Special issue of the 3rd International Conference on Computational and Experimental Science and Engineering (ICCESEN 2016)

The Role of Hydrostatic Pressure in Electrical Properties of Au/n-GaAs Schottky diodes with Substituted Polyaniline Interfacial Layer

A.F. Özdemir[a], M. Abdolahpour Salari[b,*], A. Kökce[a] and N. Uçar[a]

[a]Süleyman Demirel University, Physics Department, Isparta, Turkey

[b]Atatürk University, Physics Department, Erzurum, Turkey

Au/polymer P2ClAn(H_3BO_3)/n-GaAs Schottky barrier diodes, where P2ClAn stands for poly(2-chloroaniline), have been fabricated. To fabricate Schottky diodes with polymer interface, n-type GaAs wafer was used. The P2ClAn polymer solution was applied on the front face of the n-GaAs wafer by a pipette. The P2ClAn emeraldine salt was chemically synthesized by using boric acid (H_3BO_3). Schottky diode parameters, such as ideality factor, barrier height and series resistance have been measured, as functions of hydrostatic pressure, using the current-voltage technique. The ideality factor values of Au/P2ClAn/n-GaAs Schottky barrier diodes have decreased from 3.38 to 3.01, the barrier height has increased from 0.653 to 0.731 eV at 0.36 kbar and series resistances were ranging from 14.95 to 14.69. The results obtained from $I-V$ characteristics of Au/P2ClAn/n-GaAs Schottky barrier diodes show that pressure treatment improves the rectifying properties of the diodes. These diodes can be used as pressure-sensitive capacitors, due to pressure-dependence of diode parameters.

DOI: 10.12693/APhysPolA.132.1118

PACS/topics: 73.40.Kp, 73.20.At, 74.62.Fj

1. Introduction

The metal-semiconductor (MS) contact in the semiconductor device technology is still investigated and has attracted much attention during recent years [1–3]. The performance and stability of MS is of great importance for the electronic devices [4–6]. MS contacts have an important role in the development of semiconductor industry, due to their applications in various electronic and optoelectronic devices [7]. The parameters which characterize such contacts depend on the methods used during the fabrication [8].

Schottky contacts play an important role in the performance of semiconductor devices, for various electronic and optoelectronic applications [9, 10]. Because of their technological importance, the properties of these contacts have been studied using a variety of techniques, involving the capture or the emission of charge carriers such as $I-V$ and $C-V$ measurements, deep level transient spectroscopy and admittance spectroscopy [11].

The Schottky barrier height Φ_b, the ideality factor n, series resistance R_s and the interface state density NSS are the fundamental parameters of the Schottky barrier diodes (SBDs). It is well known that, the Rs of the neutral region of the semiconductor bulk (between the depletion region and ohmic contact), apart from n and Φ_b, is an important parameter, which causes the electrical characteristics of SBDs to be non-ideal [12, 13]. For this reason, studies on these diode parameters, especially as functions of temperature, are routinely made in SBDs. The non-ideal behavior, observed in electrical characteristics of SBDs, has been attributed to the effect of R_s, as well as to interface state energy distribution [14]. On the other hand, it has been shown that the investigation of temperature dependence of Φ_b is very helpful for understanding the problem of Fermi level pinning [15, 16].

Recently, hydrostatic pressure as well as the temperature dependencies of SBDs have been investigated in order to study the optical and electrical properties of SBDs. Uçar et al. [16] showed that the hydrostatic pressure treatment improves the rectifying properties of Au/n-InP Schottky diodes. The barrier height increases with increasing hydrostatic pressure and the Fermi level is a reference level which is pinned to the valence band maximum, as a function of pressure. In addition, Pb/p-Si Schottky diode under hydrostatic pressure shows nonideal current-voltage behavior, with an ideality factor greater than unity, that can be ascribed to the interfacial layer and the interface states. In addition, Φ_b increases with a linear pressure coefficient of 92 meV/kbar, which is higher than the pressure coefficient of the silicon fundamental band gap [17].

Semiconductor polymers are molecular analogs of inorganic semiconductors and metals. Some of these are polypyrrole, polyaniline, polythiophene, and other conjugated polymers [18, 19]. Owing to the technological importance of contacts in the electronics industry, many experimental and theoretical efforts have been devoted to contact properties of polymer/inorganic semiconductor and metal/semiconductor polymer contacts. It has been shown that Φ_b increases from 0.63 eV to 0.72 eV with increasing hydrostatic pressure, whereas n decreases in Al/conducting polymer (P3DMTPT)/p-Si/Al

*corresponding author; e-mail: m.salari@atauni.edu.tr

structure [20]. Although enormous amount of information on SBDs has been gained, little is known about the effect of pressure on these diodes. In this paper, we report the effect of hydrostatic pressure on Φ_b and n of Au/P2ClAn(H_3BO_3)/n-GaAs SBDs.

