TEMPERATURE DEPENDENCE OF ELECTRICAL CHARACTERISTICS OF Ag/n-GaAs SCHOTTKY BARRIER DIODES

A.A. ASIMOV, A.M. KERIMOVA, Kh.N. AHMEDOVA, I.A. NASIBOV
Institute of Physics of Azerbaijan NAS, AZ 1143,
H.Javid ave.,131, Baku, Azerbaijan

The electrical characteristics of Ag/ n-GaAs Schottky barrier diodes have been investigated. Measurements were carried out in the temperature range of 140-300 K. The I-V analysis based on thermionic emission (TE) theory has revealed an abnormal decrease of apparent barrier height and increase of ideality factor at low temperature region. Such behavior of barrier height (ϕ_b) and ideality factor (n) is attributed to barrier height inhomogeneities prevailing at the metal-semiconductor interface. The inhomogeneities are considered to have a Gaussian distribution with a mean barrier height of $\phi_{b\,=}$ 0,79 eV and a standard deviation of σ_{so}=0,12 V at zero bias. Moreover, Richardson constant value obtained from modified Richardson plot, $\ln(I_o/T^2)-q^2\sigma_o^2/2(kT)^2$ versus $10^3/T$ was found to be 3,51 A/K^{2}cm^2 which is much closer to the theoretical value than that obtained from conventional Richardson plot.

Keywords: Schottky barrier diode, barrier height, ideality factor, Richardson constant.
PACS: 72.10-d, 73.40 GK

INTRODUCTION

Interfaces between thin metal layers and semiconductors are used in optical detectors, solar cells [1] and chemical sensors [2-3]. The transport properties of such Schottky diodes and the dependence of the transport parameters on preparation are essential importance for the device performance. Metal-semiconductor interfaces may be characterized by photoelectrical and current-voltage ($I-V$) measurements [4-5].

Due to the technological importance of Schottky barrier diodes, a full understanding of the nature of their electrical characteristics is of greater interest [6-7]. Analysis of the current-voltage (I-V) characteristics of the Schottky barrier measured only at room temperature does not give detailed information about the conduction process and the nature of barrier formation at the metal-semiconductor (MS) interface. The temperature dependence of the I-V characteristics allows us to understand different aspects of the conduction mechanism.

Detailed knowledge of the conduction process involved is essential to extracting the barrier parameters, namely, the barrier height and ideality factor. Analysis of the I-V characteristics of SBDs based on thermionic emission theory usually reveals an abnormal decrease in the BH and an increase in the ideality factor with a decrease in temperature [8-9]. This abnormal behavior of the BH and ideality factor [8-9] have been successfully explained on the basis of a TE mechanism with Gaussian distribution of the BHs by some studies.

In this report, the I-V characteristics of the Ag/n-GaAs SBHs were measured in the temperature range of 140-300 K. The temperature dependence of the barrier height and ideality factor is discussed using TE theory with a Gaussian distribution of the barrier heights around a mean value due to BH inhomogeneities prevailing at the metal-semiconductor interface.

EXPERIMENTAL

Before the fabrication the n-GaAs wafers were chemically cleaned by methanol and acetone and then rinsed in deionized water. For the oxide present on the semiconductor, the samples were etched by H2O:HCl(1:1) solution. Then rinsed deionized water and finally samples were blown dry with nitrogen gas. After cleaning, for ohmic contact fabrication the samples were placed into the electron beam deposition system. The metal layers Ni (~10nm)/AuGe(~200nm)/Au (300nm) were evaporated at a pressure of ~5x10^{-6} torr on the backside of the samples. The samples were then annealed in a furnace for 5 minutes at 450^{o}C under N_2 gas atmosphere. For Schottky barrier diode fabrication Al and Ag metals were evaporated through a metal contact mask to give dots 2mm diameter and ~150nm thick.

RESULT AND DISCUSSION

The electrical characterizations of the device were obtained through current-voltage (I-V) measurements in the temperature range of 140-300 K. I-V characteristics of the Ag/n-GaAs Schottky barrier diode at several temperatures are shown in Fig.1.

