

Temperature dependent current-voltage (I-V) characteristics of Au/n-Si (111) Schottky barrier diodes (SBDs) with polyvinyl alcohol (Co, Ni -Doped) interfacial layer

T. TUNÇ*, İ. DÖKME^a, Ş. ALTINDAL^b, İ USLU^c

Science Education Department, Faculty of Education, Aksaray University, Aksaray, Turkey

^aScience Education Department, Faculty of Gazi Education, Gazi University, Ankara, Turkey

^bPhysics Department, Faculty of Arts and Sciences, Gazi University, Ankara, Turkey

^cChemistry Education Department, Faculty of Education, Selçuk University, Konya, Turkey

Current-voltage (I-V) characteristics of Au/PVA(Co,Ni-doped)/n-Si (111) SBDs have been investigated in the temperature range of 280-400 K. The zero-bias barrier height (Φ_{B0}) and ideality factor (n) determined from the forward bias I-V characteristics were found strongly depend on temperature. The forward bias semi-logarithmic I-V curves for the different temperatures have an almost common cross-point at a certain bias voltage. While the value of n decreases, the Φ_{B0} increases with increasing temperature. Therefore, we attempted to draw a Φ_{B0} vs $q/2kT$ plot to obtain evidence of a Gaussian distribution of the barrier heights, and to calculate the values of mean barrier height and standard deviation at zero bias, respectively.

(Received June 09, 2010; accepted July 14, 2010)

Keywords: I-V characteristics, Ideality factor, Barrier height, Interface states

1. Introduction

Conducting polymers have generated a great interest owing to most attention for possible application in molecular electronic devices because of their unique properties and versatility [1-5]. Among these polymers is Poly (vinyl alcohol) (PVA) which is a water-soluble polymer produced industrially by hydrolysis of poly (vinyl acetate) [6-8]. It has been used in fiber and film products for many years. It has also a widespread use as a paper coating, adhesives and colloid stabilizer. Recently, metal/organic semiconductor Schottky junction became an attractive as an alternate to the metal/inorganic semiconductor junction. Schottky contacts play an important role in the performance of semiconductor devices. Nonetheless, the study of interface states is important for the understanding of the electrical properties of Schottky contacts. The transport properties of Schottky junctions are defined by the barrier height at the junction and by electronic states in the forbidden gap of the semiconductor [9-13]. The barrier height depends on the surface work functions of the metal and semiconductor as well on dipoles in the interface region. In this study, we have fabricated Au/ polyvinyl alcohol (Co,Ni-doped)/n-Si Schottky diodes and current-voltage (I-V) characteristics and interfacial properties of the diode have been investigated. Polyvinyl alcohol (PVA) film was used as an interfacial layer between metal and semiconductor. PVA doped with different ratio of cobalt and nickel was produced and PVA /(Co, Ni) nanofiber film on silicon

semiconductor were fabricated by the use of electrospinning technique. In this work, we report on extraction of interface state density of Au/ polyvinyl alcohol (Co,Ni-doped)/n-Si Schottky diodes using the current-voltage (I-V) characteristics in the wide temperature range of 280-400 K. The other purpose of this paper is the calculation of the characteristics parameters such as ideality factor, barrier height, density of interface states and series resistance of Au/ polyvinyl alcohol (Co,Ni-doped)/n-Si Schottky diodes obtained from I-V characteristics at room temperature. In the previous study, we have fabricated Au/polyvinyl alcohol (Ni, Zn-doped)/n-Si Schottky diodes and temperature dependent electrical and dielectric properties of the diode were calculated from the capacitance-voltage (C-V) and conductance-voltage (G/w-V) measurements in the temperature range of 80-400 K. [14].

