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Conductivity Degradation of 4H-SiC Pin Diode with In-grown Stacking Faults

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1. Introduction

In order to realize low-loss devices for efficient inverter operation, it is necessary to identify defects that influence the electrical characteristics of the devices. In 4H-SiC bipolar devices, defects that limit carrier lifetime reflect badly on the electrical characteristics of the devices. The predominant lifetime-killing defects are believed to be the $Z_{1/2}$ center [1] and stacking faults [2]. We have reported that eliminating the $Z_{1/2}$ center through carbon implantation or thermal oxidation reduces the forward voltage drops of 4H-SiC pin diodes [3]. In this paper, we report the pure influence of 8H-type in-grown stacking faults on the electrical characteristics of 4H-SiC pin diodes with carbon implantation to reduce $Z_{1/2}$ center influence.

2. Experiment

4H-SiC pin diodes were fabricated on 4H-SiC epi-wafers with a stacking sequence of $p^+/n^-/n^+$. The doping density and thickness of the n^- drift layer are 1×10^{14} cm^{-3} and 120 μm, respectively. One of the epi-wafers contained a high density of in-grown stacking faults. The epi-wafers were treated with carbon implantation [3]; as a result, $Z_{1/2}$ center concentration was reduced to less than 1×10^{12} cm^{-3}, a value sufficient to realize a long carrier lifetime of more than 10 μsec [1].

Figure 1 shows the photo luminescence (PL) image of a fabricated 4H-SiC pin diode in sectional view. Linear luminescence, tilted 8 degrees, is observed in the drift layer of the diode. Figure 2 shows the cathode luminescence (CL) spectrums of the fabricated 4H-SiC pin diode, scanning toward the depth direction. The peak of around 480 nm indicates the existence of 8H-type in-grown stacking faults; the linear luminescence in Fig. 1 corresponds to 8H-type in-grown stacking faults [4]. For comparison of forward characteristics, another diode was prepared in which in-grown stacking faults were not observed with PL and CL.

3. Results and Discussions

Figure 3 shows the forward characteristics for 4H-SiC pin diodes with and without 8H-type in-grown stacking faults at room temperature. The forward characteristic of the diode with 8H-type in-grown stacking faults is

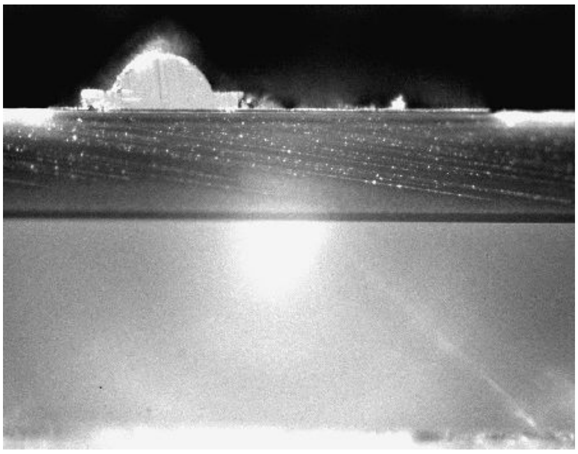

Fig. 1 Photo luminescence image of a fabricated 4H-SiC pin diode.

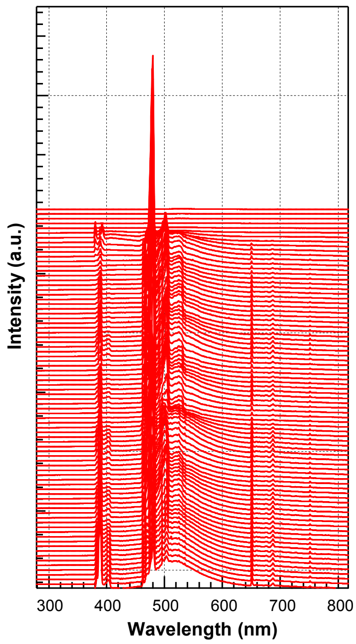

Fig. 2 Cathode luminescence spectrums of the fabricated 4H-SiC pin diode.

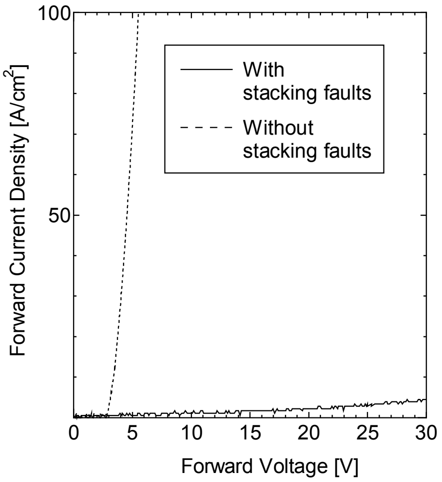

Fig. 3 Forward characteristics for 4H-SiC pin diodes with and without 8H-type in-grown stacking faults at room temperature.

