P-14-20

Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp558-559

Estimation of the surface recombination velocity from thickness dependence of the carrier lifetime in n-type 4H-SiC epilayers

Masashi Kato, Atsushi Yoshida and Masaya Ichimura

Nagoya Inst. of Tech.
Gokiso, Showa, Nagoya 466-8555, Japan
Phone: +81-52-735-5581 E-mail: kato.masashi@nitech.ac.jp

1. Introduction

4H-SiC bipolar devices are promising for application with higher voltages than 1000 V. Because the carrier lifetime is a very important parameter to control conduction and switching losses in bipolar devices, various studies for the carrier lifetime in 4H-SiC have been reported. However, only a few reports have dealt with the surface recombination velocity, *s*, [1,2], although there have been many reports on recombination centers in bulk of 4H-SiC epilayers [3,4]. Therefore, in this study, we characterize carrier lifetimes in free-standing n-type 4H-SiC epilayers and then we estimate *s* by comparison with numerical calculations.

2. Experiments

In this study, we employed an n-type 4H-SiC epilayer ($N_D=1\times10^{15}$ cm^{-3}) grown on a 4H-SiC (0001) Si-face substrate with 4° off angle toward <11 $\bar{2}$0>. At first, a 150 μm thick epilayer was grown, and then the substrate was completely removed by polishing. Then we cut the epilayer to small samples and polished again the substrate side of the samples. This substrate side polishing was finished with chemical mechanical polishing (CMP) to reduce polishing damage, and resulting sample thicknesses were 35, 65, and 120 μm (as-grown-surface samples). On the other hand, we also prepared samples polished on the epi-growth side with the CMP finishing, which had thicknesses of 33, 63, and 83 μm (both-side-polished samples). Then we measured carrier lifetimes in these samples by the microwave photoconductivity decay (μ-PCD) method with excitation light from 266, and 355 nm lasers (photon densities of 2-3$\times10^{15}$ cm^{-2}) and probe microwave of 10 GHz.

3. Results and discussions

Excess carrier decay curves for the as-grown-surface samples excited by the 355 nm laser are shown in Fig. 1. All the decay curves show initial slow decay components followed by the faster decay components. Such decay behavior indicates that the decays are initially in the high injection condition and then become in the low injection condition. For excitation of the epi-growth side (epi-side), the decays become slow with the sample thickness owing to reduction of the effect of the recombination at the surface opposite to the excitation side. On the other hand, for excitation of the substrate side (sub-side), the 65 μm and 120 μm samples show the almost same decays, while the 35 μm thick sample shows relatively fast decay. Figure 2 shows excess carrier decay curves for the both-side-polished samples. These decays also show initial slow and subsequent faster decay components. The decays become slower with thickness for both the sides, and the decays for the epi-side are slightly slow compared with those for the sub-side in the 63 and 83 μm thick samples.

In order to see the thickness dependence of the carrier lifetime, we define the 1/e lifetime as the time interval of the decay from the peak to 1/e, and we plot it as a function of the sample thickness in Fig. 3 for the as-grown-surface samples. The 1/e lifetime increases with the sample thickness for both the 266 nm and 355 nm excitation and for

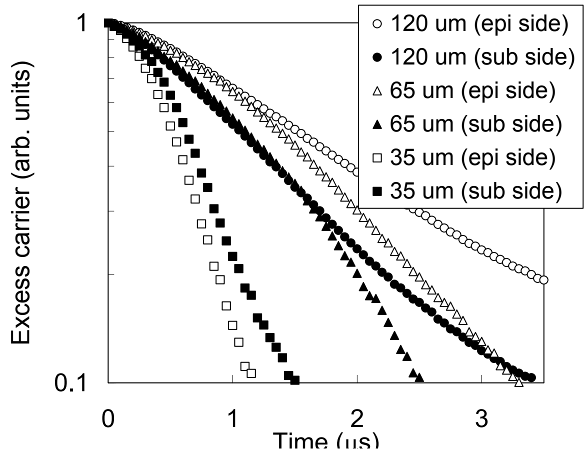

Fig.1 Excess carrier decay curves for the as-grown-surface samples excited by the 355 nm laser.

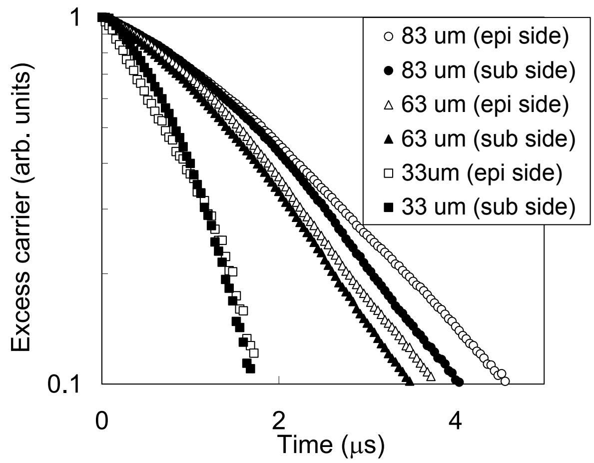

Fig.2 Excess carrier decay curves for the both-side-polished samples excited by the 355 nm laser.

both the epi-side and sub-side, except for the sub-side excitation of the 120 μm thick sample. Apparently, *s* of the sub-side of the 120 μm thick sample is exceptionally large, but the reason for that is not understood. Figure 4 shows that the 1/e lifetime as a function of the sample thickness for the both-side-polished samples. For these samples, the 1/e lifetime increases monotonically with thickness, and 1/e lifetimes for excitation of the epi-side are larger than those for excitation of the sub-side, especially when the 266 nm is used. This large 1/e lifetime for the epi-side excitation indicates smaller *s* for the epi-side than that for the sub-side even if both the sides are polished by the CMP. In addition, the 1/e lifetimes for the epi-side excitation are large in the both-side-polished samples compared with those in the as-grown-surface samples. This result suggests that *s* for the epi-side becomes smaller after the CMP.

