Electrical Properties of Te-Doped MOCVD Grown GaSb Schottky Diodes

A.H. Ramelan, K.S.A. Butcher, E.M. Goldys, T.L. Tansley, K. Tomsia
Semiconductor Science and Technology Laboratories,
Macquarie University, NSW 2109 Australia.
email : aramelan@mpce1.mpce.mq.edu.au

Abstract - Dimethyltelluride has been used as a dopant source for GaSb epilayers grown by atmospheric pressure MOCVD (Metalorganic Chemical Vapour Deposition). Schottky diodes were fabricated using Al barriers and Au-Ge-Ni as Ohmic contact. Doping densities of about 4.1×10^{18} cm^{-3} and barrier heights of 0.63 eV are found from C-V measurements, compared to 0.59 eV determined from room temperature I-V measurements. Room temperature ideality factors are around 1.3, while its variation with temperature demonstrates the role of electron tunnelling through the depletion barrier. The carrier concentration probed by C-V is confirmed by van der Pauw Hall measurements. The effect of thermal annealing on the diodes is also reported.

A. Introduction

Gallium antimonide and its related ternary and quaternary semiconductor compounds have attracted increasing interest because of their particular band structure features (narrow band gap, small electron effective mass, and high electron mobility) attractive for a large variety of electronic and photoelectronic devices [1]. Therefore, Sb-based compounds appear to be a promising alternative to InP-based systems, particularly for optoelectronic applications in the low-loss spectral region of new optical fiber communication systems.

Schottky barrier diodes are basic structures for semiconductor characterization and technology. Schottky diodes obtained by evaporating various metals on (100) Te doped n-GaSb have been reported [2]. Different barrier heights were found depending on the surface treatment: barrier heights in the range of 0.38-0.44 eV and 0.64-0.84 eV were reported, respectively, for silver and gold deposited on vacuum cleaved GaSb [2]. However, more recently it was shown that pinning of the Fermi level near the top of the valence band [3,4] is responsible for the fact that the Schottky barrier height is almost independent from the metal utilized [5]. The achievement of an ideal GaSb Schottky barrier has proven to be difficult because the oxide layer degrades the rectifying properties of any metal contact deposited on the surface. In this paper, we investigate the electrical properties of Al/n-GaSb epilayer grown by MOCVD and the effect of thermal treatment on the properties of the Schottky diodes.

B. Experiment

n-GaSb epilayers were grown on semi-insulating GaAs (100) substrates in a Thomas Swan atmospheric pressure horizontal MOCVD reactor at a temperature of 540°C and with a V/III ratio of 1.4. High purity TMGa and TMSb from Morton International were used as

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precursors and dimethylellurium (DMTe) was used as the n-type doping source. After growth the layers were degreased for 5 min in boiling trichloroethylene and rinsed by ultrasonic vibration in acetone and methanol to remove organic contaminants. Before loading the samples into the evaporation chamber, a $HCl:H_2O$ (1:1) solution was used to remove the native oxide layer on the GaSb surface, followed by a rinse in of 18 MΩ.cm deionized water, and high purity nitrogen was used to dry the samples. The samples were inserted into the deposition chamber immediately after the etching process. Ohmic contacts were formed by evaporation of Au-Ge-Ni followed by a high temperature treatment at 350°C for 5 min in an N_2 atmosphere. Before forming Schottky contacts, the samples were immersed in dilute HCl for about 30 s to remove any thin native oxide layer on the surface. The Schottky contacts were made on the opposite surface by evaporating Al with dimensions of 500x500 μm^2. After formation of the Schottky diodes, the samples were annealed in a quartz tube furnace at a temperature between 200 and 400°C for 1 min in flowing N_2. The current voltage (I-V) characteristics were measured using a Keithley 495 Picoammeter-Voltage Source.

C. Results and Discussion

C.1. C-V measurements

C-V measurements were used to determine the barrier heights. The relationship between the capacitance C and the applied voltage V in a Schottky barrier is given by [6]

$$\frac{1}{C^2} = \frac{2\left(V_{bi} - \frac{kT}{q} - V\right)}{A^2 q N_d \varepsilon_s}, \tag{1}$$

where V_{bi} is the built-in potential, and ε_s is the dielectric constant of the semiconductor (1.39×10^{-10} F/cm for GaSb). The barrier height and the doping concentration can be deduced from linear plots of $1/C^2$ vs V. Figure 1 shows a plot of the inverse capacitance per unit area squared versus reverse bias at room temperature. The capacitance was measured at 1 MHz. The doping density calculated from this graph of $n = 4.1\times10^{18}$ cm^{-3} is in good agreement with Hall data. This is the highest doping density reported in this material. From the C-V measurement data, the barrier height was found to be 0.63 eV. This value is comparable to that found for Schottky diodes formed by Al deposition on Te-doped GaSb grown using different metalorganic sources [7-9]. Capacitance-voltage (C-V) measurements were also carried out at 140 K and the barrier height was determined to be 0.66 eV. The increase in the barrier height is consistent with the Fermi level following the valence band edge as reported earlier [10]. The increase in the bandgap for GaSb between 300 and 140 K is 0.043 eV, whereas we find an increase in the barrier height of 0.03 eV.