The current through a Schottky barrier diode at a forward bias V based on the thermionic emission theory is given by the relation [10],

$$I = I_0 \exp\left(\frac{qV}{nkT}\right)\left[1-\exp\left(-\frac{qV}{kT}\right)\right] \qquad (1)$$

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

where V is the forward bias voltage, T is the absolute temperature, q is the electron charge, k is the Boltzmann constant, A is the effective diode area, $A^* = 4\pi qm^*k^2/h^3$ is the effective Richardson constant of 8,16 A/cm^2 K^2 for n type GaAs, ϕ_{bo} is the zero bias apparent barrier height (BH) and n is the ideality factor. 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

131 H.Javid ave, AZ-1143, Baku
ANAS, G.M.Abdullayev Institute of Physics
E-mail: jophphysics@gmail.com

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

The zero bias barrier height ϕ_{bo} is determined from extrapolated I_0, and is given by

$$\phi_{b0} = \frac{kT}{q}\ln\left(\frac{AA^{*}T^{2}}{I_0}\right) \qquad (4)$$

The experimental values of ϕ_{bo} and n were determined from intercepts and slopes of the forward bias *ln I* versus V plot of each temperature, respectively.

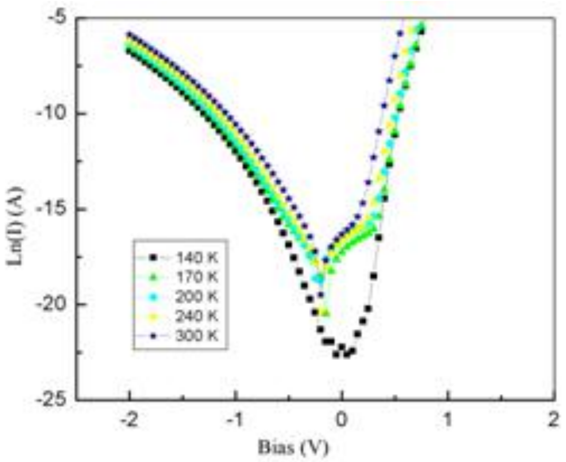

Fig.1. Experimental current-voltage characteristics of Ag/n-GaAs Schottky barrier diode at various temperatures where I_0 is the saturation current derived from the straight line intercept of *lnI* at V=0 and is given by.

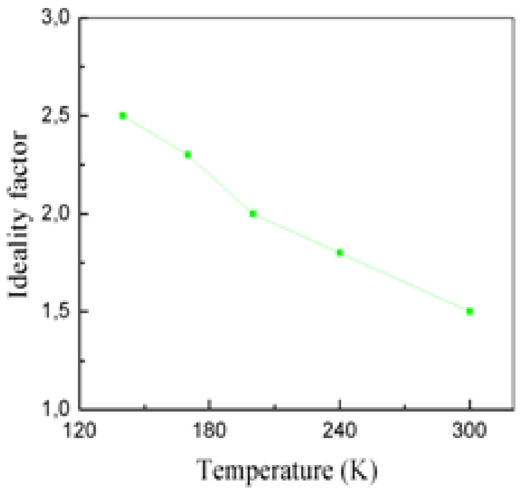

Fig.2. Temperature dependence of the ideality factor for Ag/n-GaAs Schottky diode in the range 140-300 K.

The ϕ_{bo} and n were found to be a strong function of temperature. The ideality factor n was found to increase, while the ϕ_{b0} decrease with decreasing temperature as can be seen in Figs. 2 and 3. (n=2,5 and ϕ_{bo}=0,43 eV at 140 K, n= 1,5 and ϕ_{bo}=0,65 eV at 300K)

As explained in [11-13], once current transport across the metal-semiconductor (MS) interface is a temperature-activated process; the electrons at low temperatures are able to surmount the lower barriers and therefore current transport will be

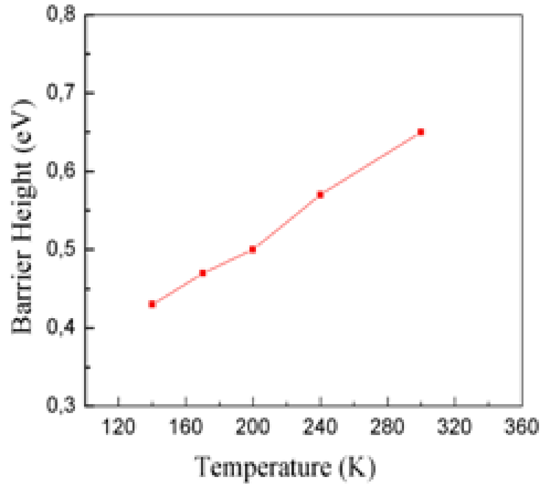

Fig.3. Temperature dependence of the zero-bias apparent barrier height for Ag/n-GaAs Schottky diode

