stirring and heating treatment. After emulsification by adding 10% polyvinyl acetate (PVA), liquid crystals and dye molecules are packed in polyisocynate, and form microcapsules with the assistance of an ammonium hydroxide additive. A purification and centrifugation treatment could uniformly improve electrical and optical performance. Diameter sizes of the microcapsules range from 4 to 10 microns as shown in Fig. 1.

B. Screen Printing

The printable paste is made from MPDMLC raw materials, PVA and a surface-leveling agent under three-roller mixing. Table I lists the different compositions and printing results of the MPDMLC paste. Better compositions of the MPDMLC pastes after the printing and driving test reveal 50%–60% MPDMLC raw materials, 5%–25% PVA and 25% surface leveling agent. This investigation screen printed MPDMLC pastes on a pre-patterned indium–tin–oxide (ITO) coated with a polyethylene terephthalate (PET) substrate, and heated to 90°C for 20 min to form a dry solidified film.

C. Packaging

This work also printed another patterned ITO/PET substrate using an ultraviolet paste, which was then cured under ultraviolet light exposure. Packaging for this substrate consists of the substrate made by step (b) under heating and laminating

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TABLE I
THE DIFFERENT COMPOSITIONS AND THE PRINTING RESULTS OF THE MPDMLC PASTE

No.	PDMLC Raw material	PVA	Surface leveling agent	Printing result
G006	30%	40%	30%	×
G007	50%	25%	25%	○
G009	50%	38%	12%	△
G010	50%	42%	8%	×
G011	60%	15%	25%	○
G012	60%	28%	12%	△
G013	60%	32%	8%	×
G014	70%	5%	25%	○
G015	70%	18%	12%	△
G016	70%	22%	8%	×

○ : Good, △ : Some pinhole, × : Bad

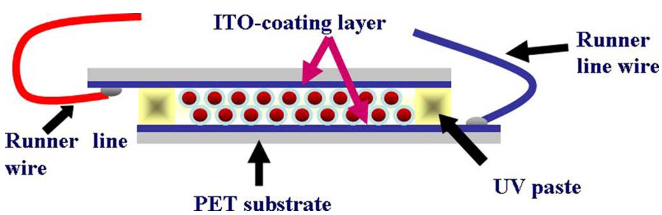

Fig. 2. Schematic illustration of a MPDMLC device.

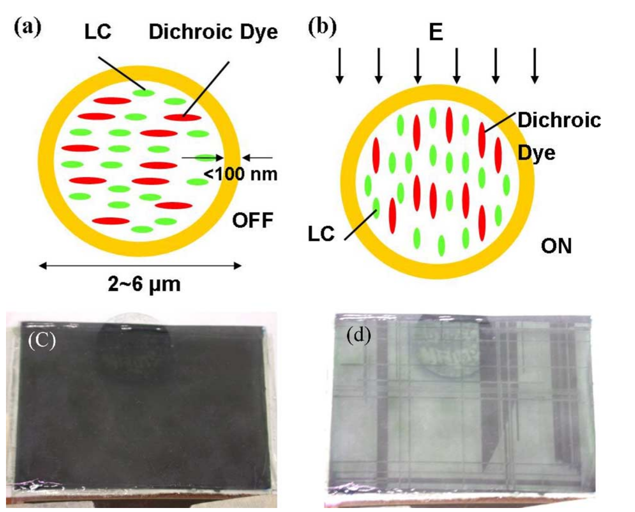

Fig. 3. Illustration of a microcapsule at turn-off state and turn-on state, respectively. (a) Random alignment of liquid crystals and dye molecules at turn-off state. (b) Device showing the dye's intrinsic color (at turn-off state). (c) Regular alignment of liquid crystals and dye molecules at turn-on state. (c) Device showing transparent (at turn-on state).

methods to form a MPDMLC device. Fig. 2 illustrates the overall structure of the MPDMLC device.

