

Improvement of electroluminescence performance of organic light emitting diodes with a liquid emitting layer

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1. Introduction

Organic light emitting diodes (OLEDs) exhibit not only high performance light emitting characteristics [1] but also unique benefits such as light weight and flexibility [2], which are difficult to realize using inorganic LEDs. Taking into account the advantages of organic materials, we developed a unique OLED containing a neat liquid semiconductor, i.e., a liquid OLED that can be used for lighting and display applications [3]. It is expected that liquid OLEDs will allow the realization of truly flexible displays because detachment between the liquid emitting layer and electrodes does not occur even when the devices are bent significantly. Furthermore, liquid emitters degraded by long-term use in an OLED can be replaced by a flow of fresh organic liquid emitters, removing the problem of OLED degradation resulting from the decomposition of organic materials.

Here, we report OLEDs with a liquid emitting layer that exhibit a significantly improved EL efficiency, maximum luminance and driving voltage compared with previous efforts. The device architecture of liquid OLEDs was improved by incorporating an electrolyte into the liquid emitting layer and a titanium dioxide (TiO₂) layer as a hole blocking layer. The driving voltage was dramatically decreased by doping a small amount of electrolyte into a liquid emitting layer. Insertion of a TiO₂ hole-blocking layer improved the carrier balance. This architecture resulted in a maximum external EL quantum efficiency (Φ_{EL}) of 0.31 \pm 0.07% and a maximum luminance of nearly 100 cd/m², which are 10 and 100 times higher, respectively, than those reported previously [3].

2. Result and Discussion

The chemical structures of the compounds used in the liquid emitting layer and the structure of liquid OLED are shown in Fig. 1. EHCz was used as the liquid host, while BAPTNCe and TBAHFP were used as the guest emitter and electrolyte, respectively, and were doped into the EHCz layer. Liquid OLEDs composed of ITO/Poly(3,4-ethylenedioxythiophene)poly(styrene-sulfonate) (PEDOT:PSS) (40 nm)/0.1wt%-TBAHFP, 16.7wt%-BAPTNCe, EHCz (1100 \pm 100 nm)/TiO₂ (10 nm)/ITO.

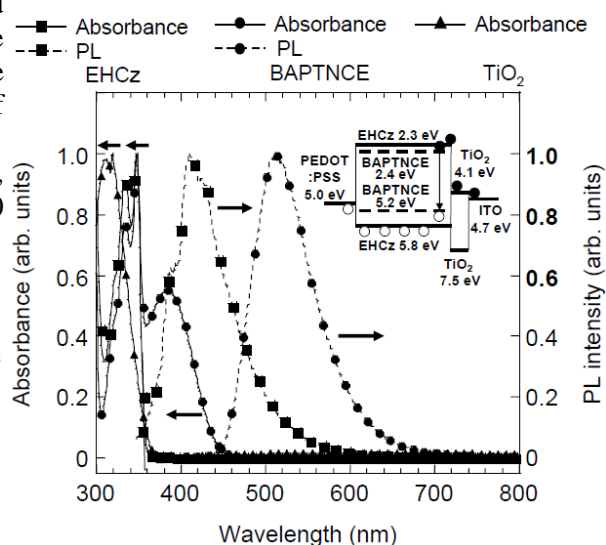
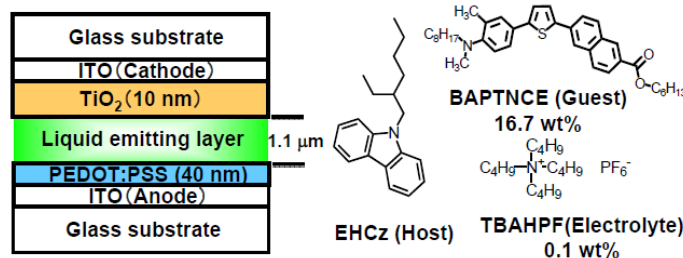


Figure 1 OLED structure and chemical structures of compounds in liquid emitting layer used in this research.

Figure 2 Spectral characteristics of compounds used in liquid OLEDs

Spectral characteristics of the host and guest compounds are shown in Fig. 2. The liquid emitting layer composed of 0.1wt%-TBAHFP, 16.7wt%-BAPTNC, and 83.2wt%-EHCz exhibited green photoluminescence (PL) with a maximum (PL_{\max}) at 511 nm and a PL quantum efficiency (Φ_F) of 55%. The energy level diagram of the ITO/PEDOT:PSS/0.1wt%-TBAHFP, 16.7wt%-BAPTNC, EHCz/TiO₂/ITO device is shown in the inset of Fig. 2.