2. Experimental

In this study, to fabricate Schottky diode with a polymer interface, n-type GaAs wafer with (100) orientation and carrier concentration of $2-5\times10^{17}$ cm^{-3} was used. The wafer was dipped into $5H_2SO_4$+H_2O_2+H_2O solution for 1.0 min and then into H_2O+HCl solution, to remove surface damaged layer and the undesirable impurities and then rinsed in de-ionized water, of 18 MΩ.

Immediately after the etching process, after removing water using high purity nitrogen, wafer was inserted into the deposition chamber. Au-Ge (88% and 12%) was evaporated on the back of the wafer in a vacuum-coating unit of 10^{-5} Torr. Then low resistance ohmic contact was formed by thermal annealing at 450 °C for 3 min in flowing N_2 environment, in a quartz-tube furnace.

The P2ClAn polymer solution was applied on the front face of the n-GaAs wafer by a pipette. The preparation of the P2ClAn(H_3BO_3) polymer and its molecular structure is described in detail in [21]. Finally, in order to realize Schottky contact, Au was evaporated on the polymer layer, deposited on the front face of the n-GaAs wafer. The surface area of Schottky contact formed in Au/P2ClAn/n-GaAs structure was 1.8×10^{-2} cm^2. The dark current-voltage measurements were made using a HP 4140 picoammeter/voltage source at room temperature.

3. Results and discussion

The $I-V$ data was analyzed under the assumption that the dominant current transport mechanism is thermionic emission. According to this theory, the $I-V$ relationship of a Schottky diode is given by [1, 22–24]:

$$I = I_s \exp\left(\frac{qV}{nkT}\right)\left[1-\exp\left(-\frac{qV}{kT}\right)\right], \tag{1}$$

where q is the electronic charge, k is the Boltzmann constant, T is the temperature, V is the applied voltage and n is the ideality factor, which is given by:

$$n = \frac{q}{kT}\left[\frac{\partial V}{\partial(\ln I)}\right], \tag{2}$$

In Eq. (1), I_s is the saturation current, derived from the straight line intercept of $\ln I$ at $V=0$ and is given by:

$$I_s = AA^*T^2\exp\left[\frac{-q\Phi_b}{kT}\right], \tag{3}$$

where A is the effective diode area and A^* is the effective Richardson constant of 8.16 A/cm^2 K^2, for n-GaAs. The $I-V$ characteristics of Au/semiconductor polymer (P2ClAn)/n-GaAs versus hydrostatic pressure, under room temperature condition are shown in Fig. 1.

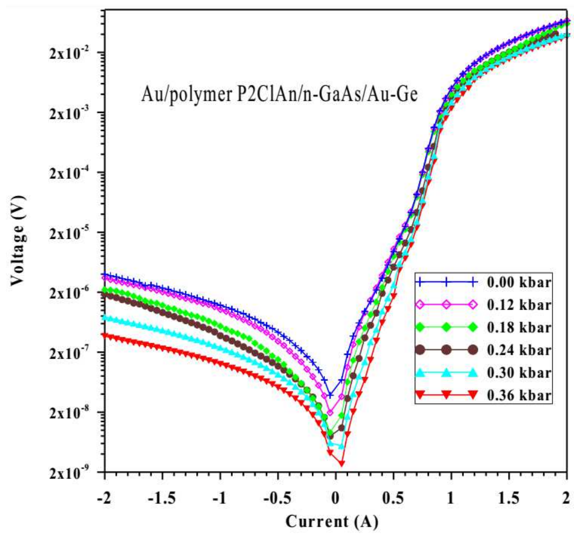

Fig. 1. The forward and reverse bias current versus voltage of Au/polymer P2ClAn/n-GaAs SBDs at several values of hydrostatic pressure.

The values of n are obtained using Eq. (2) from the linear region of these plots, indicating that effect of the series resistance R_s in the linear region is not important (Fig. 1). This R_s is the sum of the neutral bulk and ohmic contact resistance.

On the other hand, on the basis of thermionic emission theory, Φ_b is calculated with Eq. (3) from the y-axis intercepts of the semi logarithmic forward bias $I-V$ plots. As expected, the $I-V$ characteristics were not perfectly linear, and showed a downward curvature at high voltage, due to interface state density and bulk series resistance (Fig. 1).

