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GaN Schottky Diodes for Microwave Power Rectification

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1. Introduction

In microwave power transmission systems, such as wireless power distribution through steel frames in buildings, space solar power system (SSPS), and wireless charge system for electric vehicle [1], high power, high efficiency and compact components are desired. For the transmitters, class-F amplifier with AlGaN/GaN HFET will be appropriate [2]. In the receiving terminal, single shunt circuit (Fig.1) will be used where high frequency performances for higher harmonic frequencies are required [3]. For this purpose, low parasitic capacitance Schottky diode with low ON resistance, low ON offset voltage and high reverse breakdown should be developed. In this paper, we will report the design and development of lateral GaN Schottky diodes.

2. Diode Design and Fabrication

We set the target frequency of 2.45GHz, and handling power for one diode as less than 10W and breakdown voltage of 100V. Semi-insulating SiC substrate was adopted for its superior thermal conductivity than that of sapphire. From these specifications, we designed the diode as shown in Fig. 2, where the finger width and length of the anode are 2μm and 100μm, respectively. Other evaluation patterns include circular Schottky diode with diameter of 150 μm and multi-finger type with 5 and 10 fingers, respectively. The n-layer thickness was 1~1.4μm and the donor concentrations were 5×10^{15}~2.2×10^{17}cm^{-3}. To suppress the series resistance, an n^{+}-GaN layer was introduced below the Schottky barrier layer to sever as a layer for ohmic contact and a current path along the lateral direction. The thickness of this layer is 1~0.6μm and the donor concentration is 4×10^{18} cm^{-3}. To avoid parasitic capacitances, all the pads of anodes are isolated from the n^{+} GaN layer. Air-bridge wiring is used to connect the anode fingers with the pads.

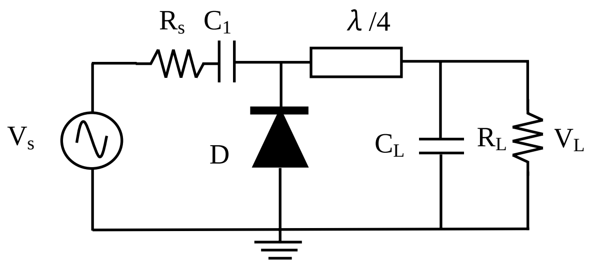

Fig.1 A single shunt circuit for microwave rectification.

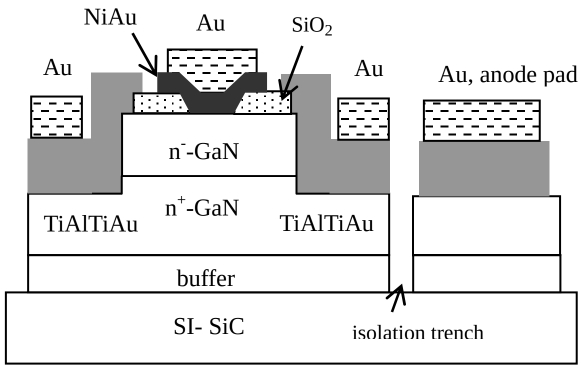

Fig. 2 Device structure of n-GaN Schottky diode on SI SiC substrate.

Standard photolithography and lift-off process were utilized to fabricate the devices. Before ohmic contact process, the n^{-}-GaN layer was removed to expose the n^{+}-GaN layer by inductively coupled plasma (ICP) etching. In the next step, similar method was used for device isolation by etching the n^{+}-GaN layer down to the substrate. The ohmic contact was formed using Ti/Al/Ti/Au (50 nm/200 nm/40 nm/40 nm) with annealing temperature of 850°C and period of 1 minute in N_2 ambient [4].

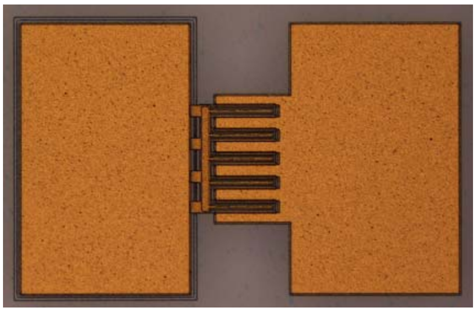

Fig. 3 The photograph of a fabricated GaN Schottky diode with 5 anode fingers

The contact resistance was evaluated to be 0.05~0.40 Ωmm by transmission line model (TLM). SiO_2 (100 nm) was deposited by PECVD for the field plate structure. Ni/Au (50nm/100nm) two-layer contact was deposited as Schottky electrode. To reduce the resistance of the electrodes, an Au layer with thickness of 1.5 μm was formed on the possible electrodes by electroplating. An air bridge was also introduced to connect the anode finger and the anode pad. Fig. 3 shows a photograph of a fabricated GaN Schottky diode with 5 anode fingers.

