# Microscopic EL spectral imaging in polymer-blend light emitting diodes

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### 1. Introduction

Recently, light-emitting diodes (LEDs) based on conjugated polymers have attracted much attention for the application of flexible display etc. They now have sufficient brightness and range of colors. However, the emission efficiency and lifetime are still not high and long in comparison with the low molecular based-organic electroluminescent devices, respectively. To improve electroluminescence (EL) performance, the fabrication of LEDs based on blends of polymers has been commonly tried [1]. The combination of blend components can allow for efficient bipolar charge transport and luminescence in solution-processed films. On the other hand, the phase separation between the blend polymers and the variation of morphology largely influence EL performance. Therefore, it is important to elucidate morphologies of blend polymers on microscopic scale for achieving high EL performance. Traditionally, atomic force microscopy (AFM) and transmission electron microscopy (TEM) have been utilized to characterize the morphology [2]. Several techniques, such as optical microscopy [3], scanning near-field optical microscopy (SNOM) [4], Raman microscopy [5] and fluorescence lifetime imaging (FLIM) [6], have been also employed to study degradation or morphology of the luminescent materials in organic LEDs.

We here demonstrate the spectral imaging for EL characterization (EL spectral imaging) in polymer-blend LEDs using the imaging micro-spectroscopy system, which has functions both micro-spectroscopy measurement and imaging analysis. This imaging technique is used to elucidate *what* and *where* emission species are located within an emission surface.

### 2. Experimental Details and EL Spectral Imaging

The two polymer-blend LEDs were fabricated by the following procedure. The poly(3,4-ethylenedioxy thiophene) : poly(styrene- esulphonic acid) (PEDOT:PSS) layer and poly(9,9-dioctyl-fluorene-*co*-benzothiadiazole) (F8BT) blended with poly(9,9-dioctylfluorene-*co*-bis-N,N' -(4-butylphenyl)-bis-N,N'-phenyl-1,4-phenylenediamine) (PFB) (weight ratio F8BT:PFB = 1:1) as the emission layer were put down onto the ITO coated glass substrates by conventional spin coating procedures. Then, one of them was annealed for 2 hours at 200°C. Furthermore, calsium and aluminium were progressively evaporated under vacuum (~10<sup>-6</sup> Torr). Finally, the device was encapsulated using an epoxy resin.

Figure 1a shows the imaging micro-spectroscopy system (LightForm Inc.) for EL spectral measurement. The

emission from a polymer blend LED surface was focused onto an entrance slit (25µm×5mm) of polychrometer through  $\times 20$  objective lens. A slice  $(1.25 \times 250 \mu m^2)$  of the emission surface through the slit was passed the prism for the spectral dispersion and detected by the charge coupled device detector (CCD 1), where the information concerning its location of long axis (250µm) were maintained. We simultaneously acquired 240 spectra (wavelengths between 420 and 540nm) equally distributed over the long axis. Therefore, the spatial resolution (the minimum unit) is  $1.25 \times 1.04 \mu m^2$ . Next, the polymer blend LED was slid in 1.25µm step using the computer-controlled microscope stage and the spectra of whole units within the observed area were captured. In addition, the microscopic EL intensity image was also observed using another CCD camera (CCD 2).

The EL spectral imaging was performed by the following procedure. EL spectra of whole units were classified into several spectra according to the difference of spectral



Fig.1. (a) The imaging micro-spectroscopy system used for EL spectral measurement, (b) Schematic explanation for EL spectral imaging.

properties, such as the emission peak wavelength, the spectral linewidth, the ratio between intensities of emission peaks (in case that an EL spectrum has two or more emission peaks). These classified spectra were stored in a spectral library and arbitrary colors were assigned to them. After this, we will call each of them "a library spectrum". Then, the spectral identification between the library spectra *and* spectrum of each unit and color-mapping were performed. For example, if the spectrum of a certain unit correlates with the library spectrum assigned color-A, its location is mapped to color-A, as shown in figure 1b. In short, one can acquire the spectral topography of emission surface in polymer blend LEDs.

## 3. Results and Discussion

Figure 2 shows AFM image (a), EL intensity image (b) and EL spectral image (c) in a F8BT:PFB blend LED with annealing, which was driven at 6V. Here, library spectra for fig.2c are not provided in this paper, but each color (black, gray and white) means different library spectrum.

Unfortunately, we couldn't find out the correlation between AFM image (fig.2a) and EL intensity image (fig.2b). This may have been attributed by low spatial resolution of EL intensity image  $(1.25 \times 1.04 \mu m^2)$ . On the other hand, the similarity between EL intensity image and EL spectral image (fig.2c) is comparatively good. The strongest and weakest EL intensity areas in fig.2b roughly correspond with white and black in fig.2c, respectively.

It is important to elucidate the origin of similarity between EL intensity and EL spectra. We should consider the following three possibilities, 1) the change of emission quantum efficiency caused by redistribution of electron states in blend-polymer, 2) light-interference phenomenon caused by the transfer of emission center (emission site) [7] and 3) light-scattering caused by film surface structure. The examination for these possibilities is currently under way.

### 4. Conclusions

EL spectral imaging in F8BT:PFB blend polymer LEDs, with and without annealing, were performed using the two dimensional imaging micro-spectroscopy system. We found that EL intensity image intimately relates to EL spectral image. On the other hand, we couldn't elucidate the correlation between AFM image and EL intensity image.

#### References

[1] A.C.Morteani, A.S.Dhoot, J-S.Kim, C.Silva, N.C.Greenham,

C.Murphy, E.Moons, S.Cina, J.H.Burroughes and R.H.Friend, Adv.Mater. 15 (2003) 1708.

[2] U.Scherf and E.J.W.List, Adv.Mater. 14 (2002) 477.

[3] J.Chappell, D.G.Lidzey, P.C.Jukes, A.M.Higgins, R.L.Thompson, S.O'Connor, I.Grizzi, R.Fletcher, J.O'Brien,

M.Geoghegan and R.A.L.Jones, Nature Materials 2 (2003) 616.

[4] R.Stevenson, R.Riehn, R.G.Milner, D.Richards, E.Moons, D-J.Kang, M.Blamire, J.Morgado and F.Cacialli, Appl.Phys.Lett. **79** (2001) 833.

[5] J-S.Kim, P.K.H.Ho, C.E.Murphy, N.Baynes and R.H.Friend, Adv.Mater. 14 (2002) 206.

[6] M.Koeberg, D.S.Elson, P.M.W.French and D.D.C.Bradley, Synth.Met. **139** (2003) 925.

[7] N.Takada, K.Tsutsumi and T.Kamata, MRS proceeding (2005, spring).



Fig.2. (a) AFM image  $(20 \times 20 \mu m^2)$ , (b) EL intensity image and (c) EL spectral image  $(23.75 \times 21.25 \mu m^2)$  in a F8BT:PFB blend PLED with annealing.