X-RAY IRRADIATION EFFECTS ON THE INTERFACE OF POLYPYRROLE/*p*-Si STRUCTURE

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ABSTRACT

The samples were prepared using mirror cleaned and polished (as received from the manufacturer) *p*-type Si wafers with (100) orientation and 15-20 Ω cm resistivity and 300-400 μm thickness. The ohmic contact was made by evaporating Al on the back of the substrate, followed by a temperature treatment at 600 °C for 3 min in a N_2 atmosphere. The native oxide on the front surface of *p*-Si was removed in a HF:H_2O (1:15) solution and finally the wafer was rinsed in deionized water before polymerization was carried out. The ohmic contact made and the edges of the *p*-Si substrate used as an anode were carefully covered by wax so that the polished and cleaned front side of the sample was exposed to the electrolyte by mounting it in an experimental set-up employed for anodization. A Pt plate was used as the cathode. Anodization process was carried out under constant current conditions of I = 1mA. The polypyrrole/*p*-Si diode was fabricated by an electrolyte being held at a constant temperature of 55 °C that was composed of 0.40 M pyrrole and 0.1 M tetrabutylammonium tetrafluoroborate. The electrolyte solution was prepared in a propylene carbonate solvent (Merck). The Polypyrrole/*p*-Si/Al structure has demonstrated rectifying behavior by the current-voltage curves studied at room temperature. The sample was exposed to x-ray irradiation up to 50 keV at constant doses in order to determine effect of x-ray radiation on interface between polypyrrole and Si semiconductor. The parameters of the structure such as barrier height, ideality factor, series resistance and interface state density are determined how to change with the irradiation. The interface state density distribution curves of device was obtained from forward bias current-voltage *(I-V)* characteristic.

1. INTRODUCTION

Polymers have a large technological and scientific importance because of their electrical properties. Polypyrrole, as conducting polymer, has the relatively good atmospheric stability, high conductivity and the ease of preparation by chemical and electrochemical polymerization [1-10]. Owing to the technological importance of metal/semiconductor polymer structures and metallic polymer/inorganic semiconductor, these devices had been extensively studied both experimentally and theoretically. Reliability and long term operation of these devices exposed to x-ray irradiation in space or laboratory environments is also important. The goal of the present study is the investigation of the radiation effects on the Polypyrrole/*p*-Si/Al structure after exposure to x-ray irradiation having different energy.

2. EXPERIMENTAL PROCEDURE

After the cleaning procedures, the ohmic contact was made by evaporating Al on the back of the Si substrate. The ohmic contact sides and the edges of the Si substrate used as an anode were carefully covered by black wax so that the polished and cleaned front sides of the sample were exposed to the electrolyte by mounting it on an experimental setup employed for anodization. A Pt plate was used as cathode. The electrolyte was composed of 0.40 M pyrrole and 0.10 M tetrabutylammoniume tetrafluoroborate. The pyrrole obtained from Fluka Chimika was used to prepare polypyrrole at room temperature. The electrolyte solution was prepared in a propylene carbonate solvent (Merck trademark). The polymer film with thickness of about 5-10 μm was electrochemically deposited on the surface of the semiconductor under a constant current density of 4 mA/cm^2. The Polypyrrole/*p*-Si structure was fabricated by holding the electrolyte at a constant temperature of 55 ^{0}C. The area of circular structures was 2.54×10^{-6} m^2. After polymerization process, the polymer-coated semiconductor was cleaned by acetonitrile for 15 min at room temperature. In this way, conductive polypyrrole polymer/semiconductor structure was obtained. All metallic surfaces were cleaned by acetone and methanol before processes. *I-V* measurements of the device were performed using a Keitley 487 Picoammeter/Voltage Source at room temperature in dark.

