TEMPERATURE DEPENDENT BARRIER HEIGHT IN Au/GaP SCHOTTKY BARRIER DIODES

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Au/GaP əsaslı Şottki diodları üçün 250-375K temperatur intervalında volt-amper *(I-V)* və volt-farad *(C-V)* xarakteristikaları alınmışdır. Sıfırıncı yerdəyişmə hündürlüklü maneə *(*Φ_{BO}*)*, ideallıq faktoru *(n)* və müqavimətin müxtəlif qiymətləri *(*R_s*)* üçün temperatur asılılıqları müəyyən olunmuşdur. Modifikasiya olunmuş Riçardson diaqramı A^* kəmiyyəti üçün 44,3 A/sm^{2}K^2 qiymətini verir. Alınmış A^* kəmiyyəti nəzəri kəmiyyətə yaxındır.

Для диодов Шоттки на Au/GaP были получены вольтамперные *(I-V)* и вольтфарадные *(C-V)* характеристики в температурном интервале 250-375К. Была обнаружена зависимость от температуры для высоты барьера с нулевым смещением *(*Φ_{BO}*)*, фактора идеальности *(n)* и различных значений сопротивления *(*R_s*)*. Модифицированная диаграмма Ричардсона дает для A^* значение 44,3 А/см^{2}К^2. Данные значения A^* близки к теоретическому значению.

The current–voltage (*I–V*) and capacitance-voltage (*C-V*) measurements on Au/GaP Schottky diodes in the temperature range 250–375 K were carried out. The zero-bias barrier height (Φ_{B0}), ideality factor (n) and series resistance (R_s) were found to be temperature dependent. The modified Richardson plot gives A^* as 44.3 A/cm^{2}K^2. These values of the A^* are close to the theoretical value.

1. INTRODUCTION

The formation of metal/semiconductor interfaces has ben studied intensively for long times because of their general importance for charge transport in semiconductor devices [1,2]. Recently more attention was paid also other semiconductors such as *GaP*. *GaP* is also the electronic material for green *LED*s and *UV* sensors. There are currently a vast number of reports of experimental studies of characteristic parameters such as the barrier height and ideality factor in a great variety of metal-semiconductor contacts. The most important feature characterizing a Schottky barrier is its barrier height ϕ_b [3]. In this paper, we have fabricated a vertical Schottky rectifier n-*GaP* substrate, and its temperature-dependent electrical characteristics have been studied. The temperature dependent electrical characteristics of Au/GaP heterostructure are investigated in the temperature range of 250-375 K. The experimental results revealed an increase in zero-bias barrier height, but a decrease in ideality factor with increasing temperature.

2. EXPERIMENTAL PROCEDURE

The semiconductor substrates used in this work were n-type S-doped GaP single crystals, with a (100) surface orientation, 300 μm thick. The wafer was chemically cleaned using the RCA cleaning procedure with the final dip in diluted HF for 30 s, and then rinsed in deionized water of resistivity of 18 MΩ cm with ultrasonic vibration and dried by high purity nitrogen. Immediately after surface cleaning, high purity gold (Au) metal (99.999%) with a thickness of 2000 Å was thermally evaporated from the tungsten filament onto the whole back surface of the wafer in the pressure of 1x10^{-7} Torr. Then, a low resistivity ohmic contact was followed by a temperature treatment at 500 °C for 3 min in N_2 atmosphere. The Schottky contacts were formed on the other faces by evaporating gold (Au, 99.999%) with a thickness of 1500 Å as dots with diameter of about 1.0 mm through a metal shadow mask in liquid nitrogen trapped high vacuum system in the pressure of 1x10^{-7} Torr. The I–V measurements were performed by the use of a Keithley 2400 sourcemeter. The C–V measurements were performed at 1 MHz by using HP 4192A LF impedance analyzer (5 Hz to 13 MHz). The I–V and C–V characteristics of the Au/n-GaP Schottky diode were studied in the temperature range of 250–375 K by using temperature controlled Janes vpf-475 cryostat.