For $\partial V/\partial(\ln I) = nkT/q + IR_s$, series resistance is determined using conventional forward bias $I-V$ characteristics, the Cheung method, and Norde's function [12]. The values of Φ_b, n and R_s, calculated under different hydrostatic pressures, are given in Table I.

TABLE I

The experimentally obtained n, Φ_b and R_s of Au/polymer P2ClAn/n-GaAs SBDs, as functions of hydrostatic pressure.

Pressure [kbar]	n	Φ_b [eV]	R_s
0.00	3.38	0.653	14.95
0.12	3.36	0.660	14.93
0.18	3.25	0.670	14.90
0.24	3.18	0.693	14.82
0.30	3.09	0.714	14.75
0.36	3.01	0.731	14.69

From Table I, Au/P2ClAn/n-GaAs SBDs show non ideal behaviour with an ideality factor greater than one. The n values of Au/ P2ClAn/n-GaAs SBDs are ranging from 3.38 to 3.01, indicating that the devices obey a metal-interface layer-semiconductor configuration rather than that of ideal SBDs. In addition, from Table I, the Φ_b value has increased from 0.653 to 0.731 eV at 0.36 kbar in Au/P2ClAn/n-GaAs SBDs. The pressure dependence of Φ_b can be explained as due to lateral inhomogeneities in local Φ_b as temperature dependence of Φ_b. By the way, this behavior of n and Φ_b under hydrostatic pressure is similar with the behavior of Al/P2ClAn/p-Si/Al [25], Al/conducting polymer (P3DMTPT)/p Si/Al [20], and Au/n-InP [17] SBDs.

Figure 2 shows hydrostatic pressure dependence of Φ_b and n for Au/P2ClAn/n-GaAs structure. From the figure, Φ_b increases with increasing pressure and n decreases with increasing pressure.

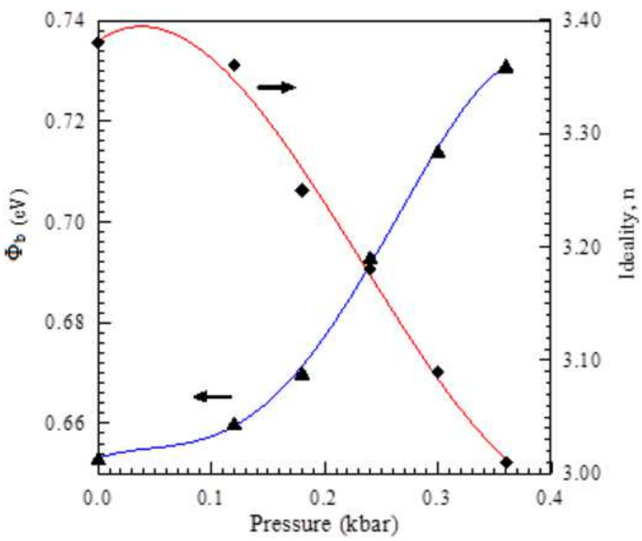

Fig. 2. Variation of zero bias barrier height and ideality factor of Au/P2ClAn/n-GaAs structure with the hydrostatic pressure.

The variation in Φ_b with pressure was fitted with the equation,

$$\Phi_b(P) = \Phi_b(0) + \alpha P, \quad (4)$$

where $\alpha = 220$ meV/kbar is the pressure coefficient of Φ_b. In early studies, the pressure coefficients of Au/n-GaAs [26], Cd/p-GaTe [27], Sn/p-Si [28] and Al/conducting polymer (P3DMTPT)/p-Si/Al [20] have been found to be 11.21 meV/kbar, -877 meV/kbar, 5.16 meV/kbar and 16.3 meV/kbar, respectively. The obtained pressure coefficient does not indicate whether the Fermi level is a reference level, which is pinned to the valence band maximum with the increasing pressure, as is indicated in the MIGSs model.

Now let us consider the relation between the R_s and the hydrostatic pressure in Au/polymer P2ClAn/n-GaAs SBDs. As seen from Table I, the R_s values show a very small decrease with increasing hydrostatic pressure. This behavior was attributed to the pressure restructuring and reordering of the interface.

