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Au/ MEH: Alq3/ITO Donor-Acceptor Blend as a Schottky Diode

KEYWORDS: Schottky barrier diode, I-V Characterization, MEH-PPV; Alq3; Bulk Heterojunction

Mahdi Hasan Suhail	Issam Muhammad Ibrahim
Department of Physics, college of science, University of Baghdad, Iraq	Department of Physics, college of science, University of Baghdad, Iraq

ABSTRACT *In this research, we investigated the metal contacts using 100 nm thick film MEH:Alq3 which is deposited onto an indium tin oxide (ITO) substrate as a test device. Electrical hysteresis phenomena were observed in the current-voltage characteristics of the device. The diode parameters such as ideality factor, series resistance, shunt resistance and barrier height are measured.*

1-Introduction

Schottky barrier diodes are one of the simplest electronic devices in semiconductor industry. The main advantage of these diodes is their high current density and low forward voltage drop [Xiaoxia Jiang et al. 2009]. Primarily the current flow in these diodes is due to the majority carriers having an inherently fast response [Yu et al. 1995].

These diodes are commonly used in switching circuits and high frequency applications because it can switch from one state to another much faster than ordinary p-n junction diodes. The behavior of organic Schottky diode depends on characteristics of the metal/organic semiconductor junction. Therefore, the understanding of electrical and electronic properties of interface between metal and organic semiconductor is important for device applications. There are more than a few possible reasons due to which the diodes show non-ideal behavior. These reasons include the effect of series resistance (Rs), formation of barrier height, insulating layer between metal and semiconductor and interface states. The series resistance is an important parameter which can lead the properties of Schottky diodes to be non-ideal [Halls et al. 1995; Muhlbacher et al. 2006].

Due to its solubility in many solvents and optical absorption in the visible wavelength range poly(2-metoxy-5 -(20-ethylhexyloxy)-1,4-phenylene vinylene), or MEH-PPV is commonly used conjugated polymer in optoelectronic devices such as light emitting diodes[Günes, Neugebauer & Sariciftci 2007; Jorgensen, Norrman,, & Krebs 2008] solar cells[Nguyen, Martini, Liu, & Schwartz 2000;Brabec, Sariciftci & Hummelen 2001; Martini, Smith, & Schwartz 2004; Coakley, & McGehee 2004; Karadeniz, Tugluoglu, Serin & Serin 2005 ;Sheng, Tong, Singh & Vardeny 2007] and photo detectors [Wang, Cuppoletti & Rothberg 2003; Brabec 2004; Magherusan, etal. 2010]. This polymer has been extensively investigated both experimentally and theoretically[Lo et al.2006; Zhao et al.2010 ; Chen et al.2011 ; Nayyar et al.2011 ; Sun, et al.2011] and it is still a subject of various research [Abdou, Orfino, Son & Holdcroft 1997; Hoshino et al.2004]. Special attention is given to bulk heterojunction structures in which the electron acceptor and the donor are mixed together in a solution and then is spin-coated and deposited as a thin layer [Ma, Yang, Gong, Lee & Heeger 2005; Li et al. 2005; Radu et al.2011]. The major problem of these devices is related with their time stability [Bundgaard & Krebs 2007], even if many researchers are trying to solve this. The architecture of the organic photovoltaic structures is important, so matching the energy level of the active layer with the work function of electrodes becomes necessary.

The polymer film morphology and consequently its optical parameters are strongly influenced by preparation conditions, molecular weight [Shi, Liu & Yang 2000], solvent choice [Amrutha & Jayakannan 2008], solution concentration and spin-coating speed. At least one of the mentioned conditions must be varied to obtain different film thicknesses.

In present study, the blend of MEH-PPV and Alq3 organic semiconductors was prepared as thin film on ITO to fabricate an organic diode. The electronic parameters such as barrier height, ideality factor, shunt resistance and series resistance of the organic diode were evaluated by current-voltage measurements.

2-EXPERIMENTAL

The ITO/ MEH:Alq3/ Au diode was fabricated on indium tin oxide coated (ITO) glass substrates (purchased from Sigma-Aldrich which is highly conductive and provides excellent transparency of >90% to allow the illuminated light to pass and to reach into the

Photoactive thin film readily). ITO anode has a 150 nm thick with a 5–15 Ω/sq sheet resistance. The powdered MEH:PPV polymer (Sigma-Aldrich, USA) is dissolved in chloroform using stirrers (10 mg/ml concentration) and kept at a temperature of 100 oC for 30 minute . The solution is filtered and spin coated on the ITO anodes to serve as the hole transporting layer (100 nm thick). The coated substrates are allowed to dry at temperature100 oC for 30 minute for solvent removal. The Alq3 was deposited using spin coating with thickness about 100 nm and dry at temperature100 oC for 30 minute. The fabrication process is completed by a thermal evaporation of the 100-nm-thick gold layer to serve as a cathode.

