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Enhancement of the Charge Carrier of the Light Emitting Electrochemical Cell by Modification ITO Surface with Organic Semiconductor Nanomaterial

Ali Kemal Havare*

Toros University, Electrical-Electronics Engineering Department, Photoelectronics Lab. (PEL), 33140, Mersin, Turkey

Email: alikemal.havare@gmail.com

Abstract

The charge mobility of the light emitting electrochemical cell (LEC) device is studied by the Space Charge Limited Current (SCLC) technique. The LEC type diode is constituted as hole only device in order to understand how affect interface modification with the 4-[(2E)-3-carboxyprop-2-enamido] benzoic acid (CABA) on the charge mobility of the device by carried out I-V measurements.

Keywords: Charge carrier; LEC; self-assembled; OLED; super yellow (PDY-132).

1. Introduction

The relation between the electronic properties of device and their interface modification has been studied extensively [1-7]. The correlation between alignment energy levels of the layers of the device and electronics properties such as charge carrier mobility resulting charge transport behavior has been widely reported [8-11]. LEC devices have suitable structures for calculating charge mobility due to their simple architecture that consist of an organic semiconductor layer(s) between a cathode electrode and a conductive transparent anode. Charges and electrons combine in this organic semiconductor layer to form light by applying an electric field to the electrodes [12,13].

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* Corresponding author.

The balanced injection of the charge carrier is one of the factors that the most affect the performance of LEC type devices [14]. Therefore, while the charges are injected between the layers, the devices with high potential energy barriers accumulate in this barrier before they reach the emitter layer, which reduces the device efficiency. To overcome such difficulties in devices, step-by-step energy transfer mechanism is used. The another technique to enhance device performance is to place a charge carrier layer between ITO/emitter or emitter/Al to achieve stable carrier injection into the emitter layer. The performance of LEC devices is enhanced by stepwise energy transfer, balanced carrier injection, and maximum exciton recombination [15-21]. Therefore, a charge-rich transport material with energy levels matching the organic semiconductor emitter layer in LEC devices increases device efficiency by minimizing the carrier-injection barrier [22-24]. At this point, the 4-[(2E)-3-carboxyprop-2-enamido] benzoic acid (CABA) material was chosen to carry the appropriate charge injector to the emitter. To test this, it was investigated how much the charge mobility of the device was increased using the SCLC technique.

In this study, it was investigated how the charge injection performance of the device was affected by the CABA formed by self-assembled technique at the ITO/organic semiconductor interface of the LEC device. Two different LEC structure with a same commercial active emitter material (super yellow, SY) [25] are fabricated as **ITO/SuperYellow(emitter)/Al (bare-LEC)** and **ITO/CABA/SuperYellow(emitter)/Al (CABA-LEC)** and it is characterized by a Keithley 2401 sourcemeter. The study only focuses on how the modified interfaces by organic semiconductor material effect on the calculation of charge mobility in LEC devices.

2. Material and Methods

2.1. Lec device fabrication

The CABA is purchased from Merck for modification the ITO (Kintec, sheet resistivity 20 Ω/sq) surface by self-assembled technique. The bottom-up technique is used to form a LEC device on ITO glass. The ITO films are cut 1.5 cm to 1.5 cm. The standard cleaning procedure of ITO substrates was carried out [26,27]. The bare ITO film is coated by self-assembled technique by immersed it in the 1mM DMSO-D6C-CABA solution for 24 hours. The ITO/CABA film was rinsed by DMSO-D6 solvent to remove the non-bounded molecules to the ITO surface. The SY polymer (PDY-132 with CAS Number: 26009-24-5 is purchased from Merck) were layered to ITO coated with 1,2-dichlorobenzene with a concentration of 2.5 mg/mL mixture [28] by Spin coater (model SPIN150) and then annealed in an inert atmosphere at 50 °C for 15 min. The aluminum under 10^{-6} Torr vacuum as 100 nm was evaporated by the thermal evaporation (NANOVAK Corporation) system. The devices **bare-LEC** and **CABA-LEC** are characterized by Keithley 2401 source.

