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Temperature-dependent current–voltage characteristics of Cr/n-GaAs Schottky diodes

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ABSTRACT

The Cr/*n*-GaAs/In Schottky contacts have been formed using dc magnetron sputtering. The current–voltage (*I–V*) characteristics of the device have been measured by steps of 20 K in the temperature range of 60–320 K. The ideality factor *n* of the device has remained about unchanged between 1.04 and 1.10 and Schottky barrier height around 0.58–0.60 eV from 320 K down to 160 K. It can be said that the experimental *I–V* data are almost independent of temperature above 160 K. After 160 K, the *n* value increased with a decrease in temperature and become 1.99 at 60 K. The *I–V* characteristics at high temperatures have been exactly explained by the standard TE model. The nature and origin of abnormal behaviors at low temperatures have been successfully explained by the current flow through the low SBH circular patches suggested by Tung and used by some studies in literature. It has been seen that the straight line of the nT vs. T plot with a T_0 value of 14 K was parallel to that of the ideal Schottky contact. Again, a lateral homogeneous BH value of 0.62 eV was calculated from the linear relationship between the ideality factor and barrier height values. It has been seen that he $\phi(T=0)$ and BH temperature coefficient α values obtained from the flat band BH and the Norde's model plots are in close agreement with each other.

1. Introduction

GaAs is an important semiconductor used for optoelectronics, fast computers, and microwave applications. The metal-semiconductor field effect-transistor (MESFET) containing a Schottky barrier gate is one of the main components in GaAs integrated circuits [1–4]. However, the fundamental mechanisms determining the Schottky barrier height (SBH) are so far not well understood [1–7]. Sputter deposition has become a widely used technique in semiconductor technology. Good adherence of the sputter-deposited material to the substrate can be achieved for a variety of materials making the contact to the substrate more intimate than can be obtained by other commonly used deposition techniques. Dry processing techniques such as sputter etching, ion milling or reactive ion etching have proven to be very useful in obtaining a semiconductor surface free of contamination [3,5,6].

The current–voltage (*I–V*) characteristics of Schottky barrier diodes (SBDs) usually deviate from the ideal thermionic emission (TE) current model [8–15]. There are currently a vast number of reports of experimental studies of characteristic parameters such as the barrier height (BH) and ideality factor in a great variety of metal-semiconductor (MS) contacts [14–27]. Schottky diodes (SDs) with low BH have found applications in devices operating at cryogenic temperatures as infrared detectors and sensors in thermal imaging [4,20,28]. Therefore, analysis of the temperature-dependent current–voltage (*I–V*) characteristics of the Schottky barrier diodes (SBDs) gives detailed information about their conduction process or the nature of barrier formation at the MS interface. However, a complete description of the charge carrier transport through a MS contact is still a challenging problem.

In the present study, the *I–V* characteristics of Cr Schottky contacts formed by dc magnetron deposition on an *n*-GaAs substrate were measured in the temperature range of 60–320 K by steps of 20 K. At low temperatures, the temperature dependent barrier characteristics of the Cr/*n*-GaAs Schottky contacts have been interpreted by means of the thermionic emission theory of inhomogeneous Schottky contacts suggested by Tung et al. [29] and Sullivan et al. [30] who consider in their model the presence of locally non-uniform regions or patches with relatively lower or higher barriers.

2. Experimental procedure

The samples have been prepared using cleaned and polished *n*-GaAs (as received from the manufacturer) with (1 0 0) orientation and 7.3×10^{15} cm^{-3} carrier concentration. Before making contacts, the *n*-GaAs wafer was dipped in $5H_2SO_4 + H_2O_2 + H_2O$ solution for

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1.0 min to remove surface damage layer and undesirable impurities and then in H_2O + HCl solution and then followed by a rinse in de-ionized water of 18 MΩ. The wafer has been dried with high-purity nitrogen, and inserted into the deposition chamber to form ohmic contact immediately after the etching process. The indium for ohmic contact was evaporated on the back of the wafer in a vacuum-coating unit of 10^{-6} Torr. Then, the GaAs/In structure was thermally annealed to form the ohmic contact at 380 °C for 3 min in flowing N_2 in a quartz tube furnace. The Schottky contacts have been formed using dc magnetron sputtering Cr as dots with diameter of about 1.5 mm on the front surface of the *n*-GaAs. The thickness of metal coverage was determined using a quartz thickness monitor placed in close proximity to the GaAs sample. Approximately 50 nm of the Cr was performed.

The current–voltage (*I–V*) characteristics of the devices were measured in the temperature range of 60–320 K using a Leybold Heraeus closed-cycle helium cryostat that enables us to make measurements in the temperature range of 10–340 K, and a Keithley 487 Picoammeter/Voltage Source in dark conditions. The sample temperature was always monitored by a copper-constantan thermocouple and a Windaus MD850 electronic thermometer with sensitivity better than ±0.1 K.