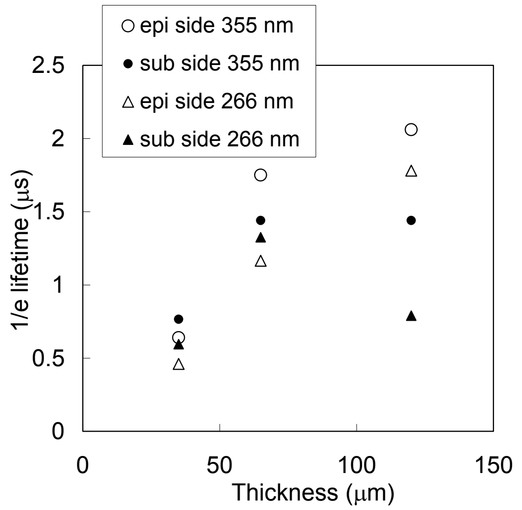

Fig.3 Thickness dependence of the 1/e lifetime for the as-grown-surface samples measured with excitation by the 266 and 355 nm lasers.

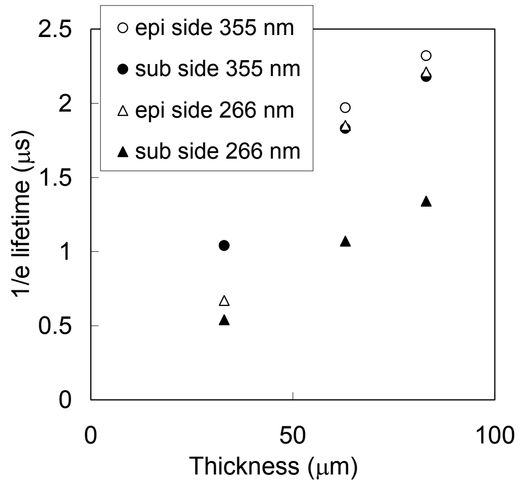

Fig.4 Thickness dependence of the 1/e lifetime for the both-side-polished samples with excitation by the 266 and 355 nm lasers.

We also estimated *s* for the both-side-polished sample by comparison with the numerical model [5]. The results are shown in Fig. 5, where experimental results with various excitation photon densities are plotted and numerical estimation is illustrated by the lines. The good fit was obtained when *s*~1000 cm/s for the epi-side and s~2000 cm/s for the sub-side assuming the bulk lifetime τ_{epi} of 5 μs and the ambipolar diffusion coefficient D_a of 4.2 cm^2/s.

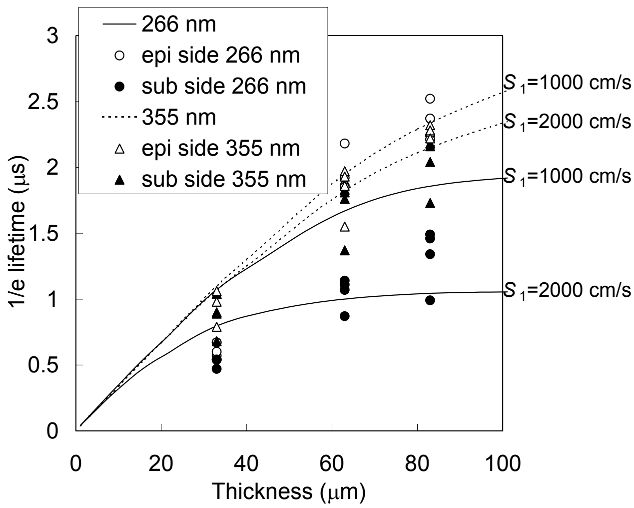

Fig.5 Comparison of experimental 1/e lifetimes for the both-side-polished samples with calculated results assuming τ_{epi} of 5 μs and D_a of 4.2 cm^2/s. S_1 corresponds to *s* for the excited surface.

4. Conclusions

We evaluated carrier lifetimes in free-standing 4H-SiC epilayers with various thicknesses. From the experimental results, we revealed that *s* is smaller on the epi-side surface after CMP than on the as-grown surface. We also estimated *s* for the both-side CMP-polished samples to be ~1000 cm/s for the epi-side and ~2000 cm/s for the sub-side by comparison with the numerical model.

References

[1] P. B. Klein, B. V. Shanabrook, S. W. Huh, A. Y. Polyakov, M. Skowronski, J. J. Sumakeris and M. J. O'Loughlin, Appl. Phys. Lett. 88 (2006) 052110.

[2] K. Danno D. Nakamura and T. Kimoto, Appl. Phys. Lett. 90 (2007) 202109.

[3] A. Galeckas, J. Linnros, M. Frischholz and V. Grivickas, Appl. Phys. Lett. 79 (2001) 365-367.

[4] 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) 033713.

[5] S. Sumie, F. Ojima, K. Yamashita, K. Iba and H. Hashizume, J. Electrochem. Soc. Vol.152, pp.G99-G106 (2005).