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Carrier Mobilities in Organic Electron Transport Materials Determined from Space Charge Limited Current

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1. Introduction

Recently, much progress has been made in development of organic light emitting devices (OLEDs).[1,2] One of the unsolved important problems, if any, is the lowering of drive voltage for further enhancement of power luminous efficiency. Charge carrier mobilities, especially electron mobility in organic thin films are known to be quite low. At least, the electron mobility is needed to increase by two orders of magnitude, for decreasing in driving voltage.

A time-of-flight (TOF) technique has been frequently used for the evaluation of electron and hole mobilities of electron and hole transport materials for OLEDs.[3] The determination of electron mobilities using TOF method sometimes meets both experimental and intrinsic difficulties. Transient photocurrent signals for electron transport in TOF measurements are usually very weak and are not detectable without introducing sensitizing layers. Detected transient photocurrents frequently exhibit a typical dispersive feature. The value of carrier mobilities obtained from the analysis of dispersive photocurrents are known to be highly dependent on a film thickness.[4] Typical thicknesses of charge transport layers in OLEDs is 50 nm, while rather thick films, the order of several μm, are used for conventional TOF measurements. In addition, we have to be very careful in referring TOF mobilities determined from dispersive photocurrent profiles for the discussions of charge transport phenomena in OLEDs. It should be also noted that TOF measurements are performed without steady-state current flow, which is quite different from a driving condition of OLEDs. In this paper, we estimated the carrier mobilities in several electron transport materials from space charge limited current (SCLC).[5] In SCLC measurements, thin films with ohmic-contact electrodes with the thickness of the order of 100 nm were used and measurements were performed under the condition of steady-state dark currents.

2.Experiment

Fig.1.shows six electron transport materials employed in this work:Tris-(8-hydroxyquinoline)aluminum(Alq), Bis(2-(hydroxyphenyl)benzoxazolate)Zinc(ZnPBO), 4,7-diphenyl-1,10-phenanrtroline(Bphen), 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline(BCP), 1,3-bis[(4-tert-butylphenyl)-1,3,4-oxadiazolyl]phenylene(OXD-7), 2-(4-biphenyl)-5-(4-tert-butylphenyl)-1,3,4-oxadiazole (PBD).

Although well-established SCLC theory has been available, measurements and analyses on based on the SCLC theory has rarely been used for the evaluation of carrier mobility in organic thin films. This reason may have been the difficulty of getting good ohmic contacts between organic layers and metal electrodes. Owing to the progress in the research of so-called buffer layers in OLEDs, an excellent electron quasi-ohmic contact has been obtained between the electron transport layer and metal electrode using LiF(0.1-0.2nm)-Al cathodes.[6] Based on this fact, we adopted lithium acetylacetonate (Liac,2nm)–Al (40nm) cathodes, which was proved to show almost the same effect with LiF(0.1-0.2nm)-Al cathodes. Electron only devices were preapred by sandwitching a thin electron transport material (180-220nm) between these two electrodes. A sample area was 2×2 mm^2 . All processes were prepared by vacuum vapor deposition. The background pressure was 2×10^{-6}Torr. Current density-voltage (J-V) experiments on the devices were performed with a source measure unit (Keithley 238) at room temperature.

