

Self-Illuminated Smart Window Based on Polymer-Dispersed Liquid Crystal Mixed with Cu-doped ZnS

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Abstract: Novel self-illuminated smart windows were fabricated consisting of Cu-doped ZnS (ZnS:Cu) powder and polymer-dispersed liquid crystal (PDLC). This smart window shows not only switchable transparency but also self-illumination without any attachable luminous body. Its electro-optical characteristics, transmittance, and luminance were investigated in relation to various applied voltages and composition ratios. The optical transmittance and luminous intensity increased with increasing applied voltages. However, the optical transmittance decreased with increasing ZnS:Cu powder content. One of the self-illuminated smart windows, which was fabricated with 9 wt% of ZnS:Cu, achieved the optical transmittance of 60.5% (at 550 nm) and the luminance of 11.0 cd/m² at 100 V. This smart window could be used as a normal switchable smart window in daytime and light-emitting signage at night.

Keywords: Self-illuminated, ZnS:Cu, Polymer-dispersed liquid crystal, Smart window

1. INTRODUCTION

A smart window is a glass whose transmission properties are altered when voltage, light, or heat is applied. Examples of technologies that enable smart windows are electrochromic (EC), liquid crystal (LC), suspended particle devices (SPD), polymer-dispersed liquid crystal (PDLC), thermochromic and photochromic [1-4]. Among these technologies, PDLC-based smart windows are the most commonly used type among the available smart windows because of their good properties, i.e., size of architectural window as large as 1×2 m, switching times as fast as 10 ~ 360 ms, transmittance as high as 85% in the visible wavelength range, and actual low cost of

production [5,6].

Recently, light-emitting smart windows have gained much attention as next-generation smart windows because they are capable of switchable transparency as well as light emission [7-9]. For example, smart windows assembled by coupling a transparent organic light-emitting diodes (TOLEDs) could be operated in different states, transparent, opaque and light emitting by varying and selecting the applied voltages. Most of the light-emitting smart windows that have been reported are coupled types between smart windows and transparent luminous bodies, such as TOLEDs [7,8] or very small-sized surface mount device light-emitting diodes (SMD-LEDs) [9].

In this study, we fabricated a novel self-illuminated smart window by mixing electroluminescent Cu-doped ZnS (ZnS:Cu) powder [10-12] and PDLC without external transparent luminous bodies. The micro-bead spacer, which is used to make a constant cell thickness in conventional PDLC smart windows, was not used in our devices because the

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micro-sized ZnS:Cu powder sufficiently functioned as a spacer. The optical characteristics of the smart windows were investigated with respect to the applied voltage and composition ratio. It has been observed that the fabricated PDLC-based smart window not only shows switchable transparency but also self-illumination.

2. EXPERIMENTAL DETAILS

A cross-sectional schematic of the light-emitting PDLC smart window fabricated in this work is shown in Fig. 1. To switch between transparent and opaque states, the PDLC layer was composed of microdroplets of liquid crystal material dispersed in a polymer matrix. A similar fabrication of PDLC layer was described in our previous study [13]. Self-illuminated smart windows were fabricated on flexible substrates with PDLC mixtures. The PDLC mixtures were prepared with various weight ratios of PDLC to ZnS:Cu powder, such as 99:1 (1 wt%) to 87:13 (13 wt%). Polyethylene terephthalate (PET) substrates, on which indium tin oxide (ITO) was deposited, were cut to $50 \times 60 \text{ mm}$ and were cleaned using acetone, ethanol, isopropyl alcohol, and deionized water. The PDLC mixture was spin-coated in the middle of two substrates, and then cured for 1 min by a UV lamp (365 nm, Spectronics ENF-240). For smart window device, we prepared by PDLC (QYPDLC-100, Qingdao QY Liquid Crystal Co., Ltd.) and ZnS:Cu powder (GG5 42, Osram Sylvania Inc.) with average particle size of $\sim 25 \mu\text{m}$ [14]. The light-emitting PDLC samples were irradiated with an ultraviolet lamp (Spectronics ENF-240) at a light intensity of 1 mW/cm^2 at 365 nm for 1 min.

