High Transmittance Liquid Crystal Display with Polarized Organic Light-Emitting Device as a Backlight Unit

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We demonstrated a highly polarized organic electroluminescence device through enhancing an orientational ordering of the conjugate polymer. The highly ordered state of the conjugate polymer and the resultant high polarizability were obtained by improving azimuthal anchoring energy through the optimal rubbing condition of a polyimide underlying the emitting layer. The polarized OLED was adapted to the twisted nematic liquid crystal cell as a backlight unit and tested the electro-optic characteristics.

1. Introduction

Many kinds of optical devices using liquid crystal (LC) require polarized light. In early studies, these devices usually used the linearly polarized light which is made from unpolarized light with a sheet polarizer. However, a polarizer absorbs about 50% of the incident light, which leads to an high power consumption for high transmittance.

Organic light-emitting diodes (OLEDs) have been focused as a light source because of the advantages of low driving voltage, high brightness, simple fabrication processes, and so on. Many researchers have reported bout the linearly polarized OLED as a light source in the backlight unit on the liquid crystal display (LCD) applications by obtaining the mono-domain alignment of organic emission layers such as stretching Langmuir-Blodgett (LB) deposition and direct rubbing methods [1-3]. The LB deposition method was first applied to the alignment of emission layers of conjugated light-emitting polymers by Neher, but fabrication processes of these devices are time consuming and incompatible in large size application [4]. And the stretching of the films has a critical limitation of the drawing ratio of the polymer backbone and they also show the low polarization ratio. Therefore, direct rubbing with alignment layer method is compatible at the point of the simple fabrication process and large size application. In direct rubbing method, they used the liquid crystalline fluorescent materials can be aligned on suitable alignment layers [5]. And this method shows the highest polarization ratio due to the re-orientation properties of the nematic liquid crystalline materials.

However, when some kinds of polymer surfaces were rubbed, the polymer chain distribution of the alignment layer was strongly affected by the rubbing condition (i.e. strength and direction) and could directly influence the anchoring energy of the surface. And also the alignment surface condition affected to the alignment of organic emission layer, which characterize the polarization ratio.

In this paper, we studied about the surface anchoring energy induced by the rubbing strength and polarization ratio of the electroluminescence devices. For high polarization ratio, we optimized the rubbing condition for high azimuthal anchoring energy. And we adopted the polarized OLED to the twisted nematic (TN) LCD as a light source for high electro-optical characteristics.

2. Experimental

To make the OLED cell, we used the ITO substrate as an anode electrode. As an alignment layer, polyimide (PI) material (AL22620 from JSR) was prepared and that was spin-coated on to the ITO substrates. The thickness of the PI layer was about 20 nm. After imidization with heating process, the PI layer was rubbed using the cotton roller with different times to control the azimuthal anchoring energy of the surface. The emission material (ADS-133YE from American Dye Sources) mixed with solvent (toluene) was spin-coated onto the rubbed PI layer and the thickness was about 60 nm. At this state, emission molecules are randomly distributed in azimuthal directions as shown in Fig. 1(d). Mono-domain alignment was induced by annealing the polymer film at nematic temperature onto the hot plate about 60 min (fig. 1(e)). And then the Ca/Al layer was deposited using the thermal evaporation method about 5 nm and 90 nm, respectively (fig. 1(f)). The experimental environments were restricted by the oxidation and humidity by processing in the glove box.

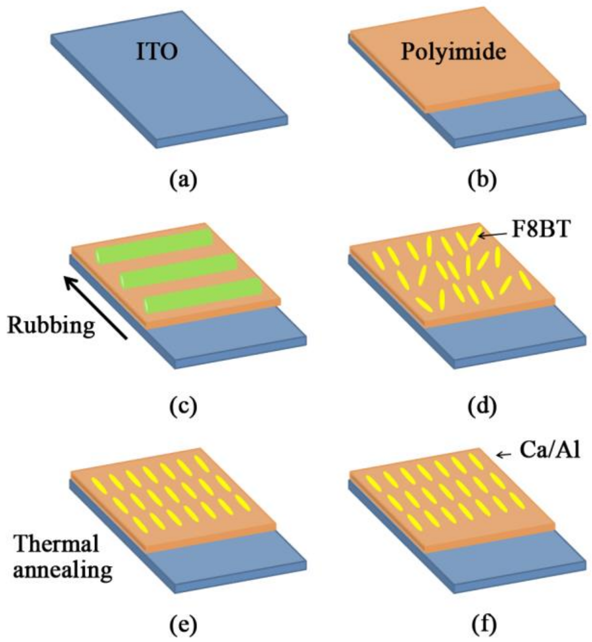

Fig. 1. Schematic diagram of fabrication process for the polarized OLED. (a) ITO substrate as anode, (b) polyimide alignment layer, (c) rubbing process, (d) emission layer coating, (e) thermal annealing of the emission layer, (f) deposition of cathode.

