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Investigations on the nonidealities in Pd/n-GaN Schottky diodes grown by MOCVD

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ABSTRACT

The effect of ammonia flow rate on the device characteristics of Pd/n-GaN Schottky diodes is discussed. The carrier concentration and hall mobility of the as grown epilayers were found to decrease with an increase in the V/III ratio. Current–Voltage (*I*–*V*) barrier height initially decreases and then increases with an increase in V/III ratio. The ideality factor and leakage current decreases with an increase in the V/III ratio. The Capacitance–Voltage (*C*–*V*) measurements of small area contacts showed a large variation in the slope of the lines of A^2/C^2 vs. V plot. *I*–*V*–*T* measurements revealed that the ideality factor and the reverse leakage current increases with temperature confirming that the conduction mechanism is through trap-assisted tunneling process or deep center hopping conduction. Device parameters of GaN Schottky diodes were found to be strongly affected by the variation in localized structural changes induced by V/III ratio.

1. Introduction

Gallium nitride (GaN) III-N semiconductor material is known for its light emitting characteristics in spite of having a large density of dislocations [1]. The metal organic chemical vapor deposition (MOCVD) grown GaN has been commercially used for fabricating various opto-electronic and micro-electronic components. Recently there is considerable interest in developing GaN nanocrystals, subsequent sublimation of which enables realization of free standing GaN which can be used for obtaining better device characteristics [2]. The advantages of GaN based electronic devices lie in the domain of high electric fields where the saturation velocities and breakdown voltages are superior to Si and GaAs and even the main competitor, SiC. However, the real life nitride devices at present cannot, as a rule, go to such high electric fields because of the problems with excessive leakage and early breakdown.

Several groups have suggested that defects in particular dislocations might play an important role in the device characteristics [3–6]. The presence of bulk non-uniformities of shallow and deep centers as revealed by various techniques is the primary reason for the nonideal performance in high electric fields. The nature of these non-uniformities and the ways they affect the device performance should be understood and technological approaches minimizing electrical non-uniformity of the materials have to be found. Even though many electronic devices have been fabricated on the GaN and related alloy systems, degradation of electrical characteristics of the Schottky devices due to the variation in the density of threading dislocations have not been studied in detail. Deeper understandings of the compensation mechanism in GaN and interface properties are critical for developing reliable high power high electron mobility transistors (HEMTs) and solar-blind detectors.

Detailed Schottky diode studies were reported for various metal contacts on n-GaN [7–12]. Recently, the dependence of device parameters on threading dislocations in GaN based light emitting diodes (LEDs) and Schottky diodes fabricated on different substrates or templates were reported [13–15]. In this paper, we present results of Pd/n-GaN Schottky diodes of 100 nm thick and 50, 100, 150, 200, 400 μm in diameters fabricated on 3 μm thick GaN grown by MOCVD with different V/III ratios. Using Hall effect measurement, *I*–*V*, *C*–*V* and *I*–*V*–*T* measurements, the dependence of the device parameters such as barrier height, ideality factor and leakage current on the quality of GaN were correlated and a suitable mechanism responsible for the nonideal behavior was discussed.

2. Materials and methods

Nominally identical, unintentionally doped n-type GaN epilayers were grown on sapphire (0 0 0 1) substrates using MOCVD system. Trimethylgallium (TMG) and ammonia (NH_3) were used as precursors. Initially the sapphire substrate was heated up to 1100 °C for about 10 min in a stream of hydrogen. 30 nm thick GaN layer was deposited as buffer at 550 °C. After buffer layer growth, substrate was heated up to 1075 °C to grow 3 μm thick unintentionally doped GaN epilayers. The optimization was carried out by keeping the gallium flow rate for all the samples at 80 μmol/s and changing the ammonia flow in the reactor from 4 to 7 SLM. The V/III ratio was changed, keeping all other growth parameters constant.

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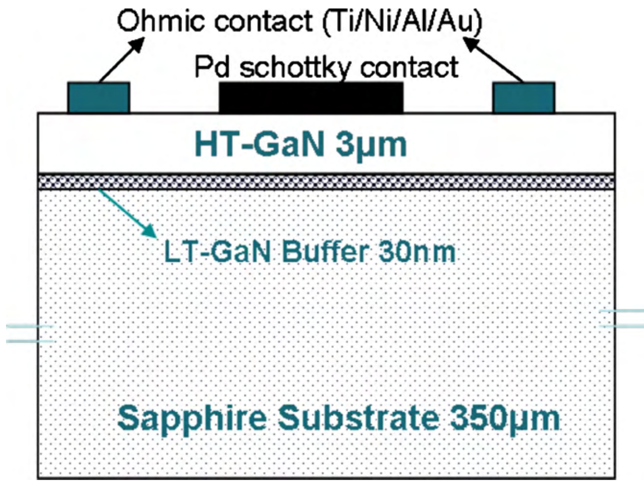

Fig. 1. The cross-sectional view of the fabricated Schottky devices.

Fig. 1 shows the device structure of the Pd Schottky diodes fabricated on GaN. Before depositing 100 nm thick palladium Schottky of varying diameters, multilayer guard ring type ohmic contacts made up of Ti/Al/Ni/Au (15/75/12/40 nm) were deposited and annealed at 950 °C for 90 s in rapid thermal annealing. All the metals were deposited using the e-beam evaporation system whereas Al was deposited by vacuum thermal evaporation after using a standard surface treatment. The pattern was realized using the photolithography technique. The diameter of the Pd Schottky contacts was varied from 50 to 400 µm. Current–Voltage (*I*–*V*) and Capacitance–Voltage (*C*–*V*) characteristics of the Schottky diodes were measured; parameters like barrier height, ideality factor and reverse leakage current were calculated from the forward and reverse *I*–*V* measurements. The capacitance was measured at 1 MHz and the *C*–*V* barrier height was also calculated. The Current–Voltage–Temperature (*I*–*V*–*T*) measurements were carried out in the temperature range of 298–390 K.

