Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp966-967

Evaluation of temperature dependence of surface recombination velocities for n-type 4H-SiC

Kimihiro Kohama, Yuto Mori, Masashi Kato and Masaya Ichimura

Nagoya Institute of Technology.
Gokiso-cho, Showa-ku, Japan
Phone: +81-52-735-5581 E-mail: cko16545@stn.nitech.ac.jp

Abstract

The surface recombination is one of the limiting factors of the carrier lifetime, which is an important parameter for performance of SiC bipolar devices. In this study, we evaluated the temperature dependence of surface recombination velocities (SRVs) for n-type 4H-SiC by microwave photoconductivity decay measurements and numerical analyses. As a result, we found thatSRVs for n-type 4H-SiC are almost constant in a temperature range from room temperature to 250°C.

1. Introduction

4H-SiC is a promising material for low loss and high voltage power devices. For ultra-high voltage application, SiC bipolar devices are superior to unipolar devices. In bipolar devices, control of the carrier lifetime is essential, and the surface recombination is one of the limiting factors of the carrier lifetime. Some experimental results of the surface recombination velocities (SRVs) have been reported so far [1-3]. However, when we design a device, we should consider operating temperature which is typically from room temperature to 250°C. Therefore, in this work, we evaluated temperature dependence of SRVs for n-type 4H-SiC by the microwave photoconductivity decay (μ-PCD) measurements and numerical analyses.

2. Experimental method

The samples were cut from a free-standing n-type 4H-SiC epilayer with a nominal doping concentration of 1.0×10^{15} cm^{-3}. We prepared the samples with various surface treatments. One of the sample sets was treated by a chemical-mechanical polishing (CMP) both on the Si- and C-faces, and we named them CMP samples. For another sample sets, we etched their surfaces by NaOH at 500°C, and we named them NaOH etch samples. We also performed reactive ion etching (RIE) in SF_6 + O_2 under a pressure of 20 Pa with 150 W for 30 min to two sample sets. RIE was performed on the Si-face to one set of samples, while it was performed on the C-face to the other set. We named the former RIE (Si-face) samples and the latter RIE (C-face) samples. All sample sets were prepared with three different thicknesses to see thickness dependence of the carrier lifetime [3]. We varied the temperature of all the samples and measured excess carrier decays by the μ-PCD method. In the μ-PCD method, we used 266 or 355 nm pulsed YAG lasers as an excitation source and by these laser we injected photon densities of 2.0×10^{13} cm^{-2} to the samples. From the μ-PCD decay curves, we estimated 1/e lifetimes $\tau_{1/e}$, which is defined as the decay time from a peak of μ-PCD signal to 1/e.

3. Results

Figure 1 shows μ-PCD decay curves observed from the 83 μm thick CMP sample excited on the Si-face by 355 nm. The decay curves showed temperature dependence: the decay became slower with increasing temperature. In measurements for the 43 or 63 μm thick CMP samples or with 266 nm excitation, the temperature dependence was weaker than that shown in Fig. 1. On the other hand, NaOH, RIE (Si-face) and RIE (C-face) samples also showed temperature dependence similar to Fig.1.

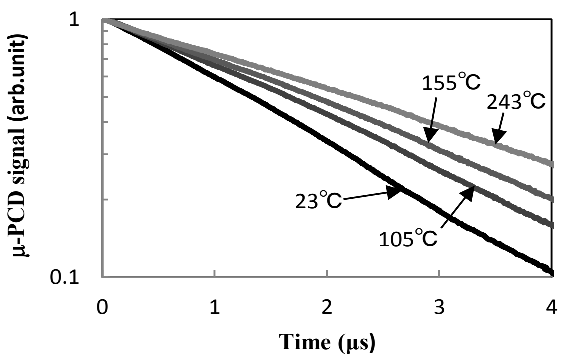

Fig. 1. μ-PCD decay curves for the Si-face of the 83 μm thick CMP sample excited by 355 nm

To evaluate temperature dependence of SRVs, we compared experimental results with numerical calculations [4]. In the calculation, we took into account temperature dependence of the diffusion coefficient D, the absorption coefficient α, the bulk lifetime τ_{epi} and the SRV S. In Ref. 5, D is given by following equation

$$D(T) = D_{300}\left(\frac{300}{T}\right)^{1.3} , \qquad (1)$$

where D_{300} is the diffusion coefficient at room temperature. We used this equation with D_{300} of 2.9 cm^2/s, which is a reported value in Ref. 6. On the other hand, temperature dependence of α was estimated from equations (2-4) in Ref. 7. To estimate the temperature dependence of τ_{epi}, we employed experimental results reported in Ref. 8. Figure 2 shows the temperature dependences of τ_{epi} for samples with and without carbon implantation in Ref. 8. These two samples show the same temperature dependence even though they have different deep level concentrations. Thus we assume that τ_{epi} for our samples also have the same temperature dependence with τ_{epi} at room temperature shfted to3 μs, as shown in the line in Fig. 2. By using these temperature dependent parameters, we calculated decay curves and obtained $\tau_{1/e}$.

