유기반도체에서의 전하수송 및 유기발광다이오드의 효율

Carrier Transport in Organic Semiconductors and the Efficiency of Organic Light-Emitting Diodes

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Organic light-emitting diodes (OLEDs) emerge as a new flat-panel display technology with superior display qualities since the first demonstration of efficient light emission by C. W. Tang.[1] In order to enhance the luminous efficiency of the OLEDs, it is necessary to optimize the device structure so that efficient injection and recombination of electrons and holes are possible.[2] Charge carrier transport is one of crucial parameters that affect the injection and balance of electrons and holes. Therefore, it is important to understand the charge transport mechanism in organic semiconductors and elucidate the correlation between the carrier mobility and the electroluminescence (EL) efficiency of OLEDs.

In this work, we studied the carrier mobility of a hole transport layer (HTL) of 4,4'-bis[N-(1-napthyl)-N-phenyl-amino]-biphenyl (α-NPD), and α-NPD doped with 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) by employing the time-of-flight photoconductivity (TOF-PC) technique. Since the hole mobility of α-NPD can be controlled by doping BCP, we can study the effect of the hole mobility on the EL efficiency of OLEDs by comparing two devices with α-NPD and BCP-doped α-NPD. We found that the BCP-doped α-NPD showed lower hole mobility and the EL efficiency is higher for the device with BCP-doped α-NPD as the HTL.

The TOF-PC measurements were performed on a 2-μm-thick α-NPD film and a 1-μm-thick BCP-doped α-NPD film. The transit time τ of the thin sheet of holes, photoexcited through a transparent ITO electrode by the N_2 pulse laser (pulse width of 0.6 ns and wavelength of 337 nm), was measured as a function of the electric field and temperature. The drift hole mobility was calculated using the relation $\mu = d^2/V\tau$. Fig. 1 shows the photocurrent waveforms of α-NPD and BCP-doped α-NPD. The electron photocurrent decreases continuously, indicating that electrons undergo severe trapping. However, the hole photocurrent waveform in both films show a characteristic plateau of the non-dispersive TOF-PC signal. The transit time is defined at the edge of the plateau where the photocurrent starts to decrease steeply as holes discharge at the opposite Al electrode. The hole mobility of pristine α-NPD is calculated about 10^{-3} cm^2/Vs at room temperature. However, the hole mobility decreases by an order of magnitude with the BCP doping: 9×10^{-5} cm^2/Vs for 10 % BCP-doped α-NPD. The field dependence is much stronger in BCP-doped α-NPD. These results indicate that BCP molecules act as hole traps.
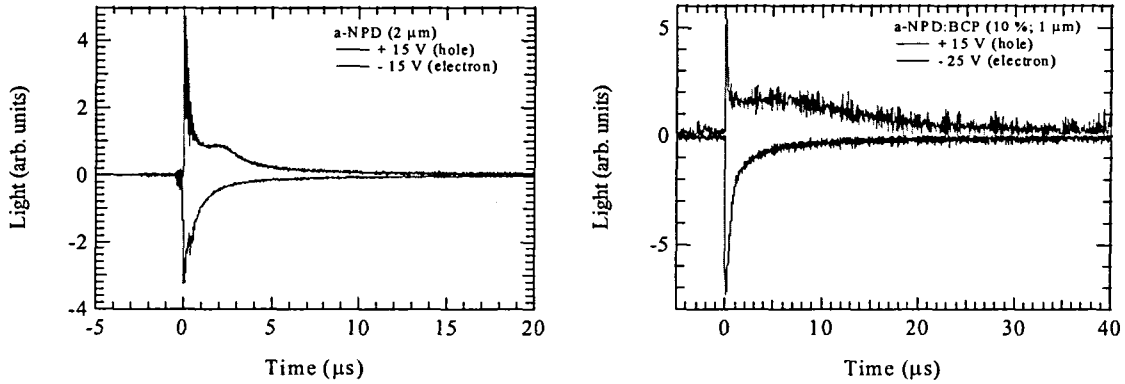
Fig. 1. The photocurrent waveforms of α-NPD and BCP-doped α-NPD.

We characterized the current-voltage-luminance dependence and the luminous efficiency for the devices with different BCP doping concentration (0, 10, 25, and 50 %) in α-NPD. The current decreases significantly at low bias voltages, consistent with the TOF-PC result that BCP acts as traps for the hole transport in α-NPD. However, the current and luminance at high bias voltage are higher for the BCP doped α-NPD compared with α-NPD alone. Therefore, the devices with the BCP-doped α-NPD show higher EL efficiency, compared with the device with undoped α-NPD. The enhanced EL efficiency is attributed to the combined effect of the enhanced electron injection at high field and the improved electron-hole balance.
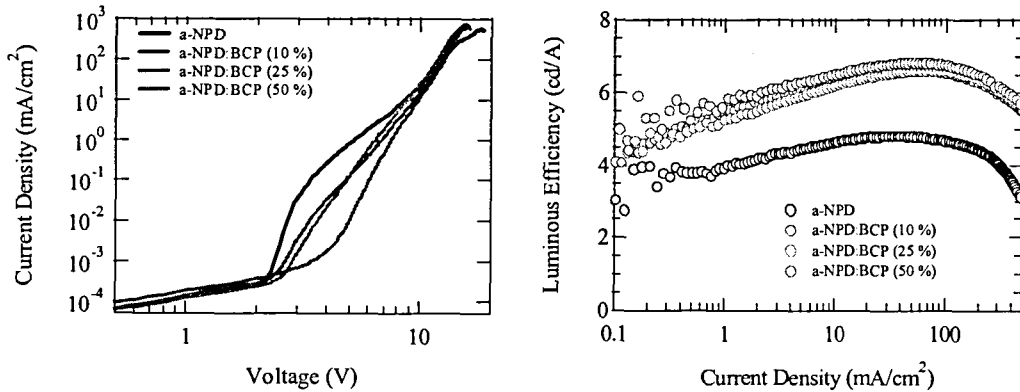

Fig. 2. The current-voltage dependence and the luminous efficiency for the devices of ITO/BCP-doped α-NPD/Alq3/LiF/Al.

In conclusion, we demonstrated that the electron-hole balance can be improved and thereby the EL efficiency can be enhanced by reducing the hole mobility of α-NPD with doping BCP.

References
[1] C. W. Tang and S. A. VanSlyke. Appl. Phys. Lett. 51, 913 (1987).
[2] E. W. Forsythe, M. A. Abkowitz, and Yongli Gao, J. Phys. Chem. B, 104, 3948 (2002).