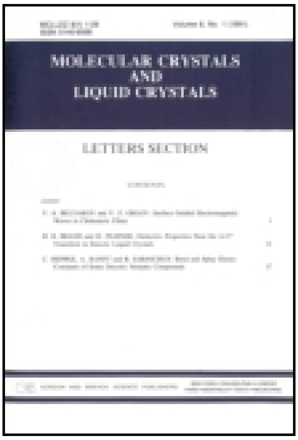

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A Reflective Display Based on Thermochromic Pigment

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This research presents thermally activated monochromatic reflective display produced by very simple method based on thermochromic pigment and its thermo-optical properties are investigated. The display exhibits maximum white reflectance of about 48%. The bright level of this thermochromic display (TCD) cell is continuously tuned by the temperature changes under adjusting the driving voltage to the TCD cell. It also showed a wide viewing angle above 80° without any optical components. This display is considerable for applications where indoor or outdoor poster information must be presented clearly with low cost.

Keywords Thermochromic display; thermochromic pigment; reflective display; electro-optic property

Introduction

Chromic displays have been explored as the emerging devices for applications of chromatic device such as electronic papers, etc. Thermochromic materials have been extensively studied in chemical, biochemical, and applied research areas because of the variable brightness and optical properties that respond to several stimulus such as heat and mechanic stress.[1–5] The applications for such materials include reflective thermochromic displays and temperature sensors.[6–8] Reflective liquid crystals (LCDs) and electrophorectic displays (EPD) have been studied for mobile devices, outdoor information displays and e-books. Although the technologies of conventional displays such as LCDs, organic light emitting diode (OLED) and so on are relatively well established for mobile displays applications, they in outdoor information displays require still high cost and complex manufacturing process. On the other hand, reflective thermochromic displays (TCDs) have much simpler fabrication process in comparison with conventional electron devices.

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Recently, a thermally actuated display fabricated from mono-color thermochromic silver-powder and embedded conductive wiring patterns have been reported by L. Liu et al.[2] The powder changes from dark state to white state above 60°C. O. Yarimaga et. al.[3] have reported a thermochromic display using conjugated polydiaceltylenes. However, the thermochromic materials were activated at 180°C which is very high for use as a display that requires low power consumption and safety. Moreover, in spite of many studies on TCDs, there have been few reports for outdoor information display application.

The requirements for the outdoor information displays do not stand with them of conventional indoor information displays. Especially, important requirements in the performance of the outdoor information displays are low power consumption and manufacturing process with low cost. Therefore, in case of the fabrication and optimization of thermo-optical properties for thermally activated display, the transition temperature of brightness and the reversibility of brightness according to temperature of thermochromic materials must be considered inevitably.[1–4] Our monochromatic thermochromic pigment considered in this research generates the transition of brightness at 38°C, which is an appropriate temperature for achievement of low power consumption in the transition of brightness. The reflective TCD exhibits high reflectance. Moreover, the maximum value of contrast ratio (CR) of our thermochromic display cell showed 3 times higher than it reported by O. Yarimaga et al. with polydiacetylene-based thermochromic display.[9]

In this paper, we present a thermally activated TCD which is very simple to manufacturing process and low cost. Furthermore, to investigate the potential of the TCD cell as an information display, electro-optical properties of TCD are investigated.

Experimental

The monochromatic thermochromic pigment was obtained from H.W. SANDS CORP. The pigment consists of microcapsules that change brightness reversibly. The transition temperature of it can be designed from −10°C to 69°C by controlling material components.[10] The exact chemical compositions of the thermochromic pigment obtained from H.W. SANDS CORP. are a secret for commercial reasons, but are supposedly similar to other formulations reported by the literature.[11, 12] A typical thermochromic pigments are based on traditional dye and pigments. The observed thermochromic effect is ordinarily a change from colored to colorless as the temperature is increased, although by mixing with pigments and traditional dyes an interchange between two single colors may be achieved.

