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Temperature dependence of current-voltage characteristics for AlGaN-based vertical conducting diodes

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1. Introduction

Owing to the wide bandgap of GaN, GaN-based electronic devices could operate at elevated temperatures. For power device reliability, a positive temperature coefficient of the breakdown voltage, *i.e.,* an increase of breakdown voltage with increasing temperature, is desirable. Though recent studies have reported negative temperature coefficients of the breakdown voltage in GaN-based Schottky and pn junction diodes because of defect-assisted tunneling through the surface or defect states [1-3], we have shown temperature-independent characteristics of the breakdown voltage for GaN-based vertical conducting diodes [4].

In a previous study, we succeeded in obtaining AlGaN-based vertical conducting diodes, which have higher critical electric fields than GaN-based diodes [5]. We have found that the breakdown voltage (V_B) increases due to the higher critical electric field with increasing Al composition. Even though the on-state resistance (R_{on}) also increases due to the relatively higher resistance of AlGaN layer with increasing Al composition, the figure of merit, V_B^2/R_{on}, of the AlGaN-based diode becomes higher than that of the GaN-based diode. Therefore, the AlGaN-based diode is more promising for high-power devices and it is of considerable interest to investigate its high-temperature performance. In this study, we investigated the temperature dependence of the current-voltage (*I-V*) characteristics of AlGaN-based vertical conducting diodes on 4H-SiC substrates.

2. Experimental procedure

The vertical conducting diode structures were grown on *n*-type 4H-SiC substrates using low-pressure metalorganic vapor phase epitaxy (MOVPE). Figure 1 shows a schematic illustration of the *p*-InGaN/*i*–$Al_xGa_{1-x}N$/ *n*-$Al_xGa_{1-x}N$ (x=0, 0.22) diode structure. The sample structure consisted of a 100-nm-thick *n*-AlGaN buffer, a 500-nm-thick *n*-AlGaN layer, a 225-nm-thick undoped-AlGaN layer, and a 140-nm-thick *p*-InGaN layer. The source gases were trimethylaluminum, trimethylgallium, and ammonia (NH_3) for the *n*- and *i*-AlGaN layers and triethylgallium, trimethylindium, and NH_3 for the *p*-InGaN layer. Bis-cyclopentadienyl-magnesium and silane were used for the *p*-type and *n*-type doping gases, respectively. The In composition in the *p*-InGaN was 10%, and the Al compositions in the *n*- and *i*-AlGaN layers were 0 and 22%. Pd/Au and Ti/Au electrodes were used for ohmic contacts for *p*-InGaN and *n*-SiC, respectively. In order to evaluate the temperature dependence of the buffer and substrate resistance, we grew a test structure, which consisted of a 100-nm-thick *n*-AlGaN buffer, a 500-nm-thick *n*-AlGaN layer. An Al/Au and Ti/Au electrodes were formed on an *n*-AlGaN layer and *n*-SiC, respectively. *I-V* characteristics were measured with a curve tracer at temperatures ranging from room temperature (RT) to 250^{o}C.

3. Results and discussion

Figure 2 shows the temperature dependence of the reverse *I-V* characteristics of the diodes with Al composition of 0 and 22%. The breakdown voltage is defined at a current density of 10 mA/cm^2 because the destructive breakdown typically occurs when the current density becomes larger than 50 mA/cm^2 at RT. For the diode with GaN, the breakdown voltage remains almost constant in spite of an increase in the measurement temperature. On the other hand, the breakdown voltage of the diode with $Al_{0.22}Ga_{0.78}N$ decreases with increasing measurement temperature. Noteworthy is that no destructive features are observed for the diode with $Al_{0.22}Ga_{0.78}N$ at 150 and 250^{o}C even when the reverse voltage of about 75 V, *i.e.,* the breakdown voltage at RT, is applied. Therefore, this decrease in the breakdown voltage is attributed to an increase in the reverse leakage current of the diode.

Figure 3 shows the temperature dependence of the forward *I-V* characteristics of the diodes with Al composition of 0 and 22%. The turn-on voltage, defined at a current density of 100 A/cm^2, decreases with temperature because of the reduced built-in potential due to the decrease in the bandgap. The on-state resistance also decreases with temperature from RT to 150^{o}C mainly because of the reduced resistance of *p*-InGaN layer with temperature [6], and then it increases with temperature from 150 to 250^{o}C because of an increase in the SiC substrate resistance due to the decrease of the electron mobility [7]. As shown in Fig. 4, the substrate resistance apparently increases with temperature from 150 to 250^{o}C. In spite of the increase in the substrate resistance, the on-state resistances of the diodes with GaN and $Al_{0.22}Ga_{0.78}N$ at 250^{o}C are still as low as 1.06 and 1.45 mΩ cm^2, respectively, because the resistance of *p*-InGaN layer monotonically decreases with temperature. These features of the temperature dependence are desirable for high-temperature operation.