3. RESULT AND DISCUSSION

The typical forward bias semi-logarithmic *I-V* characteristics of the Au/GaP Schottky barrier at different temperatures are given in Fig. 1. The structures exhibited Schottky-like current-voltage characteristics at relatively low forward current levels. The *I-V* relation for a Schottky diode based on the thermionic emission theory is given by [4]

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

where I_o is the saturation current and defined by

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

n is the ideality factor, V is the applied bias voltage, T is the absolute temperature in K, Φ_{BO} is the zero bias apparent Schottky barrier height, A is the rectifier contact area, Richardson constant (A*) is 102 A/cm^{2}K^2, q is the electron charge, k is the Boltzmann constant. Thus, the ideality factor is obtained from the slope of the straight line region of the forward bias ln*I-V* characteristics through the relation [4]

$$n = \frac{q}{kT}\frac{d(V-IR_s)}{d\ln(I)} \quad (3)$$

The saturation current I_0 was obtained by extrapolating the linear region of the ln *I-V* curve to the intercept point with the current axis at zero bias at each temperature. As shown in Fig.

2, the Φ_{BO} and n determined from semilog-forward $I–V$ plots were found to be a strong function of temperature. The ideality factor n was found to increase, while the Φ_{BO} decreases with decreasing temperature (n = 1.39 and Φ_{BO} = 0.75 eV at 250, n = 1.16 and Φ_{BO} = 0.82 eV at 375 K). As explained in [5] the current transport across the metal-semiconductor interface is a temperature activated process, the current flow will be dominated by the current flowing through those patches of low SBH at low temperatures, as shown inset Fig. 1. As the temperature increases, more and more electrons have sufficient energy to surmount the higher barrier. As a result, the effective barrier height will increase with the temperature [5]. The Rs is determined using a method proposed by Cheung and Cheung [6]. For our diode, the values of Rs are found to be 2.32, 2.30, 2.13, 1.51, 1.41Ω and 1.37 at 250, 275, 300, 325, 350 and 375, respectively.

The values of Φ_{BO} (open diamond) and Φ_{C-V} (closed squares) obtained from the forward bias I-V and C-V characteristics depending on the temperature are given in Fig. 2. While, the experimental value of Φ_{BO} decrease with a decrease in temperature, in contrary, experimental values of Φ_{C-V} increase with a decrease in temperature.

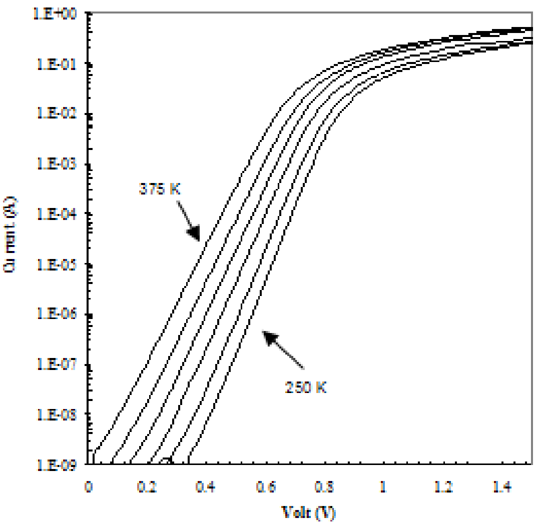

*Fig.1.*Experimental forward-bias I-V characteristics of Au/n-GaP Schottky diode at different temperatures.

The barrier height Φ_{C-V} obtained from C-V measurements decreases with increasing temperature. This is a usual behavior of Schottky diodes, which indicates that interface states are bound to valance band edge. This suggests that in this temperature range the current flow is dominated by thermionic emission. On the other hand, C-V is more likely an average measurement of the Schottky barrier height within the device active area. Therefore, it is less dependent on the temperature. The barrier height, which decreases with decreasing temperature, is called zero-bias barrier height. The barrier height obtained under flat-band condition is called flat-band barrier height and is considered to be real fundamental quantity.