dominated by current owing through the patches of lower Schottky barrier height and a larger ideality factor. As a result, the dominant barrier height will increase with the temperature and bias voltage. An apparent increase in the ideality factor and a decrease in the barrier height at low temperatures are possibly caused by other effects such as inhomogeneities of thickness and non-uniformity of the interfacial charged. This gives rise to an extra current such that the overall characteristics still remain consistent with the TE process[14]. This result is attributed to inhomogeneous interfaces and barrier heights because of a linear relationship between the barrier height and ideality factor.

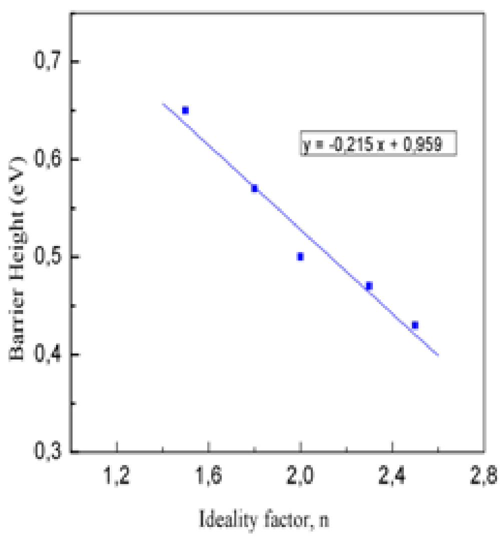

Fig.4. Zero-bias apparent barrier height vs. ideality factor of a Ag/n-GaAs Schottky diode at different temperatures.

Figure 4 shows a plot of the experimental BH versus the ideality factor for various temperatures. As can be seen from Fig. 4, there is a linear relationship between the experimental effective barrier heights and the ideality factor of the Schottky contact that was explained by lateral inhomogeneities of the BHs in the Schottky diodes [13]. The extrapolation of the experimental BHs versus ideality factors plot to n=1 has given a homogeneous BH of approximately 0.74 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 barrier inhomogeneities.

The Richardson constant is usually determined from the intercept of the $\ln(I_0/T^2)$ versus 1000/T plot. Figure 5 shows the conventional energy variation of $\ln(I_0/T^2)$ against 1000/T. The non-linearity of the $\ln(I_0/T^2)$ versus 1/T plot is caused by the temperature dependence of the barrier height and ideality factor.

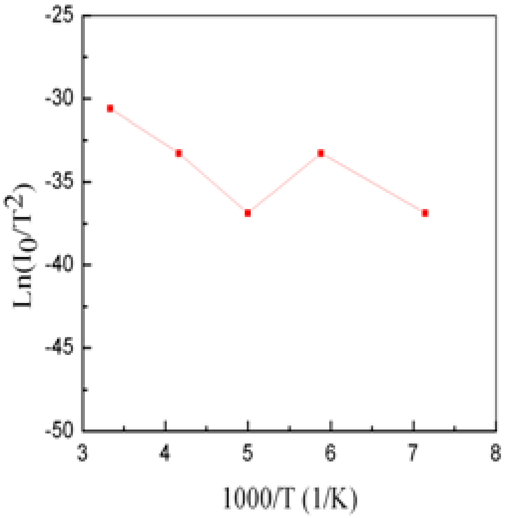

Fig.5. Richardson plot of the $\ln(I_0/T^2)$ versus 1000/T for Ag/n-GaAs Schottky barrier diode.

