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White Light-Emitting Device on Flexible Plastic Substrates

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1. Introduction

Over last several years, light-emitting devices based on organic materials have been attractive research subjects because of their potential applicability to large size flat panel displays and solid-state lighting with low fabrication costs and easy manufacturing processes. Recently, the topic of white light generation from single-layer OLEDs has also been a very active research area since this type of device can be used as a plane light source for current large size liquid-crystal display (LCD) TVs and/or flexible full color displays implemented in combination with the color filters.

Until now, all studies for generating the white light emission from either small molecules [1] or polymers [2, 3] based devices have been based on glass substrates. However, for the future flexible display or flexible solid-state lighting applications, the development of the white light on flexible plastic substrates is essential.

In this paper, we described opto-electronic properties of the single-layer polymer blend light-emitting diodes (PLEDs) fabricated on the flexible plastic substrate. We used the energy transfer concept from blue light-emitting co-polymer (donor) into red light-emitting co-polymer (acceptor) to achieve the white light emission and maximized luminance and device efficiency.

2. Device Fabrications

The fabrication process of PLED on the flexible plastic substrate has been described previously [4]. The inset in figure 1 shows the schematic of device cross-section and top-view. A Ca/Al bi-layer and ITO layer were used as cathode and anode electrode, respectively.

In our research, the high-quality ITO-coated flexible plastic substrates are used, which are based on multi-barrier-coated poly [bis(cyclopentadiene) condensate]s—"transphan" [5] with a low ITO surface roughness and a low sheet resistance, and very low water vapor and oxygen transmission rates. As a hole-injection layer (HIL), PEDOT doped with PSS was deposited on the pre-patterned ITO/plastic substrate. A polymer blend was made of polyfluorene based blue and red co-polymers, the properties of which were reported previously [6, 7]. After several experiments, blend solution of blue (donor): red (acceptor) polymer with a weight ratio of 99.4:0.6 was made to produce the pure white light emission. Polymer blend solution as light emissive layer (LEL) was then deposited by the spin coating. Finally, the Ca/Al cathode was thermally evaporated through a shadow mask at ~ 10^{-6} torr in a system directly connected to the nitrogen glove box. The dimension of complete PLED was 1.1 × 1.1 mm^2, and all optical and electrical measurements were performed in an integrating sphere system [8] in the nitrogen glovebox.

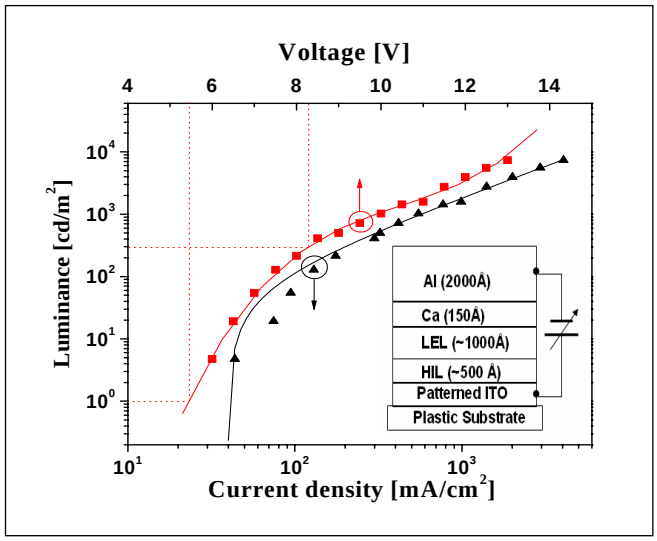

Fig 1. Luminance-current-voltage characteristics of blend PLED.

3. Opto-electronic Properties

The luminance (L) versus voltage characteristics of our polymer blend PLED are shown in Figure 1. As shown in Table 1, the white light-emitting device showed a turn-on voltage of 5.6±0.3 V, closely matching the turn-on voltage of the blue polymer (donor). The polymer blend PLED shows a very high maximum luminance of ~ 7400 cd/m^2 at 13 V, compared to 1410 and 2650 cd/m^2 produced by red and blue PLED, respectively.

