Dye-doped liquid crystal light shutter fabricated by thermally-induced phase separation

Yeongyu Choi, Seung-Won Oh, and Tae-Hoon Yoon

Department of Electronics Engineering, Pusan National University, Busan 46241, South Korea

Keywords: liquid crystal, polymer, light shutter, phase separation

ABSTRACT

A dye-doped LC/polymer light shutter fabricated with the thermally-induced phase separation (TIPS) method is demonstrated. The TIPS method does not degrade the dye during the fabrication process. The fabricated LC cell exhibits excellent optical performance, which is suitable for a light shutter with superior black color. This fabrication method can be applied for the high visibility of see-through displays.

1. INTRODUCTION

See-through displays have advanced rapidly in recent decades. Especially, organic light-emitting diodes (OLEDs) are the most popular technology in see-through displays due to its high transmittance. Each pixel of an OLED see-through display is divided into a see-through area and a display area so that the background behind a display panel is overlapped with the displayed image. However, because of the see-through area, it does not provide a black color, which reduces the visibility or degrades the image quality. Therefore, to enhance the image quality, a light shutter is placed right behind an OLED see-through display panel. The light shutter can provide a high visibility mode. It can provide black color and hide the objects behind a display panel [1].

Various types of light shutters have been studied, such as electro-chromic devices [2], suspended particle devices [3], and guest-host liquid crystal (LC) devices [4]. Among them, a guest-host LC light shutter can hide the background completely and display a black color simultaneously. In particular, a dye-doped LC/polymer composite method has been studied for their advantages, such as the high haze in the opaque state [5].

For fabrication of a dye-doped LC/polymer composite light shutter, the polymerized-induced phase separation (PIPS) has been used widely to form the polymer structure. In this method, the polymer structure is formed by UV curing inside of an LC cell. However, it has been reported that free radicals generated by UV during the PIPS process degrade dyes [6, 7]. Thermal curing of the polymer has been proposed to prevent the color change of a light shutter caused by the dye degradation. However, since the curing temperature must be lower than the nematic-isotropic transition temperature of LC, the formation of the polymer structure with thermal curing is time-consuming.

In this study, we fabricated a dye-doped LC/polymer light shutter, in which the black color is maintained. We used the thermally-induced phase separation (TIPS) method to form a polymer structure. This method does not include a chemical reaction in an LC cell. The fabrication process is simple, and there is no degradation of the dye [8]. We expect that the fabrication process may be applied for a light shutter for high visibility of see-through displays.

2. EXPERIMENTAL PROCEDURE

To fabricate a dye-doped LC/polymer light shutter for which the polymer structure was formed by the TIPS method (TIPS cell), we prepared a solution of a negative LC mixture (SP0-001, Silchem, China), poly(butyl methacrylate) (PBMA, Sigma-Aldrich, USA), and dichroic dye (X12, BASF, Germany). Two sheets of indium-tin-oxide glass substrates were spin-coated with homeotropic alignment material and baked for 1 h at 230ºC for annealing. The cell gap was maintained with silica spacers, whose diameter was 10 μm. Then, the solution was injected into an empty cell at 130 ºC and cooled to room temperature in 5 min.

To compare the electro-optic performance of light shutters, a dye-doped LC/polymer light shutter for which the polymer structure was formed by the PIPS method (PIPS cell) was fabricated as a reference. We used LCs and dichroic dyes the same as those used for a TIPS cell to make the solution, but RM 257 (Merck, Germany) and Irgacure 651 (BASF, Germany) was chosen to form the polymer structure by the PIPS method.

To confirm the electro-optic properties of all the fabricated samples, we measured the total transmittance, specular transmittance, diffuse transmittance, and haze of the samples with a haze meter (HM-65W, Murakami Color Research Laboratory).

3. EXPERIMENTAL RESULTs AND DISCUSSION

Figure 1 shows the haze values of the TIPS and the PIPS cells as a function of the applied voltage. Both cells show high haze values, but the haze of TIPS cells is higher than PIPS cells, exceeding 99%. Moreover, the haze value in the transparent state of a TIPS cell is very low [0.5%], indicating an optical property which is very suitable for application to a light shutter. This excellent optical property is thanks to the small difference in the refractive index between the LC and the polymer.

Besides, the haze of the transparent state can be lowered by reducing the amount of polymer or by lowering the curing temperature [9].

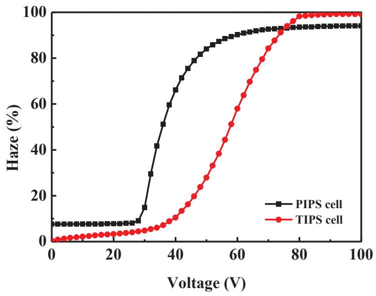

Fig. 1. The measured haze of PIPS and TIPS cells.