Figure 3a shows the difference of the current density-luminance-voltage (J - L - V) characteristics by doping TBAHFP in OLED. The undoped device showed J - V characteristics with ohmic behavior ($J \propto V^1$) at lower voltage (<20 V). J increased with a steep gradient of $n=2$ in the J versus V^n plot at higher voltage (>30 V). This indicates that carrier injection occurs above 30 V and carrier transport can be ascribed to space-charge limited current (SCLC). However, appreciable EL was not observed even at high voltage. Thus, this SCLC behavior is based on single hole carrier transport due to the presence of a large energy barrier for electron injection, as shown in the inset of Fig. 2. Doping TBAHFP into the liquid emitting layer reduced the driving voltage and yellow-green EL ($EL_{\max} = 531$ nm) was clearly observed with an onset voltage of 17 V, which is coincident with the emergence of SCLC behavior (J is proportional to V^2). These J - L - V characteristics indicate that doping an electrolyte into the liquid emitting layer provides bipolar carrier injection and transport. Electrolyte anions and cations can move to the anode and cathode side, respectively, immediately after the application of voltage, probably forming electric dipole layers at the interface of each electrode. This electric dipole layer can decrease the injection barrier, facilitating carrier injection and reducing the turn-on voltage [4].

Figure 3b shows that the insertion of a TiO₂ layer between the liquid emitting layer and the ITO cathode increases luminance and Φ_{EL} up to nearly 100 cd/m² and 0.31 \pm 0.07 %, respectively, in a device as shown in Fig. 1. This indicates that balance of holes and electrons for carrier recombination is improved by the insertion of a TiO₂ layer. The leakage of holes into the ITO cathode can be suppressed by the high energy barrier between the HOMO level of the EHCz layer (5.8 eV) and the valence band of a TiO₂ layer (7.5 eV).

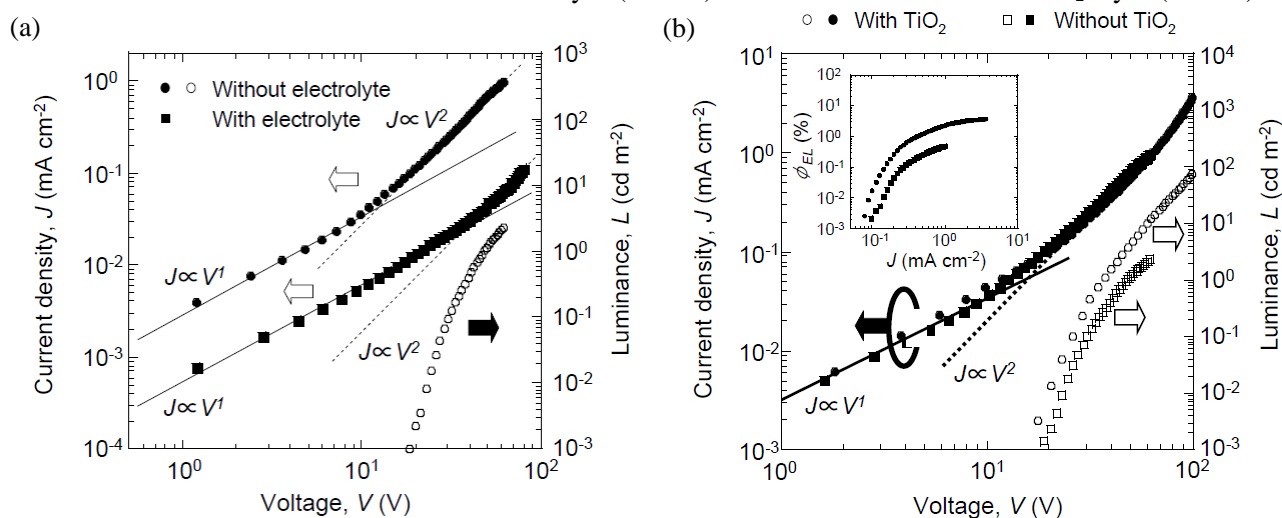


Figure 3 J - V - L characteristics of liquid OLEDs. (a) Effect of introducing electrolyte into a liquid OLED. Device structure is ITO/PEDOT:PSS (40 nm)/0.1wt%-TBAHFP, 16.7wt%-BAPTNC, EHCz(1100 \pm 100 nm)/ITO. (b) Effect of introducing a TiO₂ hole-blocking layer. Device structure is ITO/PEDOT:PSS (40 nm)/0.1wt%-TBAHFP, 16.7wt%-BAPTNC, EHCz(1100 \pm 100 nm)/TiO₂(10 nm)/ITO.

3. References

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