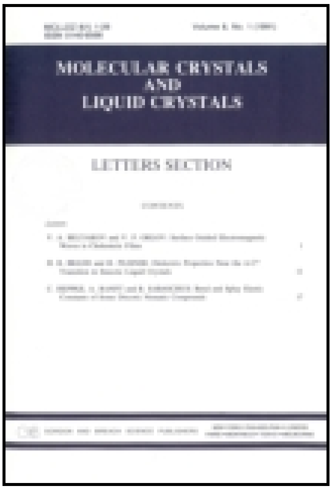

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Solution Processed PLED on Transparent Plastic Substrate for Flexible Display

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Solution Processed PLED on Transparent Plastic Substrate for Flexible Display

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We have fabricated the flexible organic light-emitting diode (OLED) displays on 10 μm colorless polyimide (CPI) substrate using polymer light-emitting diode (PLED). The CPI was chosen as a substrate for flexible device because of its high transparency of around 90% at 550 nm and relatively high temperature process of >300°C. All organic materials for OLED were deposited by spin coating technique and the OLED on PI substrate was encapsulated by the polyethylene terephthalate (PET) film with barrier layer. The PLEDs have a driving voltage of 3 V at 1000 cd/m^2, and the current efficiency of 11.7 cd/A for the device on CPI substrate at 1000 cd/m^2.

Keywords Polymer light-emitting diode; colorless polyimide; flexible display; flexible substrate

Introduction

Solution processed polymer light-emitting diodes (PLEDs) on plastic substrate have been widely studied for flexible displays because they have many attractive properties such as self-emission, light weight, extremely thin, low cost process and flexibility. [1, 2, 3] There are three types of substrates usually used for flexible displays; thin glass, stainless steel foil, and plastic. Since thin glass is brittle and heavy, it is not appropriate for the flexible device. Stainless steel foil can be easily dented during processing and is opaque, and poor surface roughness. Plastic has better flexibility compared to thin glass. However, plastic can be processed at relatively low temperatures. [4] And, a gas barrier is necessary to protect the device from the penetration of moisture and oxygen into the plastic. [5, 6] Polyimide (PI) has higher processing temperatures, good chemical resistance and excellent mechanical properties compared with other plastic substrates, but its colored and low transparent property limit application to flexible displays. [7]

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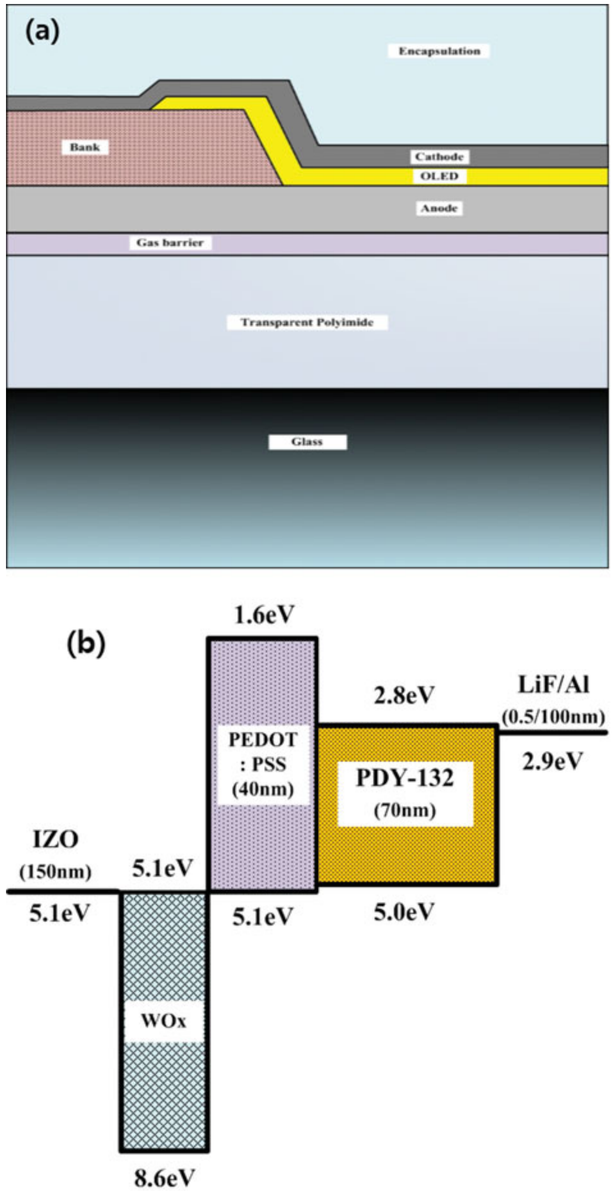

