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Optical Characteristics of a Flexible Back-Light Unit with Plasma Discharge Clusters

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A flexible back-light unit (FBLU) is fabricated by embedding plasma discharge clusters in a flexible polymer matrix. The brightness uniformity of an FBLU was measured for various combinations of optical sheets and compared with the simulated results for various bending angles. A gap between light sources causes distinctive integrated brightness curves which have two inflection points depending on bending angle. The brightness distribution of a simulated BLU was in good agreement with that of an actual plasma BLU except for a dark area that appeared at the center of the simulated BLU. The real and simulated BLUs both clearly showed an angle dependency caused by mirror images located between point light sources. On the basis of these results, it is suggested that these mirror-like images could be a major factor in determining the characteristics of FBLUs.

Keywords: Flexible back-light unit, Optical simulation, Plasma discharge cluster, Bending angle, Three-dimensional modeling

1. INTRODUCTION

Flexible displays are promising devices which have many advantages over conventional display devices. Electronic paper and organic light-emitting displays (OLED) have been proposed as possible candidates for flexible displays. However, some types of electronic paper are usable only for certain applications because of their slow response time. OLEDs have widely studied as the most promising device, but their limited ability to be encapsulated against water and oxygen vapor limits their flexibility; improvements are needed to overcome this limitation. Flexible liquid crystal displays (LCDs) made by the existing display industry using well-developed technology have a better chance of success than their competitors.

Back lights that use photoluminescence are a fascinating candidate for an flexible back-light unit (FBLU), especially the kind of FBLU used in flexible LCDs. However, before FBLUs can be commercialized, some of their technical difficulties need to be overcome, particularly the design of the flexible substrate and the low activation temperature for the phosphor process and the protective layer. Several research groups have reported flexible plasma displays that involve the use of a glass-based plasma sphere [1], a micro-cavity structure [2], or a flexible direct-current plasma structure [3]. In addition, the Shinoda Plasma Company in Japan has demonstrated the good performance and potential of a large flexible plasma display with tube arrays [4].

The characteristics of a BLU generally depend on variables such as the light guiding plate, the reflector, the pattern of the prism sheet, and the arrangement of light sources [5]. The structure of an FBLU adds one more variable: the bending angle. One important question is whether the light from an FBLU remains uniform in bent states. Various authors have researched a pho-

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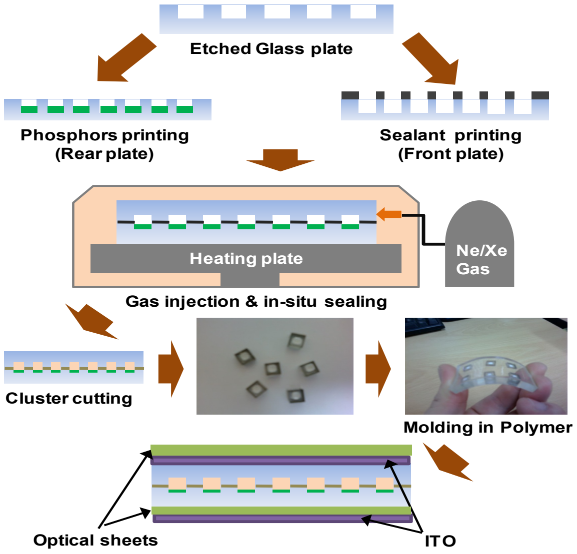

Fig. 1. Process flowsheet of the manufacturing process for an flexible back-light unit consisting of optical sheets and plasma discharge clusters embedded in a polymer matrix.

toluminescent flexible BLU for flexible LCDs and have presented a cluster-type FBLU using embedded plasma discharge clusters in a flexible polymer matrix [6]. The authors have continued that work in this paper by studying the optical properties of an FBLU with embedded plasma discharge clusters and by comparing the results to optical simulation results in bent states.

