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p-InGaN/*n*-GaN Vertical Conducting Diodes on n^+-SiC Substrate for High Power Electronic Device Applications

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1. Introduction

Due to the wide band gap of the III-nitride semiconductors, nitride-based electronic devices are promising for high-power and/or high- temperature applications. So far, we have focused on the characteristics of GaN/InGaN double heterojunction bipolar transistors (DHBTs) and have reported a high current gain (>2000) with a low-resistance *p*-InGaN base [1] and high-power characteristics (270 kW/cm^2) as a result of improving of the ohmic characteristics by the regrowth of the *p*-InGaN base [2]. All reported nitride HBTs have been grown on SiC and sapphire substrates with a lateral conducting structure. Compared with this structure, a vertical conducting structure using an *n*-SiC substrate is promising for higher current density and higher breakdown voltage with lower specific on-resistance. Moreover, *n*-SiC substrates are much less expensive than semi-insulating SiC substrates. For these advantages, we plan to adopt n^+-SiC substrate to grow GaN/InGaN DHBTs. As the first step of this study, we have grown the *p*-InGaN/*n*-GaN diodes on n^+-SiC substrates and investigated their current-voltage (*I-V*) characteristics

2. Experimental procedure

The *p*-InGaN/*n*-GaN vertical conducting diode structures were grown on n^+-SiC substrates using low-pressure metalorganic vapor phase epitaxy (MOVPE). Figure 1 shows the schematic illustration of the *p*-InGaN/*n*-GaN diode structure. The thickness of the *n*-GaN layer was varied from 225 to 900 nm to investigate the relation between the layer thickness and the breakdown voltage. Trimethylaluminum (TMA), trimethylgallium (TMG), and ammonia (NH_3) were used as source gases for the buffer and *n*-GaN layers, and triethylgallium (TEG), trimethylindium (TMIn), and NH_3 were used for the *p*-InGaN layer. Bis-cyclopentadienyl-magnesium (Cp_2Mg) and silane (SiH_4) were used as *p*-type and *n*-type dopants, respectively. The Mg doping concentration for the *p*-InGaN layer and the Si doping concentration for the *n*-GaN and the n^+-GaN layers were 4×10^{19}, 1×10^{17}, and 4×10^{18} cm^{-3}, respectively. The growth temperatures for the *n*-GaN layer and the *p*-InGaN layer were 1000 and 780°C, respectively. The mesa structure was defined by electron cyclotron resonance plasma etching using Cl_2. The size of the Pd/Au electrode for the *p*-InGaN was 100 μm×100 μm.

3. Results and discussion

Figure 2 shows the relation between the breakdown voltage and *n*-GaN layer thickness. The breakdown voltage increases proportionally with the thickness of the *n*-GaN layer. Although the breakdown field slightly decreases from 2.1 MV/cm (225 nm) to 1.8 MV/cm (900 nm), all samples show a relatively high breakdown field compared with the theoretical value (3.3 MV/cm). In general, a thick GaN layer grown on a SiC substrate has many cracks which degrade the crystal quality [3]. However, these high breakdown fields indicate that inserting an appropriate buffer layer makes it possible to grow high-quality GaN film with thickness of up to 900 nm (total thickness of GaN layer is 1.8 μm) on the *n*-SiC substrate and thereby increase the breakdown voltage.

Figure 3 shows the forward *I-V* characteristics of the diode with the *n*-GaN layer thickness of 225 nm at room temperature (RT) and at 320, 420, and 520 K. A low specific on-resistance is observed in each characteristics and it decreases from 1.26 (RT) to 0.89 (520 K) mΩcm^2 with increasing temperature. This result is attributed to the conductivity modulation caused by an increase of the injected carrier density as well as to the reduced resistance of the *p*-InGaN layer.

Figure 4 shows the reverse *I-V* characteristics of the diode with the *n*-GaN layer thickness of 225 nm at RT and at 320, 420, and 520 K. The breakdown voltage is almost constant in spite of the increase in the measurement temperature, which is desirable for high-temperature applications.

4. Conclusions

The *p*-InGaN/*n*-GaN vertical conducting diodes have been grown on n^+-SiC substrates by MOVPE and their *I-V* characteristics have been investigated. A relatively high breakdown field of the *n*-GaN layer with thickness of up to 900 nm with a low specific on-state resistance has been obtained.