3. Results and discussion

3.1. Temperature dependence of the forward bias I–V characteristics

We analyze the experimental *I–V* characteristics by the forward bias thermionic emission (TE) theory given as follows [2,3]

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

where I_0 is the saturation current derived from the straight line intercept of ln*I* at *V* = 0 and is given by

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

where *q* is the electron charge, *V* is the forward bias voltage, *A* is the effective diode area, *k* is the Boltzmann constant, *T* is the absolute temperature, A^* is the effective Richardson constant of 8.16 A cm^{-2} K^{-2} for n-type GaAs, ϕ_{eff} is the experimental zero bias BH (apparent barrier height) and *n* is the ideality factor. From Eq. (1), ideality factor *n* can be written as

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

The semilog-forward and reverse bias *I–V* characteristics of the Cr/*n*-GaAs SBDs are shown in the temperature range of 60–320 K by the steps of 20 K in Fig. 1. The experimental values of apparent barrier height ϕ_{eff} and *n* have been determined from intercepts and slopes of the forward bias ln*I* vs. *V* plot at each temperature using the TE theory, respectively (Fig. 2). The experimental values of ϕ_{eff} and *n* for the device range from 0.60 eV and 1.06 (at 300 K) to 0.40 eV and 1.99 (at 60 K), respectively. As can be seen from Fig. 2, the ideality factor *n* of the device has remained about unchanged between 1.04 and 1.10 from 320 K down to 160 K. That is, the experimental *I–V* data was fitted well over the whole bias region in the temperature range of 160–320 K. It can be said that the experimental *I–V* data are almost independent of the sample temperature and quite well obey the traditional thermionic emission (TE) model above 160 K. The SBH has remained about unchanged (around 0.58–0.60 eV) from 160 K to 320 K; and after 160 K, the SBH value become 0.40 eV at 60 K more decreasing with a decrease in temperature. After 160 K, the *n* value slightly increased with a decrease in temperature and become 1.99 at 60 K. The fact that

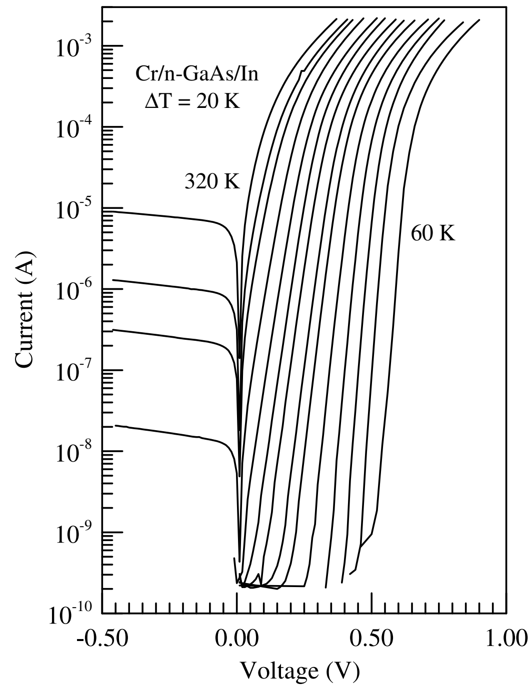

Fig. 1. Experimental forward bias current–voltage characteristics of Cr/*n*-GaAs/In Schottky contact at various temperatures.

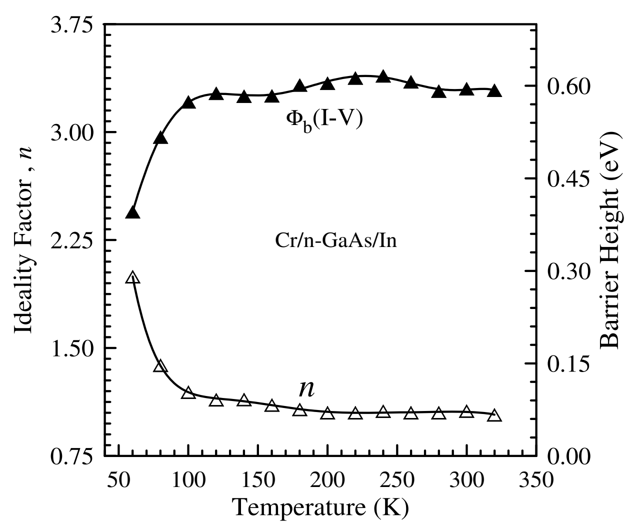

Fig. 2. Temperature dependence of the ideality factor (the open triangles) and barrier height (the filled triangles) for Cr/*n*-GaAs/In Schottky diode.

the SBH decreases and *n* increases at low temperatures may be explained by current flow through the patches of lower SBH and larger ideality factor [25–30]. That is, the nature and origin of these anomalies in some studies have been successfully explained on the basis of a TE mechanism which takes into consideration the spatial barrier distribution of the BHs, due to inhomogeneities prevailing at the MS interface [29–43]. The tunneling across the barrier can be omitted due to the low doping level of the GaAs substrate [2,3,37].

The temperature dependency of the ideality factor *n* can be more understood by a plot of *nT* vs. *T*, such a plot is given for the Cr/*n*-GaAs SBD in Fig. 3, in which the dashed straight line represents the ideal behavior of a Schottky contact i.e. with *n* = 1). The temperature dependence of the ideality factor *n*(*T*) has been frequently found to have the form of *nT* = *T* + T_0, where T_0 is a constant