III. RESULTS AND DISCUSSION

The current study packs liquid crystals and dichroic dyes in the MPDMLC materials into microcapsules. In a "turn-off" state, liquid crystals do not function and dichroic molecules align randomly inside the microcapsule as shown in Fig. 3(a). In a "turn-on" state, dichroic dye molecules rotate by following liquid crystal rotating behaviors under suitable electric field application as shown in Fig. 3(b). The microcapsule color is the same as the dichroic dye's intrinsic color. This work demonstrates three different colors (red, black and blue). The panel in the "turn-off" state displays black as Fig. 3(c) shows, while it exhibits transparent vision in the "turn-on" state as Fig. 3(d) shows. Applying suitable electric voltages on the device make it possible to show text or image if the designed pattern is pre-fabricated on the conducting line layout. The surface morphologies of MPDMLC films in the screen-printing process are rough due to screen crunodes. A surface leveling agent added into the MPDMLC paste modifies surface roughness of the MPDMLC film. This work studies and analyzes three different composition ratios (8%, 13% and 25%) of the surface-leveling agent. Fig. 4(a)–(c) shows the results. Fig. 4(a) findings show that the effects of screen crunodes cannot be eliminated without enough surface-leveling agent. Increasing the composition ratio (13%) of the surface-leveling agent improves the screen crunodes as Fig. 4(b) shows. The composition ratio of 25% of the surface leveling agent effectively eliminates screen crunode effects as Fig. 4(c) illustrates. Too much ($> 25\%$) of the surface leveling agent could break the microcapsule. Only a suitable amount can eliminate screen crunode effects without destroying the microcapsule walls. The optimum composition ratios of the MPDMLC raw materials, the PVA and the surface leveling agent are 50%, 25% and 25%, respectively.

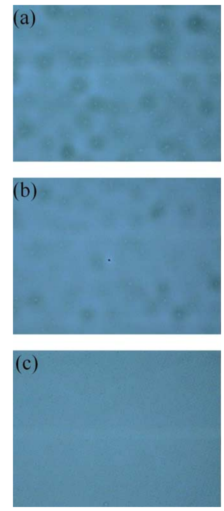

Fig. 4. Surface observation of MPDMLC films possessing three different concentration ratios of the surface leveling agent. (a) 8% agent content. (b) 13% agent content. (c) 25% agent content.

Fig. 5 shows optical reflection of the device as an electric voltage function. Turn-on voltage is the applied voltage at which the reflection starts to increase, and saturation voltage is the applied voltage above which the reflection no longer increases with increasing voltages. Findings show that the turn-on voltages for these three color pastes are all 5 V, and saturation voltages are 20 V, 30 V, and 30 V, respectively, for the red, black and blue color pastes.

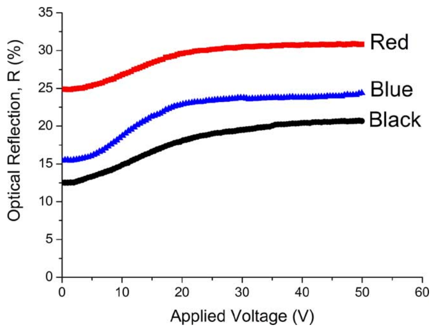

Fig. 5. Reflection measurements of three different color pastes: red; blue; and black.

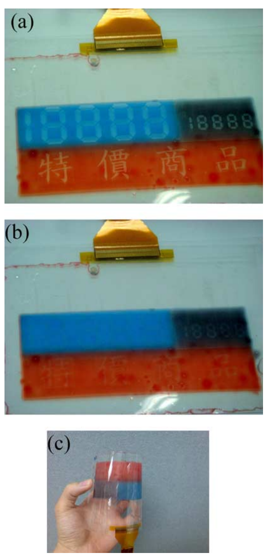

Fig. 6. Demonstration of a MPDMLC device. (a) At turn-off state. (b) At turn-on state. (c) Under flexible bending situation.

Fig. 6(a)–(c) shows the fabricated device (a 4.2-in price tag device), and Fig. 6(a) and (b) shows the devices at turn-off and turn-on states, respectively. A single device demonstrates three different background colors without any auxiliary modules, such as back lighting units and polarization plates. The turn-on state shows both numeral and Mandarin words. The PDMLC film thickness in the current device is about eight microns, which is constrained by screen-printing processes. Color contrast and light shielding is still need improvement by increasing film thickness in the future. Fig. 6(c) demonstrates this device which can flexibly bend.

IV. Conclusion

This work develops a MPDMLC device showing numeral and Mandarin words using screen printing technology with advantageous low temperature, low cost and easy panel size scaling. Compared with other PDLC devices, this device easily shows three different background colors without a back light unit or polarization plate. Digital price tag development is one possible future commercial application.

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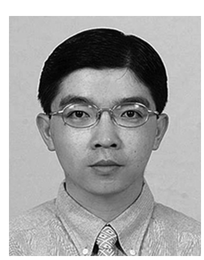

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