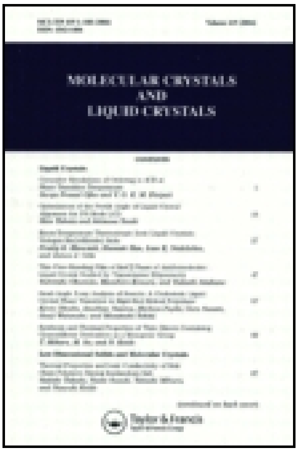

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Performance of Organic Light-Emitting Diodes Using an Emissive Material with High Hole Drift Mobility

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This study focuses on the performance of organic light-emitting diodes (OLEDs) using an emissive material with high hole drift mobility, tris[4-(5-phenylthiophen-2-yl)]amine (TPTPA), which exhibits the highest level of hole drift mobility ($1.0 \times 10^{-2}\,cm^2\,V^{-1}\,s^{-1}$) *among those reported for organic disordered systems. Clear blue emission was observed from TPTPA which was used as the hole transporting and emissive layer in the OLEDs. The maximum luminance of* $1.2 \times 10^4\,cd/m^2$, *and the maximum current efficiency of 3.9 cd/A were achieved. The short response times of electroluminescence (ca. 10 ns) were achieved under the application of rectangular-shaped voltages.*

Keywords High hole drift mobility; organic light-emitting diode; transient characteristic; tris[4-(5-phenylthiophen-2-yl)]amine

1. Introduction

Recently, there is an increased demand for the organic light-emitting diodes (OLEDs) with high-speed response in the field of optical link and optical sensor devices. For OLEDs with high-speed response, it is thought that high hole and electron mobilities are required for hole- and electron-transporting (ET) materials. In addition, high luminescence quantum efficiency and short fluorescence lifetime are also required for emitting materials.

In this study, we focused on the performance of OLEDs utilizing tris[4-(5-phenylthiophen-2-yl)]amine (TPTPA) as the hole-transporting and emissive material, which exhibits the highest level of hole drift mobility ($1.0 \times 10^{-2}\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$) [1] among

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those reported for organic disordered systems and emits blue fluorescence with a relatively high fluorescence quantum yield (0.58 in tetrahydrofuran) and a short fluorescence lifetime (1.3 ns). Three OLEDs using different electron transporting materials with different electron mobility were fabricated, and the influences of the electron mobility on the current density-voltage-luminance (J-V-L) characteristics and the transient characteristics under the application of rectangular-shaped voltages were investigated.

2. Experimental

OLEDs were fabricated by using organic molecular beam deposition system at a background pressure of 10^{-5} Pa. The device structure was indium-tin-oxide (ITO)/TPTPA(70 nm)/ETL(30 nm)/LiF(0.5 nm)/Al/Ag. Bis(2-methyl-8-quinolinato)- 4-(phenylphenolato)aluminum (BAlq), 4,7-diphenyl-1,10-phenanthroline (Bphen), tris(8-hydroxyquinoline)aluminum (Alq_3) (Luminescence Technology Corp.) and KLET-03 (Chemipro Kasei Kaisha, Ltd.) were used as ETLs. The fabricated devices were sealed using glass plates with epoxy resin in an argon-filled glove box.

The electroluminescence (EL) spectra were measured using a photonic multichannel spectral analyzer (Hamamatsu Photonics, PMA-11). The J-V-L characteristics were recorded using a 2000 multimeter (Keithley), a regulated DC power supply (Kenwood PW36-1.5AD) and a luminance meter (Minolta LS-100). Transient EL was measured by applying square-wave voltage pulses generated by an HP8114A source (Agilent). The optical pulse was observed using a photomultiplier tube detector (Hamamatsu Photonics). The EL and voltage waves were monitored by a Lecroy 104Xi oscilloscope. All of the measurements were carried out at room temperature.

3. Results and Discussion

Three OLEDs utilizing TPTPA as a hole-transporting and emissive layer, ITO/TPTPA (70 nm)/BAlq (30 nm)/LiF (0.5 nm)/Al/Ag, ITO/TPTPA(70 nm)/Bphen(20 nm)/Alq_3(10 nm)/LiF/Al/Ag and ITO/TPTPA(70 nm)/KLET-03(30 nm)/LiF Al/Ag were fabricated and their performance was examined. The electron mobilities of BAlq, Bphen and Alq_3 have been reported to be the order of 10^{-5}, 10^{-4} and 10^{-3} $cm^2 V^{-1} s^{-1}$ respectively [2,3]. In addition to these three devices, a single layer device, ITO/TPTPA(100 nm)/LiF/Al/Ag was also fabricated for comparison. The devices of TPTPA/BAlq, TPTPA/Bphen/Alq_3 and TPTPA/KLET-03 exhibited clear blue emission which originates from TPTPA. Figure 1 shows the typical EL spectra of the TPTPA/BAlq device and the single layer device. It was found that EL spectrum of TPTPA/BAlq device was almost the same as that of a single layer device. This result shows that the recombination zone could be located at the interface between TPTPA and BAlq. That is, ETLs act as the hole blocking layer.

