Device Parameters Determination by Novel Schottky Model Fitting for Organic Light-Emitting Diodes (OLEDs)

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1. Introduction

Recently OLEDs have made significant progress in brightness, lifetime and their application in large-area flat panel displays (FPD). However, the operating mechanisms such as charge-injection, transport, trapping, and recombination phenomenon in organic semiconductors are still unclear and require further investigation.


We propose a novel Schottky model to evaluate carrier injection behavior of organic semiconductor materials. Using temperature dependent current-voltage (I-V) measurements of hole only (HOD) and electron only (EOD) devices, we have obtained values for A* and the barrier height of organic-conductor interfaces.

2. Theory

Current density of a Schottky organic-conductor interface is expressed as

\[
I_{ij} = \frac{A^* T^2}{e} \exp(-\phi_B/eF) \exp(\frac{e \phi_B}{k_B T}) \tag{1}
\]

\[
A^* = \frac{A^* \sqrt{T e}}{e^2 F \mu} \tag{2}
\]

where, A*, T, e, ϕ_B, E, ε, ρ, k_B, N_0, and μ are the Richardson factor, temperature, electron charge, barrier height, applied electric field, permittivity of vacuum, relative permittivity, Boltzmann constant, state density and carrier mobility, respectively. The value for A* as proposed by J. C. Scott is dependent on N_0 and μ of the organic material. We have modified the Schottky equation to include ϕ_B.

Fitting to the temperature dependent I-V curves of HOD and EOD provides a simple and effective estimate of the values for A* and ϕ_B.

3. Experimental

We fabricated Glass/ITO/Organic/Metal structures as HOD or EOD. The ITO surfaces are UV cleaned (Novacan PSD-Pro) after IPA (isopropl alcohol) and DI (De-ionized) -water clean in ultra sonic bath. Organic materials are deposited by temperature controlled evaporation in well evacuated vacuum chamber (< 3.0×10^{-5} Pa). Metal electrodes (Al or LiF/Al) are deposited by current controlled evaporation system on organic layer. All devices are encapsulated by UV curable epoxy resin with glass lid and getter material (Dyonic).

I-V characteristics are obtained by a temperature controlled probe system, under vacuum (1×10^{-2} Pa), using a source measure unit (Keithley 2400). In this experiment, we obtained temperature dependence I-V characteristics of Glass/ITO(150nm)/NPD(70nm)/Al (100nm) and Glass/ITO(150nm)/Alq3 (70nm)/LiF(1nm)/Al(100nm) as HOD and EOD respectively.

Estimation of carrier mobility was calculated using the DI (dark injection)-SCLC (space charge limited current) method [5].

4. Results and Discussion

Fig.1(a) shows the temperature dependent I-V curves of the HOD and our Schottky model fitting results. A* is estimated from the plot of J/I^2-1/T plot (Fig.1(b)).

From these measurements and model fittings, we obtained for the hole injection values A*=5.0×10^{-3} [A/cm^2K^2], ϕ_B = 0.38 [eV]. The estimated A* value for ITO-NPD interface is five decades smaller than Al-Si interface [6].

We measured hole carrier mobility μ_h in NPD by DI-SCLC method at room temperature. As the result, we obtained μ_h=2.8×10^{-4} [cm^2/Vs]. From equation (2) and μ_h, the state density of hole carriers E_{ih} at interface area is estimated as 2.0×10^{19} [cm^{-3}].

Fig.2(a) shows the temperature dependent I-V properties of the EOD and our Schottky model fitting results. A* is estimated from J/I^2-1/T plot (Fig.2(b)). The N_0 and N_0 values are comparable with density of state (DOS) estimated by impedance spectroscopy (IS) method [7][8]. Device parameters for electron injection, are estimated as A*=2.0×10^{-4} [A/cm^2K^2], ϕ_B = 0.54 [eV]. The value of A* for the Alq3-LiF/Al interface is four decades smaller than Al-Si interface [6].


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In the near future, we will extend the model fitting for multi-layered organic devices. We have not estimated the state density of electron carriers $N_{0e}$, because the electron mobility could not be measured from the EOD by DI-SCLC. The barrier height $\mu_e$ is likely too large for estimation of electron mobility.

Fig. 3 shows illustration of OLED structured ITO/NPD/Alq/LiF/Al including the estimated device parameters.

5. Summary

We have obtained values for $A^*$, $\phi_B$, $N_0$, and $\mu_e$ as device parameters by temperature dependent I-V measurements and a novel model fitting.

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References