3. RESULTS AND DISCUSSION

The forward and reverse bias *I-V* characteristics of the devices taken at room temperature under dark conditions are given in Fig.1. As can be seen from the figure, the current-voltage characteristics of the devices show the rectifying behavior with a potential formed at the interface. Thus, it is assumed that the forward bias current of a device with series resistance is due to thermionic emission current and it can be expressed as [11]

$$I = I_o \exp\left(\frac{q(V - IR_s)}{nkT}\right) \qquad (1)$$

for $q(V - IR_s) > kT$, where $$I_o = AA^*T^2 \exp\left(-\frac{q\Phi_b}{kT}\right), \qquad (2)$$

is the saturation current density. A^* is the effective Richardson constant and equals to 32 A/cm^{2}K^2 for *p*-type Si. $\Phi_{b,0}$ values calculated from equation (2) with increasing x-ray irradiation energy for the structure. The plot of the effective barrier height versus energy is given Fig.2 for the Polypyrrole/*p*-Si structure. As can be seen from Fig.2, there are slight increases in barrier heights with increasing energy. *n* is ideality factor and is a measure of conformity of the diode to pure thermionic emission and it is determined from the slope of the straight line region of the semi-log forward bias ln*I*-*V* characteristics through the relation

$$n = \frac{q}{kT}\frac{dV}{d(\ell nI)} \quad . \qquad (3)$$

The high values of *n* can be attributed to effects of the bias voltage drop across the interfacial layer which separates the semiconductor from the metal, and therefore, of the bias voltage dependence of the barrier height. The ideality factor values of the structure calculated from equation (3) are plotted versus energy in Fig.2. The ideality factor values being significantly greater than unity are a result of interface states in equilibrium with the semiconductor at the Polypyrrole/*p*-Si interface [11-17]. That is, it can be concluded that the barrier height determined from the *I-V* characteristics is controlled by the interface states. Furthermore, there is probably an insulating oxide layer between the polymer and semiconductor substrate.

It is seen that the *I-V* characteristics deviates at higher biases due to the influence of the series resistance. To calculate the series resistance of the structures, from the equation (1), following equations can be obtained as [18]:

$$V = IR_s + n\Phi_b + \frac{nkT}{q}\ln\left(\frac{I}{AA^*T^2}\right), \qquad (4)$$

$$\frac{dV}{d\ln I} = \frac{nkT}{q} + IR_s, \qquad (5)$$

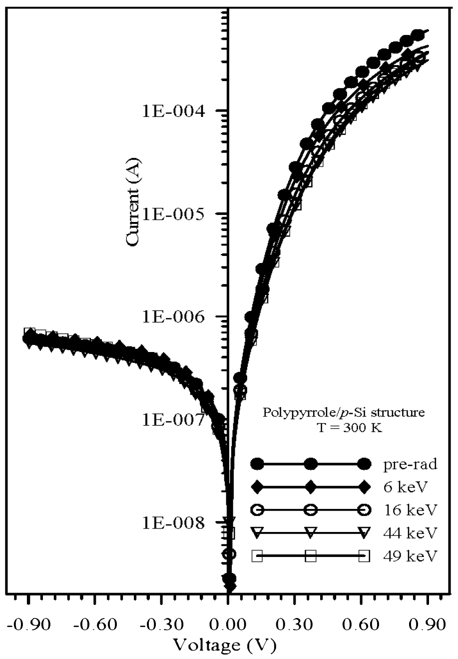

Fig. 1 The forward and reverse bias current-voltage characteristics of the Polypyrrole/*p*-Si structure as a function of irradiation energy.