2. Experimental

The Au/ polyvinyl alcohol (Co, Ni-doped)/n-Si Schottky diodes were fabricated on the n-type (phosphor doped) Si single crystals, with a (111) surface orientation, 350 μm thick, 2 inch (5.08 cm) and 0.7 $\Omega\text{-cm}$ resistivity. For the fabrication process, Si wafer was degreased in a mix of a peroxide- ammoniac solution in 10 minute and then in $\text{H}_2\text{O} + \text{HCl}$ solution and then was thoroughly rinsed in deionised water using an ultrasonic bath for 15 min. Preceding each cleaning step, the wafer was rinsed

thoroughly in de-ionized water of resistivity of $18 \text{ M } \Omega \text{ cm}$ for a prolonged time. After surface cleaning, high purity aluminium (Al) metal (99.999%) with a thickness of 2000 \AA was thermally evaporated on to the whole back surface of the Si wafer at a pressure about 10^{-6} Torr in high vacuum system. The ohmic contacts were formed by annealing them for 5 minutes at 450°C in N_2 atmosphere. 0.5 g of cobalt acetate and 0.25 g of nickel acetate was mixed with 1 g of polyvinyl Alcohol (PVA), molecular weight=72 000 and 9 ml of deionised water. After vigorous stirring for 2 h at 50°C , a viscous solution of PVA/(Co, Ni-doped) acetates was obtained. PVA(Co, Ni-doped) nanofiber film was fabricated on n-type Si by electrospinning technique[15,16]. The electrospinning system is composed (i) A high voltage power generator (ii) A syringe (iii) A collector made of a metallic material and (iv) A dosage pump (new era pump systems). The composite solution for spinning was loaded in to a 10 mL hypodermic stainless steel syringe with a needle (0.8 mm in diameter and 38 mm length) connected to a digitally controlled pump(New Era) which provides a constant flow rate of 0.02 ml/h . The metal tip of the syringe is connected to the power supply (SP-30P, Gamma High Voltage Research) and the other end is connected to the collector wrapped with Al folio. Si wafer was placed on the aluminum foil. The distance between the metal tip and the collected was kept 15 cm . Upon applying a high voltage of 20 kV on the needle, a fluid jet was ejected from the tip. The solvent evaporated and a charged fiber was deposited on to the Si wafer as a nonwoven mat. After spinning, the Schottky/rectifier contacts were coated by evaporation with Au dots with a diameter of about 1.0 mm (diode area= $7,85 \times 10^{-3} \text{ cm}^2$). A simple illustration of the electrospinning system is given in Fig. 1. The current-voltage (I-V) measurements were performed by the use of a Keithley 220 programmable constant current source, a Keithley 614 electrometer. All measurements were carried out with the help of a microcomputer through an IEEE-488 ac/dc converter card at room temperature.

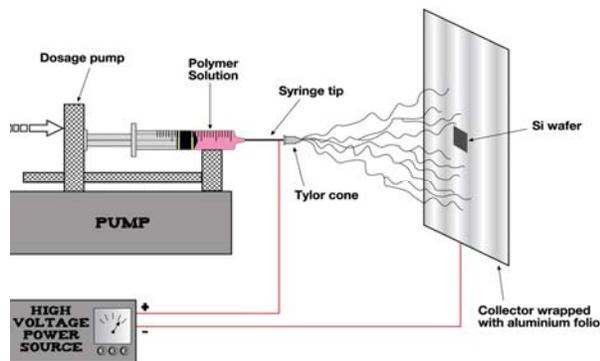


Fig. 1. Schematic representation of the electrospinning process.

3. Results and discussion

The current through a Schottky barrier diode at a forward bias 'V', based on the thermionic emission theory ($V \geq 3kT/q$), is given by the relations [2].

$$I = I_0 \exp\left(\frac{q(V - IR_s)}{nkT}\right) \left[1 - \exp\left(-\frac{q(V - IR_s)}{kT}\right)\right] \quad (1)$$

where R_s is the series resistance, V the applied voltage, n the ideality factor, q the electronic charge, k the Boltzmann constant, T is the absolute temperature in Kelvin and I_0 is the reverse saturation current and can be written as

$$I_0 = AA^*T^2 \exp\left(-\frac{q\Phi_{B0}}{kT}\right) \quad (2)$$

where Φ_{B0} is the zero-bias barrier height, A is the diode area, A^* is the effective Richardson constant and equals to $120 \text{ A/cm}^2 \text{ K}^2$ for n-type Si. The ideality factor is calculated from the slope of the linear region of the forward bias $\ln I$ - V plot and can be written from Eq. (1) as

