



Leakage current by Frenkel–Poole emission on benzotriazole and benzothiadiazole based organic devices

D.E. Yıldız^{a,*}, M. Karakuş^b, L. Toppare^{b,c,d,e}, A. Cirpan^{b,c,e,f}

^a Physics Department, Faculty of Arts and Sciences, Hitit University, 19030 Corum, Turkey

^b Department of Chemistry, Middle East Technical University, 06800 Ankara, Turkey

^c Department of Polymer Science and Technology, Middle East Technical University, 06800 Ankara, Turkey

^d Department of Biotechnology, Middle East Technical University, 06800 Ankara, Turkey

^e The Center for Solar Energy Research and Applications (GUNAM), Middle East Technical University, 06800 Ankara, Turkey

^f Micro and Nanotechnology Program, Middle East Technical University, 06800 Ankara, Turkey

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ABSTRACT

In this study three different organic semiconductors were used in the fabrication of ITO/PEDOT:PSS/Polymer:PCBM/LiF/Al configuration. Reverse current density–voltage (J_r – V) measurements of the samples were investigated to define the reverse-bias leakage current mechanisms on benzotriazole and benzothiadiazole based organic devices. Our results indicate that the J_r – V plot behaviors are given by linear dependence between $\ln(J_r)$ and $V^{1/2}$, where J_r is the reverse current density, and V is the applied voltage. This behavior is well known as the Poole–Frenkel (PF) effect where it is found to be dominating in the reverse-bias leakage current.

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1. Introduction

In the last decade, the organic semiconductor devices such as organic diodes, organic solar cells (OSCs), organic light-emitting diodes (OLEDs) and organic field effect transistors (OFETs) have been important subjects to be studied by the scientists [1–6]. Organic semiconductors are less expensive and more flexible than inorganic counterparts. This makes organic ones an alternative in many electronic structure applications [7,8]. In addition, metal/organic semiconductor junctions; Schottky diodes have been developed as an alternative to the metal/inorganic-semiconductor junctions. This may serve as a new possibility of replacement inorganic structure with the organic ones [5,6]. Recently, some studies have been focused on understanding the forward and reverse bias conduction mechanisms on the organic diodes [3,4,6,9].

On the other hand, some of the researchers reported detailed information on reverse bias conduction mechanisms where there is still a challenging problem and generally, it is difficult to discriminate Poole–Frenkel and Schottky effects [10,11]. The Poole–Frenkel (PF) effect is often used to elucidate electronic junction in thin film materials [11–13]. Physically, this effect is the thermal emission of charge carriers from Coulombic centers in the bulk of a dielectric, semiconductor [11,14–16], or acceptor or donor center of an organic semiconductor [17] which is increased by the application of an electric field [13]. Electron emission is initially checked by the electric field. This reduces the barrier height on the trap side effectively and thus increases the probability of the electron escape from the trap [12,13].

In our previous study [18], photovoltaic properties of P1, P2 and P3 have been studied. In the present study, reverse bias conduction mechanisms which control carrier transport in ITO/PEDOT:PSS/polymer:PCBM/LiF/Al organic devices for P1, P2 and P3 polymer, respectively are examined. According to the experimental results, the analysis of

* Corresponding author. Tel.: +90 364 2277006 1626.
E-mail address: desrayildiz@hitit.edu.tr (D.E. Yıldız).

In J_r - V plots indicated that the conduction in leakage current density by electron emission from a trapped state from metal/organic semiconductor interface into a continuum of interface traps. This is associated with each conductive interface [13] and therefore the reverse conduction mechanism can be well described by the Poole-Frenkel effect for such organic devices.

2. Experimental

In this study, poly(4-(2-dodecyl-2-H-benzo[d][1,2,3]triazol-4-yl)benzo[c][1,2,5]thiadiazole (P1), poly(4-(5-(2-dodecyl-7-(thiophen-2-yl)-2-H-benzo[d][1,2,3]triazol-4-yl)thiophen-2-yl)benzo[c][1,2,5]thiadiazole (P2), and poly(4-(5-(2-dodecyl-7-(4-hexylthiophen-2-yl)-2-H-benzo[d][1,2,3]triazol-4-yl)-3-hexylthiophen-2-yl)benzo[c][1,2,5]thiadiazole (P3) were synthesized according to Suzuki polycondensation reactions as previously described [19]. The organic devices were designed as ITO/PEDOT:PSS/P1:PC61BM/LiF/Al (D1), ITO/PEDOT:PSS/P2:PC61BM/LiF/Al (D2), and ITO/PEDOT:PSS/P3:PC61BM/LiF/Al (D3) configuration. Fig. 1(a) and (b) shows the schematic energy band diagram of D1, D2 and D3, and structure of ITO/PEDOT:PSS/polymer:PC61BM/LiF/Al devices, respectively. The active layer consists of the polymers (P1, P2 and P3):PC61BM (Solenne), with ratios (1:1). Indium tin oxide (ITO)-coated glass substrates were etched and cleaned by ultrasonic treatments in water, detergent, acetone, and isopropanol and then it was treated in a Harrick Plasma Cleaner for 5 min. Then a thin layer of PEDOT:PSS was spin coated on ITO substrate at 5000 rpm and baked at 130 °C for 10 min on a hot plate. The active layer was spin coated on the PEDOT:PSS layer at 1500 rpm and 2500 rpm for 60 s by Speciality Coating Systems G3P-8 Spin Coater. The thicknesses of the polymer layers were measured by AFM and found to be 70, 115 and 115 nm for P1, P2 and P3,