Unlike the case of the zero-bias barrier height, the electrical field in the semiconductor is zero under the flat-band condition. This eliminates the effect of the image force lowering that would affect the $I–V$ characteristics and removes the influence of inhomogeneity. To find out the value of Φ_{BF} use is made of the expression [7]:

$$\Phi_{BF} = n\Phi_{B0} - (n-1)(kT/q)\ln(N_C/N_D) \quad (4)$$

where N_C is the effective density of states in the valance band and N_D the carrier concentration. The $C–V$ measurements have been performed at 1 MHz in the temperature range of 250–375 K. The experimental N_D and N_C depending on the temperature were calculated from the reverse bias $C^{-2}–V$ characteristics in Fig. 3. The values of N_D and N_C are 3.13×10^{18} cm^{-3} at 250 K and 1.49×10^{19} cm^{-3} at 375 K, and 3×10^{18} cm^{-3} at 250 K and 2.74×10^{19} cm^{-3} at 375 K, respectively. The Fig. 2 shows the variation of Φ_{BF} as a function of the temperature. Φ_{BF} is always larger than zero-bias barrier height Φ_{B0}. However, the flat-band barrier height Φ_{BF} is increase with decreasing temperature.

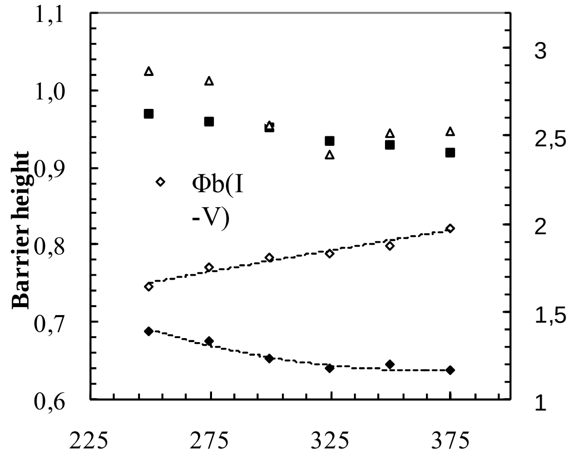

Fig.2. Temperature dependence of the zero-bias apparent barrier height and flat-band barrier height, and ideality factor for Au/n-GaP Schottky diode.

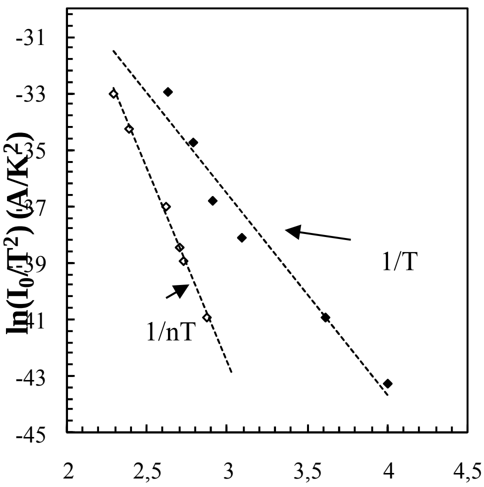

Fig. 3. A conventional and modified Richardson plot of $\ln(I_0/T^2)$ vs. 1/T for Au/n-GaP Schottky diode.

The Richardson constant is usually determined from the $\ln(I_o/T^2)$ vs $1/T$ plot. Figure 3 shows the conventional Richardson plot, which yields an effective value of A^* to be 5.23×10^{-5} A/cm^2 K^2. The A^* extrapolated from the conventional Richardson plot is typically much smaller than the theoretical value of 102 A/cm^2 K^2. Otterloo and Gerritsen [8] have shown that the *C-V* method is most accurate in determining the Schottky barrier height compared to *I-V* and photoemission methods. If we take Φ_{BO} *C-V* as the real Schottky barrier height, the temperature dependence of the barrier height will be rather small and thus can be neglected.

The temperature-dependent ideality factor $n(T)$ was proposed to be included in the expression of saturation current by Hackam and Harrop [9]; thus,

$$I_0 = AA^*T^2 - \frac{q\Phi_{B0}}{n(T)kT} \quad (5)$$

so the modified Richardson plot should be $\ln(I_o/T^2)$ vs $1/nT$ plot, as shown in Fig.3. The linearity of this plot is much better and the A^* extrapolated is 44.3 A/cm^2 K^2, which is much closer to the theoretical value of 102 A/cm^2.

4. CONCLUSIONS

Schottky rectifiers fabricated on a N type GaP substrate greatly simplify the fabrication process, and thedevices showed excellent forward current conduction. The temperature dependence of barrier heights, ideality factor and series resistance has been reported in the temperature range of 250–375 K.

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