4. Conclusions

The temperature dependences of *I-V* characteristics were investigated for AlGaN-based vertical conducting diodes. The breakdown voltage of the diode with $Al_{0.22}Ga_{0.78}N$ decreases because of an increase in the reverse leakage current. In spite of an increase in the SiC substrate resistance, the on-state resistances of the diodes with GaN and $Al_{0.22}Ga_{0.78}N$ at 250°C are still as low as 1.06 and 1.45 mΩ cm^2, respectively, because of the reduced resistance of the *p*-InGaN layer.

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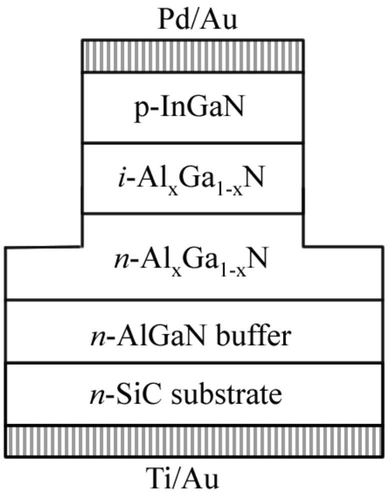

Fig. 1. Schematic illustration of the *p*-InGaN/*i*-AlGaN/*n*-AlGaN diode structure. The size of the Pd/Au electrode for the *p*-InGaN was 100 ×100 μm^2.

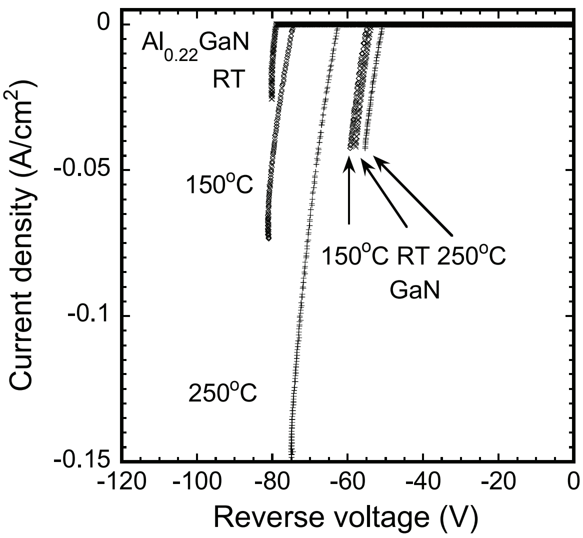

Fig. 2. Temperature dependence of reverse *I-V* characteristics.

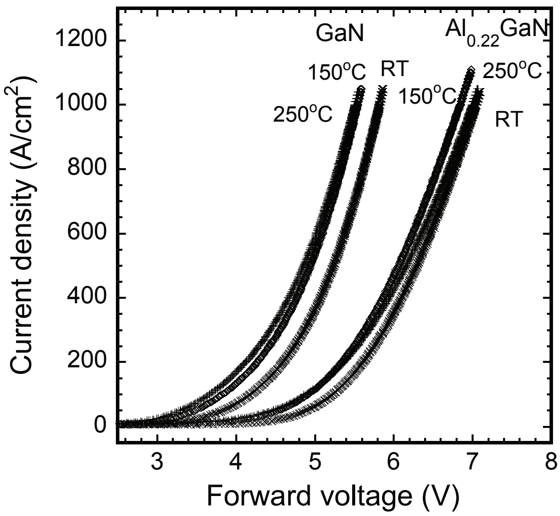

Fig. 3. Temperature dependence of forward *I-V* characteristics.

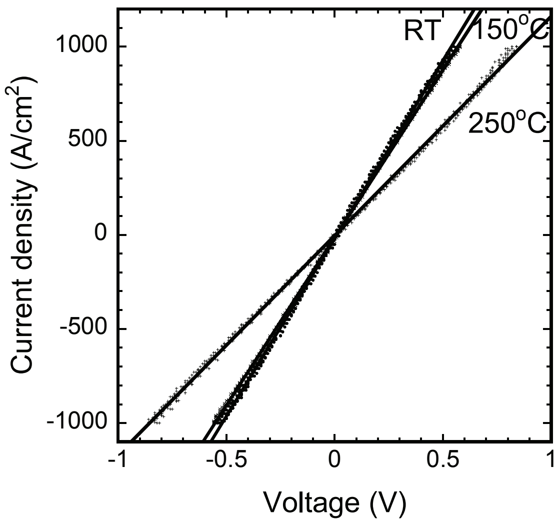

Fig. 4. Temperature dependence of *I-V* characteristics of the test structure to evaluate the substrate resistance. The SiC substrate resistance increases with temperature from 150 to 250°C.