3. Results and discussion

3.1. Hall effect measurements

Fig. 2 shows the variation of the carrier concentration and Hall mobility with respect to the V/III ratio. The hall mobility for most of the samples was greater than 500 $cm^2/V\,s$ indicating fairly good quality of GaN layers. The electron concentration of the sample varies from 5×10^{16} to $3.4 \times 10^{16}\,cm^{-3}$. Hall mobility and the electron concentration of the samples decrease while increasing the V/III ratio from 1258 to 2200.

Intrinsic defects increase due to an increase in the V/III ratio [16]. It is expected that as the ammonia flow rate increases, the concentration of the electron donating N-vacancy site decreases. A decreasing trend in electron concentration as shown in Fig. 2 can also be accounted for the increase of compensating centers caused by the high ammonia flow rates. The mobility reduction with increasing ammonia flow rate also confirms the above argument. The variation of hall mobility from 610 to 490 $cm^2/V\,s$ may be attributed to the ionized impurity scattering in GaN. Ionized impurity scattering is due to the presence of intrinsic defects [17,18].

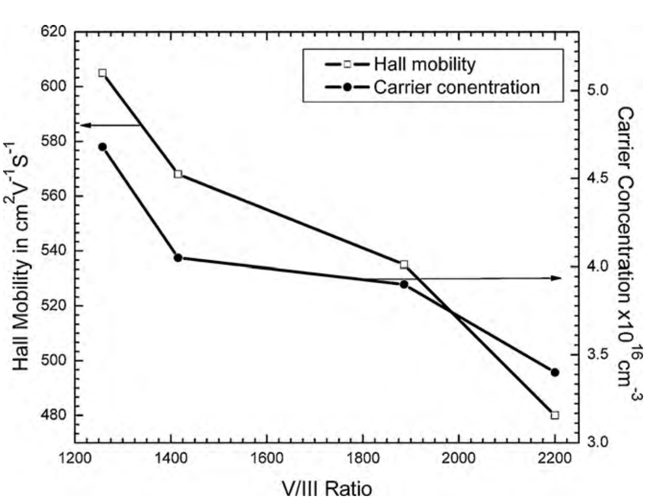

Fig. 2. The variation of Hall mobility and donor concentration with V/III ratio.

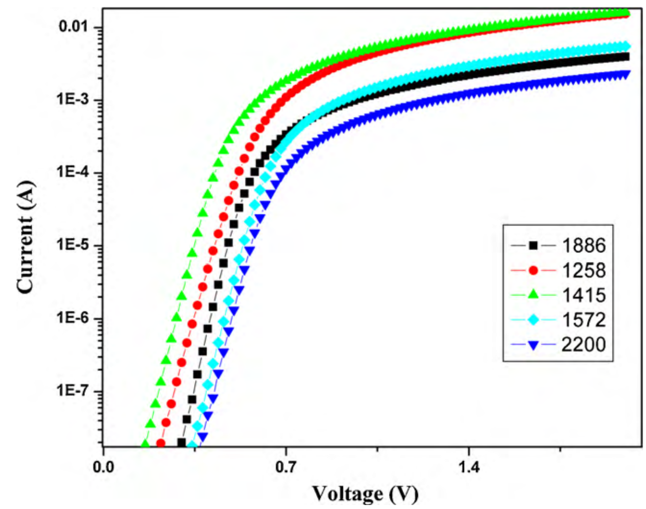

Fig. 3. Forward-bias log(*I*)–*V* characteristics of 400 µm diameter Pd Schottky contacts on GaN grown with different V/III ratio.

3.2. I–V measurements

Fig. 3 shows the typical log(*I*)–*V* characteristics of Pd Schottky contacts on GaN grown with different V/III ratio. The series resistances of all the metal contacts were found to increase from 250 to 300 Ω on increasing the V/III ratio. The barrier height ($q\phi_b$) and the ideality factor (n) were extracted using the equation below:

$$I = AA^*T^2 \exp\left(\frac{-q\phi_b}{K_B T}\right) \exp\left(\frac{qv}{nK_B T} - 1\right)$$

where A is the diode area, A^* is the Richardson constant (26.4 $A\,cm^{-2}\,K^{-2}$).

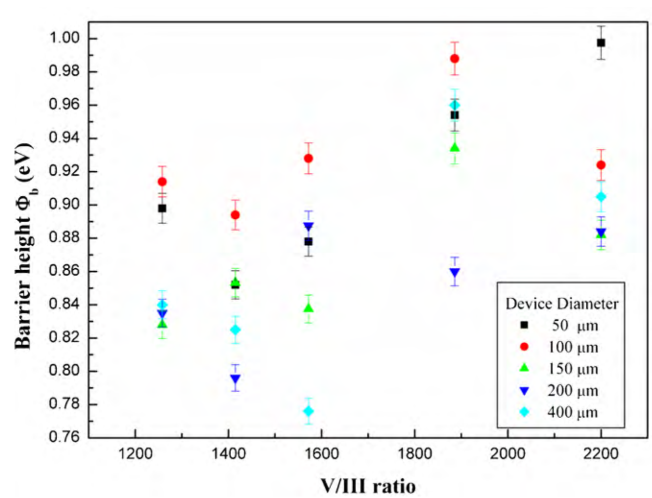

Fig. 4. The variation of barrier height extracted from the *I*–*V* characteristics of various diameter diodes with respect to the V/III ratio growth parameter.