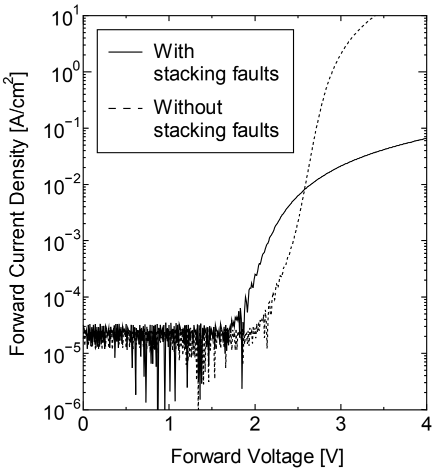

Fig. 4 Forward characteristics in low-level injection for 4H-SiC pin diodes with and without 8H-type in-grown stacking faults at room temperature.

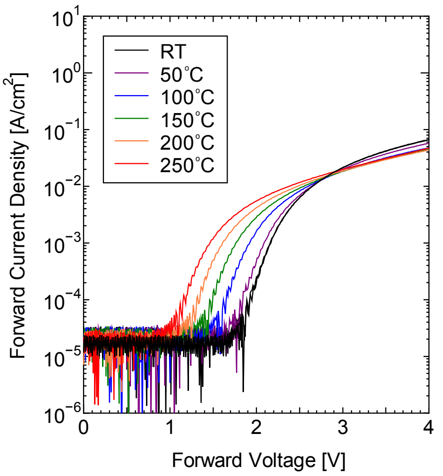

Fig. 5 Temperature dependences of forward characteristics in low-level injection for the 4H-SiC pin diode with 8H-type in-grown stacking faults.

degraded. Figure 4 shows the forward characteristics in low-level injection for 4H-SiC pin diodes with and without 8H-type in-grown stacking faults at room temperature. The recombination current of the diode with stacking faults is an order of magnitude larger than that without stacking faults. The recombination may be accelerated at a high density of 8H-type in-grown stacking faults in the drift layer. Figure 5 shows the temperature dependences of forward characteristics in low-level injection for the 4H-SiC pin diode with 8H-type in-grown stacking faults. The recombination current increases by an order of magnitude for every 50°C increase in temperature, because the theoretical intrinsic carrier density increases by two orders of magnitude for every 50°C increase in temperature.

The on-resistance of the diode with stacking faults is about 6.0 ohm-cm^2 as estimated by the slope of the curve in Fig. 3. It is an order of magnitude larger than the drift resistance of drift layer calculated from doping density and thickness. Furthermore, judging by the large recombination current, the minority carriers are killed as soon as injected from the p^+ anode into the n^- drift layer. The conductivity modulation effect thus does not occur due to poor minority carrier density, as compared to the diode with stacking faults. Given that conductivity modulation hardly occurs, the majority carrier density is simply estimated on the basis of the above on-resistance to be an order of magnitude lower than the doping density. Large amounts of electrons are assumed to be trapped at 8H-type in-grown stacking faults, the density of effective carriers that consist of untrapped electrons and contribute to conduction being lowered in comparison with the doping density. The 8H-type stacking-fault-free process is therefore essential to realizing low-loss devices.

4. Conclusions

We investigated the pure influence of 8H-type in-grown stacking faults on the electrical characteristics of 4H-SiC pin diodes with carbon implantation employed to eliminate $Z_{1/2}$ center influence. Results show that the 8H-type in-grown stacking faults reflect conductivity degradation of the forward characteristics of the pin diodes. It is assumed that large amounts of electrons are trapped at 8H-type in-grown stacking faults and the effective carrier density is lowered as compared with the doping density. The 8H-type stacking-fault-free process is essential to the realization of low-loss devices.

Acknowledgement

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References

[1] K. Danno et. al., Appl. Phys. Lett. 90, 202109 (2007)
[2] S. I. Maximenko et. al., Appl. Phys. Lett. 94, 092101 (2009)
[3] K. Nakayama et. al., Mater. Sci. Forum 679-680, 535 (2011)
[4] S. Izumi et. al., Mater. Sci. Forum 483-485, 323 (2005)