Figure 1. (a) Schematic cross-sectional view and (b) energy level diagram of flexible PLED on CPI substrate.

In this paper, the PLED was fabricated by solution process method on CPI substrate and encapsulated by PET-film with a barrier layer.

Experimental

For the development of flexible display, we have fabricated the bottom-emission PLED on CPI substrate as shown in Figure 1. We developed a detachment method to detach CPI substrate from the glass by adding a buffer layer between CPI and glass substrate. [1] The buffer layer formed below CPI layer enables the detach process easy. [7, 8, 9, 10] We

Table 1. Specification of CPI properties

Glass transition temperature (°C)	>300
Transmittance at 550 nm (%)	90
CTE at 50∼250°C (ppm/°C)	∼20
Viscosity (ps)	130
Thickness (μm)	∼10

used a CPI as a flexible substrate because it has a thickness of about 10 μm and a high transparency of around 90% at 550 nm as shown in Figure 2. It was coated on a carrier glass with buffer layer and cured at ∼ 300°C.

The specifications of the CPI-film are summarized in Table 1. Since CPI has a poor moisture and oxygen barrier property, a gas barrier layer with thickness of 125 nm was formed on the CPI substrate by plasma enhanced chemical vapor deposition (PECVD) at ∼300°C. As shown in Figure 1(b), Indium-Zinc-Oxide (IZO) with 150 nm thickness was formed by sputtering as transparent anode. All organic materials, such as tungsten oxide (WOx) as an interlayer between the anode and hole injection layer (HIL), PEDOT:PSS (poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate)) as the HIL and PDY-132 (Merck super yellow polymer, 0.5 wt% in toluene) as an emissive layer (EML) of PLED were coated by spin casting. Then, LiF as electron injection layer (EIL) and Al as cathode layer were formed by a vacuum evaporation. Finally, PET-film was used as encapsulation for flexible device.

Results and Discussion

Figure 3 shows the comparison of the current density-voltage-luminance (J-V-L) characteristics and current efficiency-luminance of the two different bottom-emission PLEDs. Device (A) is on glass substrate with a glass encapsulation and device (B) is on CPI substrate with PET-film encapsulation. The J-V-L characteristics of the two different devices are almost the same. The turn-on voltages of the two devices are 2.1 V at the luminance of

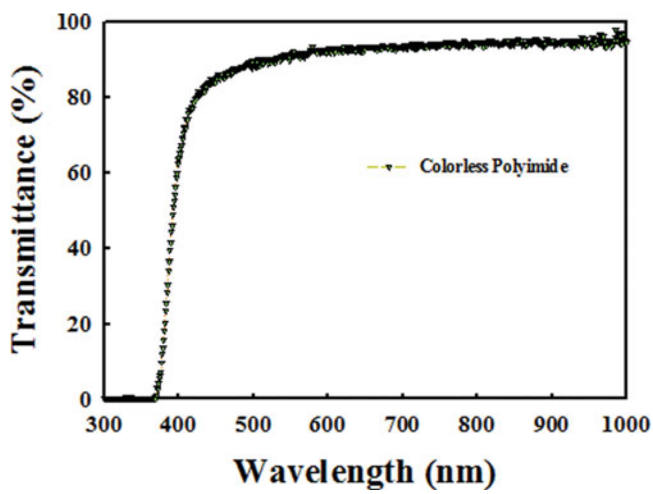

Figure 2. Transmittance of the CPI substrate.

