Thermal effects on electrical properties of rhodium-gold Schottky contacts to n-GaN

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Abstract

The Rh/Au 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 value of barrier height of the bilayer Rh/Au Schottky contacts increased from 0.57 eV for as-deposited sample to 0.82 eV for a sample annealed at 500 °C. The ideality factor also increased from 1.98 for as-deposited sample to 3.0 for the sample annealed at 500 °C. It is found that the bilayer Rh/Au contacts to n-GaN are some what unstable at higher temperatures.

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/Au 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.

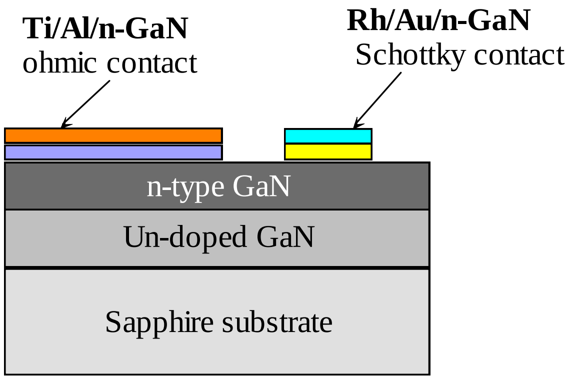

Figure 1: The schematic of the Rh/Au/n-GaN Schottky diodes.

Schottky contacts to n-GaN with a circular diameter of 1 mm were formed with 50 nm thick Rh/Au (25nm/25nm) using electron beam evaporation system with the base pressure of 2×10^{-6} torr. Then the Rh/Au/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/Au/n-GaN Schottky contacts measured as a function of annealing temperature are shown in Fig 2. The characteristics of Rh/Au/n-GaN Schottky diodes are also uniform over different annealing temperatures.

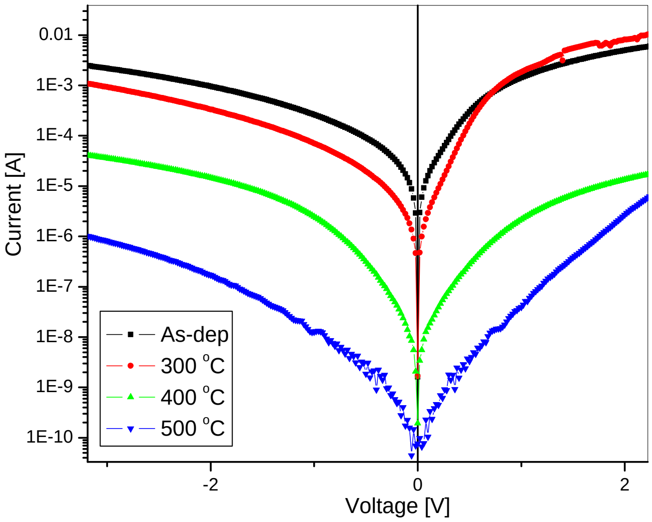

Figure 2: I-V characteristics of Rh/Au Schottky contacts on n-type GaN as a function of annealing temperatures.

For the as-deposited sample, the leakage current at 1 V is 2.3x10^{-4} A and the same for the samples annealed at temperatures 300 °C, 400 °C and 500 °C are 7.2x10^{-5} A, 2.6x10^{-6} A, and 1.4x10^{-8} A respectively.

Table 1: The Schottky barrier heights and ideality factors of Rh/Au 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	0.57	0.62	1.98
300°C	0.62	0.66	1.83
400°C	0.75	0.83	2.21
500°C	0.84	1.05	3.00

Table 1 shows the values of ideality factor and SBH estimated using fig 3 for Rh/Au Schottky diodes. The values of ideality factor increase from 1.98 for as deposited sample to 3.0 for the sample annealed at 500 °C and indicate the non-ideal behaviour of the diodes.

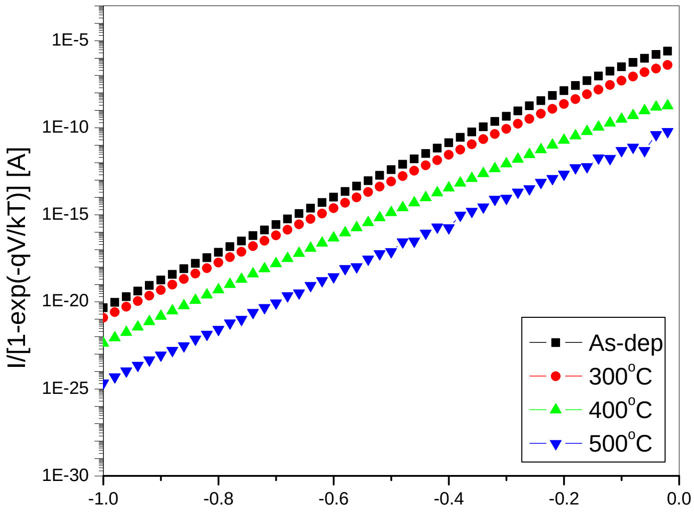

Figure 3: The plot of I/[1-exp (-qV/kT)] against V for Rh/Au Schottky contacts annealed at different temperatures.

