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INVESTIGATION OF CURRENT-VOLTAGE CHARACTERISTICS OF Ni/GaN SCHOTTKY BARRIER DIODES FOR POTENTIAL HEMT APPLICATIONS

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In the present work, the I-V characteristics of Ni/GaN Schottky diodes have been studied. The Schottky diodes, having different sizes using Ni/Au and ohmic contacts using Ti/Al/Ni/Au were made on n-GaN. The GaN was epitaxially grown on c-plane sapphire by metal organic chemical vapor deposition (MOCVD) technique and had a thickness of about 3.7 μm. The calculated ideality factor and barrier height from current-voltage (I-V) characteristics (at 300 K) for two GaN Schottky diodes were close to ~1.3 and ~ 0.8 eV respectively. A high reverse leakage current in the order of 10^{-4} A/cm^2 (at – 1 V) was observed in both diodes. A careful analysis of forward bias I-V characteristics showed very high series resistance and calculation for ideality factor indicated presence of other current transport mechanism apart from thermionic model at room temperature.

Keywords: *GaN, SCHOTTKY DIODE, THERMIONIC, CURRENT-VOLTAGE, XRD, AFM.*

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1. INTRODUCTION

GaN is a III-V semiconductor of wurtzite structure and has a direct bandgap of 3.39 eV at room temperature. And since the critical breakdown electric field is roughly proportional to the square of the energy bandgap, so GaN with a breakdown voltage 3.5 MV/cm is best suited for high power applications [1]. As GaN based transistors can operate at much higher temperature and can work at much higher voltages than Si, Ge and GaAs based transistors, they make ideal power-amplifiers at microwave applications. The saturation velocity of GaN is 2.5 times of Si so that it can be used for high frequency applications.

Detailed understanding and optimization of GaN and AlGaN Schottky barrier properties are critical for III-nitride device technologies such as high power high electron mobility transistors (HEMTs) and solar-blind detectors [1-4] because the performance of GaN-based devices can often be limited by the quality of Schottky and Ohmic contacts. According to Schottky-Mott model the barrier height equals the difference between metal work function and electron affinity (χ) of semiconductor [2]. Metals like Pt (5.65 eV), Pd (5.12 eV) and Au (5.1 eV), which have high work function values, are expected to form good Schottky contacts on GaN (χ = 4.1 eV). Throughout the literature, studies have revealed various dependencies of the Schottky barrier height on the forward bias ideality factor [5], choice of Schottky metal [6, 7], influence of surface damage [8], and material quality [9]. Due to the importance of these parameters in ultimate device applications, quantitative determination of their values and factors that affect their accuracy within the usual current-voltage models that are applied to this problem need to be understood. Maximizing the Schottky barrier height, minimizing reverse leakage current, and minimizing their variation over large area are all key to advancing the performance of these devices and to enhance manufacturability. This paper describes the current-voltage characteristics of Ni/GaN Schottky diode and the possible mechanism to understand the behavior of the diodes formed.

2. EXPERIMENTAL

The samples used in this work were about 3.7 μm thick GaN epitaxial layers grown on c-plane sapphire substrates using metallorganic chemical vapor deposition (MOCVD) technique. Prior to metallization, the samples were boiled and ultrasonically cleaned in trichloroethylene acetone and iso-propanol, at 340 K and then dipped in 1:1 HCl for 2 min to remove the native oxide. Finally the clean samples were rinsed in deionized water and blown with dry nitrogen before deposition. The Ti/Al/Ni/Au (20/100/20/100 nm) ohmic contacts were deposited on n-GaN at the edges by e-beam deposition system at a base pressure of 10^{-8} mbar. The contacts were annealed using rapid thermal annealing at 550 °C for 1 min and then at 700 °C for 30 seconds. Again a pre-metal dip in 1:1 HCl was given before Schottky metal deposition. Thick bilayer dots of Ni/Au (40/150 nm) were deposited using a window mask having two different dot sizes (0.3 mm, 1 mm dia.). The current-voltage (I-V) characteristic measurements were performed to electrically characterize the fabricated diodes. A computer controlled Keithley Source Meter (Model-2400) was used for these measurements. Carrier concentration for GaN samples was estimated from Hall measurements to be around 1.2×10^{16} cm^{-3}. The surface morphology of the GaN substrate was studied using a Veeco multimode AFM and Philips X'pert pro XRD system was used for X-ray diffraction analysis.

