Enhancement of the Coupling-Out Efficiency by Sandwiching a Teflon-AF Layer Between the Glass and the ITO Layer in the Front Structure of Flat Panel Displays

Hong-Sub Bae, Jong-Ku Park, Hyun-Woo Ryu, Chang-Duk Kim, Hyeong-Rag Lee, Do-Hyung Kim and Ilsu Rhee*

Department of Physics, Kyungpook National University, Daegu 702-701

(Received 2 May 2007)

In the front structure of a flat-panel display, a Teflon-AF (amorphous fluoropolymer) layer is sandwiched between the glass and the ITO layer to reduce the total reflection of light from the denser glass to the air. The light transmittance through this Teflon-AF sandwiched sample was measured using both a photometer with scattered laser light as its light source and a luminescence meter with a mercury-free flat discharge lamp as its light source. An enhancement of the transmitted light was observed with both measurements. With the mercury-free flat discharge lamp, an enhancement of more than 60 % was observed. The Teflon-AF sandwiched structure appears to be a viable method to increase the coupling-out efficiency of flat panel displays.

I. INTRODUCTION

The light generated by organic molecules should pass from a higher to a lower refractive index material in an OLED (organic light emitting diode) structure [1,2]. In this process, the light experiences total reflection and is trapped in the form of waveguide modes leaking out to the sides [3]. This phenomenon is a major reducer of the coupling-out efficiency in flat panel displays, such as OLEDs. In OLEDs, the light experiences a total reflection twice - once when it passes from the ITO (indium tin oxide) to the glass, and once when it passes from the glass to air. The coupling-out efficiency in an OLED is calculated to be 17.3 % if the cathode is assumed to be a perfect reflector and if the refractive index of the organic material is 1.7 [4]. Several efforts have been tried to resolve this problem by sandwiching a lower refractive index material between the ITO layer and the glass [5–7]. A silica aerogel is an ideal material for this purpose because its refractive index is close to unity. The aerogel film, however, is too brittle, and a complex super-critical drying process is required to form it [3]. The device efficiency can also be enhanced by introducing either a micro lens system [4,7] or periodic microstructures [8,9] to couple the guided modes to useful far-field radiation. However, processes to form micro lens systems and periodic microstructures are complicated and may not be practical.

The present study tests a very simple and effective way to reduce total reflections by sandwiching a Teflon-AF layer between the ITO layer and the glass. Teflon-AF [10] is a transparent and viscous liquid. Its refractive index is relatively low, 1.31 and 1.29 at a wavelength of 633 nm for AF 1600 and AF 2400, respectively. We used Teflon-AF 1600. Teflon-AF 1600 has a relatively high refractive index, but it has a higher viscosity than Teflon-AF 2400 and can easily be formed into a uniform film by using a spin coating method.

The light generated by organic molecules acts as a point source and is scattered in all directions before entering the ITO layer. The light rays at incident angles higher than the critical angle are totally reflected and leak out to the sides. For the present study, a diffuser was first used in close contact with the film in order to scatter the incident laser light in all directions and to mimic a point light source [11]. Later, a phosphor layer was pasted on the Teflon-AF layer to use a mercury-free flat discharge lamp as a light source. An enhancement of the light transmission of more than 60 % was observed for the sample with a sandwiched Teflon-AF layer compared to the bare glass.

It is hoped that the structure could be used to increase the coupling-out efficiency of flat panel displays.

PACS numbers: 78.20.Ci, 42.70.Jk
Keywords: Coupling-out efficiency, Teflon-AF, Total reflection

*E-mail: ilrhee@knu.ac.kr

-567-
Fig. 1. AFM picture to check the surface roughness of the Teflon-AF layer on glass.

Fig. 2. Schematic figure for the measurement of the light transmittance using a photometer.

Fig. 3. Dispersion of the light source through the bare glass (left) and the glass with a Teflon-AF layer (right).