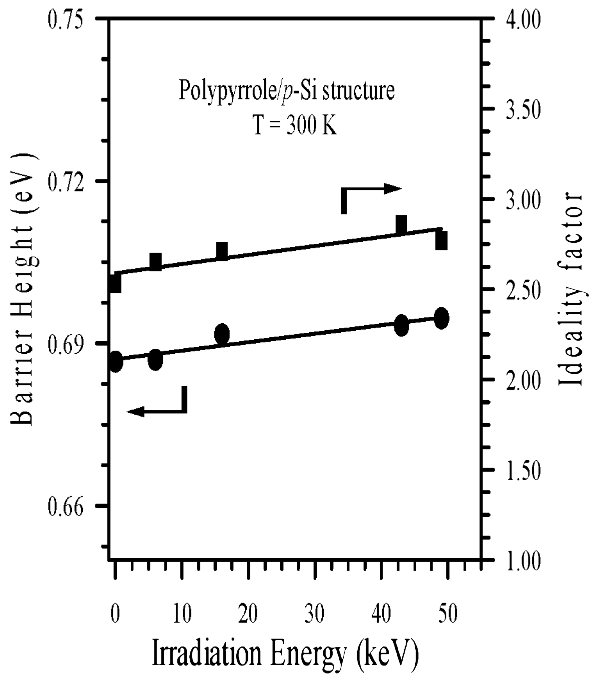

Fig. 2 Barrier height and ideality factor versus irradiation energy.

Where Φ_b is the barrier height obtained from data of downward curvature region in the forward bias *I-V* characteristics. Equation (5) should give a straight line for the data of downward curvature region in the forward bias *I-V* characteristics. Thus, the slope and y-axis intercept of a plot of $dV / d \ln I$ versus I will give R_s and nq/kT, respectively. Series resistance values of the structure calculated from equation (5) are plotted versus energy in Fig.3. From this figure, it can be said that the series resistances of the structures have not changed seriously with increasing energy. In Fig.4, it is shown the energy distribution curves of the interface states have been determined from the experimental *I–V* characteristics with respect to increasing irradiation energy. As can be seen from the figure, there is slightly the exponential growth of the interface-state density from midgap towards the top of the valence band. That is, the x-ray radiation exposure has not varied considerably the characteristics parameters of the structures over the range up to the x-ray energy of 50 keV. Others [19-21] reported that the particle and photon irradiation (γ-ray) deteriorate the metal semiconductor interface of Schottky structures by resulting higher ideality factor and series resistance with increasing irradiation energy because of the generation of irradiation induced defects at the interface. But, characteristics parameters such as barrier height, ideality factor and series resistance of the Polypyrrole/*p*-Si structure fabricated in this study are not affected by x-ray irradiation exposure. We think that the irradiation induced defects can not form between polymer semiconductor interface up to 50 keV energy. In conclusion, we have demonstrated that the Polypyrrole/*p*-Si diode structure is safely used as devices in irradiative environments having photon energy of 50 keV.

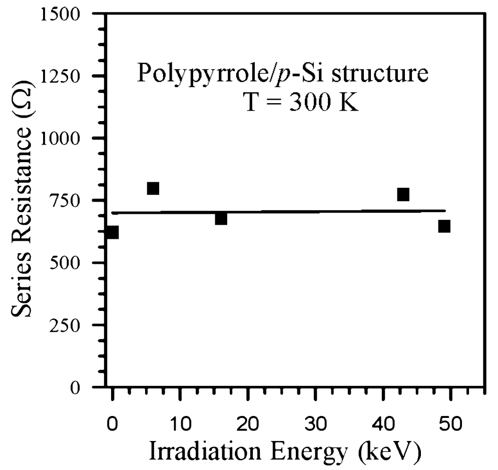

Fig. 3 Series resistance versus irradiation energy.

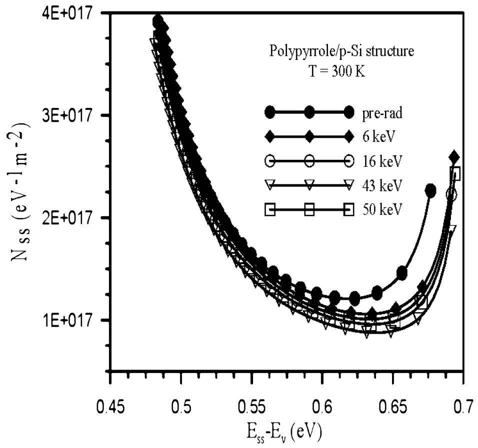

Fig. 4 The energy distribution curves of the interface states obtained from the forward bias *I-V* characteristics with increasing irradiation energy.

4. REFERENCES

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