In this research, we fabricated the thermochromic cell composed of patterning indium tin oxide (ITO)-heater array on sodalime glass substrate, non-thermochromic pigment layer and monothermochromic pigment film as shown in Fig. 1. The ITO-heaters were designed roughly to be 0.5×0.5 cm^2 with spacing of 1 mm between adjacent cells. The spacing plays thermal isolation among adjacent cells. The thermochromic pigment is selected, whose color is black at room temperature and turned into white in about 38°C. The particle size of the thermochromic pigment is distributed below 6 μm as shown in scanning electron microscopy (SEM) of Fig. 1(c). Thermochromic display cell was fabricated by following that: Deposition of the ITO film was performed on glass substrates by RF magnetron sputtering. The ITO target used was in 90 wt.% In_2O_3 and 10 wt.% SnO_2. All the substrates were ultrasonically cleaned in acetone and distilled water, successively, and then dried on a hot plate at 100°C for 5 minutes. The deposition was carried out at 20 sccm of Ar gas that was controlled by a mass flow-meter. The base pressure of the sputtering system was 5×10^{-6} Torr and the working pressure was 8×10^{-4} Torr. The applied RF power was 15 W and

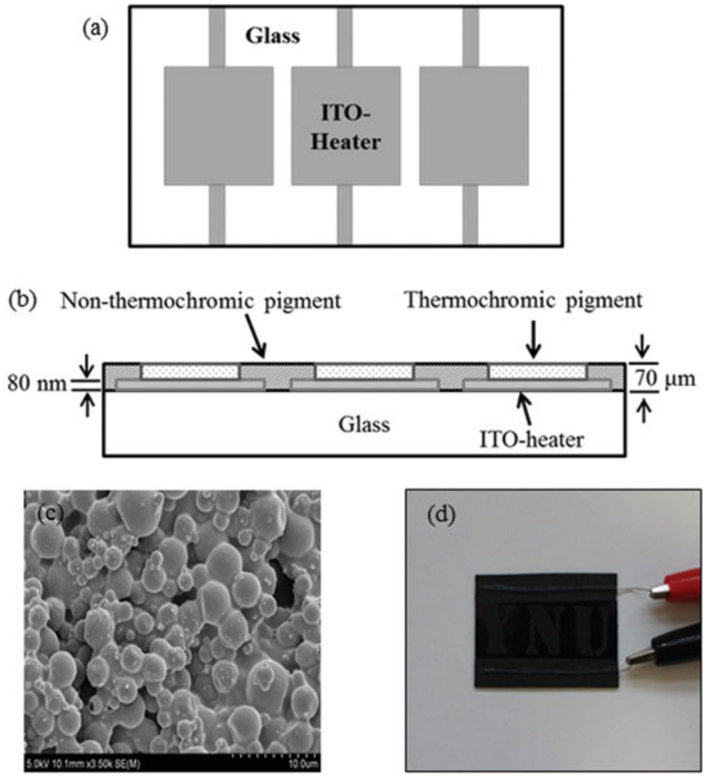


Figure 1. (a) Sketch of patterned ITO-heater array on glass (b) Cross-sectional device schematics (c) SEM image of thermochromic pigment coated on a glass, (d) fabricated thermochromic display cell.

this was kept constant during all processes. The depositions were carried out at 250°C for 40 minutes. The thickness of the ITO film is about 80 nm. The thermochromic pigment glass deposited selectively by a patterned mask was coated onto the patterned ITO sputtered. This carried out using a spraying method and then dried for 10 minutes at room temperature. Here, because heating material is ITO conductor which has a proper resistance, a temperature can be controlled by adjusting properly electrical current. A fabricated thermochromic display cell is shown in Fig. 1(d). Spectral reflectance as a function of applied voltage was measured using a cary 5000 UV-VIS-NIR spectrophotometer (Agilent-Korea).

Results and Discussion

We activated the thermochromic display cell under variations of the applied voltage that can drive current in cell, which generates the brightness changing temperature. The experiment was performed at room temperature (25°C). Also, the temperature of the thermochromic cell was measured using a thermometer with a thermocouple probe directly attached to the center of the display cell. The temperature was read at steady state as a function of the applied voltage. Figure 2 shows average temperature according to voltage during repetitive voltage cycles and pixel images of the thermochromic cell with the monochromatic thermochromic pigment when voltages are changed from 0 V to 5 V. As expected, we can know the