II. EXPERIMENTS

The glass substrate was prepared by cleaning with acetone and methanol, and then by blow drying with nitrogen gas. The Teflon-AF film on the glass was then formed by spin coating at 1500 rpm for approximately 1 min. A small amount of FSM 660 (Cytonix) was added to improve the adherence of Teflon-AF to the glass substrate [12]. Then, the coated film was dried at 160°C for almost 12 hours. The process of slow drying seemed to greatly reduce the surface roughness of the film. The thickness of the film was measured with a Kosaka Lab film thickness measurement system and was determined to be about 1 µm. The surface roughness of the film was checked by using an AFM (atomic force microscope, Bioscope Digital Instrument) and was found to be within 5 nm (Fig. 1).

The experimental set-up for the measurement of the position-dependent transmittance of the laser light through the sample is shown in Fig. 2. A He-Ne laser (UNIPHASE USA 0.95 mW) was used for the light source. The light generated by organic molecules in the OLED is scattered in all directions before entering the ITO layer. The light rays at incident angles higher than the critical angle are totally reflected and leak out to the sides. To mimic the behavior of the point light source in the OLED, a diffuser (DFB1-30C02-240, ground glass diffuser) was placed in close contact with the sample. This diffuser scattered the incident laser light in all directions before it entered the sample.

The ray diagram through the sample is schematically depicted in Fig. 3. The light rays with incident angles greater than the critical angle are shown to be totally reflected and to leak out to the sides of the glass. We can see in this figure that the Teflon-AF layer, having a lower refractive index than that of the glass, acts like a collector of the light rays that otherwise would be totally reflected. The light passing through the sample was collected by the optical fibers in the optical cable that was mounted in a precision linear translator (resolution of 0.1 mm) and then detected by a photometer (PASCO, OS8020). The position-dependent intensity signal of the transmitted light was measured by moving the optical fiber sensor with a linear translator in 0.2-mm increments. The profile of the transmitted light intensity was obtained using a CCD camera (Sigma Koki SKDCE-2) instead of a photometer. The phosphor layer was pasted onto the Teflon-AF layer so that the light emitted by a phosphor atom acted as a point light source. A thin layer of ITO was added between the phosphor layer and the glass because phosphors will not adhere to the polymer layer of the Teflon-AF. A schematic figure for the sample and the structure of the mercury-free flat discharge lamp [13,14] is shown in Fig. 4. In this figure, the distance between the lower and the upper plates is about 4 mm. The dielectric layer (SiO$_2$/TiO$_2$/PbO, 62 µm) in the lower plate protected the electrode. The phosphor layer in the lower plate enhanced the luminescent efficiency. The ultraviolet photons generated by Xe atoms hit the phosphors in the upper plate to produce visible light. This visible light entered the sample in the upper plate.

The sample was placed into a vacuum chamber in a dark room. The chamber was pumped out using a turbo pump, then, the Xe gas was put into the chamber to a pressure of 68 Torr. The Xe atoms in the vacuum chamber were excited by using an alternating voltage source
III. RESULTS AND DISCUSSION

The position-dependent transmittance of the laser light through the sample is shown in Fig. 7. This was obtained by using the experimental setup shown in Fig. 2. Each data point represents the intensity of the transmitted light collected by the optical cable, which had a diameter of 1 mm. The distance between the sample and the optical fiber sensor was 5 cm. The optical fiber sensor was moved from −1.0 cm to +1.0 cm relative to the center of the optical bench by using a linear translator. Thus, the data shown in Fig. 7 cover about ±11° for the light transmitted through the sample. As this figure illustrates, the enhancement of the light transmittance by sandwiching a Teflon-AF layer is greater in the center region. The overall enhancement for this angle of the transmitted light was determined to be about 20 %. Normally, the enhancement of the transmittance is defined as the increase of the light transmittance summed over all the front angles (±180°). However, our enhancement result, 20 %, covers only angles of ±11° and thus, represents the enhancement of transmittance only for a small portion of the front angles. We concluded that enhancement of the transmitted light in this case was due to a reduction of the total reflection by the sandwiched Teflon-AF layer. This enhancement of the transmitted light.
light could be verified with a CCD camera. The intensity profile of the transmitted light is shown in Fig. 8. By comparing the volumes of the light intensity for the two samples, we confirmed that the transmitted light was enhanced by approximately 20%.

