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GaN Schottky Barrier Diodes with TiN Electrode for High Efficiency Microwave Power Rectification

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Abstract

GaN Schottky barrier diodes (SBDs) with low turn-on voltage are developed with reactively-sputtered TiN electrodes. The diodes have 0.5 V turn-on voltage compared with 1.2 V for the diodes with Ni electrode, while the on-resistance and the reverse breakdown characteristics are almost the same. They will be expected to improve the RF/DC conversion efficiency of the rectenna circuits for wireless power transmission.

1. Introduction

Recently, wireless power transmission, such as electric vehicle power charging and energy harvesting, has been attracting much attentions [1]. The RF to DC conversion efficiency in the receiving section strongly depends on the performance of the Schottky barrier diode (SBD) used in the rectenna circuits, such as on-resistance, off-capacitance and turn-on voltage. For high efficiency, the reduction of turn-on voltage to breakdown voltage ratio is important [2, 3].

In our previous report on GaN SBD for microwave power rectification with Ni electrode [4], the turn-on voltage was 1.16 V. In this paper, we will report GaN SBDs with lower turn-on voltage by the application of TiN Schottky electrode.

2. Device Structure

Figure 1 is the cross sectional view of the GaN SBD. The epi-wafers are grown on *c*-plane sapphire with n^+ access layer of about 3 μm in thickness and sheet resistance of about 25 Ω. For the n-type active layers, two kinds of layers are prepared, one with the impurity density of 3×10^{17} cm^{-3} and thickness of 0.4 μm (sample 1 and 2), and the other with the impurity density of 1×10^{17} cm^{-3} and thickness of 1.0 μm (sample 3 and 4).

The fabrication process started from the active layer mesa formation followed by deep trench isolation with inductively coupled plasma (ICP) dry etching. After those, Ti/Al/Ti/Au (50/200/40/40 nm) were deposited by sputtering for cathode ohmic electrodes. They were annealed at 850 ℃ for 1 min in N_2 ambient. Then, Ni/Au (10/10 nm) were deposited for anode Schottky electrode on sample 2 and 4, while TiN/Ni/Au (10/5/5 nm) on sample 1 and 3. The TiN film was formed by a reactive sputtering in Ar:N_2 (15:3 sccm) mixed gas atmosphere [5]. Next, Au film with thickness of about 1 μm was electroplated on all the electrodes. Finally, post annealing at 300 °C was conducted.

3. Electrical Properties

Figure 2 shows the Schottky barrier height ϕ_b and ideality factor *n* which were extracted from the current-voltage (*I-V*) characteristics of a circular Schottky diode with radius of 50 μm. The Schottky barrier height and the ideality factor of the TiN diode were around 0.5 eV and 1.1, respectively. The Schottky barrier height and the ideality factor of the Ni diode were around 0.9 eV and 1.14-1.30 eV, respectively. In addition to the lower barrier height than Ni electrode, it was also revealed that the TiN diode had better uniformity. From capacitance-voltage (*C-V*) measurement, Schottky barrier height of 0.42 eV for TiN diode and 1.12 eV for Ni diode were obtained and, thus, the lower barrier height is also confirmed.

Figure 3 and Fig. 4 show the *I-V* characteristics of finger-type diodes with finger size of 2×50 μm^2 and impurity density of 3×10^{17} cm^{-3} and 1×10^{17} cm^{-3}, respectively. Turn-on voltage of about 0.5 V and 1.2 V were extracted from the diodes with TiN and Ni electrodes, respectively. The on-resistances were 15.0 Ω and 27.3 Ω for the wafers with impurity density of 3×10^{17} and 1×10^{17} cm^{-3}, respectively, not depending on the anode metals. The reverse breakdown characteristics were shown in Fig. 5 and Fig. 6. Breakdown voltage of about 40 V was achieved for both the sample 1 and 2, while breakdown voltage of over 100 V was achieved for both the sample 3 and 4. It was clear that the TiN diode had the same breakdown voltage but a half of turn-on voltage comparing with the Ni diode.

4. Conclusion

Low turn-on voltage was demonstrated with TiN electrode for GaN SBDs while keeping the low on-resistance and high breakdown voltage of those with Ni electrode. It is expected that the RF/DC conversion efficiency of rectenna circuit will be improved with TiN based GaN SBDs.

References

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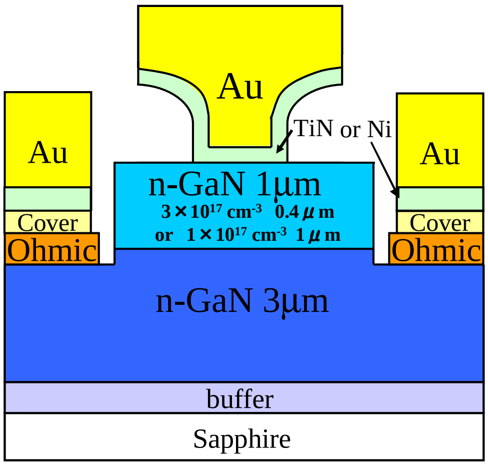

Fig. 1 The cross sectional view of the GaN SBD.