C.2. I-V characteristics

Current voltage (I-V) measurements were used to characterize the Schottky barrier diodes. Thermionic emission theory predicts the current voltage characteristics of Schottky diodes to be given by [11]

$$I = I_o \exp\left(\frac{qV}{nkT}\right)\left[1-\exp\left(-\frac{qV}{kT}\right)\right] \quad (2)$$

In Eq. (2) the saturation current I_o is expressed as :

$$I_o = AA^*T^2 \exp\left(-\frac{q\Phi_b}{kT}\right) \quad (3)$$

where q is the electron charge, V is the applied voltage, A is the effective diode area, k is the Boltzmann constant, T is the absolute temperature, A^* is the effective Richardson constant of 5.1 A $cm^{-2}K^{-2}$ for GaSb [12], Φ_b is the barrier height and n is an ideality factor which can be determined accurately from the slope of the linear part of a $\ln(I/1-\exp(-qV/kT))$ versus V plot and from Eq. (2). The ideality factor n can be written as

$$n = \frac{q}{kT}\left[\frac{dV}{d(\ln I)}\right] \quad (4)$$

As shown in Figure 2, current-voltage (I-V) measurements for the diode were conducted at temperatures of 140, 200, 300 and 320 K.

The ideality factor n tends to decrease with increasing temperature. The range of the values (1.3-3.7) and the temperature dependence behaviour suggest a conduction mechanism controlled by thermionic emission. The high value of the ideality factor at low temperature is probably due to a potential drop of the interfacial layer, and to recombination currents through the interfacial states at the junction.

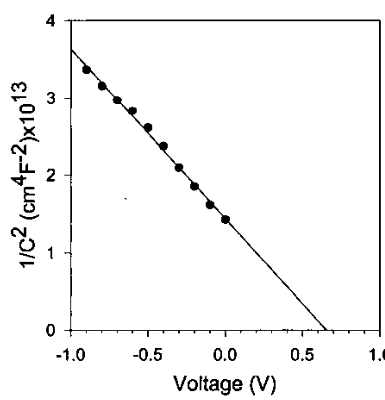

Figure 1. Inverse capacitance vs reverse bias at room temperature.

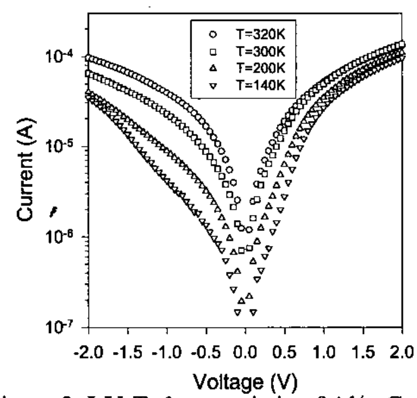

Figure 2. I-V-T characteristic of Al/n-GaSb Schottky diode.

C.3. Samples Annealing

The electrical properties were compared at various annealing temperatures. The effect of annealing is clearly observed. The I-V characteristics of the Al/n-GaSb Schottky diode at different annealing temperatures is shown in Figure 3. At room temperature, the diode shows a relatively good forward and reverse characteristic with a breakdown voltage of about 1.5 volt. The breakdown voltage decreases to about 0.5 volt as the annealing temperature reaches 300°C, and further decreases as the annealing temperature is increased. The barrier height measured from I-V characteristics as a function of the annealing temperature for Al/n-GaSb is shown in

Figure 4. The barrier height decreased from 0.59 eV to 0.37 eV for the sample annealed at 300°C for 1 minute. The barrier lowering may be partly due to the increase in doping concentration at the metal-semiconductor interface as confirmed by C-V measurements, resulting in an increased tunneling component. Finally, the Schottky diodes become resistor-like (ohmic) as the annealing temperature is raised to 400°C due to interaction of the metal and semiconductor [13].

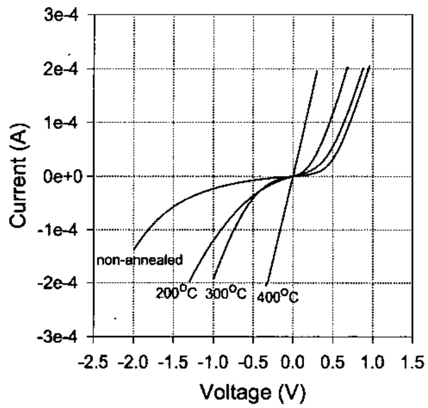

Figure 3. I-V characteristics of the Al/n-GaSb diode at different annealing temperatures.

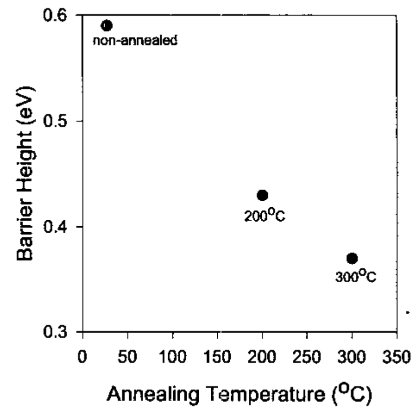

Figure 4. The barrier height as a function of annealing temperature.

D. Conclusions

In conclusion, we have reported the properties of Al/n-GaSb Schottky diodes doped with DMTe and with doping density of 4.1×10^{18} cm^{-3}. We found barrier heights using both C-V and I-V measurements. The barrier height found in C-V measurements increased as the temperature decreased and was consistent with the pinning of the Fermi level at the valence band.

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