The *C-V* characteristics of Rh/Au 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]

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

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].

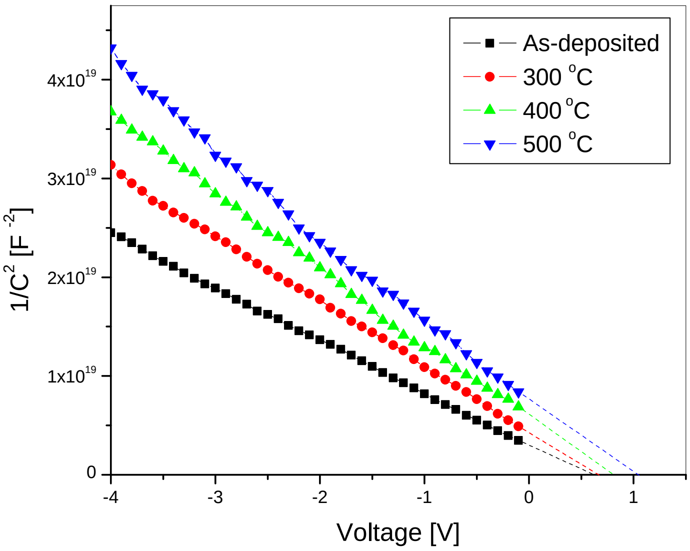

Figure 4: A plot of $1/C^2$ versus V for Rh/Au Schottky contacts annealed at different temperatures.

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

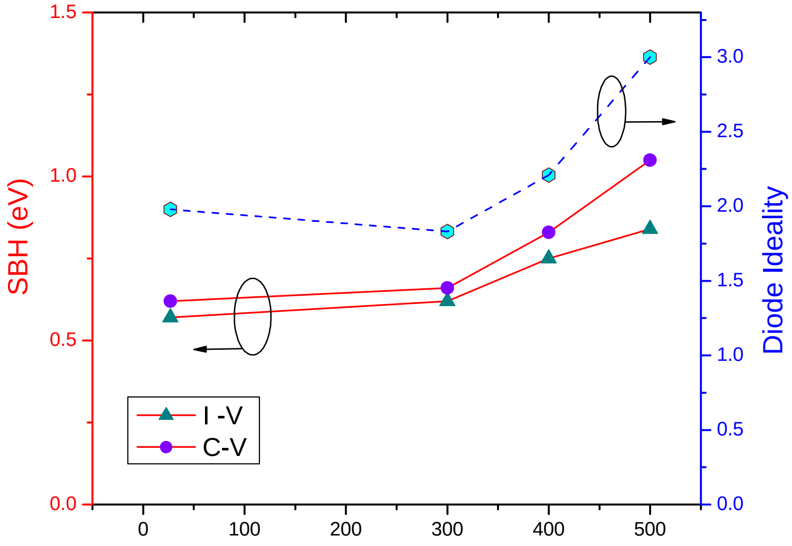

Figure 5: The barrier heights and diode ideality factors of Rh/Au/n-GaN as a function of annealing temperature.

The plot of Schottky barrier heights and ideality factors of Rh/Au contacts versus annealing temperature is shown Fig 5. The barrier heights due to I-V and C-V characters are almost equal at lower annealing temperatures. The values, however, differ slightly at higher temperatures. The barrier heights increase with increase in temperature and results in drastic collapse in reverse leakage currents. This behaviour is in agreement with the findings by the other researchers [21]. The increase in barrier heights due to higher annealing temperatures may be because of the reduction in the density of interfacial defects [22]. The diode ideality also increases with increase in annealing temperature. This suggests that the current transport mechanism in these diodes may not purely due to thermionic emission. The addition of Au layer between Rh and n-GaN makes the contacts thermally unstable.

4. Conclusions

The thermal behaviour of Rh/Au Schottky contacts to n-GaN have been studied been by means of I-V and C-V techniques. The contacts exhibited larger reverse leakage currents, which were in the order of mA. The bilayer Rh/Au Schottky contacts to n-GaN behaved differently from monolayer contacts. 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. It is found that the bilayer Rh/Au contacts to n-GaN are some what unstable at higher temperatures.

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