High Efficiency and Long Lifetime for Organic Light-Emitting Diode Using New Electron Transport Materials

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Abstract

We demonstrated high power efficiency and long lifetime in organic light-emitting diode (OLED) using new electron transport materials (ETMs). Electroluminescent device with these ETMs showed lower driving voltage than that with Alq_3. The device lifetime with a new ETM was 2 times longer than that with Alq_3.

1. Introduction

OLED technology has been rapidly developed and being put into several practical uses (1). However, it dose not satisfy completely an industrial demand for the efficiency and working stability, which are to be improved toward the commercialization. We chose ETM as the key substrate to achieve the high performance of OLED, because little attention has been paid on ETM less than HTM (2) (3). In this presentation, we would show the relative contributions of newly synthesized ETMs to both power efficiency and lifetime on green OLED devices.

2. Experimental

New ETM-1 and ETM-2 were synthesized by conventional process, and highly purified by train-sublimation.

The 25 × 25 mm glass substrates coated with indium tin oxide (ITO) with a sheet resistance of 20 $\Omega\cdot sq^{-1}$ as the anode, were sequentially ultrasonicated in a commercial detergent and rinsed in ultrapure water. The substrates were exposed to an UV/ozone for 30 min before the vacuum deposition of organic materials. We fabricated several devices to evaluate the ETM properties. The devices were hermetically packaged in a dry nitrogen glove box with < 1 ppm oxygen and moisture concentration.

The current-voltage properties and the EL luminance were measured using a KEITHLEY Inc. source meter 4ZA4 and a Topcon Inc. luminance meter BM-9. The operational lifetime characteristics were determined at 20 mA/cm^2 DC driving condition. The electron mobility of the ETMs were measured by time-of-flight technique.

3. Results and Discussion

Table 1 shows various properties of the ETMs.

Table 1. P roperties of electron transport materials

		Alq_3	ETM-1	ETM-2
T_g	(°C)	175	141	177
mp	(°C)	413	279	340
LUMO	(eV)	-2.8	-3.0	-3.1
HOMO	(eV)	-5.8	-6.2	-6.2
PL film	(nm)	515	429	439

T_gs, determined by DSC (differential scanning calorimetry), of the new ETMs are high enough to use practically. The highest occupied molecular orbital (HOMO) levels of each material were measured with the photoelectron emission spectrometer (AC-3, Riken Keiki). The lowest unoccupied molecular orbital (LUMO) levels were estimated with the optical bandgaps obtained from the onset of the absorption spectra.

We evaluated the electron injection properties of the ETMs. Figure 1 shows the *J-V* characteristics of single layer devices whose structures were [ITO/ETM(60 nm)/LiF(1 nm)/Al(100 nm)].

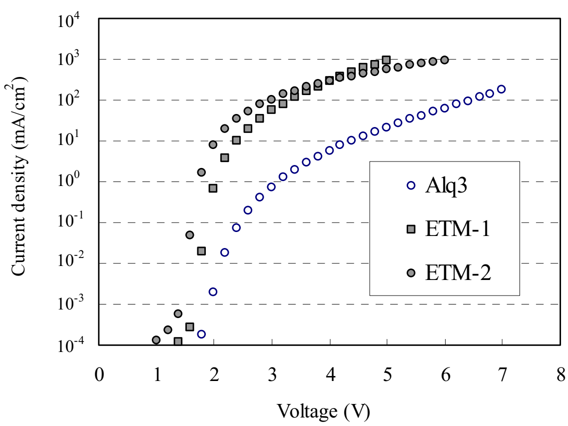

Fig. 1. *J-V* characteristics of single layer device of ITO/ETM/LiF/Al

The electron injection voltages of the devices with new ETMs were lower than that of Alq_3 by 2 V. Compared with Alq_3, we gave lower LUMOs to ETM-1 (-3.0 eV) and ETM-2 (-3.1eV), suggesting that the electron injection from a cathode would be enhanced.

For mobility measurement, we also fabricated devices which were comprised of [ITO/ETMs(*d* µm)/Al(100 nm)] where *d* varied more than 2 µm. The electron mobility of the ETMs, which estimated from the intersection of the transit photocurrent profile, were 5×10^{-6}, 4×10^{-5} and 2×10^{-5} cm^2/Vs at electric field 400 $(V/cm)^{1/2}$ for Alq_3, ETM-1 and ETM-2, respectively. Figure 2 shows the electric field dependence of the electron mobility. The electron mobility of ETM-1 and ETM-2 are 10 times higher than that of Alq_3 at each electric field. The disorder parameters (σ) from analysis of mobility measurements are 107 (ETM-1) and 93 meV (ETM-2) [4].