2. EXPERIMENTAL

Square plasma discharge clusters were embedded in a polymer matrix as follows: a glass substrate with a thickness of 3 mm was etched to create an appropriate discharge space. Then a phosphor and MgO protective layer was formed by spin coating (MgO solution was prepared using a similar method reported in another report [7,8]). With an etched rear glass, a green phosphor (Kasai Optonix P8G-P1, P884 [10 wt%]) was then printed and fired at 500°C. A glass sealant was printed on the front and rear of the glass. After the sealant dried, the front plate and rear plate were kept under a constant pressure, and clipping took place in a vacuum chamber. When the panels were set, the vacuum chamber was pumped to 8.5×10^{-5} Torr. Next, a Ne + Xe gas mixture with 5% or 50% of Xe was injected and maintained at 300 Torr. The sealing was done at 500°C for 30 minutes in the vacuum chamber. Finally, die-shaped clusters were separated from the sealed part using a laser cutter and embedded in a silicone polymer matrix. A transparent polydimethylsiloxane was used as a flexible substrate. The FBLU was fabricated as follows: clusters were placed in a square container of silicone elastomer with a 10% hardening agent and solidified through polymerization of the monomer. Indium tin oxide (ITO) was deposited on the front of the polymer matrix as an electrode by means of DC sputtering, and commercial ITO film was attached to the rear of the polymer matrix. Diffuser sheets and prism sheets (Kolon Co., Ltd., Korea) were added to the FBLU to improve the optical properties of the BLU. The detailed experimental conditions are illustrated in Fig. 1.

The diffuser sheet in Fig. 2(a) was fabricated as follows: a mixture of acrylic polyol, polymethylmethacrylate powder, and toluene (at a weight ratio of 1.24:1:3) and 1.5 wt% of a hardener was spin-coated onto a polyethylene terephthalate film at 1,500 rpm for 15 seconds and then left to dry at room temperature for 10 minutes. Figure 2(b) shows a surface image of the diffusion sheet used in this study.

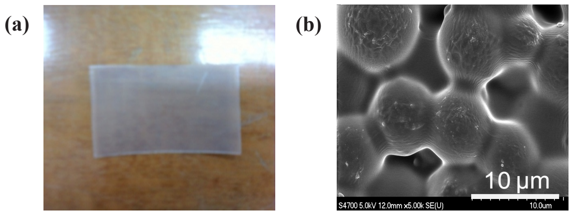

Fig. 2. (a) A diffuser sheet consisting of poly(methyl methacrylate) powder and a polyethylene terephthalate film with a thickness of 125 µm; (b) a surface scanning electron microscope image of (a).

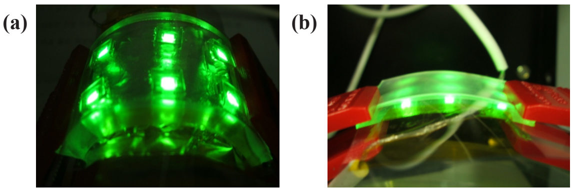

Fig. 3. Image of a bent flexible back-light unit consisting of plasma discharge clusters embedded in a polymer matrix: (a) without optical sheets, (b) with optical sheets.

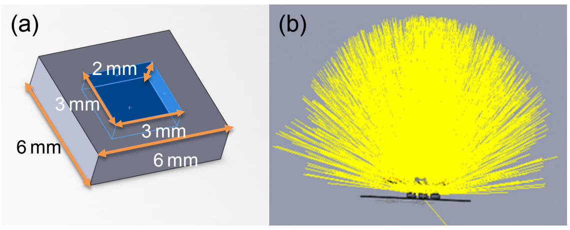

Fig. 4. (a) Cross section of a point light source for an flexible back-light unit simulation that emits light with the following characteristics: a unit wavelength of 580 µm, 0.13 lumens, and one million rays; (b) artificially created yellow radiations from the light source.

The electrodes were connected to a square pulse with a 40% duty ratio at 1.8 kV with 40 kHz by using a pulsed power supply (FT LAB HPI_500). The luminance values of each cluster were measured with a Konica Minolta CS-200.