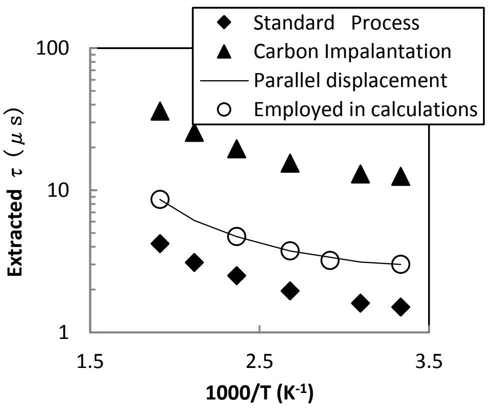

Fig. 2. Temperature dependence of reported τ_{epi}. The line is parallel displacement from the reported dependence with τ_{epi} of 3 μs at room temperature, and the circles are employed values in the calculations.

Fig. 3 shows temperature dependence of experimental $1/\tau_{1/e}$ of the CMP samples with excitation of the Si-face by 355 nm excitation, and also shown are calculated $1/\tau_{1/e}$ with S=2000 cm/s for the Si-face and S=5500 cm/s for the C-face. These Ss are the same values as reported in Ref. 3, and here we assume that they are temperature independent. Values of calculated $\tau_{1/e}$ are different from experimental $\tau_{1/e}$. However, if we focus on the temperature dependence, experiments and calculations show similar tendency. They are almost constant from room temperature to 70°C and it increases with temperature above 70°C. In addition, the slopes above 70°C are similar between experiments and calculations. Therefore, calculations reproduced temperature dependence of experimental $\tau_{1/e}$.

Fig. 4 shows temperature dependence of $1/\tau_{1/e}$ of RIE (Si-face) samples obtained from the decay curves with 355 nm excitation along with calculated $1/\tau_{1/e}$ with S=2500 cm/s for the Si-face and S=5000 cm/s for the C-face at room temperature [3]. We found that temperature dependence is almost the same between experiments and calculations with constant Ss as obtained from the CMP samples. Such similar temperature dependence between experiments and calculations with constant Ss were also obtained from NaOH etch samples and RIE(C-face) samples. Therefore, we conclude that temperature dependences of the SRVs are weak for the n-type 4H-SiC surfaces.

4. Conclusions

We found that temperature dependences of the SRVs are weak for the CMP, NaOH etch and RIE treated n-type 4H-SiC surfaces. Therefore, we can employ constant SRVs in a temperature range from room temperature to 250°C in bipolar device simulations.

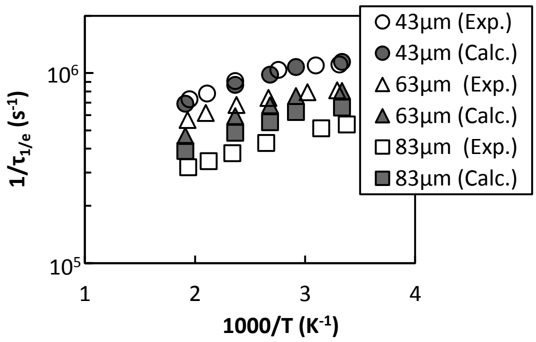

Fig. 3. Temperature dependence of experimental and calculated $1/\tau_{1/e}$ and for the Si-face of the CMP samples excited by 355 nm

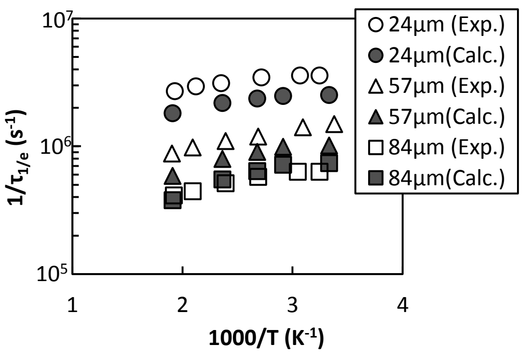

Fig. 4. Temperature dependence of experimental and calculated $1/\tau_{1/e}$ and for the Si-face of RIE (Si-face) samples excited by 355 nm

Acknowledgements

This work is supported by JSPS KAKENHI 25390067.

References

[1] A. Galeckas, J. Linnros, M. Frischholz, and V. Grivckas, Appl. Phys. Lett. **79** (2001).

[2] P. B. Klein, R. Myers-Ward, K. –K. Lew, B. L. VanMil, C. R. Eddy Jr., D. K. Gaskill, A. Shrivastava, and T. S. Sudarshan, J. Appl. Phys. **108** (2010).

[3] Y. Mori, M. Kato, and M. Ichimura., J. Phys. D: Appl. Phys. **47** (2014) 335102.

[4] M. Kato, A. Yoshida, and M. Ichimura., Jpn. J. Appl. Phys. **51** (2012).

[5] P. B. Klein, R. Myers-Ward, K. -K. Lew, B. L. VanMil, C. R. Eddy, Jr., D. K. Gaskill, A. Shrivastava, and T. S. Sudarshan, J. Appl. Phys. **108** (2010).

[6] T. Hayashi, T. Okuda, J. Suda, and T. Kimoto., Jpn. J. Appl. Phys. **53** (2014)

[7] N. Watanabe, T. Kimoto, and J. Suda., Jpn. J. Appl. Phys. **53** (2014).

[8] A. Tanaka, K. Nakayama, K. Asano, T. Miyazawa, and H. Tsuchida., Jpn. J. Appl. Phy. **53** (2014).