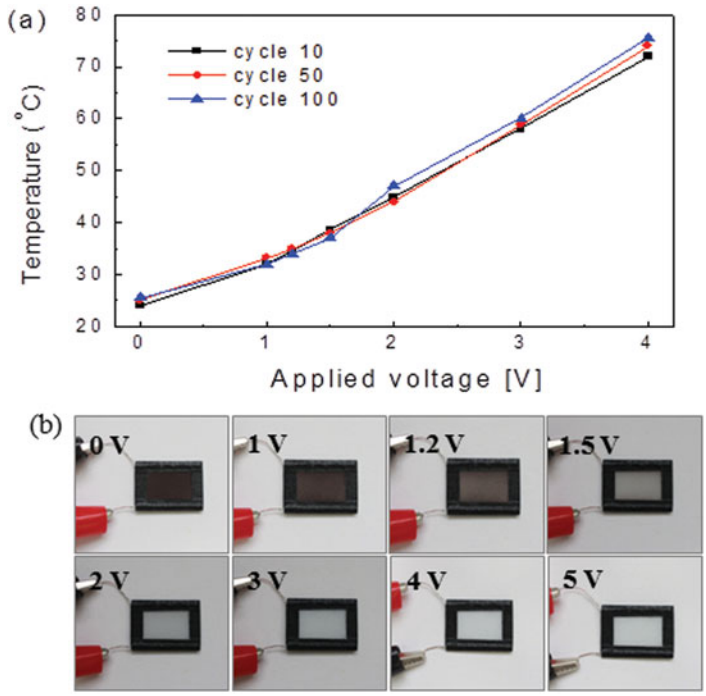


Figure 2. (a) Dependence of temperature during repetitive cycles and (b) photo images of the thermochromic display cells with monochromatic thermochromic pigment when voltage is changed from 0 V to 5 V.

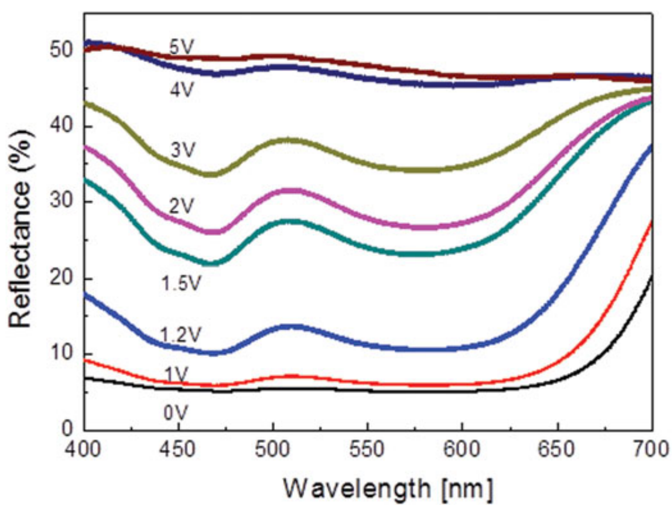
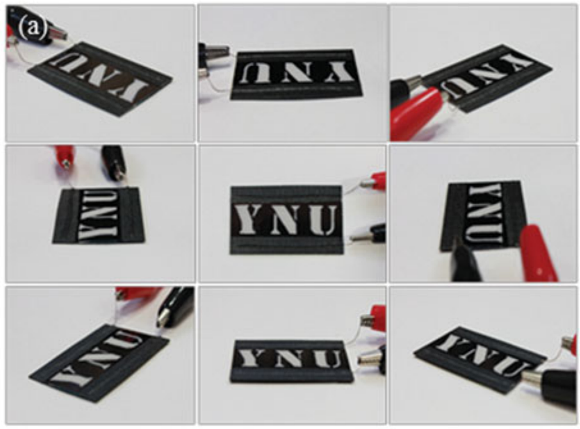


Figure 3. Reflectance spectra of monochromatic thermochromic material coated on ITO substrate under various voltages.