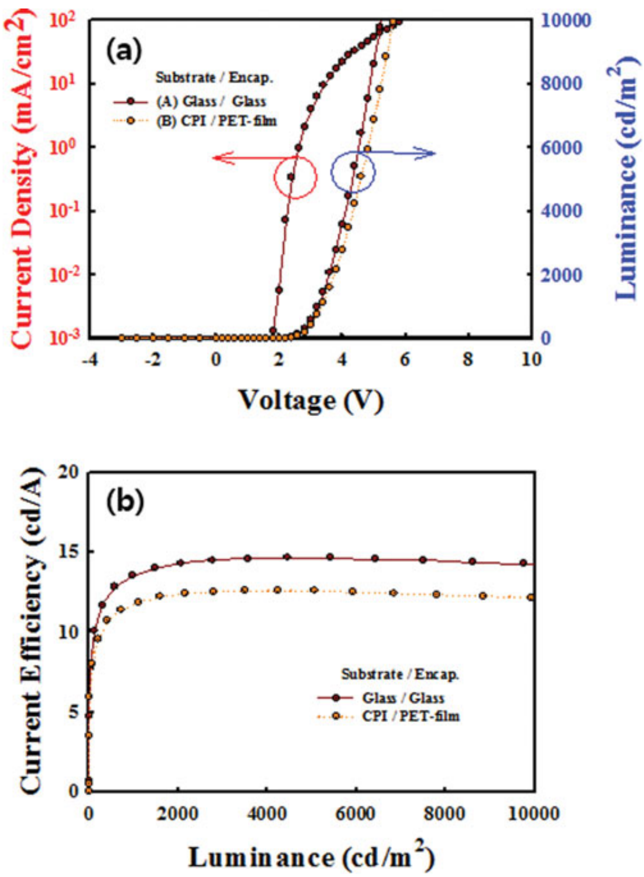

Figure 3. (a) Comparison of the current density-voltage-luminance (J-V-L) characteristics and (b) current efficiency-luminance of the two different devices on CPI substrate; (A) on glass substrate with a glass encapsulation and (B) on colorless polyimide substrate with a PET-film encapsulation.

1 cd/m^2 and the driving voltages are 3 V at 1000 cd/m^2 as shown in Figure 3(a). [11, 12] The current efficiency-luminance characteristics are somehow different because glass has higher transmittance compared with CPI substrate. The current efficiencies of devices (A) and (B) are 13.5 cd/A and 11.7 cd/A at 1000 cd/m^2, respectively, as shown in Figure 3(b). The performance of PLED is similar between devices (A) and (B), even though CPI is not fully transparent compared with glass substrate.

We measured the performance of PLED before and after detachment from a glass substrate. Figure 4 shows the J-V-L characteristics and current-luminance of the flexible PLED on CPI substrate with PET-film encapsulation before and after detachment. The current density increases slightly after detachment even though it looks similar in J-V-L plot because of log scale of current density. The decrease in current efficiency is due to the increase in current density after detachment even though the luminescence is similar. The turn-on voltage and driving voltage are 2.0 V and 3.47 V, respectively, as shown in Figure 4(a). The current efficiency-luminance characteristic changed a little from 11.1 cd/A to 10.1 cd/A, after being detached from a glass substrate. [13]