In order to explain the abnormal behavior between the theoretical and experimental values of Richardson constant, it is assumed that the distribution of the barrier heights is a Gaussian distribution of the barrier heights with a mean value ϕ_b and a standard deviation σ_s [8,15]

$$I(V) = A^* T^2 \exp\left[-\frac{q}{kT}\left(\phi_b - \frac{q\sigma_s^2}{2kT}\right)\right]$$

$$\times \exp\left(\frac{qV}{n_{ap}kT}\right)\exp\left[1-\exp\left(-\frac{qV}{kT}\right)\right] \qquad (5)$$

with

$$I_0 = AA^* T^2 \exp\left(\frac{q\phi_{ap}}{kT}\right) \qquad (6)$$

where n_{ap} and ϕ_{ap} are the apparent ideality factor and apparent barrier height at zero bias, respectively, and are given by

$$\phi_{ap} = \phi_{b0}(T=0) - \frac{q\sigma_{s_0}^2}{2kT} \qquad (7)$$

$$\left(\frac{1}{n_{ap}} - 1\right) = \rho_2 - \frac{q\rho_3}{2kT} \qquad (8)$$

The temperature dependence of σ_s is usually small and thus can be neglected.[9] However, it is assumed that σ_s and ϕ_b are linearly bias dependent on Gaussian parameters such that $\bar{\phi}_b = \bar{\phi}_{b0} + \rho_2 V$ and standard deviation $\sigma_s = \sigma_{s0} + \rho_3 V$, where ρ_2 and ρ_3 are voltage coefficients which may depend on T, and they quantify the voltage deformation of the BH distribution [9-17]

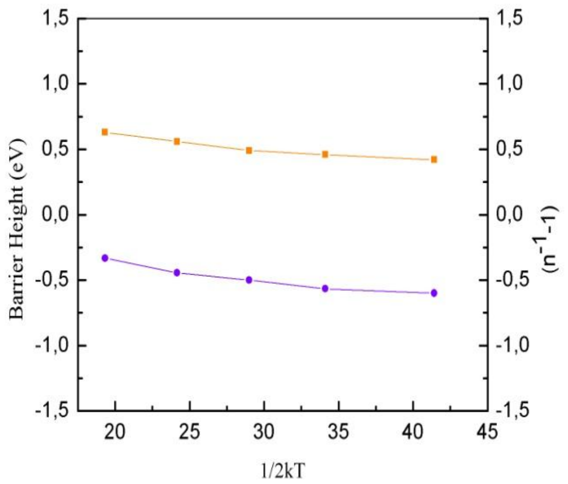

Fig.6. Zero bias apparent barrier height and ideality factor versus 1/2kT of Ag/n-GaAs Schottky barrier diode according to the Gaussian distribution of the barrier heights.

Fitting of the experimental data to Eqs. (2) and (3) gives ϕ_{ap} and n_{ap}, respectively, which should in turn obey Eqs. (7) and (8). Thus, the plot of ϕ_{ap} versus 1/2kT shown in Fig. 6 should be a straight line giving ϕ_{b0} and σ_{s0} from the vertical intercept and slope. As can be seen in Fig. 6, the values of ϕ_{bo} = 0,79 eV and σ_{so} = 0,12 V were obtained from the experimental σ_{ap} versus 1/2kT plot and in the same figure, the plot of n_{ap} versus 1/2kT should be a straight line that gives voltage coefficients ρ_2 and ρ_3 from the vertical intercept and slope, respectively. The values of ρ_2 = 0,48 V and ρ_3 = 0,027 V were obtained from the experimental n_{ap} versus 1/2kT plot. By comparing the ϕ_{b0} and σ_{s0} parameters, it is seen that the standard deviation which is a measure of the barrier homogeneity is 12% of the mean barrier height. Since the lower value of σ_{s0} corresponds to a more homogeneous barrier height, this result indicates that the Ag/n-GaAs device has larger inhomogeneities at the interface. This inhomogeneity and potential fluctuations dramatically affect low temperature I-V characteristics.

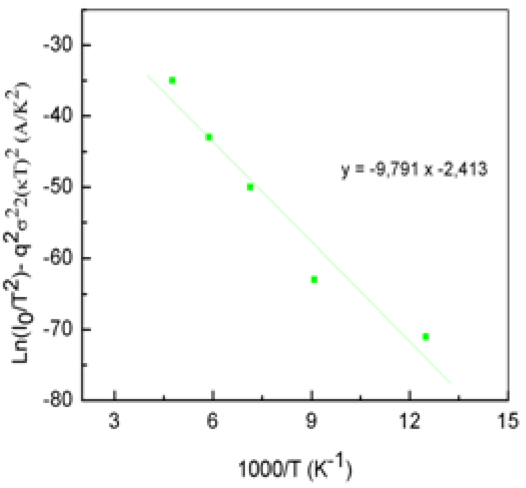

Fig.7. Modified Richardson $\ln(I_0/T^2)$-$q^2\sigma_0^2/2(kT)^2$ versus 1000/T plot for Ag/n-GaAs Schottky barrier diode according to the Gaussian distribution of the barrier heights.