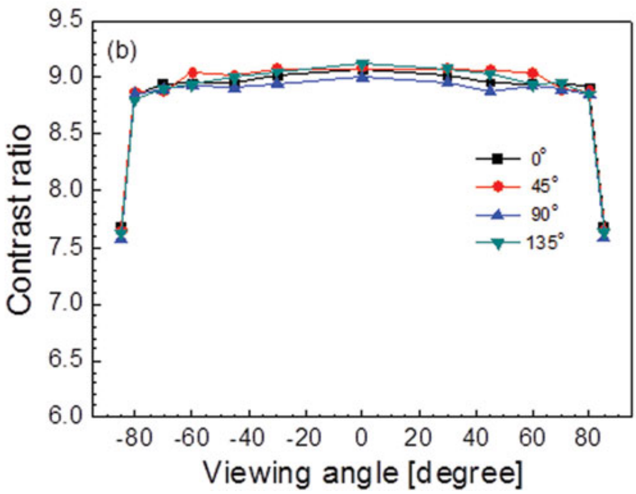


Figure 4. (a) Photo images taken from thermochromic display cell with a logo of "YNU" under the applied voltage of 4 V, (b) Contrast ratio characteristics according to polar angles at each azimuthal angle.

temperature increases almost linearly as a function of applied voltage as shown in Fig. 2(a). Also, the obtained temperature change according to applied voltage is approximately same without significant change during each repetitive cycle. Increasing the applied voltage of the cell decreased the turn on time. When applying a voltage above 4 V, the cell turned from black state to white state within 1 second, but turn off time was observed about 8 s at the room temperature. The dark state was observed at below 1 V, while by applying a voltage above 2 V, the brightness of pixel is changed from dark state to white state within a few seconds as shown in Fig. 2(b). Moreover, the cell has a reliability without significant change in repetitive turn-on/off as a crucial factor for the performance of display. In addition, since the temperature of heating effects with increasing applied voltage is increased homogeneously, various gray levels with the continuous brightness can be obtained in the thermochromic display cell.

We measured the spectra reflectance of thermochromic display cell as function of applied voltage to confirm this fact by experimental data. Figure 3 shows variations of reflectance spectra with various voltages of thermochromic display cell coated with the monochromatic thermochromic pigment. With increasing applied voltage, the intensity of white reflectance is increased by about 48% in all visible range. These results mean that the reflectance can be varied by controlling the magnitude of an applied voltage to thermochromic display cell. The pigment shows a clearly distinct spectrum, which is a crucial factor in the achievement of a reflective fine gray level according to temperature. At the dimension of the sample ($1.5 \times 2.5\ cm^2$), a current required to produce maximum white reflectance was 0.26 A at a voltage of 4 V, which corresponded to about 1 W of supplied power.

To investigate the potential of the cell as an information display, we took a photograph of the thermochromic cell from nine directions as shown in Fig. 4(a) and investigated characteristics of contrast ratio (CR) according to polar angles at each azimuthal angle (0°, 45°, 90°, and 135°) as shown in Fig. 4(b). Photo images of the thermochromic cell with a logo of "YNU" at an applied voltage of 4 V are shown in Fig. 4(a). The central photo image of Fig. 4(a) was taken at the normal viewing direction. The photo images surrounded by central photo image were taken in the right, left, upper, lower, and diagonal directions tilted by 80° from central normal direction. Based on Figure 4(a), we can see that this thermochromic display cell has excellent viewing angle showing almost the same image quality in all directions without any additional optical components. In order to confirm the good viewing angle, we measured the contrast ratio according to viewing angles. As shown in Fig. 4(b), this is confirmed by the fact that CR values is over approximately 8:1 at almost all directions including polar angle over 80°. Furthermore, maximum CR value of our thermochromic display cell measured at 4 V (75°C) showed about 9:1 which is much larger than maximum CR value (2.87:1 at 165°C) measured at polydiacetylene-based thermochromic display reported by O. Yarimaga et al.[9]

Consequently, the proposed monochomatic reflective thermochromic cell show great potential in low-end e-paper and various poster information display applications even though its slow response time.

Conclusions

We have presented a reflective display characterized by thermochromic pigment. Our proposed thermochromic display (TCD) was fabricated by spray method and has very simple fabrication process which is related to cost effective. The grey levels were tuned by adjusting voltage that drives current to display cell. The reflective TCD exhibited a wide viewing angle of over 80° and high reflectance. Although our proposed reflective thermochromic display is not ideal for practical application, it has a potential to low-end e-paper and various poster information display applications.

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