The transmittance was also measured with a mercury-free discharge lamp as a light source, as shown in Fig. 5. A transmittance enhancement was also seen in the Teflon-AF sandwiched sample, as shown in Fig. 9. The data were taken in increments of about 1 second for two minutes. The initial increase in the transmittance (noted as efficiency in Fig. 9) was due to the instability of the discharge lamp. The overall decrease in the efficiency with time is due mainly to a decrease in the luminescence efficiency of the phosphors from continuous heating. This decrease in efficiency was observed to be greater in the first 30 seconds for the bare glass sample. The reason for this is not yet clear. However, as Fig. 9 shows, the initial enhancement in the efficiency for the Teflon-AF sample was about 30%, and this enhancement increased to as high as 60% after 30 seconds - a tendency that continued thereafter. This enhancement of the transmitted light was much greater than that for a previous measurement with the scattered laser light as a light source. This was expected because the light generated from the phosphors pasted to the Teflon-AF layer was much more like a point source than was the scattered laser light. The possibility of practical application of this structure to a flat panel display, for example, an OLED system, can be clearly examined further by depositing an organic layer onto a comparable sample and measuring the enhancement of the transmitted light as described above - an initiative that is ongoing.

Fig. 8. Three-dimensional images for position-dependent transmitted light as measured by using a CCD camera.

For improvements of the brightness of the image and of the energy efficiency in a flat panel display, it is important to resolve the low coupling-out efficiency. For example, in an OLED, a glass (thickness: \(t \sim 1\) mm, refractive index: \(n \sim 1.52\)), an ITO layer (\(t \sim 100\) nm, \(n \sim 1.8\)), an organic layer (\(t \sim 0.1\) nm, \(n = 1.6 \sim 1.8\)), and a cathode layer are used. Assuming that the cathode layer is a perfect reflector and that the refractive index of the organic layer is 1.7, one can calculate the overall coupling efficiency to be just 17.3% [4]. Several reports have suggested ways [4–9] to resolve this low coupling-out efficiency in flat panel displays. In the present study, the coupling-out efficiency was increased by sandwiching a Teflon-AF layer between the glass and the ITO layer - a simple and effective method.
IV. CONCLUSION

We observed enhancement in light transmittance for a Teflon-AF sandwiched sample compared with a bare glass sample. The Teflon-AF layer was sandwiched between an ITO layer and the glass to reduce the total reflection of the light passing from glass to air. The transmittance of the scattered laser light through the sample was measured by using both a photometer and a CCD camera. In these measurements, we could observe an enhancement of around 20 % of the transmitted light for the front angles of ±11°. This enhancement increased to more than 60 % in the transmittance measurement when a mercury-free flat discharge lamp was used as a light source. In this case, the light generated by phosphors pasted onto the Teflon-AF layer can be considered as a real point-light source. Thus, much higher enhancement could be expected.

There have been many efforts to reduce side leakage of light and, consequently, to increase the coupling-out efficiency in flat panel displays. In this paper we report a relatively simple and effective way to achieve this goal. We concluded that the sandwiched Teflon-AF layer greatly enhanced the light transmittance through a reduction of the total reflection.

ACKNOWLEDGMENTS

This project was supported by the Korean Ministry of Commerce, Industry and Energy (contract numbers: 10018373, 10021967). The authors participated in the project as an entrusted team. The principal contractors of this project are AVACO Co. Ltd and Hanil Polymer Co. Ltd.

REFERENCES