For measurement of the electro-optic performance of the light-emitting PDLC smart windows, an experimental setup was built with a voltage source (CVF1-D200, TOKYO SEIDEN Inc.), CCD detector (AvaSpec-2048, Avantes), and sample stage which was used to monitor the parallel light transmittance and luminosity of the PDLC sample cells. The curves of the applied voltage versus transmittance were obtained by applying an external electric field across the light-emitting PDLC smart window samples. The image analysis of smart window was characterized by field-emission scanning electron microscopy (S-4200, Hitachi).

3. RESULTS AND DISCUSSION

The optical characteristics of the light-emitting PDLC smart windows with various composition ratios and applied voltages are presented in Fig. 2. All of the smart windows showed the typical behavior of PDLC smart windows with the OFF/ON state of PDLC transmittance under forward bias conditions. It was observed that the light transmittance increased as the voltage was gradually increased. At applied voltages higher than 80 V, high transmittance values of 60% were observed, although there were relatively small differences among all samples. However, as a result of confirming the transmittance in the visible light region, the maximum transmittance decreases as the composition ratio of the ZnS:Cu powder increases, and a higher applied voltage is required based on the equal transmittance. It seems that the decrease in transmittance with increased ZnS:Cu powder content in the light-emitting smart window structure could be attributed to the increasing

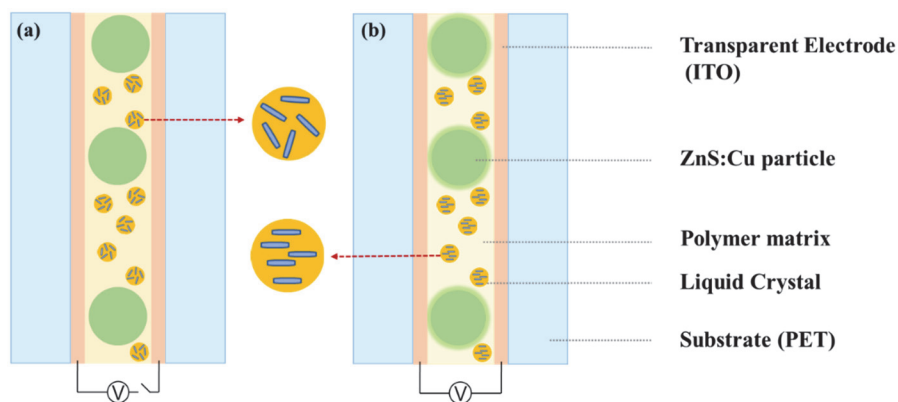


Fig. 1. Schematic diagram of self-illuminated PDLC smart window and turning (a) off and (b) on according electric field.

tendency of the opaque ZnS:Cu particles to aggregate. Switchable transparency, which is used in typical PDLC smart windows was accomplished by using ZnS:Cu powders, although the PDLC-ON transmittance was not as high as that of the typical PDLC smart window.

Figure 3(a) shows luminance curves of PDLC smart windows with various composition ratios and applied voltages. It was observed that the composition ratio of ZnS:Cu powder and applied voltage mainly affected the luminosity values of the fabricated smart windows. The luminance values of smart