3. Result and Discussion

In LCD, the surface anzimuthal anchoring energy of nematic LC is proportional to the rubbing strength [6]. The strong rubbing strength affected to the chain distribution of alignment polymer, and the high ordered polymer chain make highly ordered alignment of nematic LC molecules due to high azimuthal anchoring energy. In our study, when we increase the rubbing strength by increasing the rubbing times, the azimuthal anchoring energy was gradually increased to 2.4 X 10^{-4} J/m^2 till 6-times rubbing processing using torque balance method [7]. After that, the azimuthal anchoring energy was saturated even increase the rubbing times because alignment of the polymer chains of alignment layer was saturated. Even though we measured the azimuthal anchoring energy using nematic LCs, we can analogize the anisotropic alignment of emitting materials from the azimuthal anchoring energy of the alignment layer because the used emitting material in this study has liquid crystalline characteristics in proper temperature range. After coating the emitting material on the alignment layer, the emitting layer has mono-domain alignment during annealing process at the nematic temperature range of the emitting material. The unidirectional alignment of emitting material could make the polarized emitting light.

Figure 2 shows the measured polarization ratio of the fabricated electroluminescence (EL) devices by varying the rubbing conditions. As we observed in anchoring energy properties, the polarization ratio is rapidly increased until 7-times rubbing and then decreased at the 8-times rubbing cases. Figure 2(b) shows the EL image of the fabricated sample with 7-times rubbing condition. The polarizers are located on top of the cell and the light can pass through the polarizers when the rubbing axis is parallel to the transmission axis of the polarizer. And light is blocked by the polarizers when we rotate the polarizer perpendicular to the rubbing axis. Therefore, we can notice that the our polarized OLED shows the anisotropic luminescence characteristics and the measured polarization ratio was about 22 : 1 at the 7-times rubbing case.

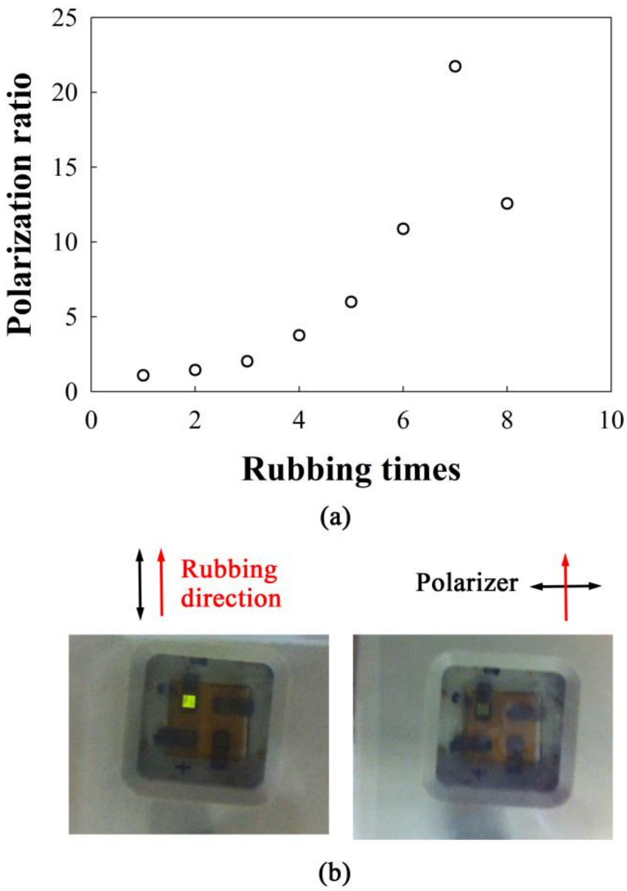

Fig. 2. The measured (a) polarization ratio of the EL by varying the rubbing strength and EL characteristics for 7 times rubbing devices by adopting the different polarizer direction.

We adapted the polarized OLED as a backlight unit to the TN LC cell. The optic axis of an OLED and an analyzer are perpendicular each other, and the TN LC cell are positioned between light source (polarized OLED) and an analyzer as conventional TN LCD. Figure 3 shows the calculated voltage-transmittance characteristics depending on the polarization ratio of polarized OLED as a backlight unit. For low polarization ratio, the contrast ratio is very low due to poor black state. For high polarization ratio, it shows very good black state as compared to the TN cell with two crossed polarizers. The transmittance of the conventional TN cell with two crossed polarizer is blow the 50% because a polarizer located between light source and LC cell absorbs about 50% of the incident light. However, there is no absorbance of the incident light when we use the polarized OLED as a backlight unit without polarizer. The transmittance of the TN cell using the polarized OLED with high polarization ratio is more than two times than the conventional TN LC cell's one, as shown in Fig. 4.