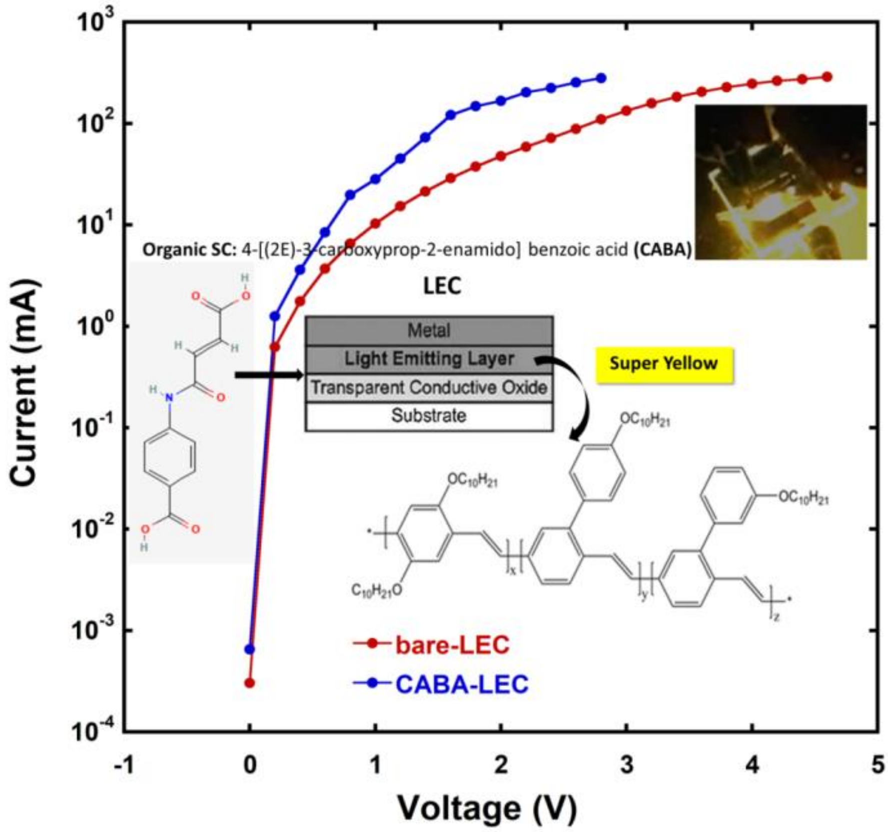

Figure 1: I-V characteristic and structure of bare-LEC and CABA-LEC diodes that are fabricated at Photoelectronics Lab (PEL), Toros University.

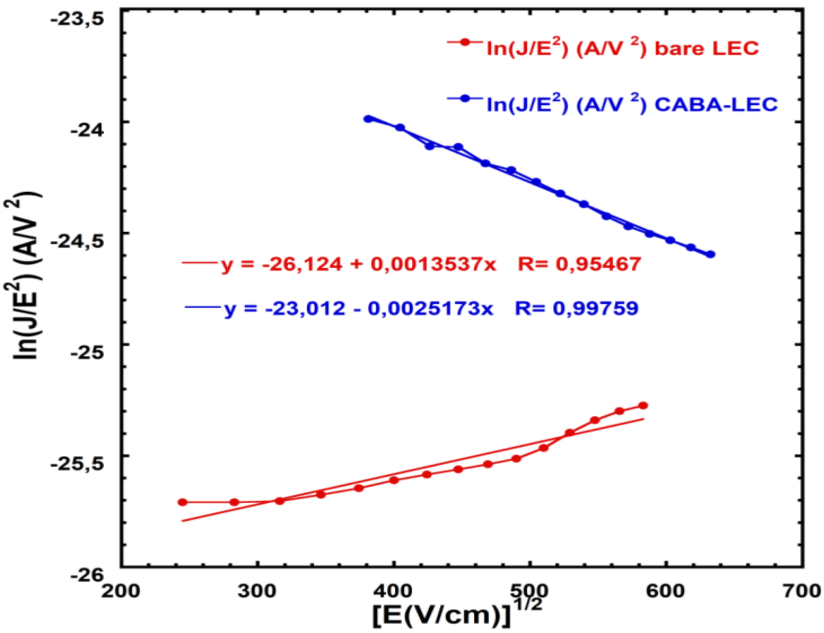

Figure 2: The log J versus $E^{1/2}$ of the bare-LEC and the CABA-LEC diode.

