Effect of Indentation on *I-V* Characteristics of Au/n-GaAs Schottky Barrier Diodes

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Au/n-GaAs Schottky barrier diodes (SBDs) have been fabricated. The effect of indentation on Schottky diode parameters such as Schottky barrier height (ϕ_b) and ideality factor (n) was studied by current-voltage (*I-V*) measurements. The method used for indentation was the Vickers microhardness test at room temperature. The experimental results showed that the *I-V* characteristics move to lower currents due to an increase of ϕ_b with increasing indentation weight, while contacts showed a nonideal diode behaviour.

Key words: Schottky Barrier Diode; Barrier Height; Ideality Factor; Indentation; Fermi Level Pinning.

1. Introduction

Schottky contacts on GaAs have been widely used in metal-semiconductor field-effect transistors (MESFETs), Schottky diodes and other microwave devices [1 – 4]. Because of their technological importance, the properties of these contacts have been studied, using a variety of techniques involving the capture or emission of charge carriers, such as current-voltage (*I-V*) and capacitance-voltage (*C-V*) measurements, deep level transient spectroscopy (DLTS) and admintance spectroscopy [5]. The Schottky barrier height (ϕ_b) and the ideality factor (n) are the fundamental parameters of the Schottky barrier diodes (SBDs). Clearly, the Schottky barrier formation has been a subject of great interest for many years. More recently, hydrostatic pressure has been employed as a tool in the investigation of these properties of SBDs [6 – 11]. In these studies, the SBD parameters such as the series resistance (R_s), n and ϕ_b have been measured as a function of hydrostatic pressure using the *I-V* technique. By these studies, it has been shown that the Schottky barrier formation can be explained with the Fermi level pinning. Shan et al. [11] and Schilfgaarde et al. [6] showed that the pressure coefficients of ϕ_b of Pt/n-GaAs and Au/n-GaAs SBDs have a value of 11 and 11.6 meV/kbar, respectively, and the pressure coefficient of ϕ_b of GaAs contacts is the same as the fundamental gap of GaAs [12]. Various models, such as defect states arising from defects near the interface and metal-induced gap states (MIGSs) have been proposed to explain the pinning of the Fermi level which gives rise to the Schottky barrier [6 – 9, 11].

In particular, in some studies the effect of plastic deformation introduced by Vickers microindentation on the electric behaviour of semiconductors and SBDs has been studied by *C-V*, *I-V* measurements and infrared (IR) absorption [13 – 15]. In these studies it has been found that the photoconductivity decreases after indentation due to a decrease of the mobility of electrons through their interaction with the dislocation created in the structure. Moreover, the ϕ_b variation has been explained by the pinning model of the Fermi level based on the majority carrier defects. On the other hand it has been shown that the interface states, generation-recombination, image force lowering, and thermionic field emission theories have been put forward to explain greater n values than unity as commonly applied in the case of metal-Si Schottky contacts [16]. Also, the band gap reduction has been shown as the reason for the smaller ϕ_b values obtained for a Ti/strained-Si Schottky diode [17].

The fabrication of contacts to n-GaAs with enhanced ϕ_b values has important ramifications for the design and performance of GaAs integrated circuits. So, the ability to control the ϕ_b values will provide advantageous manipulation in device applications. In this paper we report the effect of indentation on some properties such as ϕ_b and n of Au/n-GaAs SBDs.

2. Experimental

The SBDs were prepared using cleaned and polished n-GaAs (as received from the manufacturer) with (100) orientation and $2-5 \cdot 10^{17}$ cm^{-3} carrier concentrations. Before making contacts, the n-GaAs wafer was dipped in a $5H_2SO_4 + H_2O_2 + H_2O$ solution for 1 min to remove any damaged surface layer and undesirable impurities, and then in $H_2O + HCl$ solution. Following a rinse in de-ionized water of 18 MΩ, the wafer was dried with high-purity nitrogen and inserted into the deposition chamber immediately after the etching process. For ohmic contacts, Au-Ge (88% : 12%) was evaporated on the back of the wafer in a vacuum coating unit of 10^{-5} Torr. After that, low resistance ohmic contacts were formed by thermal annealing at 450 °C for 3 min in flowing N_2 in a quartz tube furnace. The SBDs were made by evaporation of Au as dots with a diameter of approximately 1.35 mm onto all of the n-GaAs surfaces. Microindentation was performed using a Vickers microhardness test on the surface of Au/n-GaAs SBDs with a pyramidal diamond indenter with square base at room temperature. The *I-V* characteristics of SBDs with various weights (0, 25, 50, 100 g) were measured using a HP 4140B picoampermeter in the dark. On the other hand, the *I-V* characteristics were also measured as a function of the indentation time under a constant weight of 50 g.