3. Results and Discussion

Figure 4 shows the I-V characteristics of a one-finger diode (n^-=4.0×10^{16} cm^{-3}) with anode electrode size of 2×100 μm^2. The reverse leakage current is below 1×10^{-5} A at the reverse bias of -20 V. The turn-on voltage is about 0.8 V which is defined as the voltage where the forward current reaches 200A/cm^2. The on-resistance is 25.6 Ω which is defined as a differential resistance in the high forward voltage region. It decreases to 6.6 Ω and 4.5 Ω for the 5-finger device and 10-finger device, respectively.

The one-finger on-resistances become 10.7 Ω, 13.0 Ω and 208.3 Ω for the doping level of 2.2×10^{17} cm^{-3}, 1.2×10^{17} cm^{-3} and 5.0×10^{15} cm^{-3}, respectively. For a circular Schottky diode with doping of 1.2×10^{17} cm^{-3}, under zero bias, the capacitance is 7.52×10^{-8} F/cm^{-2}.

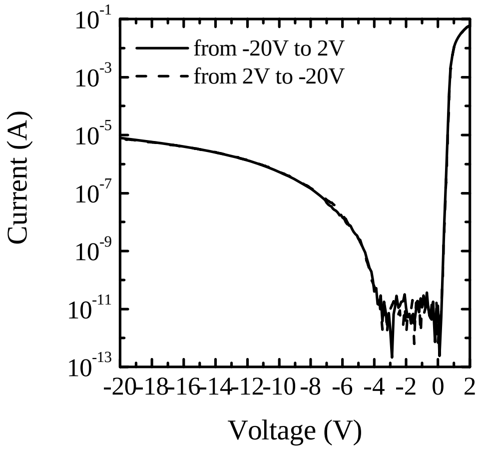

Fig. 4 I-V characteristics of Schottky diode (2×100 μm^2) with doping level of 4.0×10^{16} cm^{-3}.

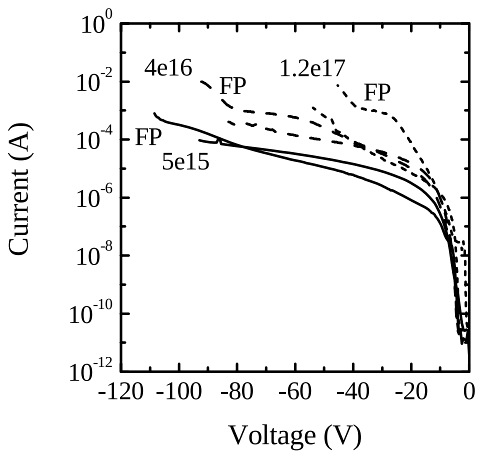

Fig. 5 Breakdown characteristics of Schottky diode at reverse bias.

From the reverse I-V characteristics of the device that is shown in Fig. 5, the breakdown voltages for the devices with field plate are about -108 V and -93 V for the doping levels of 5.0×10^{15} cm^{-3}, 4.0×10^{16} cm^{-3} respectively. When the doping level is over 1.0×10^{17} cm^{-3}, the breakdown voltages decreases to about -50 V. The measured breakdown voltage is much lower than that expected. The reason is considered to be the relatively higher density of dislocation in GaN epitaxial layer [5].

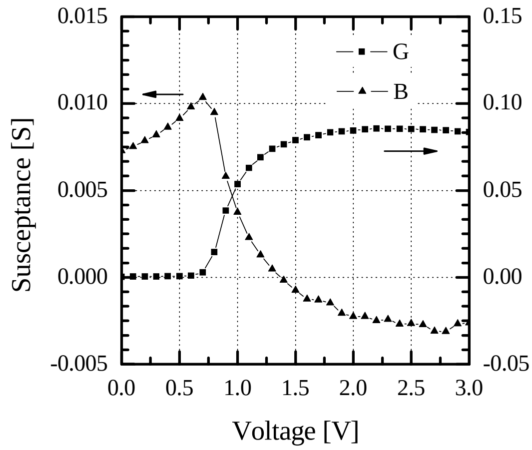

Fig. 6 The measured admittance of the single finger diode at 2.45GHz by microwave network analyzer.

Figure 6 shows the admittance of the single finger diode (n^-=2.2×10^{17} cm^{-3}) measured at 2.45 GHz. The conductance increase at 0.7 V, which is the ON offset voltage determined by the Schottky characteristics. It saturates at 0.08 S or 12.5 Ω due to diode series resistance. From TLM measurements, contact resistance and sheet resistance for the n^+ layer were 0.052 Ωmm and 92.9 Ω, respectively, indicating that the access resistance from Ohmic contact to n^- region is 5.8 Ω. The corresponding electron mobility in the n^- region is estimated as 234 cm^2/Vs. The susceptance sharply decreases as conductance increases. This is typical for Schottky diode in which no diffusion capacitance exits. The negative susceptance may come from the wiring inductance in the anode finger electrode.

4. Conclusion

We fabricated high voltage lateral GaN Schottky diodes for microwave power rectification. In this research, we have not fully utilized GaN high breakdown characteristics, but it matches the levels of silicon counter parts. By increasing the breakdown voltage and decreasing the access resistance, GaN Schottky diodes will play key roles in microwave power transmission applications.

Acknowledgement

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