$$n = \frac{q}{kT} \left(\frac{dV}{d(\ln I)} \right) \quad (3)$$

The zero-bias barrier height Φ_{B0} is determined from the extrapolated I_0 , and is given by

$$\Phi_{B0} = \frac{kT}{q} \ln \left[\frac{AA^*T^2}{I_0} \right] \quad (4)$$

The semi-logarithmic I-V characteristic of the Au/PVA (Co, Ni-doped)/n-Si Schottky diode, measured at different temperatures over the range 280 – 400 K are shown in Fig.2. As can be seen in Fig.2, the forward and reverse bias currents of the diode increase with increase of temperature due to the increase in the numbers of carrier charges across the barrier height. This suggests that the carrier charges are effectively generated in the junction with temperature. It is seen that the temperature can improve the reverse and forward performance of the diode. The forward bias I-V characteristic is exponential at low bias voltages. But, at higher voltages, a deviation in I-V characteristic is observed due to series resistance and interfacial layer. The values of zero-bias barrier height Φ_{B0} and ideality factor (n) were calculated from Eqs. (3) and (4) for each temperature, respectively.

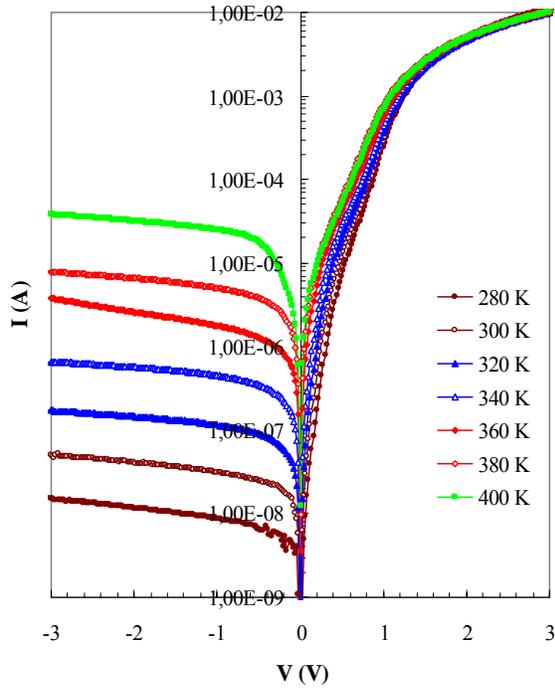


Fig. 2. The experimental forward bias I-V characteristics of the Au/ PVA (Co, Ni-doped)/n-Si Schottky diodes at various temperatures.

As shown in Table 1, the experimental values of Φ_{B0} and n for the Au/ PVA (Co, Ni-doped)/n-Si Schottky diode ranged from 0.908 eV and 1.51 (at 400 K) to 0.747 eV and 2.13 (at 280 K), respectively.

Table 1. Temperature dependent values of various diode parameters determined from I-V characteristics of Au/ PVA (Co, Ni-doped)/n-Si Schottky diodes in the temperature range of 280-400 K.

T(K)	I_0 (A)	n	Φ_{B0} (eV)	Φ_{Bf} (eV)
280	$2,72 \times 10^{-9}$	2,13	0,7470	1,362
300	$9,76 \times 10^{-9}$	2,09	0,7709	1,372
320	$1,90 \times 10^{-9}$	1,83	0,8074	1,283
340	$5,06 \times 10^{-8}$	1,70	0,8327	1,243
360	$1,81 \times 10^{-7}$	1,62	0,8458	1,208
380	$3,97 \times 10^{-7}$	1,55	0,8705	1,195
400	$5,54 \times 10^{-7}$	1,51	0,9084	1,225

As shown in Fig. 3 and 4, the values of n and Φ_{B0} determined from semi-logarithmic forward bias I-V characteristics are strong function of temperature. The obtained results from I-V characteristics show that there is a decrease in Φ_{B0} and an increase in the ideality factor with decreasing temperature. Similar results have been reported in the literature [11].