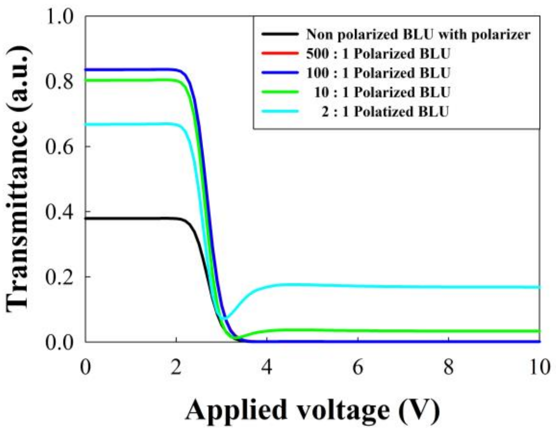

Fig. 3. Calculated voltage-transmittance characteristics depending on the polarization ratio of polarized OLED as a backlight unit.

Figure 4 shows the microscopic textures of the TN LC cell with one analyzer and a polarized OLED as a backlight unit depending on applied voltages. The cell configuration is same as the calculated cell conditions. The cell size was 2.5 cm X 2.5 cm, and we could get the uniform texture of whole cell area. At initial state, the TN cell shows the bright state because the incident polarized lights are guided along the TN structure, and the polarization direction is changed to parallel to the analyzer. When we applied voltage, the LC molecules are rise up to a substrate and the incident polarization direction is not changed. As a result, we could get the dark state. The texture shows the green light because we used the emission material which emits green lights.

Figure 5 shows the voltage-transmittance characteristics of TN cell. It shows the characteristics of a normally white TN LC cell. In our study, the contrast ration was about 12: 1 and the black state was not so good because we used the polarized OLED with 10:1 polarization ratio. If we used the OLED with high polarization ratio, we could get high contrast ratio. Hereafter, additional research will be performed to analyze the mechanism of the emission material's alignment and to enhance the polarization ratio.

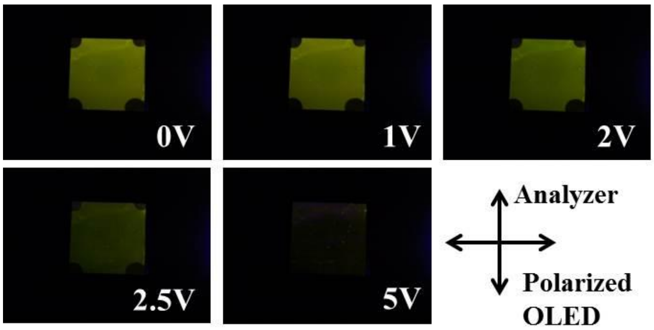

Fig. 4. Microscopic textures of TN LC cell with one analyzer and polarized OLED as a backlight unit depending on applied voltages.

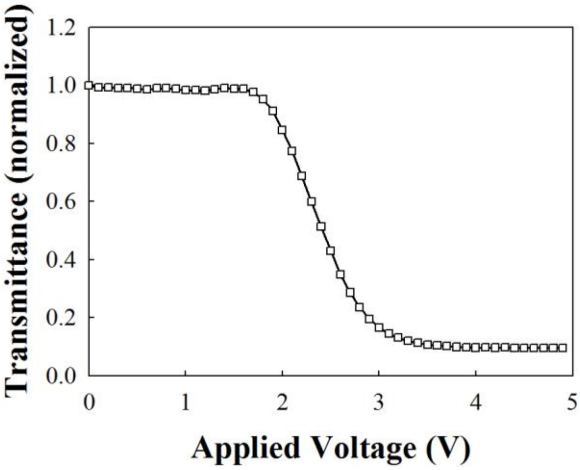

Fig. 5. Voltage-transmittance characteristics of TN LC cell with polarized OLED as a backlight unit.

4. Conclusions

We studied about the relationship between surface anchoring energy induced by the rubbing strength and polarization ratio of the electroluminescence devices. By increasing the rubbing times, the azimuthal anchoring energy is increased rapidly then saturated. The high azimuthal anchoring energy makes unidirectional alignment of emitting materials. Therefore, the polarization ratio is changed according to the rubbing condition and we could achieve the highly polarized (~ 22 : 1) OLED devices. And also, we adapted the polarized OLED to the TN LC cell as a backlight unit for high transmittance characteristics. We believe that the polarized OLED is a leading candidate as a light source for the optical devices using LCs.

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