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Temperature Dependence of TiN-Anode GaN Schottky Barrier Diode Characteristics for Microwave Power Rectification

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Abstract

The temperature dependence of the GaN Schottky barrier diodes (SBDs) with TiN and Ni anode for microwave power rectification was evaluated in the temperature range of 25-175 °C. Reduction of turn-on voltage, increasing of leakage current and increasing of Schottky barrier height were confirmed with the temperature increasing. The leakage current of GaN SBDs with TiN anode agrees well with the thermionic emission model. It is independent on the temperature for the Ni anode and is much higher than the calculated result due to the possible defect-assisted tunneling effect.

1. Introduction

Recently, microwave wireless power transmission, such as electric vehicle power charging, energy harvesting, and ubiquitous energy, has been attracting much attentions [1, 2]. 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 circuit. GaN is an attractive material to develop the SBD because of its advantages of high-breakdown voltage, high-frequency and high-temperature operation. We have reported that for a GaN SBD developed for microwave power rectification, the turn-on voltage became about 0.5 V if TiN anode was used [3]. However, the junction temperature will probably increase due to the high-temperature environment and self-heating. In this case, an evaluation of the change in the electrical properties of the SBD itself and the change in the power conversion efficiency of the rectenna circuit become very important. In this paper, we will report the temperature dependence of the GaN SBDs with TiN Schottky anodes.

2. Device Structure

Figure 1 shows the cross-sectional view of the GaN SBD. The epi-wafer is grown on a c-plane sapphire substrate with a buffer layer, an n^+-GaN access layer and n^--GaN drift layer. The thickness of the access layer is about 3 μm with a sheet resistance of about 25 Ω/square. The thickness of the drift layer is about 1 μm with impurity density of 1×10^{17} cm^{-3}.

The fabrication process started from the drift layer mesa formation by etching to the access layer with inductively coupled plasma (ICP) dry etching. Next, deep trench isolation to the sapphire substrate was created by using the same way. After that, Ti/Al/Ti/Au (50/200/40/40 nm) was deposited by sputtering for the cathode ohmic electrodes followed by annealing at 850 °C for 1 min in N_2 ambient. Then, TiN/Ni/Au (10/5/5 nm) was deposited for the anode Schottky electrode. Samples with Ni/Au (10/10 nm) anode were also prepared for comparison. The TiN thin film was synthesized by reactive sputtering in Ar:N_2 (15:3 sccm) mixed gas atmosphere [4]. Next, Au film with thickness of about 1μm was electroplated on all the electrodes. Finally, post-annealing at 300 °C was conducted for 10 min.

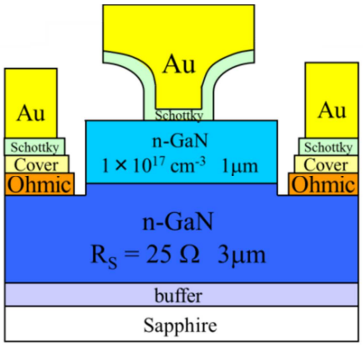

Fig. 1 The cross-sectional view of the GaN SBD.

3. Electrical Properties

To investigate the temperature characteristics of the GaN SBDs, current-voltage (*I-V*) characteristics of several circular-type SBDs with radius of 50 μm were measured by changing the temperature of the prober stage to 25 °C, 75 °C, 125 °C, and 175 °C. In addition, the *I-V* characteristics were also measured when the temperature returned to room temperature (25 °C).

Figure 2 show the forward characteristics of a circular Schottky diode with TiN and Ni anode. The turn-on voltage is about 0.45 and 0.85 V at 25 °C for the TiN and Ni diode, respectively. The turn-on voltage decreases as the temperature increasing. The leakage current of the TiN diode is about 10^{-6} A under -10 V at 25 °C and increases as the temperature in-

creasing (Fig. 3). The leakage current level agrees well with the calculated result according to the thermionic emission model under the same Schottky barrier height (SBH). However, the reverse leakage current of the Ni diode is independent on the temperature and is much higher than the calculated result (Fig. 4). Interface state caused by the Ni anode may exist at the Ni/GaN interface, leading to defect-assisted tunneling effect and causing the reverse current leakage comparable to the low-SBH TiN diode [5].

