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OCVD Characteristics of 4H-SiC PiN Diode with Carbon Implantation

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Abstract

The open circuit voltage decay (OCVD) characteristics of the 4H-SiC pin diodes with the carbon implantation process are investigated. The bulk carrier lifetime in the fabricated devices can be estimated by using the OCVD measurement. The carrier lifetime at a high injection level (τ_{HL}) of the fabricated diode with the carbon implantation is 10.5 µs, which is extremely longer than that of the diode with the standard process.

1. Introduction

To realize UHV SiC bipolar devices, the bulk carrier lifetime improvement is highly significant, because the conductivity modulation determines the forward voltage drop and strongly depends on the bulk carrier lifetime. The carbon implantation [1] or the thermal oxidation [2] improves the bulk carrier lifetime of epi-wafers. In contrast, the device fabrication processes degrade the bulk carrier lifetime, such as through high temperature annealing or surface oxidation [3, 4]. Accurate estimation for the bulk carrier lifetime of the fabricated devices is important. By using the open circuit voltage decay (OCVD) measurement, the bulk carrier lifetime in the fabricated devices can be estimated. In this paper, we investigate the OCVD characteristics of the 4H-SiC pin diodes with the carbon implantation process, and the temperature dependence of the estimated carrier lifetime.

2. Device Fabrication

Figure 1 shows the device structure of a fabricated 4H-SiC pin diode. The n^- drift layer and the p^+ anode layer were grown on the n^+ substrate by epitaxial growth in the vertical hot wall reactor [5, 6]. The thickness and the donor concentration of the n^- drift layer are 120 µm and 7×10^{13} cm^{-3}, respectively. The diode active area is 2.3 mm × 2.3 mm. The carbon implantation process was employed to improve the bulk carrier lifetime. In the standard process, the carbon implantation was not applied. Figure 2 shows the fabrication process of pin diodes with the carbon implantation process [1]. After p^+ epitaxial growth, carbon atoms with a box sharp profile were implanted at 600°C. The concentration and the depth of the box sharp profile are 5×10^{20} cm^{-3} and 250 nm, respectively. The activation annealing process was performed at 1730°C for 30 minutes. After the annealing, the layer, which consisted of implanted carbon atoms, was removed by reactive ion etching.

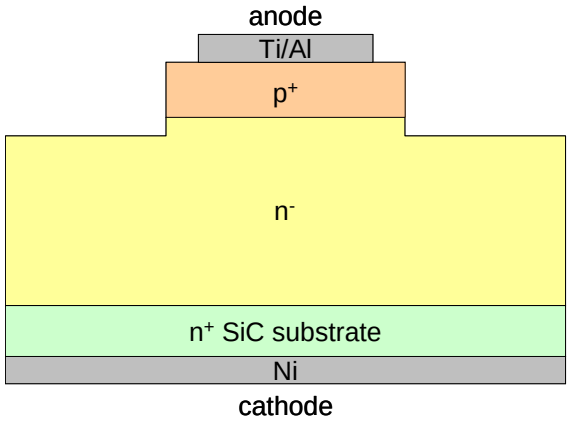

Fig. 1 Device structure of a fabricated pin diode.

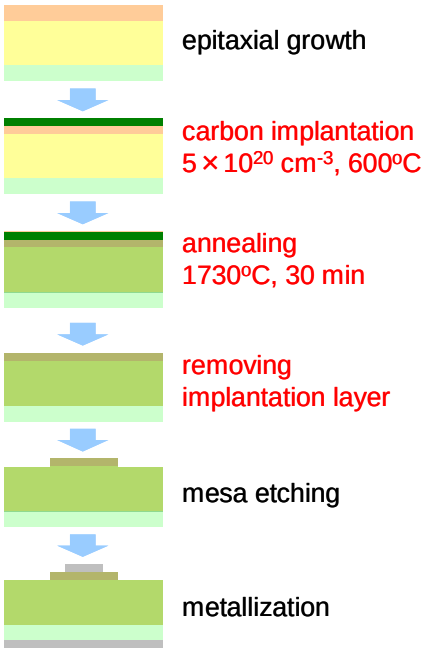

Fig. 2 Fabrication process of pin diodes with the carbon implantation process.