3. RESULTS AND DISSCUSSION

Prior to device characterization, thin films of GaN on sapphire substrates were characterized by X-ray diffraction and AFM for analyzing film quality (shown in Fig. 1a and 1b, resp.). XRD data revealed that GaN layer were grown in c-axis direction. We did AFM studies for morphology investigation of surface of epitaxial layers. From the AFM images, we observed that the surface of GaN on sapphire was very smooth with rms roughness about 1nm. This is a necessary condition for intact contact formation and hence reduction of interface state densities between metal and semiconductor. The typical dislocation density in these epilayers was in the order of 10^{8} cm^{-2}.

Current-voltage measurements were performed at room temperature for all diodes (D1 = 0.3 mm and D2 = 1mm dia.). I-V for ohmic contacts showed good linearity and symmetry over all voltage ranges as shown in Figure 2 b.

The standard diode equation from thermionic model in simple form can be written as:

$$\ln(J) = \frac{qV}{nkT} + \ln(J_s) \quad \text{for } qV > 3kT, \tag{1}$$

where q is the electron charge, k is Boltzmann's constant, and T is the temperature [2]. Plot of ln J against V in forward direction should give straight line for region where V > $3kT/q$.

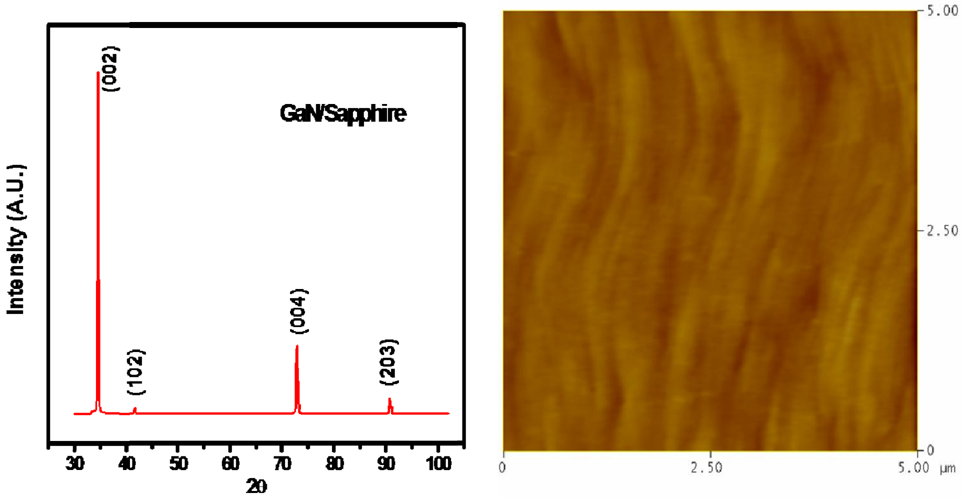

***Fig.* 1** – *XRD (a) and AFM (b) image of GaN epitaxial layer grown on sapphire*

From Eq. (1), we can extract the ideality factor n and the saturation current density J_S, which is expressed as [2].

$$J_s = A^* T^2 \exp\left(\frac{-q\Phi_{b0}}{kT}\right) \tag{2}$$

where A^* is the Richardson constant (for n-type GaN is 26.64 A K^{-2} cm^{-2}).

The barrier height is given by the Eq. (2). Based on these equations the saturation current and ideality factor of each diode were extracted by fitting the linear regions of the forward curves shown in the Fig. 2a. The sample had a linear region of approximately four decades indicating that diodes were of good quality. Using only the linear region assured negligible influence from series resistance which was almost of same order in both diodes. The values of ideality factor suggest that the thermionic emission was the dominant transport mechanism in the diodes.

The barrier height for D2 was greater than D1. The max. barrier height as calculated for D2 was 0.82 eV, which was lesser than the theoretical value 1.1 eV. This could be due to either presence of barrier inhomogeneities [8-9]. Similar variation of Schottky barrier height and ideality factor was also quoted by Chen et al. in their Au/Ni/n-GaN diodes [10]. They ascribed this to presence of surface states at the metal semiconductor interface. Reverse leakage current density for D1 was higher than D2. This could be due to the 1/radius dependence of edge leakage current. Zhou et al. also reported similar results [11]. If the quality of barrier layer as well as the GaN below is improved (low dislocation density), lower ideality factor and also the higher barrier height can be obtained.