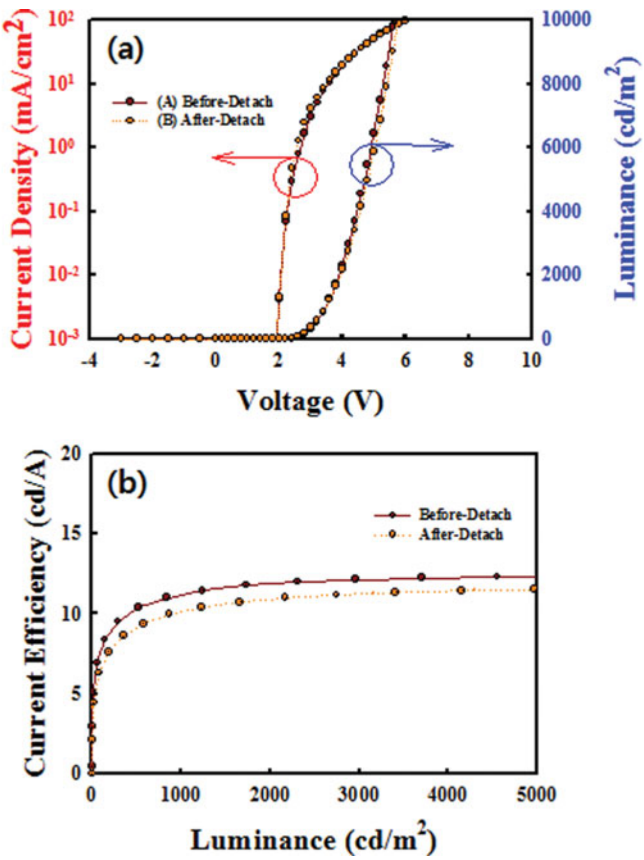

Figure 4. (a) The current density-voltage-luminance (J-V-L) characteristics and (b) current efficiency-luminance of the flexible PLED on CPI substrate with PET-film encapsulation before and after-detachment.

Figure 5 shows photographs of the flexible PLED device (a) before and (b) after detachment. The device has an active area of 1 cm^2 with PET-film encapsulation. Since the device is fabricated on ultra-thin plastic substrate of about 10 μm, this device is very thin and flexible. As shown in Figure 5(b), all devices emitted yellow light without defects even after being detached from a glass substrate. [14, 15, 16, 17]

After detachment process, we performed a bending test on the PLEDs device. In order to confirm that the PLED on the flexible CPI substrate has no significant degradation under bending test, we measured the performance of the device before and after bending test at the radius of 4 mm. As shown in Figure 6, the current efficiency under bending with curvature radius of 4 mm decreases by 3.7% compared to its initial value (flat state) of 1000 cd/m^2. The decrease in the luminance is related with cylindrical shape of OLED. Because the OLED emits the light radially, its luminescence is less that that measured from flat OLED. However, after returning to the flat state the luminescence becomes the same as the initial value. This indicates that the OLED on plastic has almost no degradation during bending.

Figure 7 shows optical images of the flexible PLED before and after turn-on during bending test with bending radius of $R = 4$ mm. We found that the device has no significant

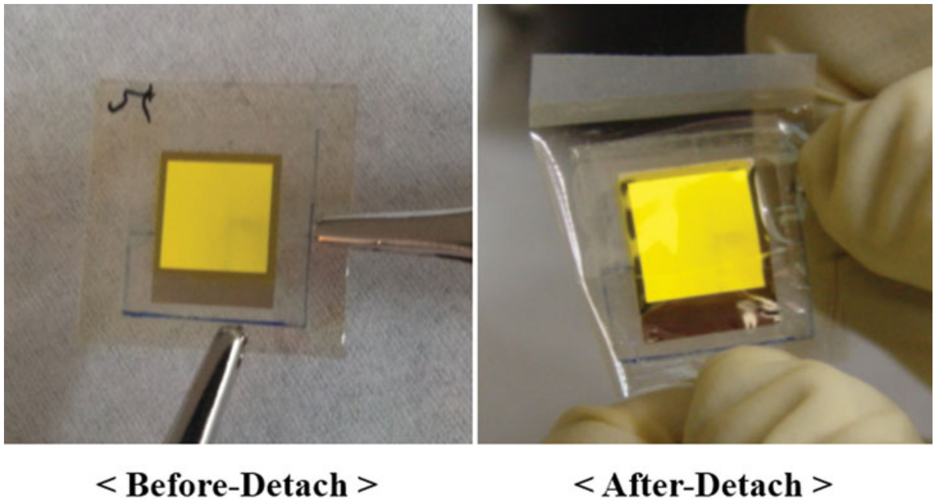

Figure 5. Optical images of a solution processed flexible PLED on CPI substrate. (a) Before and (b) after detachment (active area of $1cm^2$).