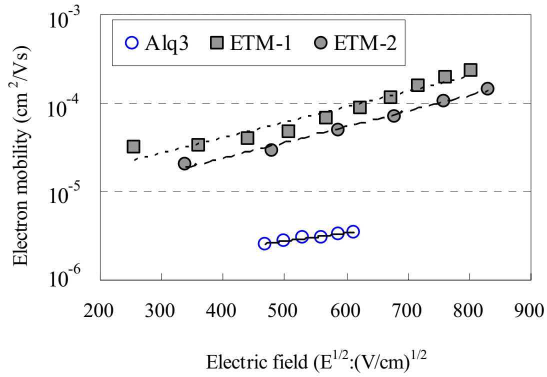

Fig. 2. Electric field dependence of electron mobility

We fabricated green OLED devices which were comprised of [ITO/CuPc(25 nm)/NPD(45 nm)/Alq_3 (40 nm)/ETM(20 nm)/LiF(1 nm)/Al(100 nm)]. *J-V* characteristics of the devices with each ETMs are shown in Figure 3. The driving voltage (defined as the voltage required to give a current density of 100 mA/cm ^{2}) of the device with ETM-2 was significantly reduced to 6.4 V, which was smaller value than that with the standard device by 1.4 V. This result suggests that reduction of the driving voltages is due to high electron injection properties from the cathode and high electron mobility of the new ETMs

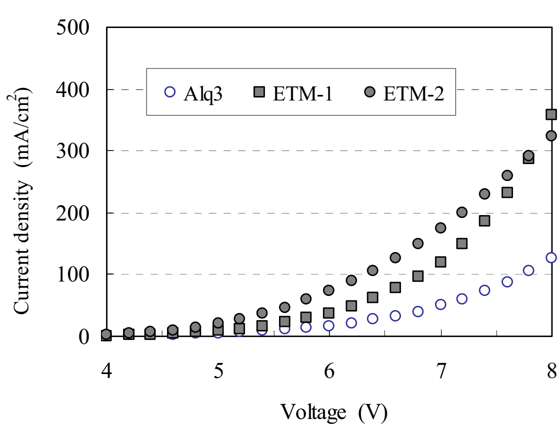

Fig. 3. *J-V* characteristics of the devices

Figure 4 shows power efficiency of the devices. As the results of reducing driving voltage of the new devices, the corresponding power efficiencies with ETM-1 and ETM-2 increased to 3.2 and 2.9 lm/W, while 2.6 lm/W was obtained from Alq_3 device. It should be noted that the device with ETM-2 keeps high power efficiency even in high current density region. Low HOMO and wide bandgap of ETM-2 would allow itself to act as "hole blocking layer" raising power efficiency and energy confinement.

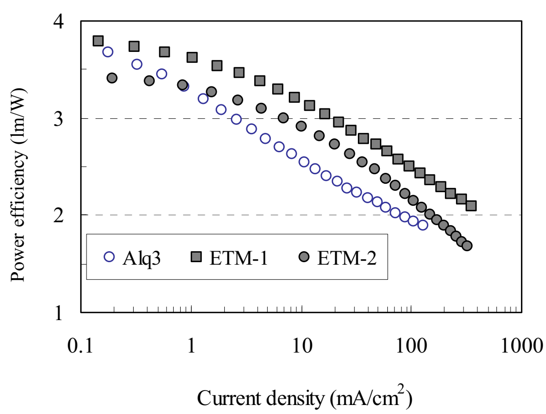

Fig. 4. Power efficiency of the devices

The lifetime evaluation of the devices was conducted at current density of 20 mA/cm^2 and 85 °C. Figure 5 and 6 show *luminance-time* and *operating voltage-time* characteristics, respectively. The half-luminance lifetime of the device using ETM-2 was more than 2 times as long as that of Alq_3, and reached 400 hours.

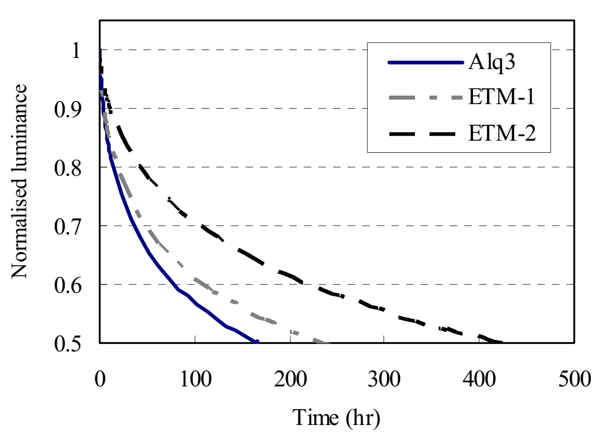

Fig. 5. Lifetime of the devices at 85 °C

The operating voltage with ETM-1 and ETM-2 slightly increased 0.57 and 0.18 V after 150 hours, while 1.10 V for Alq_3 device. Thus, electroluminescence devices with new ETMs could be expected to reduce the power consumption during long-period operations. We consider that the good working stabilities were due to heat and electron resistance of the new ETMs.

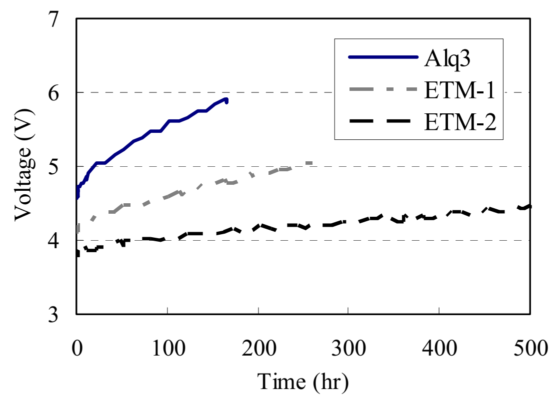

Fig. 6. Voltage rising of the devices at 85 °C

4. Summary

We found the relationship between the material properties and OLED performances and achieved the improvements both power consumption and lifetime on the electroluminescent device with new ETMs.

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