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Fabrication and Electrical Characterization of Near Ideal (n=1.1) Schottky Barrier Diodes of Au on n-GaSb

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Near ideal schottky barrier diodes of Au on liquid phase epitaxially grown n type GaSb have been fabricated by optimising surface preparation condition before forming metal contact on GaSb. Electrical properties of these schottky barriers have been investigated by I-V and C-V measurements over a range of temperatures from 180K to 370K. Barrier height of near ideal schottky barrier diode is 0.46eV and follows "2/3E_g rule".

1. Introduction

Among the III-V compound semiconductors, GaSb which is potentially important material for IR sources and detectors[1] is least studied material and there exist few reports on the electrical properties of schottky diodes of this material[2-6]. It has been suggested in past that schottky diode of Au on n-GaSb have barrier height (Φ_B) 0.6eV and does not follow well known "two-third E_g" rule[7]. However this Φ_B value is based on C-V measurements, which can be modified considerably by interfacial layers. Richardson plot with ideality factor close to unity, which can determine Φ_B more accurately, has not been reported so far for Au-GaSb schottky diodes. Recently n>2 for Au schottky contacts on UHV and air cleaved GaSb has been reported[8] which shows "effective barrier height" (0.49-0.52eV) obtained by curve fitting procedure. This may be partly because GaSb has high rate of oxidation in atmosphere which results in a thick oxide layer between metal and semiconductor. In presence of an oxide layer, the ideality factor of the diode generally turns out to be large and it is difficult to use thermionic-emission model to obtain Φ_B from I-V measurements. Therefore fabrication of near ideal schottky contact is of much importance for our understanding of device properties. In the present work, we for the first time report fabrication of schottky diodes with ideality factor n=1.1. I-V and C-V measurements show that barrier height of Au on n-GaSb follows 2/3E_g rule.

2. Sample Preparation

The materials used is this work were grown by LPE on (100) n^+-type GaSb substrates at about 500°C[9]. Te was used as n-type dopant to obtain carrier concentration of about $3\text{-}5\times10^{16}cm^{-3}$.

For the fabrication of schottky barrier diodes, we first investigated conditions for surface preparation of GaSb before forming the schottky contact and found it to be somewhat critical due to high oxidation rate of GaSb in atmosphere[10]. Following procedure

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resulted in fabrication of diodes with ideality factor n=1.1: A back contact of Au-Ge-Ni is alloyed to n^+ substrate of LPE n-GaSb. Organically cleaned sample is oxidized in water and etched in dilute HCl several times. Finally the sample is etched in a mixture of HF and H_2O. It is then briefly rinsed in DI water, dried in the folds of clean filter paper and quickly loaded into the vacuum chamber. This last step is critical and in order to ensure better ideality factor, the exposure of each cleaned sample to water and air atmosphere is minimized to less than 1 minute. Before evaporating the metal, sample is first desorbed by heating to ~125°C and then cooled back to room temperature to avoid interdiffusion of constituent at the surface. Then Au is evaporated through a glass mask containing holes of 400μm diameter to form metal semiconductor contact. Sample is now ready for electrical measurements.

3. Characterization

3.1. C-V Characteristics

1MHz C-V measurements were carried out over a temperature range 180-370K(Fig.1) and barrier heights as a function of temperatures

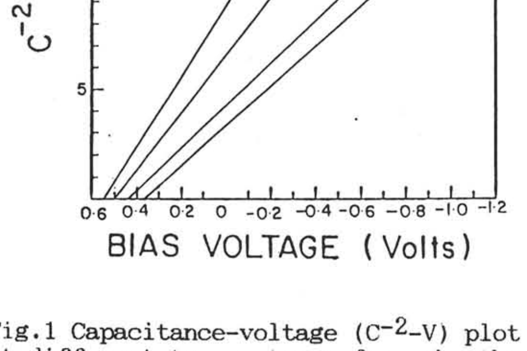

Fig.1 Capacitance-voltage (C^{-2}-V) plot at different temperatures for schottky diodes of Au-n-GaSb.

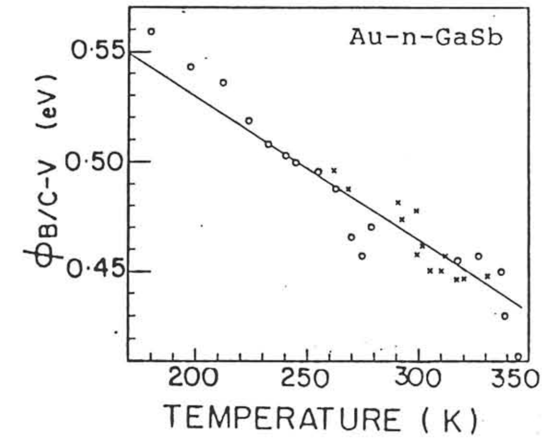

Fig.2 Barrier height as a function of temperature obtained from C-V data.