The Optisworks optical simulation tool was used for three-dimensional modeling of a plasma discharge cluster to predict brightness distribution [9]. As shown in Fig. 3, the results were then compared with those of a plasma discharge FBLU at various bending angles. Figure 4(a) shows the setup for a simulated light source with a square column (3 mm × 3 mm × 2 mm) in glass: it emits a unit wavelength of 580 µm with 0.13 lumens and one million rays based on a real plasma cluster with a green phosphor. The light source has a 2-mm gap and is enclosed by a poly(methyl methacrylate) light guide plate with 99% transparency and a refraction index of 1.489. To obtain an even spread of light, a prism sheet was placed on the light source; the linear pattern on the sheet had a width of 64 µm and a depth of 73 µm. The distance between the light detector and the prism sheet was fixed at 40 cm to replicate the real measurement conditions. As shown in Fig. 4(b), a pattern of yellow lines was used to check the artificially created radiations from the light source. The variability and distribution of the luminescence from the FBLU were then calculated with respect to the number of diffusion sheets at

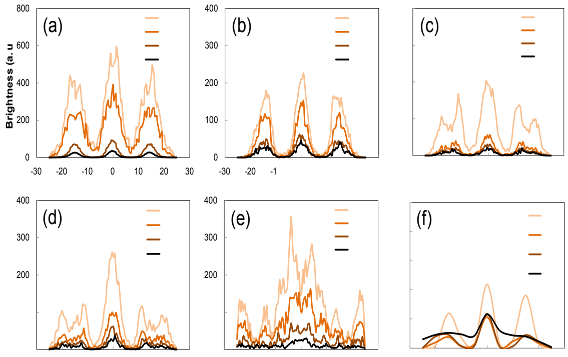

Fig. 5. Simulation results in relation to the number of optical sheets and the bent angles; (a) 0°, (b) 10°, (c) 20°, (d) 30°, and (e) 40°; and (f) comparisons of the optical outputs of 10 diffuser sheets as a function of bending angle.

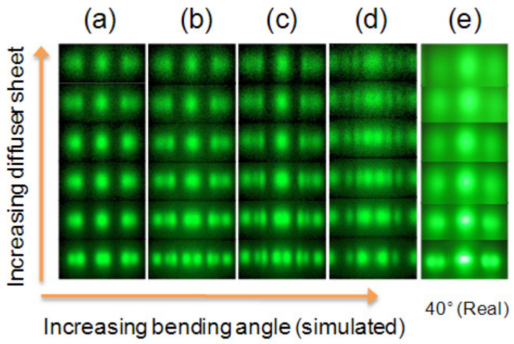

Fig. 6. Images of the light output of ((a) to (d)) a simulated flexible back-light unit (FBLU) and (e) a real FBLU.

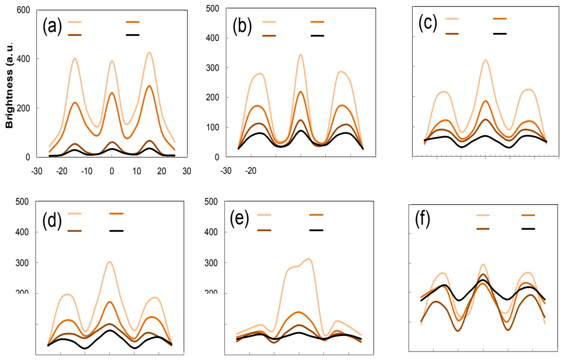

Fig. 7. Brightness distributions from a real back-light unit in relation to the number of optical sheets and the bending angle; (a) 0°, (b) 10°, (c) 20°, (d) 30°, and (e) 40°; and (f) a comparison of the optical output of 10 diffuser sheets as a function of bending angle.

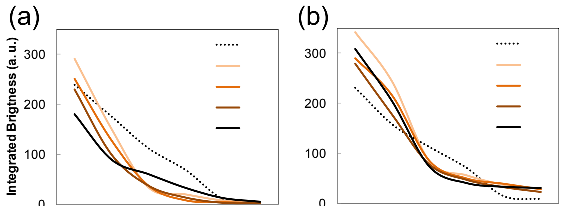

Fig. 8. Integrated brightness of (a) the simulated back-light unit (BLU) and (b) a real BLU in relation to the number of optical sheets and the bending angle.

various states for angles of 10°, 20°, 30°, and 40°. To measure the real distribution of light from the plasma FBLU, a reflector and prism sheets were attached underneath and on top of the FBLU.

