Electrical characterization and study of thermal stability of rhodium Schottky contacts to n-GaN

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Abstract

The Rh Schottky contacts to n-GaN semiconductor have been characterized and their thermal stability has been investigated. Schottky barrier heights were determined as a function of annealing temperature by both current-voltage (I-V) and capacitance-voltage (C-V) techniques and compared. Ideality factors were also computed to draw conclusions on the junction behaviour. The values of barrier heights and ideality factors of the monolayer Rh Schottky contacts are relatively low and remained stable over a range of annealing temperatures up to 500 °C.

1. Introduction

Chemically and thermally stable Gallium nitride (GaN) semiconductor with a wide direct band gap (3.4 eV) is one of most promising materials for optoelectronic devices such as blue light emitting diode [1], laser diodes [2] and ultraviolet photovoltaic/photoconductive detectors [3,4] and for high power/temperature/frequency devices such as high electron mobility transistors (HEMTs) [5] and metal semiconductor field effect transistors (MESFETs) [6]. The optimised operation of these devices requires thermally stable and reliable ohmic and Schottky contacts. This necessitates the study of physics of interface between metals and GaN at different temperatures.

Extensive work on Schottky contacts to n- GaN has been reported. A number of metals such as Pt, Pd, Au, Ti, Ni, Cr and W have been used to fabricate Schottky contacts and their Schottky barrier heights (SBH) have been measured. Few of them have also reported measurements of SBH as a function annealing temperatures. Guo et al [7] studied Ni/n-GaN Schottky contact and reported a barrier height of 0.56 eV and 0.66 eV by C-V and J-T methods respectively. For instance, Duxstad et al. [8] studied the behavior of Pt and Pd contacts on GaN and reported that till 700C the contacts were stable. Binari et al. [9] measured the Schottky barrier heights of Ti on GaN as 0.58 eV. Ni/Au (30/300 nm) Schottky barrier contacts to n-GaN,

J. Osvald et al. [10*] observed that the SBH decreased with decrease in temperature and reported the SBH as 0.53 V at 320 K and 0.16 V at 80 K. For the same bi-layer contacts Yuanping Sun et al. [11] reported the increase of SBH form 0.689eV for un-annealing to 0.603eV for annealed sample at 250C, decrease to 0.63eV for annealed sample at 350C, further increase to 0.86eV at 600C and dropping to 0.67eV at 850C. In this work we investigated the behaviour of Schottky barrier heights of Rh contacts to n-GaN with reference to change in annealing temperatures. We also present here the ideality factor at different annealing conditions of the contacts.

2. Experimental Details

The n-GaN films used in this work for the formation of Schottky contacts were grown on a basal plane sapphire substrates by low-pressure metal-organic chemical vapour deposition (MOCVD). A 2 μm thick undoped GaN layer was first grown upon which another 2 μm thick layer of n-GaN:Si ($n_d = 4.07 \times 10^{18}$ cm^{-3}) was grown.

The n-GaN layer was initially degreased ultrasonically with warm trichloroethylene and later by acetone and methanol for 5 min. each. This sample was then dipped into boiling aqua regia [HNO_3:HCL=1:3] for 10 minutes to get rid of the native oxides and rinsed in de-ionized water. The samples were directly loaded into the electron beam evaporation system and metal bilayer Ti (15 nm)/Al (30 nm) was deposited to form ohmic contacts on a portion of the semiconductor [Fig 1]. Then the specimen was annealed in a rapid thermal annealing (RTA) system at 850 °C in nitrogen ambient for 30 s.