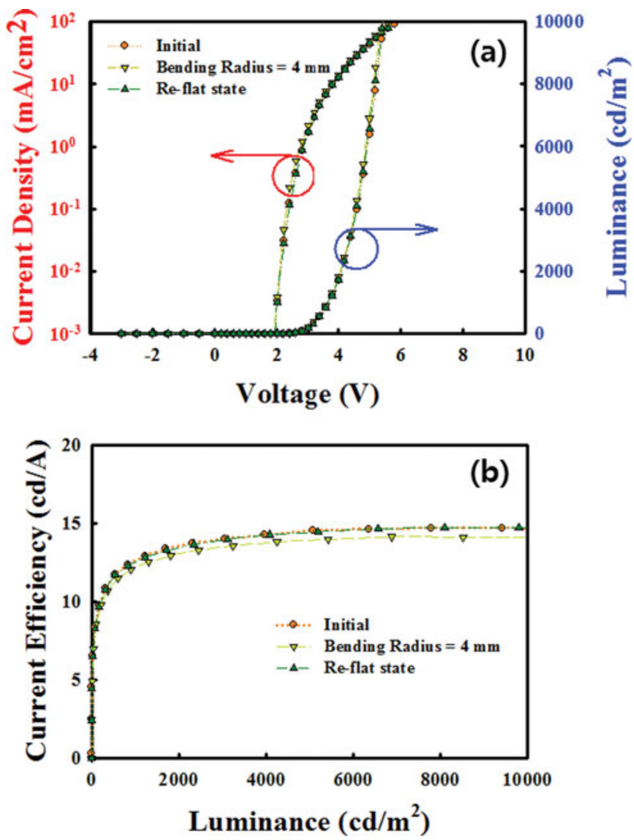

Figure 6. (a) The current density-voltage-luminance (J-V-L) characteristics and (b) current efficiency-luminance of the flexible PLED on CPI substrate with PET-film encapsulation before, during and after bending with radius of R = 4 mm.

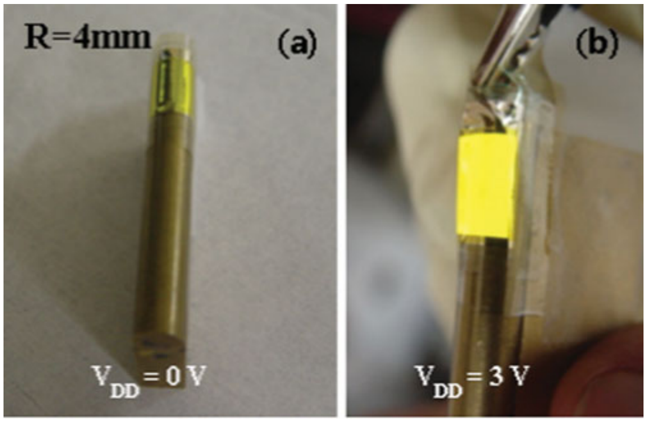

Figure 7. Images of a solution processed flexible PLED on CPI substrate, (a) before and (b) after bending test with bending radius of R = 4 mm (active area of 1 cm^2). The PLED was turn on during bending test.

degradation of the image under bending. [18, 19, 20] These results indicate that flexible PLED on CPI substrate has a high potential for its application as flexible display.

Conclusions

We have fabricated a solution processed PLED on CPI substrate. The CPI substrate has a thickness of about 10 μm and a high transparency of around 90% at 550 nm. Also, it can withstand high temperature at >300°C. The PLED have low-driving voltage of 3 V at 1000 cd/m^2, and the current efficiency of 11.7 cd/A for the device on CPI substrate at 1000 cd/m^2. From the detachment test, the PLED device can be easily detached from the glass substrate without any damage. After being detached, the flexible PLED can be bent to the bending radius of 4 mm. These results indicate that the flexible PLED was mechanically and optically stable on flexible CPI substrate.

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