Figure 1 also shows the luminance versus current

Table I. Comparison of device performances

Properties	White	Red	Blue
Voltage (V @ 1 cd/m^2)	~ 5.6	~ 2.8	~ 4.8
EEmax (cd/A)	~ 1.96	~ 0.27	~ 0.69
PEmax (lm/W)	~ 1.09	~ 0.23	~ 0.33
Lmax (cd/m^2)	~ 7366	~ 1410	~ 2652
CIE coordinate	(0.33, 0.33)	(0.59, 0.29)	(0.16, 0.23)

density (L-J) characteristics. As in the well-known diode equation, current increases exponentially with the applied bias. Since the rate of radiative recombination is proportional to the density of injected electrons and holes, the luminance is expected to increase linearly with current density. We observed this linear relationship up to 10^3 cd/m^2 as shown in figure 1, and no saturation of L-J characteristics was observed over the measured J range.

Knowing L and J, the emission efficiency (EE) and power efficiency (PE) can be calculated for our polymer blend PLED from following equations:

$$EE = \frac{L}{J}, \text{ and } PE = \frac{\Phi}{IV} = \frac{\pi L}{JAV} = \frac{\pi EE}{AV} \qquad (1)$$

where Φ is the total luminous flux, L is luminance, and A is the area of PLED. Enhanced EE and PE were obtained for our polymer blend PLED in comparison with both single blue and red polymer PLEDs as shown in Table 1. For the polymer blend device, EE larger than ~1.8 cd/A was obtained over the luminance ranging from 1000 to 7400 cd/m^2. Higher PE value was also observed for the polymer blend PLED. The maximum PE of 1.1 lm/W was obtained at ~ 1023 cd/m^2 for our polymer blend PLED with the white light emission. Enhancements of both PE and EE value for our blend PLED are due to the energy transfer from the donor to acceptor polymer [9].

4. CIE Color Coordinates

From EL spectra shown in figure 2, we can calculate the CIE color coordinates [10]. It should be noticed that these CIE coordinates are very sensitive to polymer blend composition [9]. It showed that in our experiment the optimal polymer blend ratio for the pure white light was 99.4:0.6. The resulting CIE coordinates was (0.33, 0.33) and the EL spectrum shows the balanced red and blue light emission. The white light emission from PLED is also shown in inset of figure 2.

5. Conclusions

In this paper, we demonstrated that by blending red polymer as acceptor in donor blue polymer matrix, we could successfully produce the pure white light-emission

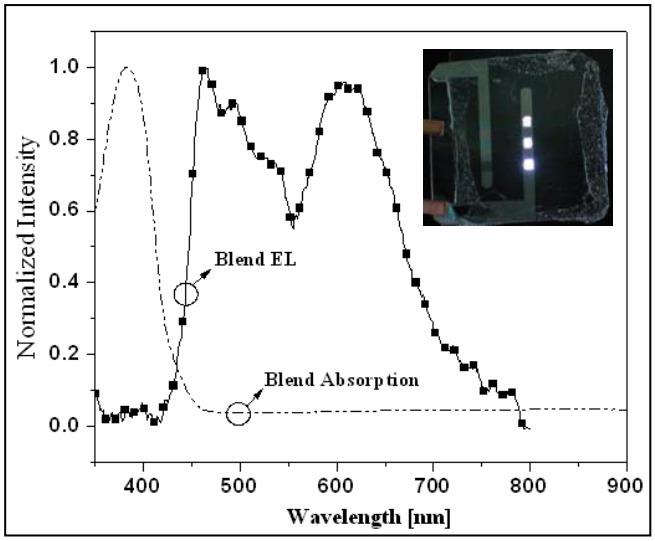

Fig 2. EL spectra and white emission from blend PLED.

from our device of which CIE coordinate is (0.33, 0.33). In comparison with the single red or blue polymer device on plastic substrate, increased luminance and improved device efficiency from our single-layer white light-emitting device have been obtained due to the energy transfer from donor to acceptor polymer: EE ~ 2.0 cd/A, PE ~ 1.1 lm/W, and Lmax ~ 7400 cd/m^2.

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