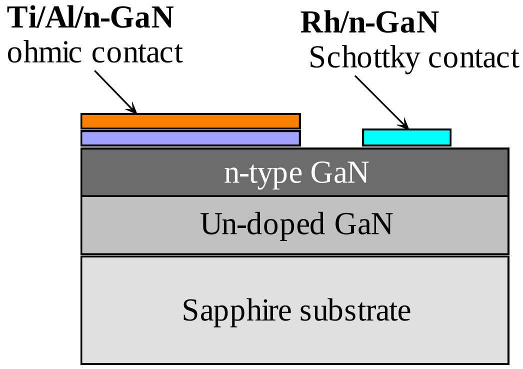

Figure 1: The schematic of the Rh/n-GaN Schottky diodes.

Schottky contacts to n-GaN with a circular diameter of 1 mm were formed with 50 nm thick Rh (99.999 %) using electron beam evaporation system with the base pressure of 2x10^{-6} torr. Then the Rh/n-GaN specimens were annealed in RTA system at temperatures ranging from 300 to 500 °C for 1 min in nitrogen ambient.

Schottky barrier heights of the contacts were determined using current-voltage (*I*-*V*) and capacitance-voltage (*C*-*V*) techniques. *I*-*V* measurements were done using Keithley source measure unit (Model No. 230) and *C*-*V* measurements were carried out using Hewlett-Packard LCR meter (Model No. 4274 A). All electrical measurements were done at room temperature.

3. Results and discussion

The forward and reverse *I*-*V* characteristics of Rh/n-GaN Schottky contact measured as a function of annealing temperature are shown in Fig 2.

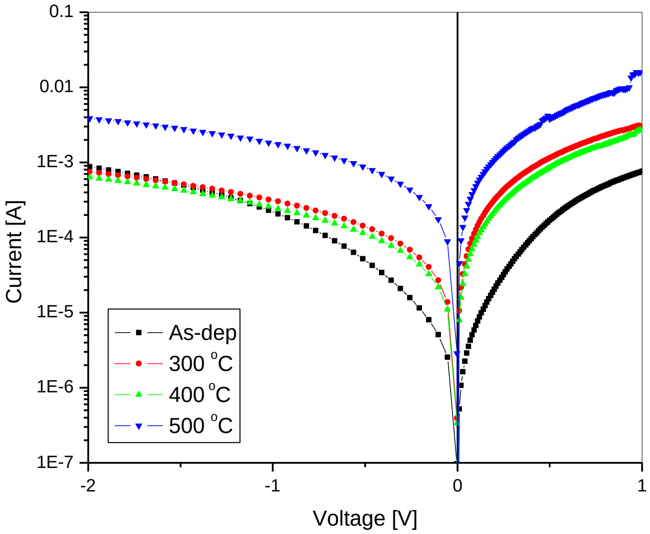

Figure 2: I-V characteristics of Rh Schottky contacts on n-type GaN as a function of annealing temperatures.

The characteristics of Rh/n-GaN Schottky diodes are uniform over different temperatures. For the as-deposited sample, the leakage current at 1 V is 2.3x10^{-4} A and remains almost same for other samples annealed at temperatures 300 °C and 400 °C. It increases to 1.8 x 10^{-3} A for the sample annealed at 500 °C.

The barrier height and ideality factor of a metal-semiconductor contact were determined using thermionic emission theory is given by [12]

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

with $$I_o = SAT^2 \exp\left(\frac{-\phi_b}{kT}\right). \quad (2)$$

Here, I the current, q the electron charge, V the applied voltage, T the absolute temperature, S the contact area, n the ideality factor, A the effective Richardson constant (26.4 A cm^{-2} K^{-2} for n-GaN) [13], and ϕ_b the Schottky barrier height (SBH). Equation (1) shows that the logarithmic plot of I / [1 – exp (–qV/kT)] against V [Fig. 3] is linear and I_o is obtained from the y-axis intercept at zero voltage. Using these I_o values in equation (2), the SBH were determined. Table 1 shows the values of SBH for as-deposited and annealed sample.