Figure 2 shows the J-V-L characteristics and the current efficiencies of the three devices. It was found that the driving voltage of the OLEDs is lower as the electron drift mobility of the ETLs is higher. Devices of TPTPA/BAlq, TPTPA/Bphen/Alq_3 and TPTPA/KLET-03 exhibited the maximum luminance of 6.0×10^3, 2.3×10^3 and 1.2×10^4 cd/m^2 respectively, and the maximum current efficiencies were 1.5, 1.3 and 3.9 cd/A, respectively. The TPTPA/KLET-03 device showed the higher luminance and current efficiency than TPTPA/BAlq and TPTPA/Bphen/Alq_3 devices, which

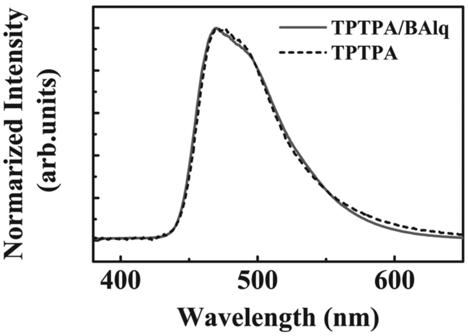
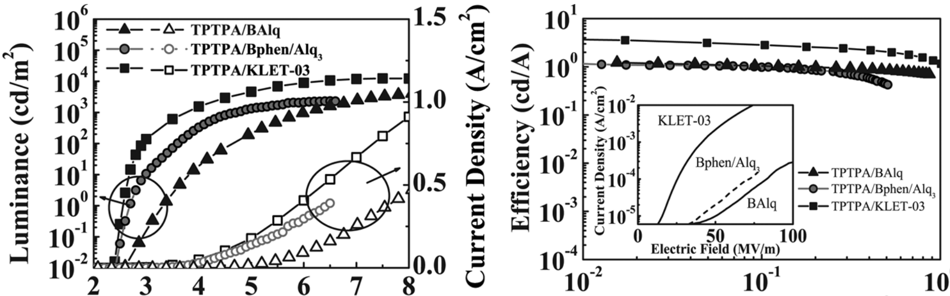


Figure 1. EL spectra of the OLEDs of ITO/TPTPA(100 nm)/LiF/Al/Ag and ITO/TPTPA(70 nm)/BAlq(30 nm)/LiF/Al/Ag.

might be attributable to the improved hole-electron balance due to the higher electron mobility of KLET-03 than BAlq and Bphen. The improved carrier balance was evidenced by the J-electric field(E) characteristics of the electron-only devices of Al/ETL/LiF/Al/Ag using these ET materials. Inset of Figure 2(b) clearly shows that the electron current density was increased in the order of KLET-03, Bphen/Alq_3 and BAlq. Since the LUMO energy levels of BAlq, Bphen and KLET-03 are almost the same (−2.9, −3.2, and −3.0 eV, respectively), the difference in the electron current density for the present electron only devices is thought to be responsible mainly for the difference in the electron mobilities of the ETL materials.

Next, we investigated the transient characteristics of TPTPA/BAlq and TPTPA/KLET-03 devices under the application of rectangular-shaped voltages (Duty cycle: 10%, Frequency: 1 kHz, Pulse width: 10 μs). Figure 3 shows the applied pulse voltage dependence of the rise and decay times. The decay (rise) time is defined as the time required to change the optical response from 90 (10) to 10% (90%) of its total intensity change. At low applied voltage, both devices showed rise times of $\sim 10^3$ ns and decay times of ~10 ns, respectively. While the decay times for these devices were almost independent of the voltage, the rise times was improved with



(a) (b)

Figure 2. (a) J-V-L characteristics and (b) current efficiencies of the TPTPA/BAlq, TPTPA/Bphen/Alq_3 and TPTPA/KLET-03 devices. Inset of Figure 2(b): J-E characteristics for the electron-only devices of three ETLs, BAlq, Bphen and KLET-03.

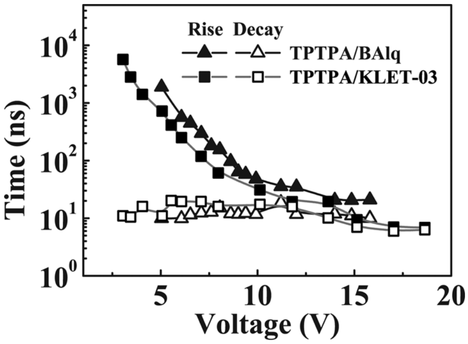


Figure 3. The applied pulse voltage dependence of the rise and decay times for the TPTPA/BAlq and TPTPA/KLET-03 devices.

the increased voltage. It was found that the minimum rise and decay times for TPTPA/KLET-03 device (7 ns and 6 ns) were shorter than those for TPTPA/BAlq device (37 ns and 12 ns). Under the application of voltage on the OLEDs, the accumulation of charges takes place, and hence, the resistance (R) – capacitance (C) time constant should be reduced as possible for improving the response time. Since the R is defined as $(ne\mu)^{-1}$, where n is the density of charge carriers, e is the elementary electronic charge, and μ is the mobility, it is expected that R should be reduced by the use of ET materials having high electron mobilities. On the other hand, the decay time was limited by the diffusion speed of residual charge carriers at the TPTPA/ETL interface, which is related with the mobilities of ETLs.

4. Conclusion

In this research, the OLEDs utilizing TPTPA as the hole-transporting and emissive material and three ET materials with different electron mobilities were fabricated. The influence of the electron mobility on the performance of OLEDs was investigated. These devices emitted blue light, and the maximum luminance of $1.2 \times 10^4\,\mathrm{cd/m^2}$ and the maximum current efficiency of 3.9 cd/A were achieved for TPTPA/KLET-03 device. It was found that the driving voltage of the OLEDs becomes lower as the electron drift mobility of the ETLs is higher. In addition, the response times of the EL under the application of rectangular-shaped voltage become shorter as the electron mobility of the ETLs is higher. The extreme short response times of ca 10 ns was achieved for the TPTPA/KLET-03 device. This study shows that the OLEDs using TPTPA as the hole-transporting and emissive material and ET material with the high electron mobility are expected to be applied to the electro-optical conversion devices for high-speed switching applications in the field of optical link and optical sensor devices.

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