References

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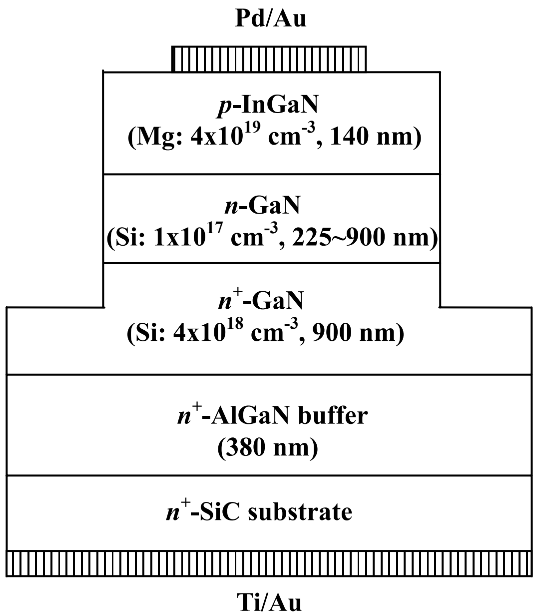

Fig. 1 Schematic illustration of the *p*-InGaN/*n*-GaN diode structure. The size of the Pd/Au electrode for the *p*-InGaN was 100 μm×100 μm.

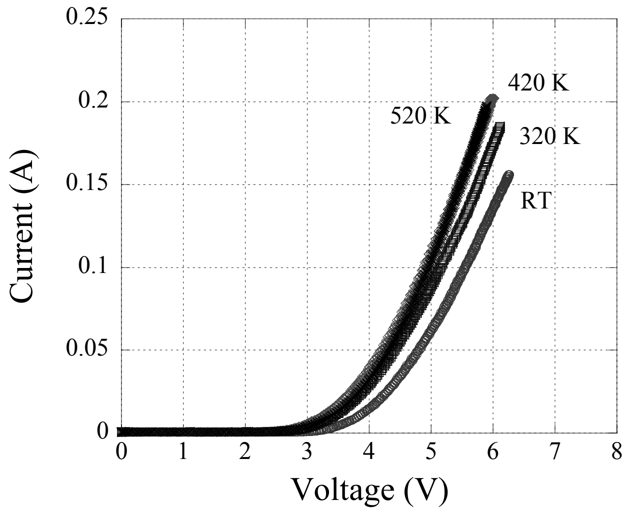

Fig. 3 Forward *I-V* characteristics of the diode with *n*-GaN layer thickness of 225 nm at RT, and at 320, 420, and 520 K. The specific on-resistance decreases from 1.26 (RT) to 0.89 (520 K) mΩcm^2 with increasing measurement temperature.

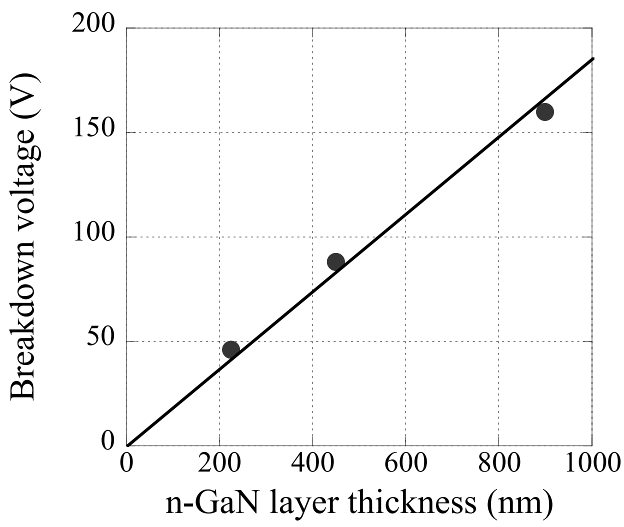

Fig. 2 Relation between the breakdown voltage and the thickness of the *n*-GaN layer. The breakdown voltage increases proportionally with *n*-GaN layer thickness.

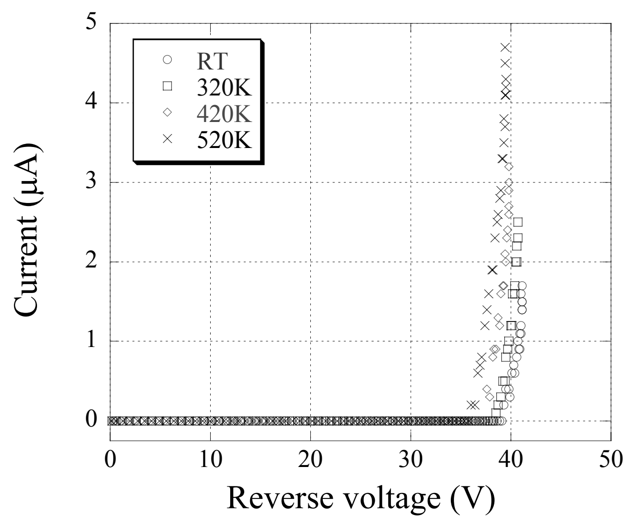

Fig. 4 Reverse *I-V* characteristics of the diode with *n*-GaN layer thickness of 225 nm at RT and 320, 420, and 520 K. The breakdown voltage is almost constant.