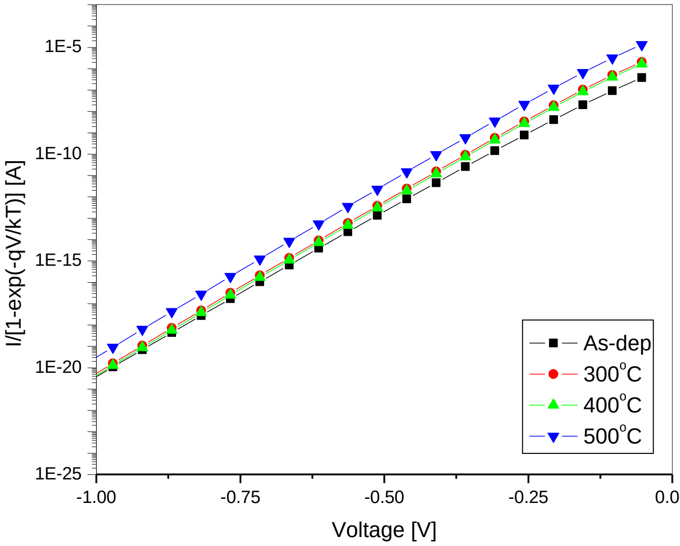

Figure 3: The plot of I/[1-exp (-qV/kT)] against V for Rh Schottky contacts annealed at different temperatures.

Using a plot of natural log of current versus forward bias voltage, for small forward currents (plot not shown), the ideality factors (n) were calculated. For the as-deposited Rh Schottky diodes ideality factor was found to be 1.17. For the other annealed samples, it is in the range between 1.20 and 1.25, as listed in table 1.

Table 1: The Schottky barrier heights and ideality factors of Rh Schottky contacts to n-GaN as a function of annealing temperature.

Annealing	***SBH ϕ_b(eV)***		***Ideality***
temperature	***I-V***	***C-V***	***factor n***
As-dep	***0.60***	***0.98***	***1.17***
300°C	0.56	0.88	1.20
400°C	0.56	0.77	1.21
500°C	0.51	0.65	1.25

The *C-V* characteristics of Rh Schottky diodes were measured as a function of annealing temperatures. Figures 4 show the plots of $1/C^2$ versus bias voltage for different annealing temperatures. The C-V relationship for Schottky diode is given by [12]

$$\frac{1}{C^2} = \left(\frac{2}{\varepsilon_s qNA^2}\right)\left(V_{bi} - \frac{kT}{q} - V\right) \qquad (3)$$

Where $\in_s$ is the permittivity of the semiconductor ($\in_s = 9.5 \in_0$), V is the applied voltage. The x-intercept of the plot of $1/C^2$ versus V, V_0, is related to the built in potential V_{bi} by the equation $V_{bi} = V_0 + kT/q$. The barrier height is given by the equation

$$\phi_b = V_0 + V_n + kT/q.$$

Here $V_n = (kT/q) \ln (N_c/N_d)$. The density of states in the conduction band edge is given by $N_c = 2 (2\pi m^* kT/h^2)^{3/2}$, where $m^*=0.22m_o$ and its value was 2.53×10^{18} cm^{-3} for GaN [14].

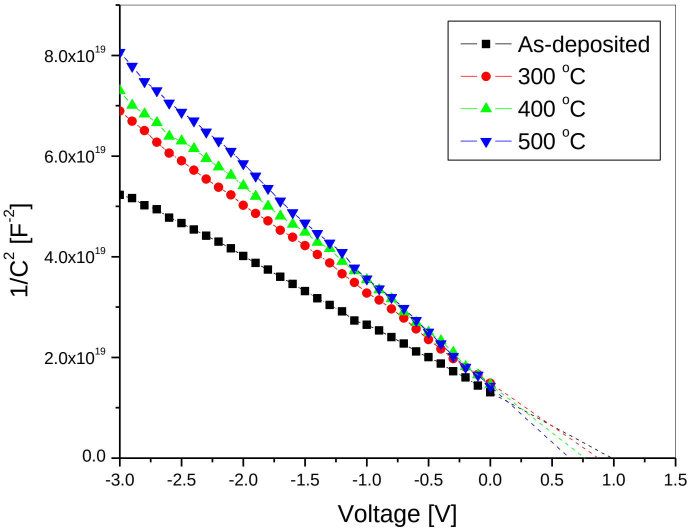

Figure 4 A plot of $1/C^2$ versus V for Rh Schottky contacts annealed at different temperatures.