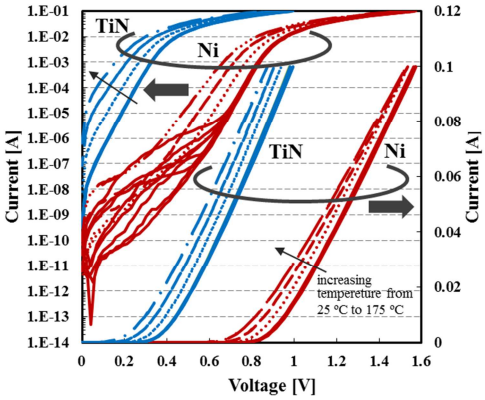

Fig. 2 Forward characteristics of the diodes with TiN and Ni anode in both linear and logarithmic scales.

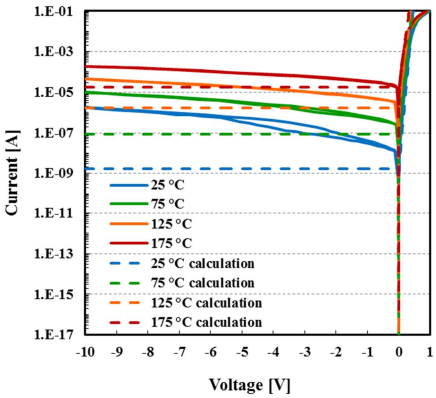

Fig. 3 Reverse characteristics of the TiN diode under different temperature.

Figure 5 shows the ideality factor and the SBH. At 25 °C, the ideality factor and SBH are around 1.08 and 0.58 eV for the TiN diode, 1.10 and 0.96 eV for the Ni diode, respectively. The SBH of the TiN anode is as about half as that of the Ni anode, which is respondent for the lower turn-on voltage of the TiN diode. The ideality of the TiN is lower than that of the Ni diode. For the both devices, the ideality factors decreased at high temperature and had no obvious change at room temperature. While for the SBH, it increased at high temperature and also had also no obvious degradation at room temperature.

4. Conclusion

Temperature dependence of the GaN SBD with TiN anode for microwave power rectification was evaluated. The leakage current of GaN SBDs with TiN anode increases with the temperature increasing and agrees well with the thermionic emission model. The reverse leakage current of the Ni anode is independent on the temperature and is much higher than the calculated result duo to the possible defect-assisted tunneling effect. Changes on the ideality factor and the SBH were observed at high temperature. They kept stable if the temperature returned to room temperature.

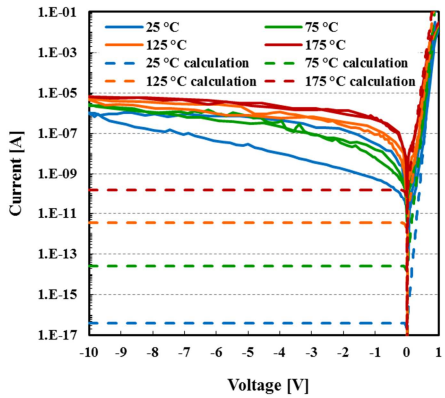

Fig. 4 Reverse characteristics of the Ni diode under different temperature

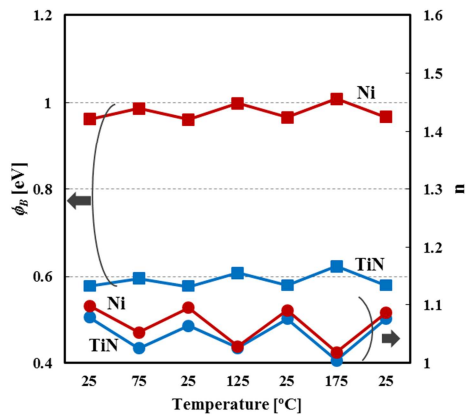

Fig. 5 The ideality factor and SBH of the SBDs with TiN and Ni anode.

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