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Electrical characterization of Au/poly (linoleic acid)-g-poly(methyl methacrylate) (PLiMMA)/n-Si diode in dark and under illumination

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ABSTRACT

In this study, poly (linoleic acid)-g-poly(methyl methacrylate) (PLiMMA) graft copolymer is used as an interfacial layer in a Schottky diode for the first time. Au/poly (linoleic acid)-g-poly(methyl methacrylate) (PLiMMA)/n-Si diode was fabricated and main electrical characteristics of the diode were investigated using I–V measurements in dark and under illumination at room temperature. Ideality factor (n), barrier height (Φ_{B0}) and serial resistance (R_s) values of the diode were found as 2.8, 0.87 eV and 8096 Ω for dark, and 6.3, 0.71 eV and 676 Ω for 100 mW/cm^2 illumination intensity. Also, the reasons of deviation from ideal thermionic emission theory were investigated using Cheung&Cheung method and Card&Rhoderick's function which are used for calculating voltage dependence of barrier height ($\Phi_B(V)$), series resistance (R_s) and number of surface states (N_{ss}) of the Au/PLiMMA/n-Si diode.

1. Introduction

When a metal is contacted with a semiconductor, it may act in two ways; it either behaves like an ohmic contact or show property of a rectifying contact. This behavior depends on work functions of the metal and semiconductor. Rectifying contacts are also called as Schottky contacts whereas ohmic contacts are also called as back contacts. In the case of rectifying contact, the fabricated metal/semiconductor (MS) structure is basically a diode whose rectifying contact is also called as MS contact [1]. In order to obtain an effective MS contact device, an interfacial layer is used to improve the device's electro-optical characteristics [2–4]. Silicon (Si) based Schottky diodes, having a rectifying MS junction, play an important role in integrated circuit technology. These types of diodes have been used for many purposes; such as rectifiers, solar cells, photo diodes, detectors, capacitors, etc [1–17]. Such device variety is particularly due to the interfacial layer between semiconductor and metal. In general, an interfacial layer is used to passivite active dangling bonds on Si surface originated from interruption of the crystal lattice. This way, with an appropriate interfacial layer, Schottky diode can be converted into useful devices as mentioned above. Furthermore, Schottky diodes' electro-optical characteristics such as the ideality factor (n), leakage current (I_o), zero-bias barrier height (Φ_{B0}), series resistance (R_s) and interface-state density (N_{ss}) are controlled and improved by using an appropriate interfacial layer [1–5,13,16–18].

Recently, polymeric layers have been used as interfacial layer in Schottky diodes extensively since polymeric materials have simpler and cheaper fabrication process compared with inorganic materials. In the literature, several polymers were used and investigated as a result of suitable electrical, dielectric and physical properties [1–18]. Almost all of them were found appropriate for Schottky diodes due to some advantages and positive results. Also, some of them are used firstly in the electronic devices. These type of investigations are rather important for new alternative or more efficient/cheaper materials to achieve more effective devices.

One type of mostly used polymeric materials is graft copolymers for which there are many polymerization methods for synthesis in the literature [19–22]. An important one of these methods is free radical polymerization by using macroperoxy initiators [20,23] since this polymerization system does not require any metal catalyst or solvent that may be harmful to the environment. PLina-g-PMMA (PLiMMA) graft copolymer was synthesized by several researchers to investigate drug release features [24], DNA adsorptions [25], protein adsorption and bacterial adherence [26]. In addition to various applications of this polymer in the literature, poly (linoleic acid)-g-poly(methyl methacrylate) (PLiMMA) by the polymerization of MMA initiated by PLina was synthesized by the authors of this study, and is used as an interfacial layer in a Au/PLiMMA/n-Si

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diode and main electrical parameters of the diode were investigated.

2. Experiments

For the fabrication of Au/PLiMMA/n-Si diode structure, n-type (P-doped) single crystal silicon wafer was used as substrate with (100) surface orientation, 500 μm thick and 2″ diameter. For every semiconductor device there are at least two metal contacts to form connections, i.e. ohmic and rectifying contacts. An ohmic contact should have a negligible junction resistance in comparison with the total resistance of the device. Metals such as Ag, Al, Al–Au, Au–Sb, Ni, Sn and Ti are well known for achieving good ohmic characteristics in Si-based MS structures. Among these, Ag is often used with Si to form ohmic contact due to lower junction resistance. Hence, after the ultrasonic cleaning process of the n-Si wafer, high purity Ag metal (99.999%) with thickness of about 250 nm was thermally evaporated onto the back surface of the wafer in the vacuum environment (1×10^{-6} Torr) and this back layer was annealed at 350 °C for 30 min to achieve better ohmic feature.

In order to remove thin oxide layer formed during annealing, the front side of the wafer was cleaned with 20% HF solution. Synthesized PLiMMA graft copolymer was used as interfacial polymer layer. The interfacial PLiMMA graft copolymer was solved in dimetil formamid (DMF) and coated onto the Si by electrostatic spraying device. This solution was loaded into a syringe with a nozzle (0.8 mm in diameter) and the nozzle-collector distance is kept at 15 cm, while flowing rate and voltage are kept at 0.8 mL/h and 28 kV, respectively. Morphological investigation of this polymeric surface was realized using a field effect guns-scanning electron microscope (FEG-SEM). The micrograph given in Fig. 1 showed almost homogenous nanofibers with ~200 nm thickness.