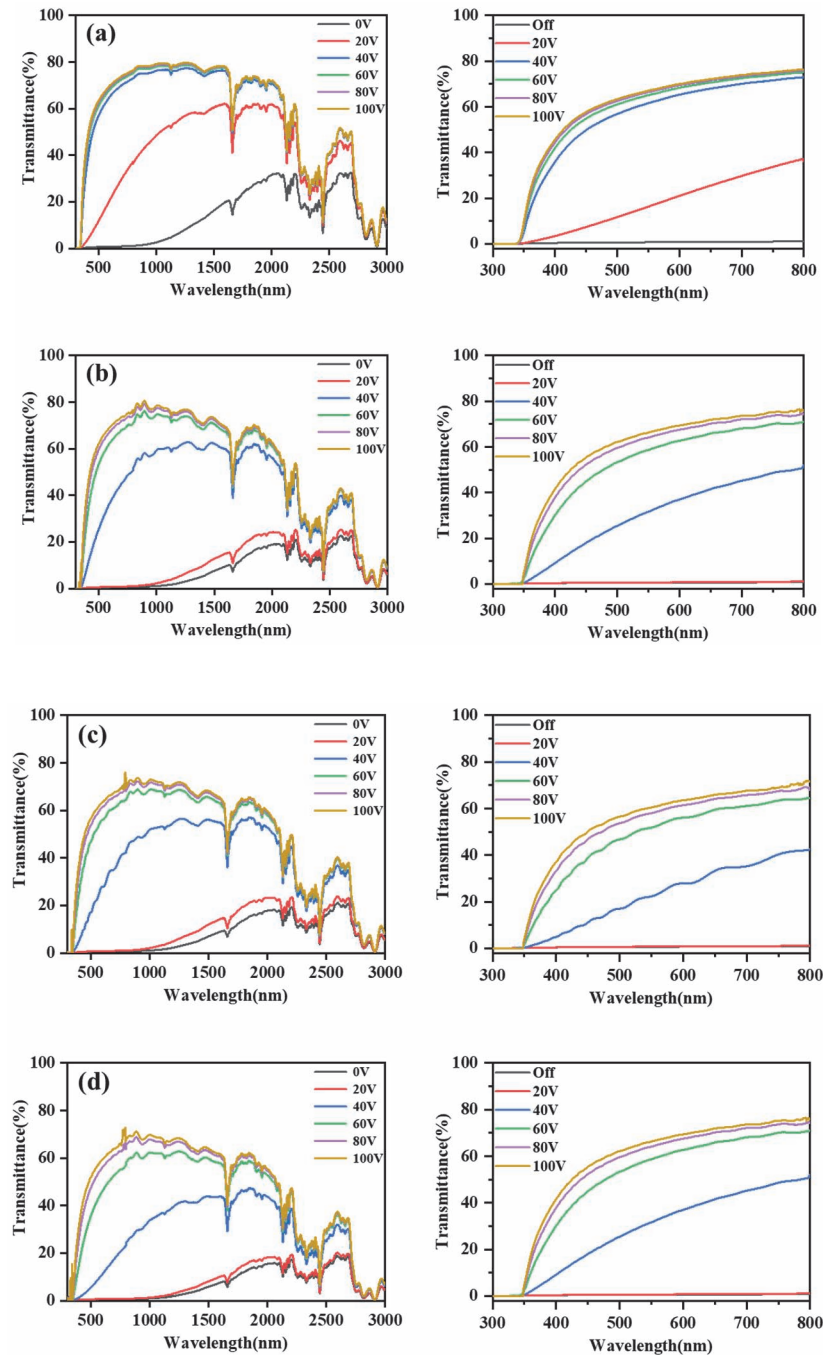


Fig. 2. Transmittance of the self-illuminated PDLC smart window with various voltages and the weight ratios of (a) ZnS:Cu 1 wt%, (b) 5 wt%, (c) 9 wt%, and (d) 13 wt%.

windows increased with increasing applied voltage and composition ratio of ZnS:Cu particle and light-emitting phenomena started at the applied voltage of about 60 V. As shown in the Photoluminescence results according to the ZnS:Cu composition ratio in Fig. 3(b), luminescence intensity increase with the content of powder. This behavior could be explained by comet-shaped electro-luminescence emission occurs along the Cu_xS precipitates in Cu-activated ZnS phosphors in the bipolar field-emission model proposed by Fischer [15]. As shown in Fig. 3(a), the light-emitting smart windows with the included ZnS:Cu ratio above 5 wt% preserved their light-emitting characteristic up to 280 V. However, in the case of a little composition ratio of about 1 to 3 wt%, the PDLC smart window is damaged at an applied voltage above 260 V. It seems that the ZnS:Cu ratio is less

than 5 wt%, it cannot sufficiently act as a spacer, resulting in a problem in driving the PDLC smart window device. Therefore, as the composition ratio of ZnS:Cu increases, the space between the substrates is uniformly separated, so that a uniform electric field prevents short circuit of the device. Figure 3(c) and 3(d) show that the flexible PET substrate and polymer matrix are melted in PDLC smart window regardless of day and night mode in case of ZnS:Cu ratio 3 wt% at 260 V.