Ideality factor n, barrier height Φb, shunt resistance Rsh and series resistance Rs of junction diode are calculated from conventional I-V characteristics and these parameters are also verified using Cheung's functions and Norde's function.

The current-voltage characteristics of the Schottky junction can be analyzed by the following relation [Rhode rick 1978]:

$$I=I_o \exp(qV/nkT)\,[1-\exp(-qV/kT)] \quad (1)$$

Where Io is the saturation current and can be given as:

$$Io=AA^*T^2\exp(-q\Phi b/kT) \quad (2)$$

Where V is the applied voltage, T is the temperature, A is the effective diode area, A* is the effective Richardson constant and k is the Boltzmann constant. The value of ideality factor n can be calculated as:

$$n=q/kT\,(dV/d\ln I) \quad (3)$$

Forward bias current-voltage characteristic at low voltage are linear in semi-log scale, but at higher voltages the characteristics deviate from linear behavior due to effect of series resistance. The barrier height is obtained from (2) and is given by:

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Φ_b =kT/qln (AA*T²/Io) (4)

By using thermionic emission theory, the ideality factor n and BH Φb can be obtained from the slope and the current axis intercept of the linear region of the forward bias I-V plot, respectively. To determine the effect of series resistance on the Schottky diode characteristics, Cheung and Cheung introduced another characterization technique to determine the key parameters of diode like barrier height, series resistance and ideality factor. According to Cheung's functions, the thermionic emission model for a Schottky diode having junction resistance at V> 3KT/q in the forward I-V characteristics is written as [Cheung & Cheung 1986]:

dV / d(ln I) = n(KT / q) + IRs (5)

The factor IRs is the voltage drop across the series resistance of the Schottky diode.

3-RESULTS AND DISCUSSION
The measured forward and reverse bias current-voltage characteristics of the mix of the two materials MEH:PVV and Alq3 as a ITO/ MEH: Alq3/ Au surface type Schottky diode at room temperature is shown in figure 1.

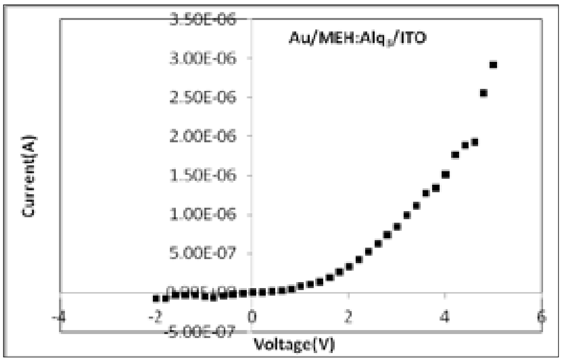

Figure- 1- Current-voltage (I-V) characteristics of Au/ MEH:Alq3/ITO Schottky barrier diode

The weak voltage dependence of the reverse bias current and the exponential increase in the forward bias current are the characteristic properties of rectifying contacts. It can be seen from figure 1 that the current-voltage characteristics of the Schottky diode are nonlinear, asymmetric and show good rectification behavior with very small leakage current.

From ln I versus V characteristics, shown in figure 2, the current curve in the forward bias region becomes dominated by series resistance from contact wires or bulk resistance of the organic materials, giving rise to the curvature at high current in the semi log I-V plot. The n value was calculated from the linear portion of forward bias I-V curve in semi-logarithmic scale using equation (4). The value of Φb was determined using equation (3).

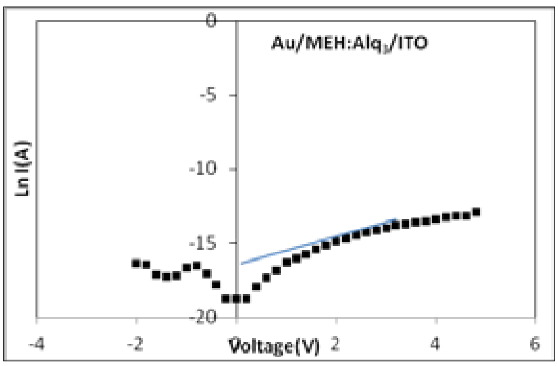

Figure- 2- Semi-logarithmic I-V characteristics of Au/ MEH:Alq3/ITO Schottky barrier diode