4. Conclusions

The Au/polymer P2ClAn/n-GaAs structure shows a rectifying behaviour. The results obtained from $I-V$ characteristics of Au/polymer P2ClAn/n-GaAs SBDs show that Φ_b increases with the increasing hydrostatic pressure, whereas n decreases. This result shows that diode quality improves with the increasing hydrostatic pressure. However, the obtained n values indicate that the diodes behave according to metal–interface layer–semiconductor configuration, rather than according to ideal SBDs configuration.

Acknowledgments

We thank Dr. Aysegül Öksüz for her contribution by synthesizing polymer P2ClAn(H_3BO_3).

References

[1] S.M. Sze, *Physics of Semiconductor Devices*, 2nd ed., Wiley, New York 1981.

[2] E.H. Rhoderick, R.H. Williams, *Metal-Semiconductor Contacts*, 2nd ed., Oxford University Press, Oxford 1988.

[3] J.H. Warner, U. Rau, in: *Springer Series in Electronics and Photonics*, J.F. Luy, P. Russer (Eds.), vol. 32, 1994.

[4] M. Ahmetoğlu, A. Kara, B. Kucur, *Acta Phys. Pol. A* **130**, 206 (2016).

[5] Ç.Ş. Güçlü, A.F. Özdemir, A. Kökçe, Ş. Altindal, *Acta Phys. Pol. A* **130**, 325 (2016).

[6] S. Kaci, A. Kwffous, I. Bozetine, M. Trari, O. Fellahin, *Acta Phys. Pol. A* **130**, 463 (2016).

[7] A. Umapathi, V. Rajagopal Reddy, *Microelectron. Eng.* **114**, 31 (2014).

[8] M. Siada, A. Keffousb, S. Mammaa, Y. Belkacemb, H. Menari, *Appl. Surf. Sci.* **236**, 366 (2004).

[9] H. Serrar, R. Labbani, C. Benazzouz, *Acta Phys. Pol. A* **130**, 51 (2016).

[10] S. Salleh, H.F. Abdul Amir, A. Kumar Tiwari, F. Pien Chee, *Acta Phys. Pol. A* **130**, 93 (2016).

[11] I.A. Cola, M.G. Lupo, L. Vasanelli, A. Valentini, *Solid-State Electron.* **36**, 785 (1993).

[12] S.K. Cheung, N.W. Cheung, *Appl. Phys. Lett.* **49**, 85 (1986).

[13] H. Norde, *J. Appl. Phys.* **50**, 5052 (1979).

[14] E. Ayyildiz, C. Temirci, B. Bati, A. Turut, *Int. J. Electron.* **88**, 625 (2001).

[15] S. Kumar, Y.S. Katharria, S. Kumar, D. Kanjilal, *Solid-State Electron.* **50**, 1835 (2006).

[16] N. Ucar, A.F. Ozdemir, D.A. Aldemir, S. Cakmak, A. Calik, H. Yildiz, F. Cimilli, *Superlattices Microstruct.* **47**, 586 (2010).

[17] N. Ucar, A. Faruk Ozdemir, D.A. Aldemir, G. Cankaya, *Z. Naturforsch.* **66**, 576 (2011).

[18] A. Turut, F. Koleli, *J. Appl Phys.* **72**, 818 (1992).

[19] S. Aydogan, M. Saglam, A. Turut, *J. Polym. Sci.: Part B* **44**, 1572 (2006).

[20] N. Ucar, A.F. Ozdemir, A. Calik, A. Kokce, *Superlattices Microstruct.* **49**, 124 (2011).

[21] A. Gök, B. Sarı, *J. Appl. Polym. Sci.* **84**, 1993 (2002).

[22] R.H. Williams, G.Y. Robinson, *Physics and chemistry of III–V compound semiconductor interfaces*, in: C.W. Wilmsen (Ed.), Plenum Press, New York 1985.

[23] E.H. Rhoderick, R.H. Willams, *Metal-Semiconductor Contacts*, Clarendon Press, Oxford 1998.

[24] A. Ziel, *Solid State Physical Electronics*, 2nd ed., Prentice-Hall, Englewood Cliffs 1968.

[25] A.F. Özdemir, D.A. Aldemir, A. Kokce, S. Altindal, *Synthetic Metals* **159**, 1427 (2009).

[26] G. Cankaya, N. Ucar, E. Ayyildiz, H. Efeoglu, A. Turut, S. Tuzemen, Y.K. Yogurtcu, *Phys. Rev. B* **60**, 15944 (1999).

[27] G. Cankaya, B. Abay, *Semicond. Sci. Technol.* **21**, 124 (2006).

[28] M. Cakar, C. Temirci, A. Turut, G. Cankaya, *Phys. Scr.* **68**, 70 (2003).