3. Results and Discussion

Figure 1a shows the semilog forward and reverse bias dark *I-V* characteristics of Au/n-GaAs SBDs at indentation weights from 0 to 100 g. From this figure, a strong dependence of the *I-V* characteristics on the indentation weight is evident for forward bias, although the *I-V* characteristics for reverse bias remained and the diode showed good agreement with the simple thermionic emission theory as expected. The *I-V* characteristics were not perfectly linear and showed a downward curvature at high voltages. 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 SBDs is given by [3, 18, 19]

Table 1. The experimentally obtained barrier height ϕ_b, ideality factor n and dislocation density N as a function of indentation weight for Au/n-GaAs SBDs.

	Indentation weight			
	0 g	25 g	50 g	100 g
ϕ_b (eV)	0.53	0.54	0.55	0.57
n	1.05	1.09	1.09	1.11
$N \cdot 10^4$ (cm^{-2})	0.8	3.1	6.4	9.7

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

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

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

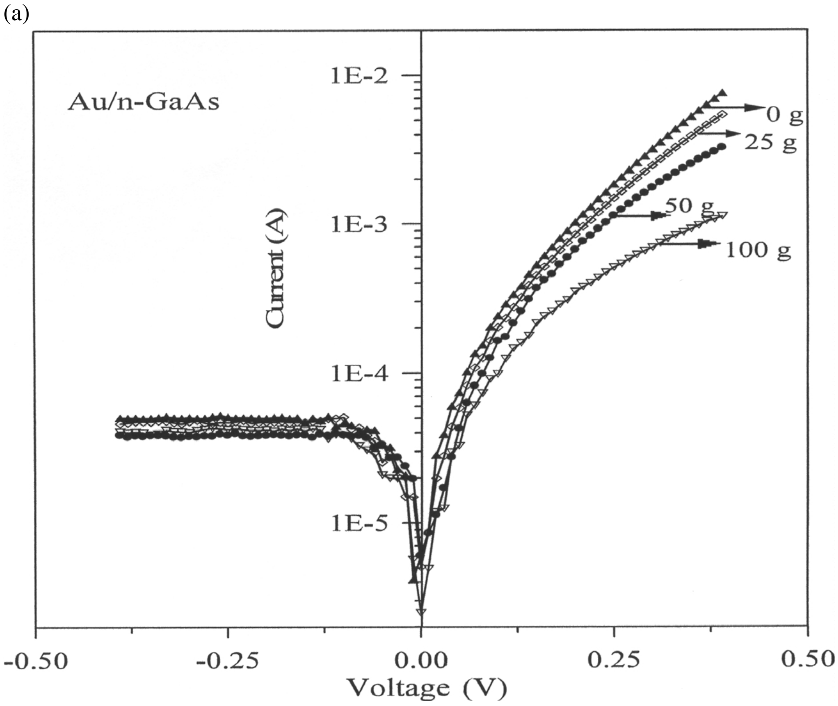
In (1), I_s is the saturation current derived from the straight line intercept of $\ln I$ at $V = 0$, and is given by

$$I_s = A\overset{*}{A}T^2 \exp\left[\frac{-q\phi_b}{kT}\right], \qquad (3)$$

where A is the effective diode area and $\overset{*}{A}$ the effective Richardson constant of 8.16 A/(cm^2 K^2) for n-GaAs. The values of n were calculated using (2) in the linear region of the semilogarithmic forward bias *I-V* plots, indicating that the series resistance effect in the linear region is not important, and the values of the barrier height of Au/n-GaAs SBDs were calculated with the help of (3) from the y-axis intercepts of the semilogarithmic forward bias *I-V* plots.

Table 1 shows the values of ϕ_b and n obtained with the help of (1) and (2) from the *I-V* characteristics of Au/n-GaAs SBDs. As can be seen from Table 1, the Au/n-GaAs SBDs show nonideal behaviour with an ideality factor grater than one. The n values of Au/n-GaAs SBDs, ranging from 1.05 to 1.11, indicate that the device obey a metal-interface layer-semiconductor configuration rather than ideal SBDs. With an increase in the indentation, the *I-V* characteristics move to lower currents. We say that the indentation results in a considerable decrease in the current with an increasing ϕ_b. The decrease of the current can be explained by a decrease of the mobility of electrons due to collisions with dislocations. In this study, molten KOH was used to reveal dislocations in Au/n-GaAs SBDs [20]. Figure 2 shows the etch

(a)



(b)