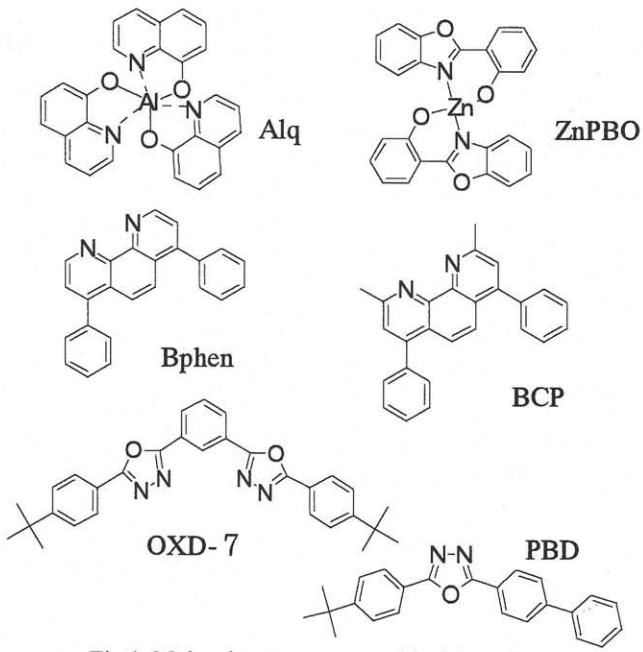

Fig.1. Molecular structures used in this study.

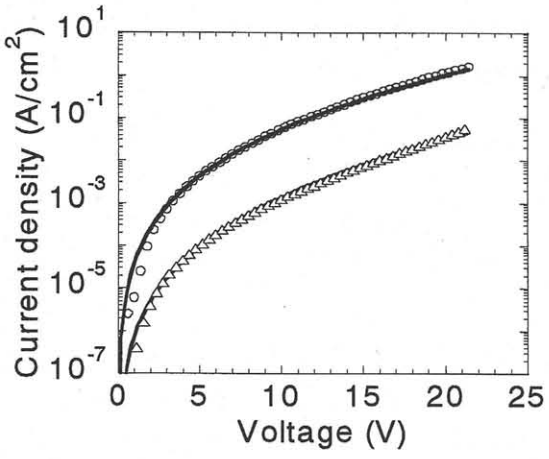

Fig. 2. Current density vs voltage for electron dominated OXD-7(circles) and Alq(triangles) at room temperature. The drawn lines represent the predictions of SCLC model incorporating the mobility, Eq.(1)

3.Result and discussions

In Fig.2, steady state J-V measurements are depicted. It was found that mobility is thermally activated and has the characteristic field dependence associated with hopping transport:

$$\mu(E) = \mu_0 \exp(\gamma\sqrt{E}) \qquad (1)$$

with μ_0 the zero-field mobility and γ describing the field-activation of the mobility.[7] Taking into account this dependence of the mobility on applied electrical field, we estimated the values of μ_0 and γ from the fitting of J-V curves of all samples. The values obtained in this way are listed in Table I for the six materials.

Table I . Zero-field mobility, field-activation and electron mobilities at 1MV/cm in OLEDs electron transport materials.

Sample	μ_0 (cm^2/Vs)	γ (cm/V)	μ (at 1MV/cm)
Alq_3	4.7×10^{-9}	0.0061	2.1×10^{-6}
ZnPBO	7.0×10^{-9}	0.0071	8.5×10^{-6}
Bphen	1.5×10^{-8}	0.0086	8.1×10^{-5}
BCP	2.3×10^{-8}	0.0096	3.4×10^{-4}
OXD-7	2.9×10^{-7}	0.0055	7.1×10^{-5}
PBD	4.1×10^{-9}	0.0075	7.4×10^{-6}

Among six materials investigated in the present study, the electron mobilities estimated from TOF measurements are known only in two cases, Alq and Bphen, 1.4×10^{-6} cm^2/Vs (4×10^5 V/cm) and 3.9×10^{-4} cm^2/Vs (2×10^5 V/cm) respectively.[8,9] Compared with these two values, the electron mibilities obtained from SCLC theory were slightly low. We should say the difference is quite small, because mesuring conditions are very different. No clear relationship between molecular structure and electron mobilities was found at present. It should be noted that five electron transport materials show nearly one or two order of magnitude higher mobilities than Alq does. The electron mobilities of phenanthroline derivative (BCP, Bphen) and oxadiazole derivatives (OXD-7) are high enough to be comparable with those of conventional hole transport materials. These facts suggest that we may find good possibility for low driving voltage in OLEDs using those classes of electron transport materials.

4.Conclusions

We evaluated electron mobilities of six electron transport materials useful for OLEDs from SCLC measurements. The high electron mobilities, almost equal to those for hole transport materials, were observed in phenanthroline and oxadiazole derivatives.

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