(Fig.2) were obtained by using the analysis in Ref.11. From Fig.2 we obtain $\Phi_B(0)=0.66$eV and slope of the curve gives a value of $\alpha=-6.6\times10^{-4}$eV/K and $\Phi_B(300K)=0.47$eV.

3.2. I-V Characteristics

Current-voltage measurements performed at several temperatures are shown in Fig.3 (lnI vs V plot). The ideality factor obtained from these curves is nearly 1.2 at room temperature. It improves to and saturates to a value of 1.1 in the temperature range 340-370K. At lower temperature ideality factor worsens (Fig.4). We consider the limiting valure of n to be the result of a remnant interfacial layer as given by Rhoderick[12]

$$n = 1 + \frac{\frac{\delta}{\varepsilon_i}\left[\frac{\varepsilon_s}{W} + q^2 D_{sb}\right]}{1 + \frac{\delta}{\varepsilon_i} q^2 D_{sa}}$$

where D_{sa} and D_{sb} are densities of interface states which are in equilibrium with metal Fermi level and semiconductor Fermi level. For n=1.1 we find values of δ=25A, $D_{sa}=1\times10^{13}$ $cm^{-2}eV^{-1}$ and $D_{sb}=2\times10^{12}cm^{-2}eV^{-1}$.

In the regime of ideality factor n=1.1, Richardson plot $\ln I_0/T^2$ vs 1000/T is linear (Fig.5) and hence we apply thermionic emission theory to determine barrier height[7]

$$I_0(T) = SA^*T^2 \exp\frac{-(\Phi_B-\alpha T)}{kT}\exp(-C\chi^{1/2}\delta).$$

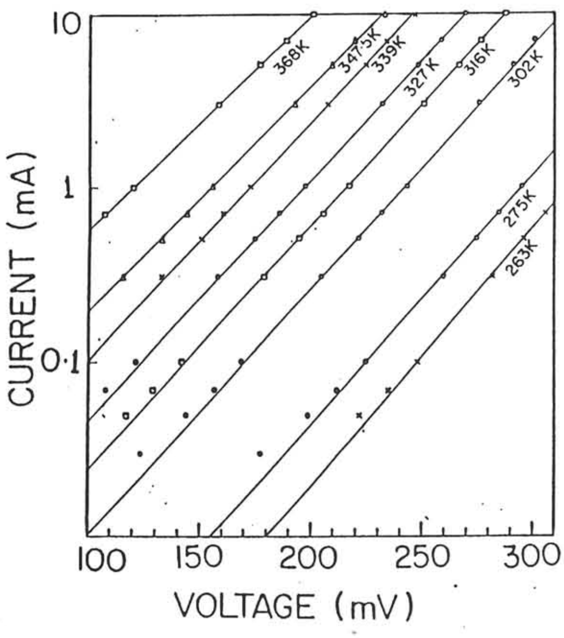

Fig.3 Current-voltage (lnI-V) plot at different temperatures for schottky diodes of Au-n-GaSb.

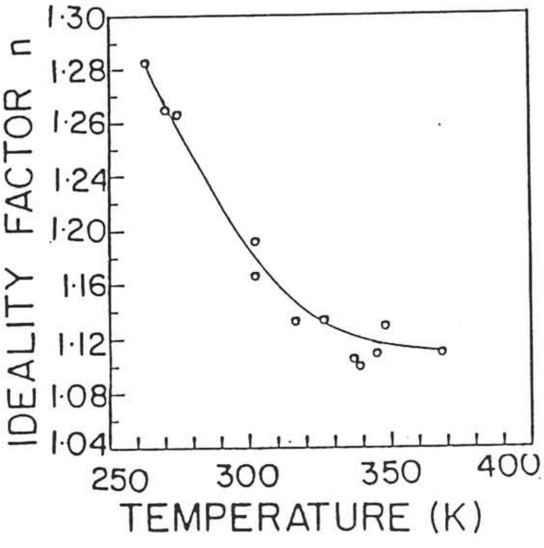

Fig.4 Ideality factor (n) as a function of temperature.

where S is the area in cm^2, A^* the Richardson constant in $Amp{\cdot}K^{-2}$, δ the oxide thickness in A and χ the mean barrier height in eV at the oxide-semiconductor interface. Slope of the Richardson plot gives barrier height at 0K ($\Phi_B(0)$). $\Phi_B(0)$ obtained in this manner is 0.58eV and the corresponding value at room temperature, $\Phi_B(0)-\alpha T$, will be much less than the $\Phi_B(300K)=0.60eV$ reported in the literature[2-6].