Table 1 also shows the values of SBH for Rh/n-GaN Schottky diodes computed using C-V characteristics. The variation of SBH and ideality factor of Schottky diodes of Rh/n-GaN with respect to annealing temperatures are shown in figures 5.

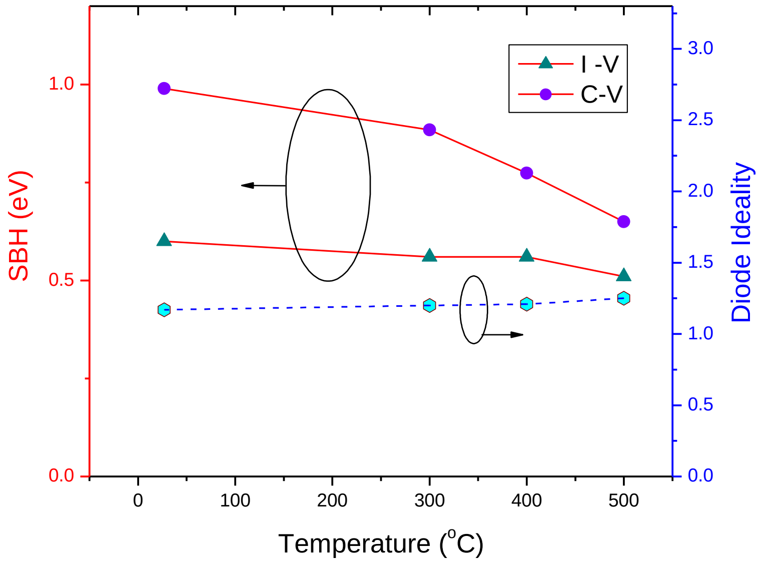

Figure 5: The barrier heights and diode ideality factors of Rh /n-GaN as a function of annealing temperature.

Fig. 5 shows a plot of barrier height of Rh/n-GaN as a function of annealing temperature. It is noticed that the barrier height of the Rh Schottky diode decreases a bit upon annealing from 0.60 eV for as deposited to 0.51eV for contacts annealed at 500 °C. The smaller values of the measured SBH imply the presence if interface states [15]. The figure also shows that, except for a slight change (change $\Delta n=0.08$), the diode ideality factor stays same for all annealing temperatures up to 500 °C. This indicates the stability of the diode over a moderate range of annealing temperatures. The values of ideality factor range through 1.17 to 1.25. These near unity values suggest that the current in forward bias follows thermionic emission model of conduction [16]. The difference in the values of barrier heights estimated by I-V and C-V fits suggests the presence of native oxides at the metal junction to the semiconductor [17] [18][19] and is also ascribed to the lowering of barrier height by the image force due to current follow [20]. The observed larger reverse leakage currents, of the order of milli-amperes, are due to the lower values of barrier heights.

4. Conclusions

The thermal behaviour of Rh Schottky contacts to n-GaN have been studied been by means of I-V and C-V techniques. Both SBH and ideality factor values for the monolayer Rh Schottky contacts to n-GaN were found to be relatively low and stable over a moderate range of annealing temperatures. The contacts exhibited larger reverse leakage currents, which were in the order of mA. The value of barrier height, 0.57 eV for as-deposited sample, increased to 0.82 eV on annealing the sample at 500 °C. The ideality factor also increased from 1.98 for as-deposited sample to 3.0 for sample annealed at 500 °C.

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