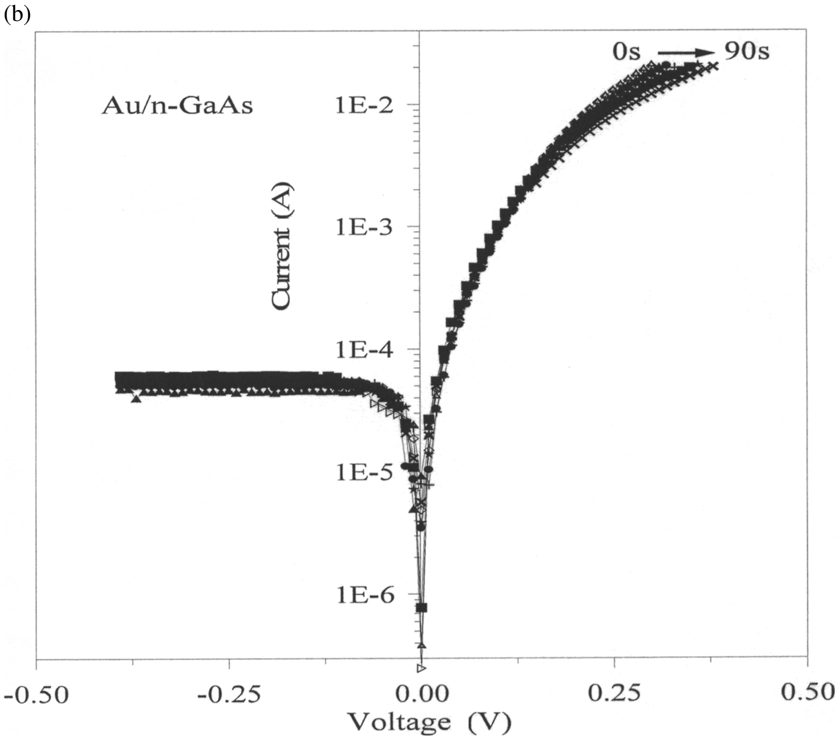


Fig. 1. The forward and reverse bias current versus voltage of Au/n-GaAs SBDs as a function of (a) indentation weight and (b) indentation time.

pits obtained from Au/n-GaAs SBDs. The dislocation density (N) was determined by counting the etch pits on the surfaces of Au/n-GaAs SBDs and is given in Table 1.

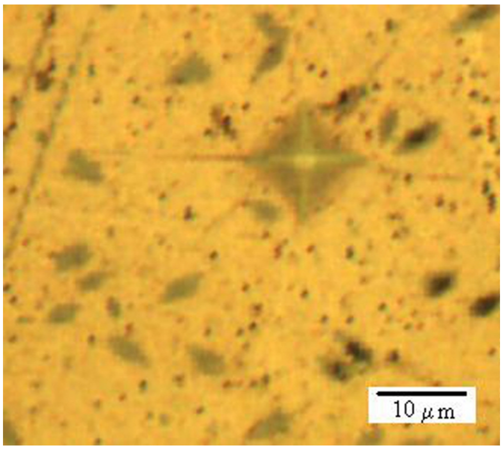


Fig. 2. Etch pits produced on the surface of Au/n-GaAs SBDs.

Despite theoretical and experimental effort, the Schottky barrier formation mechanism is not completely understood. The most popular models of Schottky barrier formation are Fermi level pinning by MIGSs and native defect models [6, 7, 9, 11]. To explain the Schottky barrier formation under hydrostatic pressure, many studies have been performed, based on pressure coefficient calculations using these models. In this study, as can be seen from Table 1, ϕ_b increases with the increasing dislocation density. We think that the ϕ_b variation (40 meV) is explained by the pinning model of the Fermi level. This model assumes Fermi level pinning at the dislocations introduced with indentation.

Figure 1b shows the indentation time dependence of the *I*-*V* characteristics of Au/n-GaAs SBDs under a constant indentation weight of 50 g. There is no measurable shift in the *I*-*V* characteristics which implies that there is no change in the value of ϕ_b (0.51 eV) and n (1.09) for Au/n-GaAs SBDs. As can be seen from Figs. 1a and b, the forward *I*-*V* characteristics were not perfectly linear and showed a downward curvature at high voltage. This downward curvature has been explained with the presence of the effect of R_s, apart from the interface states [21]. In our study, the downward curvature becomes obvious with the increasing indentation weight and indentation time.

To sum up, the indentation affects the parameters of SBDs. The Fermi level is a reference level which is pinned to dislocations as a function of the indentation. The slight increase in the ϕ_b values with increasing indentation weight is due to an increase in the band gap.

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