As we know, the ideality factor measures the conformity of the diode to pure thermionic emission. The transport properties of the devices cannot be well modeled by thermionic emission if the ideality factor is much larger than unity [Aydın & Turut 2007]. Thus, the ideality factor 22.83indicates that the thermionic emission is not the dominant transport mechanism. The value of n barrier diode is greater than one because of the irregularities in thickness of organic film, oxide layer at the interface, dominant of recombination current and series resistance. Higher values of ideality factors are attributed to secondary mechanisms, which include interface dipoles due to interface doping or specific interface structure, as well as fabrication induced defects at the interface [Tung 1992; Schmitsdorf, Kampen & Monch 1997; Monch 1999; Ltaief et al. 2004]. According to Tung 1992 the large values of n may also be attributed to the presence of a wide distribution of low-Schottky barrier patches caused by laterally barrier inhomogeneous. Also, recombination generation, and tunneling may be possible mechanisms that could lead to an ideality factor value greater than unity [Vanalme et al.1999]. The higher value of ideality factor may be attributed to effects of the voltage drop across the interfacial layer [Rhoderick & Williams 1988; Lonergan 2004].

The applied bias voltage across the junction has significant effect on the barrier height [Mtangi et. al. 2009]. The value of the barrier height of the sample ITO/ MEH: Alq3/ Au was determined and found to be 0.578 eV. It should be known that barrier height is the contact potential barrier that exists at the interface between the organic layer and metal.

The I-V characteristics of the diode are affected by parasitic resistances such series, Rs and shunt resistance, Rsh. These resistances are important factors in performance of the diode and the determination of these resistances is necessary to device performance. The series resistance Rs, which strongly contributes to the electrical characteristics of junction diodes, and was found from the junction resistance versus bias voltage V plot as shown in figure 3. The Rsh value was determined from the lower current region.

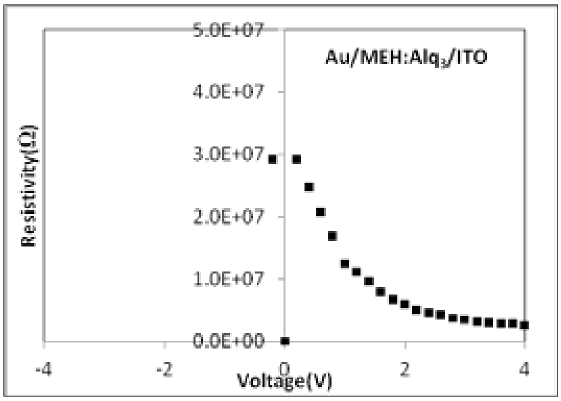

Figure- 3- Junction resistance vs. voltage graph of Al/ MEH: Alq3/ITO Schottky diode

The value of Rs, equal to 2387KΩ, is extracted from the lower region in forward bias of the R vs. V characteristics. The series resistance is significant in the non-linear of the I-V characteristics. While the shunt resistance Rsh, which is the highest value of resistance in the reverse bias of the R vs. V, plot, is found to be 30000 KΩ. This resistance arises from the leakage of current. The resistance and ideality factors calculated from the *I –V* curve and Cheung's function show good agreement with each other.

The MEH:Alq3 organic semiconductor has low conductivity, therefore, the series resistance of the diode is very high. On the other hand, the bulk resistance, Poole-Frenkel and space charge limited current effects can cause higher values of ideality factor [32].

From figure 4 we observed that the current densities increased with increase of voltage. We concluded that electron traps – rather than hole traps—are induced. In this case electron–hole recombination will mostly take place near the electron-transporting layer.

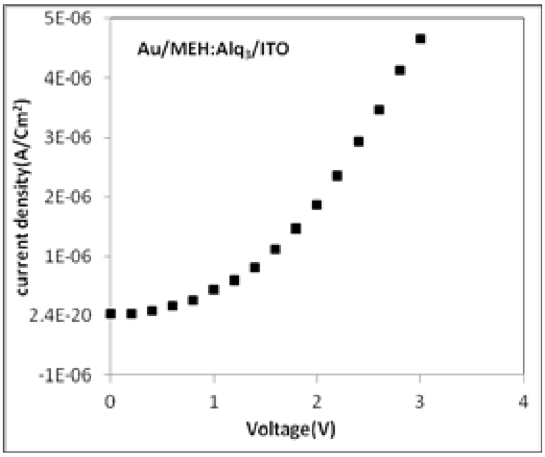

Figure -4- Current density versus voltage for ITO/MEH:Alq3/Au Schottky diode.

Thus, solution processing may lead to a reduction in the electron transport mobility as a result of electron charge traps.

4. Conclusion

In this work we reports the fabrication of Au/ MEH:Alq3/ITO Schottky barrier diode by a spin coating technique. The electrical properties of the diodes are investigated from I-V characteristics using thermionic emission model and Cheung's functions. The key diode parameters such as ideality factor, barrier height, shunt resistance and series resistance are also extracted from I-V characteristics. The diode indicates a non-ideal current-voltage behavior with ideality factor of 22.83. At higher voltages, the space limited current mechanism is dominant in the organic diode.

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