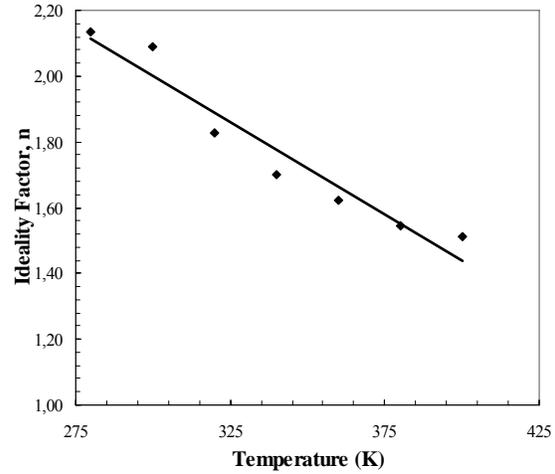


Fig. 3. The variation in the ideality factor with temperature for Au/ PVA (Co, Ni-doped)/n-Si Schottky diodes.

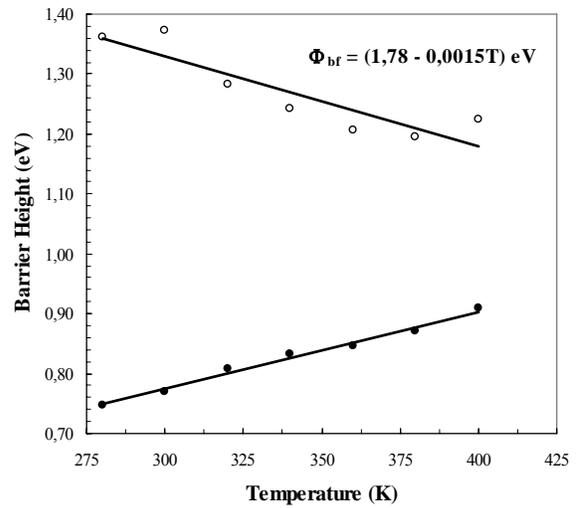


Fig. 4. Temperature dependence of zero-bias barrier height and flat-band barrier height for Au/ PVA (Co, Ni-doped)/n-Si Schottky diodes.

Also, It is seen from Fig. 4, the flat band barrier height Φ_{bf} can be calculated from the experimental ideality factor and zero-bias BH Φ_{B0} according to [9, 17-19].

$$\Phi_{bf} = n\phi_{B0} - (n-1) \frac{kT}{q} \ln \left(\frac{N_C}{N_D} \right) \quad (5)$$

where N_C is the effective density of states in the conductivity band, and N_D is the carrier doping density of n-type Si with $5.86 \times 10^{15} \text{ cm}^{-3}$. As shown in Fig. 2, the temperature dependence of the flat band BH can be expressed as

$$\Phi_{bf}(T) = \Phi_{bf}(T=0) + \alpha T \quad (6)$$

where Φ_{bf} is the flat band BH extrapolated to $T = 0$ K, and α is its temperature coefficient. The obtained experimental values, Φ_{B0} , Φ_{bf} and n were reported in Table 1. This result is attributed to inhomogeneous interfaces and barrier heights. Also Schmitsdorf et al. [20] used Tung's theoretical approach and they found a linear correlation between the experimental zero-bias SBHs and ideality factors. Fig. 5 presents the barrier height versus the ideality factor for various temperatures. As shown in Fig. 5, shows a plot of the experimental BH versus the ideality factor for various temperatures. The straight line in Fig. 5 is the least squares fit to the experimental data. It is seen from Fig. 5, there is a linear relationship between the experimental effective BHs and the ideality factors of the Schottky contact that was explained by lateral inhomogeneities of the BHs in the Schottky diode.

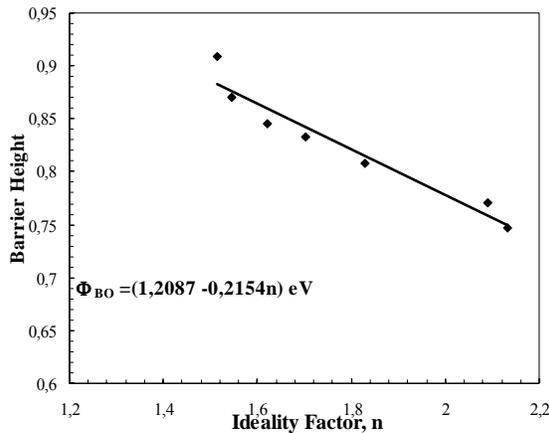


Fig. 5. Linear variation of apparent barrier height vs. ideality factor.