The conventional Richardson plot is now modified by combining with Eqs. (6) and (7) in the following:

$$In\left(\frac{I_0}{T^2}\right)-\left(\frac{q^2\sigma_{s0}^2}{2k^2T^2}\right)=In\left(AA^*\right)-\frac{q\bar{\phi}_{b0}}{kT} \qquad (9)$$

The modified $\ln(I_0/T^2)$ - $(q^2\sigma^2_{s0}/2k^2T^2)$ versus 1000/T plot, given in Fig. 7, should give a straight line with the intercept at the ordinate determining A^*. As shown in Fig.7, the modified Richardson plot gives as A*= 3,51 A/cm^{2}K^2, without using the temperature coefficient of the barrier heights. It can be seen that the value of the modified Richardson constant A* = 3,51 A/cm^{2}K^2 is in closer agreement with the theoretical value of A*= 8,16 A/cm^{2}K^2.

CONCLUSION

The current-voltage characteristics of Ag/n-GaAs Schottky barrier diodes were measured in the temperature range of 140

-300 K. It was observed that while the zero-bias barrier height ϕ_{b0} decrease, the ideality factor n increases with a decrease in temperature. The characteristics of the structure have been interpreted on the basis of the assumption of a Gaussian distribution of barrier heights due to barrier height inhomogeneities that prevail at the interface. It was noted that barrier inhomogeneities at the interface cause deviation in the zero-bias barrier height and ideality factor at low temperatures. The inhomogeneities can be described by the Gaussian distribution of the barrier heights with a mean barrier height $\phi_{b0=}$ 0,79 eV and standard deviation σ_0= 0,12 V. The experimental results of σ_{ap} and n_{ap} fit very well with the theoretical calculations related to the Gaussian distribution of σ_{ap} and n_{ap}. The Richardson constant obtained as A*= 3,51 A/cm^{2}K^2, by means of the modified Richardson plot. This value of the Richardson constant is in close agreement with the theoretical value of 8,16 A/cm^{2}K^2.

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

[2] *H. Nienhaus, H.S. Bergh, B. Gergen, A. Majumdar, W.H. Weinberg, and E.W. McFarland.* Phys. Rev. Lett. 82, 446 (1999).

[3] *W. Göpel and K.D. Schierbaum, in Sensors, edited by W. Göpel, J. Hesse, and J.N. Zemel* (VCH, Weinheim,1991)Vol.2, p.429ff.

[4] *B.B. Kuliev, B. Lalavich, M. Yousuf, and D.M. Safarov.* Sov. Phys.Semicon. 17, 875(1983).

[5] *M. Prietsch.* Phys. Rep. 253,163 (1995).

[6] *R.T. Tung.* Mater. Sci. Eng. R35, 1 (2001).

[7] *S. Zhu, R.L. Van Meirhaeghe, C. Detavernier, G. P. Ru, B. Z. Li and F. Cardon.* Solid-State Commun. 112, 611 (1999).

[8] *Y.P. Song, R.L. Van Meirhaeghe, W.H. Laere and F. Cardon.* Solid-State Electron. 29, 633 (1986).

[9] *S. Zhu, R. L. Van Meirhaeghe, C. Detavernier, F. Cardon, G. P. Ru, X. P. Qu and B. Z. Li.* Solid-State Electron. 44, 663 (2000).

[10] *E.H. Rhoderick and R.H. Williams.* Metal{Semiconductor Contacts (Clarendon Press, Oxford, 1988).

[11] *Zs. J. Horva'th.* Solid-State Elecron. 39, 176 (1996).

[12] *S. Karata_s, S. Altindal, A. Turut and A. Ozmen.* Appl. Surf. Sci. 217, 250 (2003).

[13] *R.T. Tung.* Phys. Rev. B 45, 13509 (1992).

[14] *S. Chand and J. Kumar.* Semicond. Sci. Technol. 10, 1680 (1995).

[15] *J.H. Werner and H.H. Güttler.* J. Appl. Phys., 69, 1522 (1991)

Recevied:15.03.2018