Figure 4(a) shows the transmittance and luminosity of the PDLC smart windows according to the ZnS:Cu weight ratio. The fabricated smart windows had a trade-off between transmittance and luminosity depending on weight ratio of ZnS:Cu. Considering both transmittance and luminosity, the proper composition ratio of ZnS:Cu is 7 to 9 wt%, of which 9 wt% is the most stable. The performance of the light-

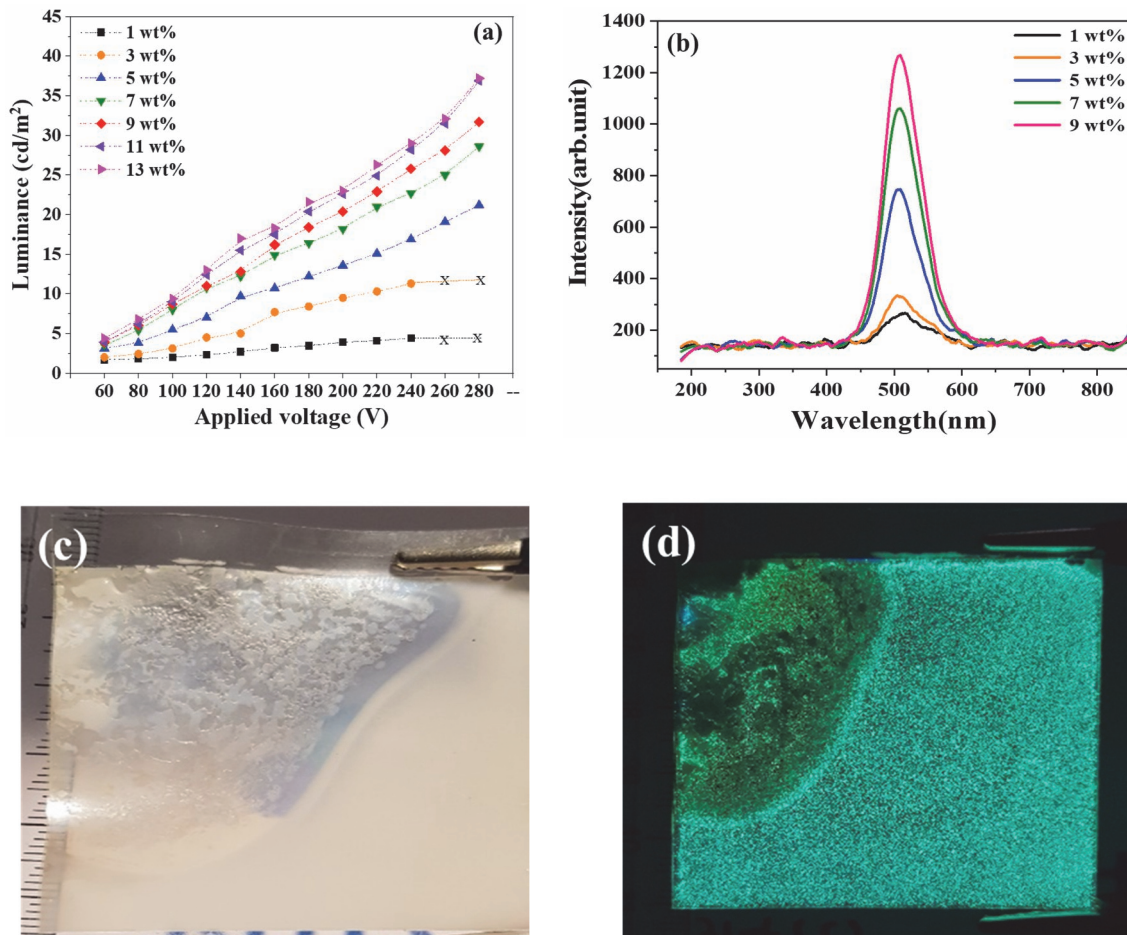


Fig. 3. Electroluminescence property of the self-illuminated PDLC smart window. (a) Luminance curves according to applied voltages to ZnS:Cu weight ratio, (b) photoluminescence intensity according to ZnS:Cu weight ratio, (c) day mode, and (d) night mode of the device with 3 wt% of ZnS:Cu after burning at 260 V.