The last step is the deposition of Au rectifying circular dots of 1 mm in radius and ~250 nm thick on PLiMMA film by thermal evaporator with the pressure of 1×10^{-6} Torr.

After the fabrication steps, current–voltage (I–V) measurements of the diode were performed using Keithley 2400 sourcemeter by at room temperature in the dark and under various illumination intensities. A halogen lamp was used as the light source during measurements under illumination.

3. Results and discussion

The Au/PLiMMA/n-Si Schottky diode was formed and current–voltage (I–V) plots in dark and under various illumination intensities were given in Fig. 2. For in dark condition, the diode has

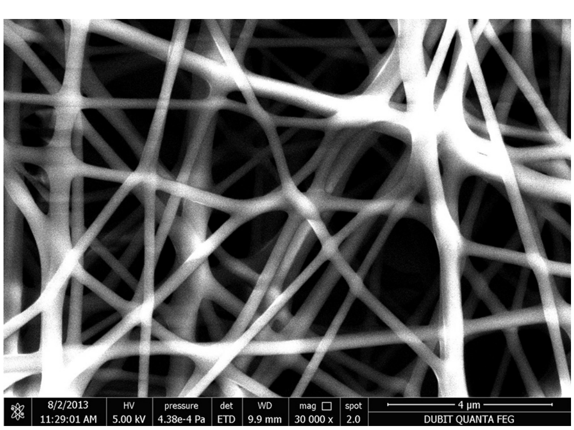

Fig. 1. The FEG-SEM micrograph of PLiMMA polymeric interfacial layer.

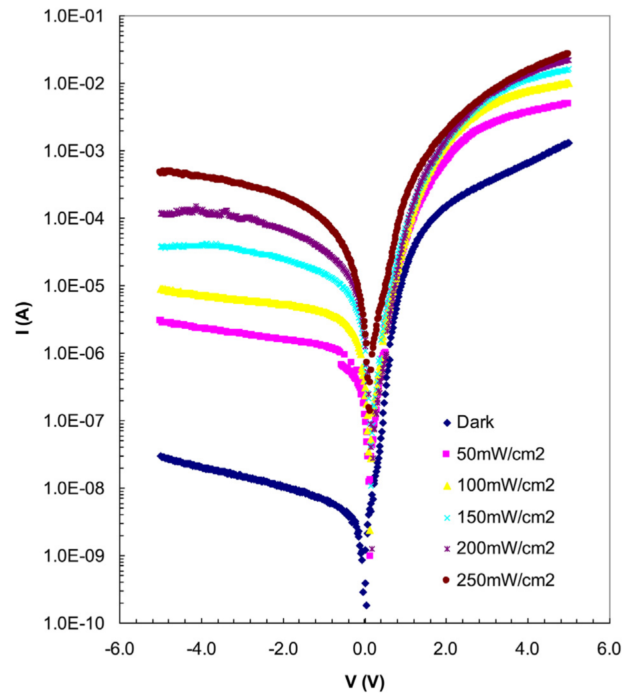

Fig. 2. Forward and reverse bias I–V characteristics of Au/PLiMMA/n-Si diode in dark and under illumination.

rather sufficient rectifying ratio with a value above 10^4. Voltage dependence of the current is given with well known thermionic emission theory equation for this type diode as below [12–17].

$$I = I_0\left[\exp\left(\frac{qV}{nkT}\right) - 1\right] = AA^*T^2 \exp\left(-\frac{q\Phi_{B0}}{kT}\right)\left[\exp\left(\frac{qV}{nkT}\right) - 1\right] \tag{1}$$

here, I_0, q, n, k and T are reverse saturation current, the electronic charge, ideality factor, Boltzmann constant and absolute temperature in Kelvin, respectively. A, A^*, and Φ_{B0} are diode area, effective Richardson constant, and zero-bias barrier height, respectively.

Applying Eq. (1). to I–V plots, main electrical parameters of the diode can be obtained in dark and under various illumination intensities. The obtained values together with other values obtained by other calculations were given in Table 1. As can be seen in the table, while the Φ_{B0} values decrease with the increasing illumination intensity, I_0 and n values increase. The additional charge carriers that occurred due to illumination make the reverse bias current increased. So, an increase occurred in I_0 and n. The increase in I_0 and n values with increasing illumination intensity indicates deviation from thermionic emission theory, and it may be attributed to the decreasing series resistance (R_s) and increasing number of surface states (N_{ss}). There are few reasons of the deviation from thermionic emission theory and bending behavior in the semi-logarithmic I–V curves, these can be listed as R_s, N_{ss}, voltage dependence of ideality factor ($n(V)$) and barrier height ($\Phi_B(V)$) due to the existence of interfacial polymer layer [4,8,9,13–15].

R_s changes through the bias regions and it is more effective on I–V characteristics in strong forward bias region due to larger voltage drop (IR_s) in this region. There are various techniques to calculate R_s. Among them, Ohm's law is simply used in order to obtain behavior of the resistance in each bias region such that resistance (R_i) value at any bias is given by $R_i = dV/dI$. Calculated R_i values were given in Fig. 3. In the forward bias region, resistance,