respectively. The device fabrication was completed by thermal deposition of LiF (0.6 nm) and Al (80 nm) cathode under reduced pressure. The cathode was thermally evaporated as LiF (0.6 nm) and Al (80 nm) layer at a pressure of 2×10^{-6} mbar through a shadow mask. Devices were fabricated with an active area of 0.06 cm². The current–voltage characteristic measurements were carried out in Mbraun glovebox (moisture < 0.1 ppm; oxygen < 0.1 ppm) at dark. The C - V characteristics of ITO/PEDOT:PSS/polymer/LiF/Al organic devices were carried out with a Keithley 4200 semiconductor analyzer at 10 kHz.

3. Result and discussion

The dark J - V plots of the organic structures at room temperature are presented in Fig. 2. The forward and reverse current density as a function of voltage for ITO/PEDOT:PSS/P1:PC61BM/LiF/Al (D1), ITO/PEDOT:PSS/P2:PC61BM/LiF/Al (D2) and ITO/PEDOT:PSS/P3:PC61BM/LiF/Al (D3) organic devices are shown. The ITO/PEDOT:PSS/polymer:PC61BM/LiF/Al organic devices behave like a Schottky diode at low current. The organic devices show low rectification factors (RR) which are 14.64, 14.27 and 11.34 at ± 0.5 V for D1, D2 and D3, respectively. In addition, RR is 13.20, 12.19 and 11.60 at ± 0.2 V for D1, D2 and D3. These results indicate that the RR increases with an increase in bias voltage. This may be attributed to the bias voltage dependence of barrier height that may originate from inhomogeneous barrier formation [4].

That is, the thermionic emission over ITO/PEDOT:PSS/polymer:PC61BM/LiF/Al organic devices is important at the low applied voltage. Therefore, J - V curve in the forward direction was analyzed using thermionic-emission theory [4–6,20,21].

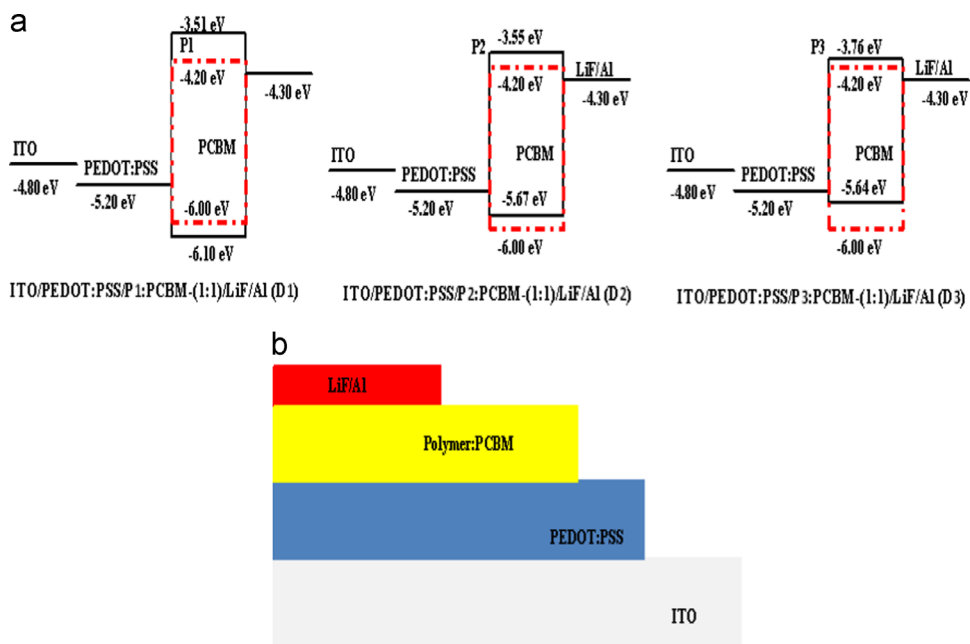


Fig. 1. (a) Energy band diagram and (b) schematic diagram of ITO/PEDOT:PSS/polymer/LiF/Al organic devices.

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