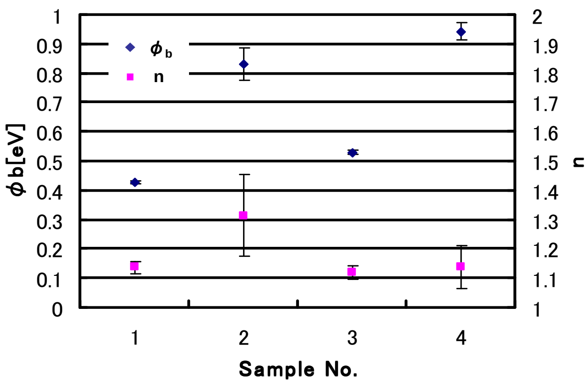

Fig. 2 The Schottky barrier heights and the ideality factors for the GaN SBDs with TiN (sample 1 & 3) and Ni (sample 2 & 4) electrode.

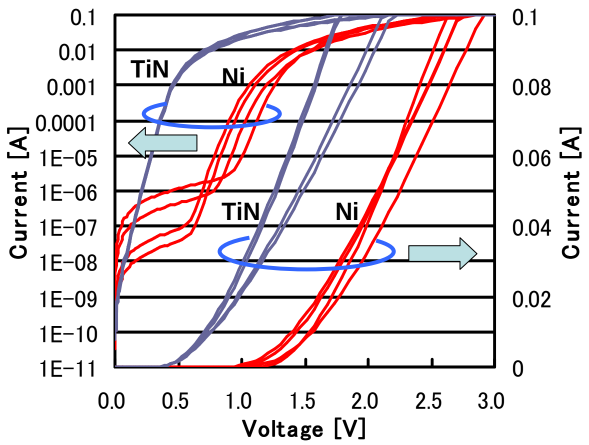

Fig. 3 *I-V* characteristics of the diodes with the active layer impurity density of 3×10^{17} cm^{-3} and thickness of 0.4 µm in both linear and logarithmic scales.

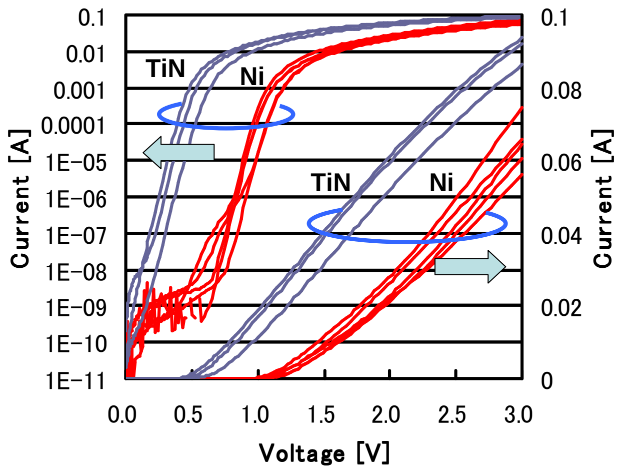

Fig. 4 *I-V* characteristics of the diodes with active layer impurity density of 1×10^{17} cm^{-3} and thickness of 1.0 µm in both linear and logarithmic scales.

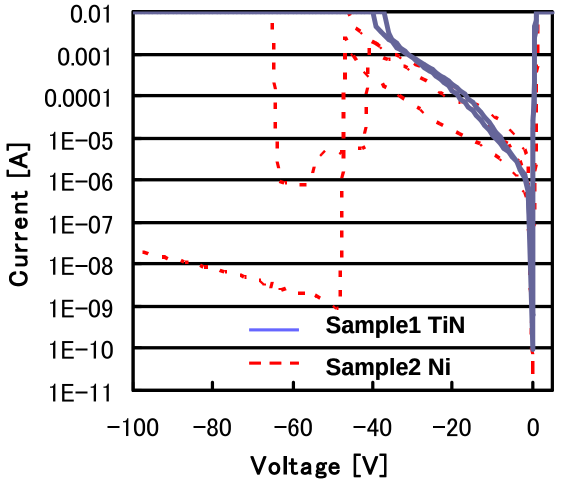

Fig. 5 The reverse *I-V* characteristics of the diodes with active layer impurity density of 3×10^{17} cm^{-3} and thickness of 0.4 µm.

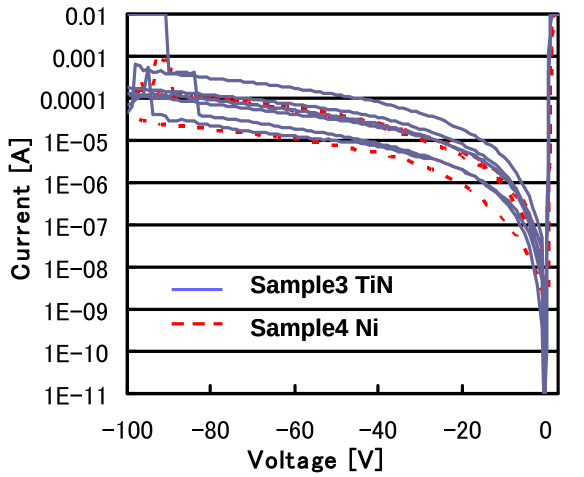

Fig. 6 The reverse *I-V* characteristics of the diodes with active layer impurity density of 1×10^{17} cm^{-3} and thickness of 1.0 µm.