The extrapolation of the experimental BHs versus ideality factors plot to $n = 1$ has given a homogeneous BH of approximately 0.993 eV. Thus, it can be said that the significant decrease of the zero-bias BH and increase of the ideality factor especially at low temperature are possibly caused by the BH inhomogeneities.

4. Conclusions

The current conduction mechanism across Au/ PVA (Co, Ni-doped)/n-Si Schottky diode have been investigated using forward bias I-V measured in the temperature range of 280–400 K. The basic diode parameters such as the ideality factor and barrier height were extracted from electrical measurements of Au/ PVA (Co, Ni-doped)/n-Si Schottky diode. The ideality factor of Au/ PVA (Co, Ni-doped)/n-Si Schottky diodes decreased with the increase in temperature but the barrier height

increased. The changes are quite significant at low temperatures. Temperature dependence behaviour of Φ_{B0} (I-V) and n is attributed to Schottky barrier inhomogeneities by assuming a GD of BHs due to barrier inhomogeneities that prevail at M/S interface.

References

- [1] R. K. Gupta, R. A. Singh, Materials Chemistry and Physics **86**, 279 (2004).
- [2] V. C. Nguyen, K. Potje-Kamloth, Thin Solid Films **338**, 142 (1999).
- [3] Li-Ming Huang, Ten-Chin Wen, A. Gopalan, Thin Solid Films **473**, 300 (2005).
- [4] Ş. Aydoğan, M. Sağlam, A. Türit, Polymer **46**, 563 (2005).
- [5] K. R. Rajesh, C. S. Menon, Journal of Non-Crystalline Solids **353**, 398 (2007).
- [6] N. Bouropoulos, G. C. Psarras, N. Moustakas, A. Chrissanthopoulos, and S. Baskoutas, Phys. Stat. Sol. (a) **205**, 2033 (2008).
- [7] S. M. Pawde, Kalim Deshmukh, Sanmesh Parab, Journal of Applied Polymer Science **109**, 1328 (2008).
- [8] A. H. Salama, M. Dawy, A. M. A. Nada, Polymer-Plastics Technology And Engineering **43**, 1067 (2004).
- [9] İ. Dökme, I. M. Afandiyeva, Ş. Altındal, Semiconductor Science and Technology **23**, Article Number: 035003 (2008).
- [10] İ. Dökme Physica B: Condensed Matter **388**, 2007.
- [11] İ. Dökme, Ş. Altındal, Physica B: Condensed Matter **391**, 59 (2007).
- [12] İ. Dökme, Ş. Altındal, Physica B Condensed Matter **393**, 328 (2007).
- [13] İ. Dökme, Ş. Altındal, Semiconductor Science and Technology **21**, 1053 (2006).
- [14] İ. Dökme, Ş. Altındal, T. Tunç, İ. Uslu, Microelectronics Reliability **50**, 39 (2010).
- [15] İ. Uslu, B. Başer, A. Yaylı, M.L. Aksu, e-Polymers **145**, (2007).
- [16] İ. Uslu, H. Daştan, A. Altaş, A. Yaylı, O. Atakol, M. L. Aksu, e-Polymers **133**, (2007).
- [17] K. Akkılıç, F. Yakuphanoglu, Microelectronic Engineering **85**, 1826 (2008).
- [18] L. F. Wagner, R. W. Young, A. Sugermen, IEEE Electron. Dev. Lett. **4**, 320 (1983).
- [19] İ. Dökme, Ş. Altındal, M. Mahir Bülbül, Applied Surface Science **252**, 7749 (2006).
- [20] R. F. Schmitsdorf, T. U. Kampen, W. Mönch, Surf. Sci. **324**, 249 (1995).

*Corresponding author: tctunc@gmail.com