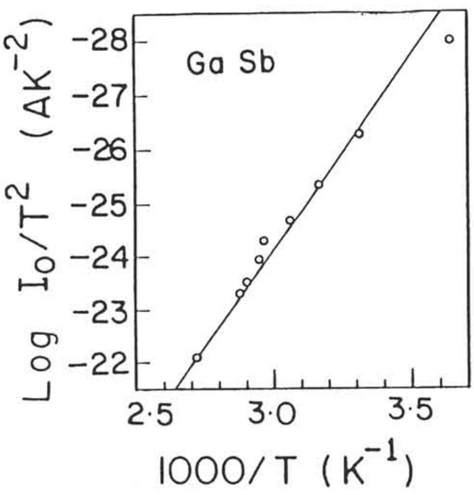

Fig.5 Richardson plot of schottky diodes of Au-n-GaSb.

3.3. Discussions

Analysis of I-V and C-V data shows that the value of $\Phi_B(0)$ determined from C-V measurements is considerably larger than the value of $\Phi_B(0)$ determined from I-V measurements. This difference can be attributed to the presence of interfacial layer δ in which[12])

$$\Delta = \Phi_B(C\text{-}V)-\Phi_B(I\text{-}V) = \nu V_D + V_1^{1/2}V_D^{1/2} + \frac{1}{4}\frac{V_1}{1+\nu}$$

where $\nu = \dfrac{q^2 D_{sb}\delta}{\varepsilon_i}$ and $V_1 = 2q\varepsilon_s N_D \dfrac{\delta^2}{\varepsilon_i^2}$

Therefore in the temperature range where the ideality factor n and the difference in Φ_B values Δ is determined by the interfacial layer δ, D_{sa} and D_{sb}, we can estimate the value of Δ for values of δ, D_{sa}, and D_{sb} mentioned above. We found for n=1.1, Δ is 0.085eV which corresponds to difference in the measured values of $\Phi_B|_{C-V}=0.66eV$ and $\Phi_B|_{I-V}=0.58eV$ at 0 K.

In our work, for the diodes with n=1.1 Richardson plot gives $\Phi_B(0)=0.58eV$. Using the value of $\alpha=-6.6\times10^{-4}eV/K$, $\Phi_B(300K)$ is found to be 0.39eV. It may be remarked however that the value of α for most semiconductors lies between 3-4×10^{-4}eV/K. Therefore if we consider value of α as 4×10^{-4}eV/K then Φ_B(300K)=0.46eV which is similar to Φ_B(300K)= 0.47eV obtained from C-V measurements for diodes with n=1.1. Now since the bandgap of GaSb is E_g=0.70eV[7] and Φ_B=0.46eV at 300K, we see that the schottky diodes of Au on n-GaSb follows "two-third E_g" rule[7].

Next, room temperature Φ_B, obtained from C-V measurements by us for diodes having poor ideality factor (n≃2) is 0.60eV which is close to the value of 0.61eV reported by Mead and Spitzes[2] from C-V data, by Chin[3] from room temperature I-V and photoemission techniques, and by Nagao[5] from I-V. None of these authors have reported values of n, which of prime importance in determination of Φ_B. The value of Φ_B=0.61eV obtained by Chin, from internal photoemission at 300K is doubtful because the bandgap of GaSb, E_g(300K)= 0.7eV, is close to the measured value of barrier height, Φ_B=0.60eV, the energy range for Φ_B determination from internal photoemission technique ($\Phi_B \leq h\nu \leq E_g$) is small, the onset of electron-hole pair excitations across the bandgap for $h\nu \simeq E_g$ will contribute to the photocurrent in the range of Φ_B measurements and this can cause serious error in the Φ_B value by this technique. Our results clearly indicates the lower value of Φ_B for near ideal schottky diodes measured from Richardson plots.

Next the increase in the value of n at low temperature can be caused by different mechanisms. These includes i)generation recombination, ii)thermionic field emission, and iii)tunneling current. All these may contribute to the total observed current at a given bias. Our results of I-V measurements in reverse bias at different temperatures[13] indicates that the current flow in high temperature region, T>300K is dominated by thermionic-emission current and at low temperature T<300K possibly by the thermionic field emission, both in the forward bias as well as reverse bias.

4. Conclusions

We can say that surface preparation of GaSb is very critical and we have been able to reproducibly fabricate diodes with ideality factor n=1.1 by optimizing surface preparation condition which minimizes the interfacial layer. The value of barrier height for diodes having n=1.1 is 0.46eV and follows "2/3E_g rule".

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