3. RESULTS AND DISCUSSION

The simulation results shown in Fig. 5 reveal that the brightness is reduced in relation to the number of optical sheets and the bending angle. By contrast, the uniformity of the brightness increases as the number of diffuser sheets increases, although the brightness of the BLU light source is reduced.

Interestingly, as shown in Fig. 6, a mirror-like image of the light source is generated by the imaginary simulated light source between the two light source images when the BLU is bent. As the bending angle of the BLU increases, the light distribution fluctuates considerably. Moreover, the peak brightness of the BLU changes enormously with the addition of a single diffuser sheet. In Fig. 6, a bending angle of 10° yields the maximum brightness at the zero position of the X-axis; however, the maximum-brightness spot is divided in two at a bending angle greater than 20° due to the mirror-like images that appear between the light source images. In addition, as shown in Fig. 5, the medium-intensity brightness peaks also fluctuate depending on the bending angle. The fluctuations in brightness were reduced as the number of diffuser sheets was increased and reached a minimum level for the largest number of diffuser sheets.

In comparison with the brightness distribution of the simulated BLU, the actual plasma BLU in Fig. 7 has a similar brightness distribution. However, the uniformity and reduction of the brightness in relation to the number of optical sheets and the bending angle appear to differ. When the real BLU was bent, mirror-like images of the light source could be observed between the light source images. As the bending angle was increased, the three point lights in the BLU appeared to become six point lights, probably due to the prism sheet.

Interestingly, as shown in Fig. 7(f), brightness uniformity is greatly improved at 40°. The greatest difference between the simulated and measured results is the existence of a dark area at the center of the simulated BLU. In the simulated results for the BLU with a single diffuser sheet, the dark area occurs near the zero position of the X-axis; however, no dark area was observed in the real BLU. Instead, one point light in the real BLU became separated into two point lights; these two points became connected and formed a linear emitting light at higher bending angles. The positions of the mirror images from both real and simulated BLUs varied in relation to the bending angle and produced different brightness distributions. The brightness distributions from the real and simulated BLUs with 10 diffuser sheets, as shown in Fig. 6, have a clear angle dependency caused by the mirror images. The results for the real and simulated FBLUs confirm that the largest difference between the FBLUs and the normal BLUs is the existence of the mirror-like images in the FBLUs; this factor is a major characteristic of FBLUs.

As shown in Fig. 8(a), the integrated brightness of the simulated BLUs has a distinctive curve shape with two inflection points whose positions depend on the bending angle. In addition, the BLUs show a gradual decrease in total brightness as the bending angle is increased. Simulated bent BLUs have a higher overall brightness when they have one or two diffusers. The integrated brightness of real BLUs, as shown in Fig. 8(b), follows a similar trend to that of the simulated BLUs, although the brightness depends on the bending angle. However, regardless of the number of diffuser sheets, the real BLUs have a higher integrated brightness than in the case of a 0° simulated BLU; they also have clear inflection points. The reason for the higher integrated brightness in both cases is apparently related to the gap between the light sources.

4. SUMMARY AND CONCLUSIONS

In summary, in an application of an FBLU, a cluster-type plasma discharge lamp was fabricated and embedded in a flexible polymer matrix. The brightness uniformity of the BLU was measured for various combinations of optical sheets, and the results were compared with the simulated results for various bending angles. The integrated brightness curves for real and simulated BLUs have distinctive shapes with two inflection points whose positions depend on the bending angle. The brightness distributions of the simulated and actual plasma BLU are similar. Both the real and simulated BLUs clearly show an angle dependency caused by the mirror images that appear between the point light sources. On the basis of the results obtained for the real and simulated FBLUs, it can be concluded that the greatest difference between the FBLUs and normal BLUs is the existence of a mirror-like image. This suggests that the mirror-like image in the FBLU could be one of the major characteristics of FBLUs.

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