The total transmittances of TIPS and PIPS cells are shown in Fig. 2. In the transparent state, the TIPS and PIPS cells shows almost the same total transmittance [65.4% and 66.2%] because both LC cells contain the same concentration [1%] of the same dichroic dye. When the voltage is applied to the LC cells, the PIPS cell exhibited a brown color, as shown in Fig. 3, because of the degradation of dye molecules by free radicals, as discussed in section 1. On the other hand, the TIPS cell exhibited a black color as we intended.

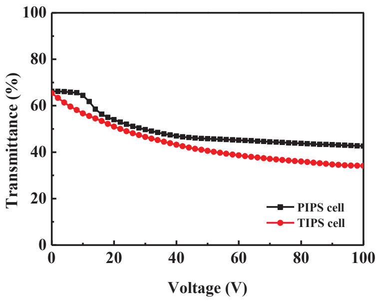

Fig. 2. The measured total transmittance of PIPS and TIPS cells.

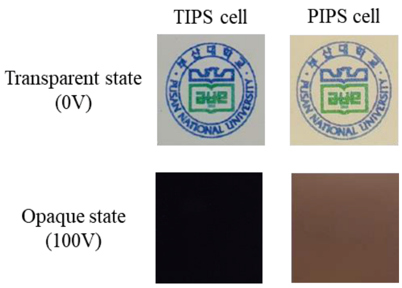

Fig. 3. Images of TIPS and PIPS cells.

To achieve the superior opaque state, a voltage higher than 80 V must be applied to the TIPS cell. The operation of a light shutter is separated from an OLED display panel, and a light shutter can be driven simply by a voltage source, not by pixel driving with thin-film transistors. Nevertheless, studies for lowering the operation voltage are essential to reduce power consumption.

4. CONCLUSION

In summary, we fabricated a dye-doped LC/polymer light shutter for which the polymer structure was formed with the TIPS method. The TIPS method is a simple fabrication process without any degradation of the dye. The fabricated LC cell exhibited excellent optical performance with a superior black color, which is suitable to apply to a light shutter. We expect that this fabrication process may contribute to the high visibility of see-through displays.

Acknowledgment

This work was supported by the National Research Foundation of Korea Grant funded by the Korea government (MSIP) (No. 2017R1A2A1A05001067).

REFERENCES

[1] J. Yeon, T.-W. Koh, H. Cho, J. Chung, S. Yoo, and J.-B. Yoon, “Actively transparent display with enhanced legibility based on an organic light-emitting diode and a cholesteric liquid crystal blind panel,” *Opt. Express*, **21**, 10358 (2013).

[2] A. Azens and C. G. Granqvist, “Electrochromic smart windows: Energy efficiency and device aspects,” J. Solid State Electrochem., **7**, 64 (2003).

[3] R. Vergaz, J.-M. Sánchez-Pena, D. Barrios, C. Vásquez, and P. Contreras-Lallana, “Modelling and electro-optical testing of suspended particle devices,” *Sol. Energy Mater. Sol. Cells*, **92**, 1483 (2008).

[4] G. H. Heilmeier and L. A. Zanoni, “Guest-host interactions in nematic liquid crystals. a new electrooptic effect,” Appl. Phys. Lett., **13**, 91 (1968).

[5] G. H. Lee, K. Y. Hwang, J. E. Jang, Y. W. Jin, S. Y. Lee, and J. E. Jung, “Characteristics of color optical shutter with dye-doped polymer network liquid crystal,” Opt. Lett., **36**, 754 (2011).

[6] S. Yang, P. Wang, X. Yang, L. Shan, W. Zhang, X. Shao, and R. Niu, “Degradation efficiencies of azo dye Acid Orange 7 by the interaction of heat, UV and anions with common oxidants: Persulfate, peroxymonosulfate and hydrogen peroxide,” J. Hazard. Mater. **179**, 552 (2010).

[7] B.-H. Yu, S.-M. Ji, J.-H. Kim, J.-W. Huh, and T.-H. Yoon, “Fabrication of a dye-doped liquid crystal light shutter by thermal curing,” Opt. Mater., **69**, 164 (2017).

[8] Y. Choi, S.-W. Oh, T.-H. Choi, and T.-H. Yoon, “Formation of polymer structure by thermally -induced phase separation method for a dye-doped liquid crystal light shutter,” Dyes Pigm, **163**, 749 (2019).

[9] B.-G. Jeon, T.-H. Choi, S.-M. Do, J.-H. Woo, and T.-H. Yoon, “Effects of curing temperature on switching between transparent and translucent states in a polymer-stabilized liquid-crystal cell,” *IEEE Trans. Electron Devices*, **99**, 1-7 (2018).