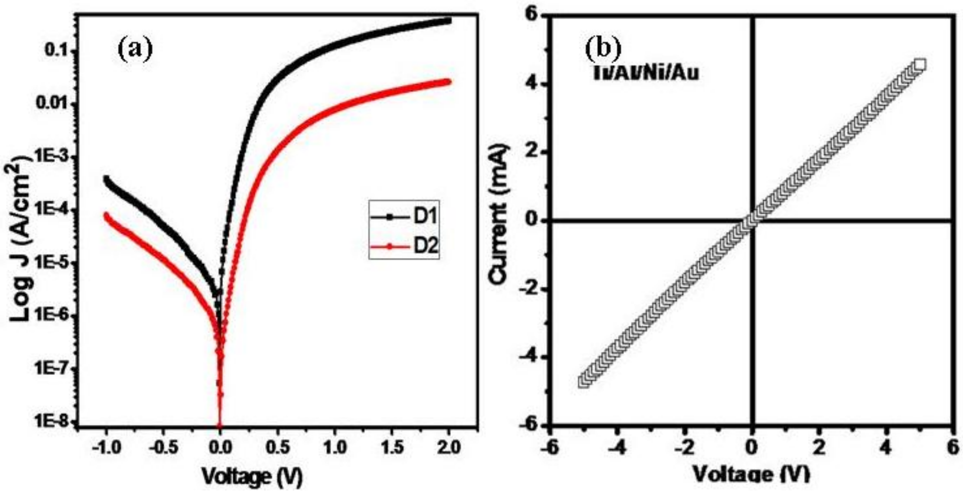

***Fig.* 2** – *Experimental current-voltage characteristics of Ni/GaN Schottky diode (a) and Ti/Al/Ni/Au ohmic contacts (b) on GaN*

Table 1 – *Calculated Schottky diode parameters*

Parameters	D1 (d = 0.3 mm)	D2 (d = 1mm)
Φ_{b0}	0.73 eV	0.82 eV
n	1.33	1.39
JR (– 1V)	3.82×10^{-4}Acm^{-2}	7.83×10^{-5}Acm^{-2}
RS	~ 8 kΩ	~ 10 kΩ

4. CONCLUSION

Ni/GaN Schottky diodes were fabricated and basic diode parameters such as ideality factor and barrier height were extracted from current-voltage measurements. The ideality factors were found to increase and Schottky barrier heights decreased for diodes having smaller diameter. We suggest that presence of surface states or some other mechanisms like thermionic field emission may also be affecting the thermionic emission current transport mechanism.

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REFERENCES

1. Y. Zhou, M. Li, D. Wang, C. Ahyi, C.C. Tin, J. Williams, M. Park, N.M. Williams, A. Hanser, *Appl. Phys. Lett.* **88**, 113509 (2006).
2. S.M. Sze, *Physics of Semiconductor Devices* (New York: Wiley: 1981).
3. F.G. Posadaa, J.A. Bardwell, S. Moisa, S. Haffouz, H. Tang, A.F. Bracaa, E. Mucoza, *Appl. Surf. Sci.* **253**, 6185 (2007).
4. J.C. Carrano, T. Li, P.A. Grudowski, C.J. Eiting, R.D. Dupuis, J.C. Campbell, *Appl. Phys. Lett.* **72**, 542 (1998).
5. M. Mamor, *J. Phys. Condens. Matter* **21**, 335802 (2009).
6. M.L. Lee, J.K. Sheu, S.W. Lin, *Appl. Phys. Lett.* **88**, 032103 (2006).
7. S. Oyama, T. Hashizume, H. Hasegawa, *Appl. Surf. Sci.* **190**, 322 (2002).
8. A.R. Arehart, B. Moran, J.S. Speck, U.K. Mishra, S.P. Denbaars, S.A. Ringel, *J. Appl. Phys.* **100**, 023709 (2006).
9. K.H. Lee, S.J. Chang, P.C. Chang, C.H. Kuo, *Appl. Phys. Lett.* **93**, 132110 (2008).
10. P.S. Chen, T.H. Lee, .L.W. Lai C.T. Lee, *J. Appl. Phys.* **101**, 024507 (2007)
11. Y. Zhou, D. Wang, C. Ahyi, C.C. Tin, J. Williams, M. Park, N.M. Williams, A. Hanser, E.A. Preble, *J. Appl. Phys.* **101**, 024506 (2007).