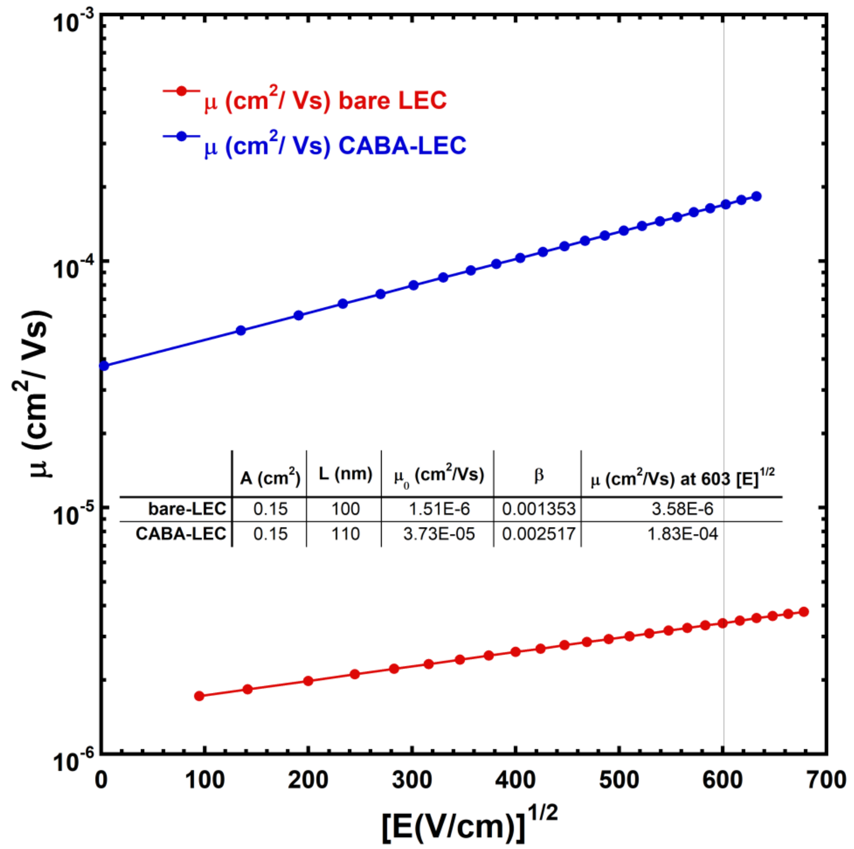

Figure 3: The mobility values μ versus $E^{1/2}$ of the bare-LEC and CABA-LEC diode.

2.2. Space Charge Limited Current (SCLC) Method

The I-V data (Fig. 1) of the LEC device was obtained by Keithley 2401. The charge mobility, μ, characterization of LEC diode is considered by the I-V data. The μ calculations [29] of LEC were made with the SCLC [30] approach. The SCLC technique is expressed with the following equations;

$$J = \frac{9}{8}\varepsilon\varepsilon_0\mu\frac{E^2}{L} \quad (1)$$

$$\mu(E) = \mu_0 exp(\beta\sqrt{E}) \text{ (Poole-Frenkel equation)} \quad (2)$$

$$J = \frac{9}{8}\varepsilon\varepsilon_0\frac{E^2}{L}\mu_0 ex\,p\left(\beta\sqrt{E}\right) \quad (3)$$

Here, E is the electric field, ε and ε_0 is the dielectric constant and the permeability of empty space, L is the organic layer thickness (eq. 1), β is the Poole-Frenkel coefficient, μ_0 is the mobility in the zero electric field and μ is the mobility (eq. 2). The SCLC technique can provide an understanding of how the ITO/CABA interface affects the charge mobility of the diode by analyzing the graph of log J versus $E^{1/2}$ (Fig. 2) and by graph of the mobility values μ versus $E^{1/}2$ (eq. 3) of the bare-LEC and the CABA-LEC diode (Fig. 3).

3. Result and Discussion

The Poole-Frenkel coefficient, β and μ_0 were calculated by Poole-Frenkel equation. $\varepsilon = 3$ and $\varepsilon_0 = 8.85\times10^{-12}$ Fm^{-1} were taken in eq. (3). The mobility μ vs. $E^{1/2}$ of the bare-LEC and CABA-LEC diodes are graphed to infer from how the mobility changes in the diode change with electric field (Fig. 3). The mobility of the bare-LEC and CABA-LEC are 3.4×10^{-4} cm^2/Vs and 1.7×10^{-2} cm^2/Vs respectively under 603 $(V/cm^2)^{1/2}$ electric field.

Table 1: The charge mobility results of the bare LEC and the LEC modified with CABA by SCLC approach technique.

	A (cm^2)	L (nm)	μ_0(cm^2/Vs)	β	μ(cm^2/Vs) at 603 $[E]^{1/2}$
bare-LEC	0.15	100	1.51E-4	0.001353	3.40E-4
CABA-LEC	0.15	110	3.73E-3	0.002517	1.70E-2

SCLC approach technique is used to calculate the charge mobility of the LEC diode. The SCLC approach, the mobility μ of CABA-LEC diode is found by factor ~10^2 comparing the bare-LEC (Table 1). The reason for the higher mobility may be that the high energy of the occupied electronic levels of the conjugate structure of CABA caused an extra energy level at the ITO/organic semiconductor interface, causing the charges to move easily within the junction. The charges are tunneling by the CABA interface easily to HOMO level of SY polymer.

4. Conclusion

The charge mobility results of bare-LEC and CABA-LEC are compered. In order to understand how effect the CABA layer as interface on the charge mobility of the LEC, the SCLC technique is preferred. The charge injection of the LEC is significantly affected by the ITO/organic semiconductor interface, CABA. The results show that CABA enhance charge mobility of diodes by contributing to the energy levels of the ITO/organic semiconductor interface and so that it can increase the charge tunneling from ITO to the HOMO level of SY. The mobility results of the diodes exhibited that the more charges tunneling from ITO to SY molecular orbitals due to the less values of the barrier height of the diode. Besides the correlation between matching interface and charge mobility is one of the important parameters to consider in terms of energy level alignment at the ITO/organic semiconductor interface.

5. Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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