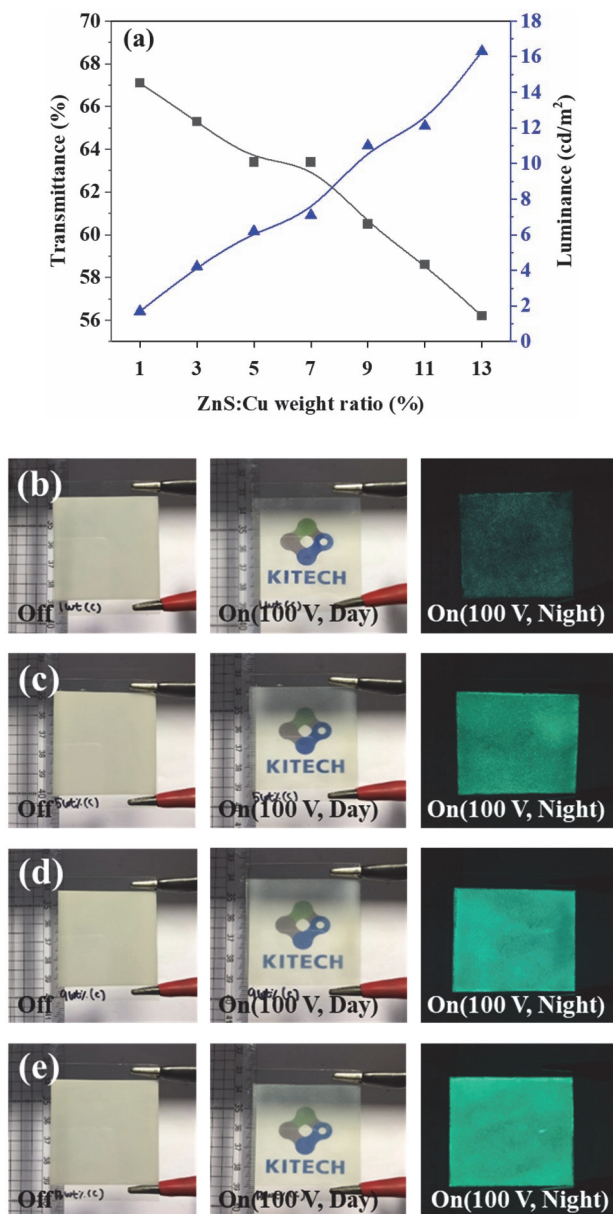


Fig. 4. Transmittance and luminance of self-illuminated PDLC smart window at 100 V. (a) Luminance and transmittance curves, images following the weight ratio of (b) ZnS:Cu 1 wt%, (c) 5 wt%, (d) 9 wt%, and (e) 13 wt%.

emitting smart window fabricated with the composition ratio of ZnS:Cu with 9 wt% and an applied voltage of 100 V exhibited an optical transmittance of 60.5% (at 550 nm) and a luminosity of 11.0 cd/m^2 as shown in Fig. 4(a). Figure. 4(b), (c), (d), and (e) show images of the transmittance mode (day) and light-emitting mode (night) of the smart windows fabricated with ZnS:Cu weight ratios of 1, 5, 9, and 13 wt%, respectively.

4. CONCLUSIONS

We added ZnS:Cu to fabricate PDLC smart windows that can convert between transparency and light emission without attaching an artificial luminous body. The mixed ZnS:Cu of our device can function as a ball spacer with an average size of $\sim 20 \mu m$, enabling uniform and stable self-illuminated smart window operation. It can also be easily applied to existing PDLC fabrication processes. The self-illuminated smart windows tended to have lower transmittances than those of conventional PDLC smart windows due to the addition of ZnS:Cu particles. Therefore, we have proposed an optimal guideline considering the tradeoff between transmittance and luminosity. In our system, the device fabricated with 9 wt% of ZnS:Cu is optimal. The smart windows fabricated for this experiment can be used as switchable transmittance smart windows in the daytime and light-emitting signage at night.

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