3. Results and Discussions

The OCVD measurements were performed at a forward current density of 100 A/cm^2. The turn-off dI/dt is 13 A/μs. Figure 3 shows the OCVD waveforms of fabricated pin diodes at room temperature. The carrier lifetime at a high injection level, τ_{HL}, is estimated by the following equation:

$$t_{HL} = -\frac{2kT}{q}\left(\frac{dV}{dt}\right)^{-1} \qquad (1)$$

where dV/dt is the linear part of the voltage decay curve [7]. The τ_{HL} of the diode with the carbon implantation is 10.5 μs at room temperature and is extremely longer than that of the diode with the standard process, 1.3 μs. Figure 4 shows the temperature dependences of OCVD waveforms of a fabricated pin diode with the carbon implantation process. The τ_{HL} of carbon implanted diode becomes longer with the increase of the temperature to 34.7 μs at 250°C. Figure 5 shows Arrhenius plot of τ_{HL} of a carbon implanted diode with a temperature range from 27°C to 250°C. The activation energy estimated by the Arrhenius plot is 0.07 eV. This value corresponds approximately to the energy level of the shallow recombination center, which possesses a sufficiently strong emission rate at elevated temperatures [8].

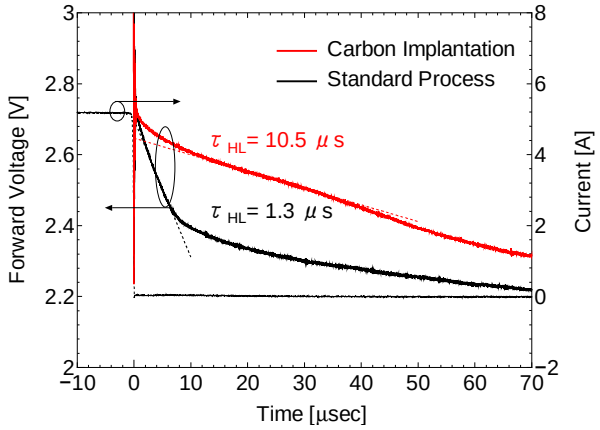

Fig. 3 OCVD waveforms of fabricated pin diodes with the standard process and the carbon implantation process at RT.

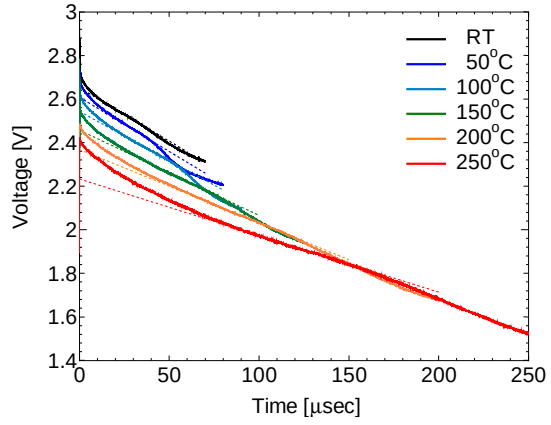

Fig. 4 Temperature dependences of OCVD waveforms of a fabricated pin diode with the carbon implantation process.

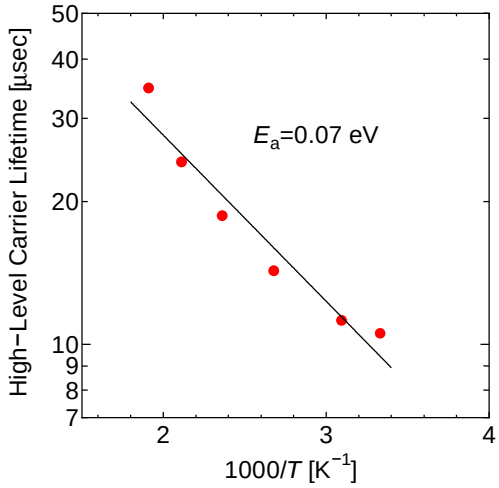

Fig. 5 Arrhenius plot of extracted high-level carrier lifetimes of a carbon implanted pin diode.

4. Summary

We investigated the OCVD characteristics of the 4H-SiC pin diodes with the carbon implantation process, and the temperature dependence of the estimated carrier lifetime. The τ_{HL} of the diode with the carbon implantation is 10.5 μs at room temperature and is extremely longer than that of the diode with the standard process, 1.3 μs. Moreover, the τ_{HL} of the carbon implanted diode becomes longer with the increase of the temperature to 34.7 μs at 250°C. The activation energy estimated by the Arrhenius plot is 0.07 eV. This value corresponds approximately to the energy level of the shallow recombination center, which possesses a sufficiently strong emission rate at elevated temperatures.

Acknowledgement

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