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Microwave reflectivity from 4H-SiC in the high injection condition: impacts of the electron-hole scattering

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Abstract

The carrier lifetime and mobility in a high injection condition are key parameters for design of bipolar devices. Microwave photoconductivity decay (μ-PCD) is a popular method to evaluate the carrier lifetime in silicon carbide (SiC). For evaluation of the carrier lifetime by μ-PCD measurements, we usually assume that the microwave reflectivity is proportional to the excess carrier concentration. In this study, we discussed origins of loss of proportionality of μ-PCD signals in the high injection condition for 4H-SiC and suggested decrease of the mobility due to the electron-hole scattering.

1. Introduction

Carrier lifetime and mobility in the high injection condition are key parameters for design of bipolar devices. At present, microwave photoconductivity decay (μ-PCD) is a popular method to evaluate the carrier lifetime in silicon carbide (SiC), because this method has been widely employed in the Si industry [1]. In μ-PCD measurements, we have assumed that the microwave reflectivity is proportional to the excess carrier concentration. However, as discussed in our previous report [2], the proportionality will be lost in the high injection condition because of the two origins: (i) the large conductivity change due to the high density of excited carriers, and (ii) decrease in the mobility of carriers by the electron-hole scattering [3]. We have already discussed origin (i) by observing dependence of the microwave reflectivity on the injected photon density [2]. In this study, to find influences of origin (ii), we observed μ-PCD decay lifetimes from 4H-SiC in the high injection condition, and then we discussed decrease of the mobility by the electron-hole scattering.

2. Experimental methods

A sample was an n-type 4H-SiC free-standing epilayer with doping concentration of 10^{15} cm^{-3} with 83 μm. The size of the sample was approximately 1×1 cm. We excited carriers in the sample using pulsed YAG lasers with a pulse width of 1-3 ns and wavelengths of 355 nm or 266 nm. Spot sizes of the lasers are ~4 mmϕ and ~2 mmϕ for 355 nm and 266 nm lasers, respectively. We continuously irradiated the sample with 10 GHz microwave from a Gunn diode through waveguides with 22.86×10.16 mm. These apparatuses are the same as used in our previous μ-PCD measurements [4]. We observed the reflected microwave signal just after excitation (the μ-PCD peak) as a function of the injected photon density which is controlled by rotating a λ/2 plate positioned before a Glan-Prism. For excitation of a small area within the sample, we inserted a ceramic pinhole with various sizes near the excitation side of the sample [2]. We also observed decay curves of the μ-PCD signals with the small area excitation.

3. Results and discussion

Figure 1 shows dependence of the μ-PCD peak on the injected photon density in a log-log plot for the Si-face of the sample excited by 355 nm. The absolute signal depends on the sample thickness, the distance between the waveguide and the sample and so on, and thus we focus on the slope of each data in the figure. When the slope is unity (the diagonal lines in this figure), the microwave reflectivity proportionally depends on the excess carrier concentration. Without the pinhole, the μ-PCD peak is proportional to the photon density below the photon density of ~5×10^{13} cm^{-2}. On the other hand, for photon densities above ~5×10^{13} cm^{-2}, the slope is less than unity, and thus the microwave reflectivity is not proportional to the excess carrier concentration. With the pinhole, the slopes are steeper than that without the pinhole, and with the pinhole of 25 μmϕ, the slope is nearly unity up to the injected photon density of 8×10^{16} cm^{-2}. The effect of the pinhole indicates significance of origin (i), and origin (i) can be suppressed by the small area excitation using the pinholes as discussed in Ref. 2. However, with the pinholes of 100-500 μmϕ, the slopes are still less than unity. Therefore, origin (ii) cannot be negligible for the cause of the loss of the proportionality.

We calculated the mobility on the basis of a model of the electron-hole scattering reported in ref. 3 with setting the electron and hole mobilities in equilibrium as 1000 and 100 cm^2/s, respectively as Fig. 2 in Ref. 2. By using calculated mobilities, we estimated dependence of the conductivity on the excess carrier concentration as plotted by the circles in Fig. 2. As shown in this figure, the proportionality is lost above the excess carrier concentration of 10^{16} cm^{-3} due to decrease of the mobilities by the scattering. The excess carrier concentration of 10^{16} cm^{-3} corresponds to an injected photon density of ~1×10^{14} cm^{-2}, which is a similar value to an injected photon density at which the proportionality is lost in Fig. 1. Therefore, even without origin (i), we expected that the carrier lifetimes measured by μ-PCD are apparently different from actual lifetimes in the high injection condition. The dashed line in Fig. 2 is the calculated apparent carrier lifetime due to decrease of the mobilities normalized by that with the equilibrium mobilities. The apparent carrier lifetime increases from the excess carrier concentration of ~10^{16} cm^{-3} and shows and maximum at the excess carrier concentration of ~10^{18} cm^{-3}.

To observe variation of the apparent carrier lifetime, we performed μ-PCD measurements with the pinholes. In these measurements, we adopted injected photon densities as low as possible to observe signals because origin (i) still concerns. The observed μ-PCD decay curves with 355 nm excitation are shown in Fig. 3. The observed μ-PCD decay curves depend on the excess carrier concentration. Here, we defined the 1/e lifetime as the μ-PCD decay time from a peak to 1/e, and the observed 1/e lifetimes are plotted by rhombuses in Fig. 2 along with those obtained by 266 nm excitation. As estimated by the calculation, the observed 1/e lifetimes have peaks at excess carrier concentration of 1-5×10^{18} cm^{-3}. These results suggest that origin (ii) should be considered in the loss of the proportionality in the microwave reflectivity and the electron-hole scattering is influential in the high injection condition.

3. Conclusions

In this study, we discussed μ-PCD signals in the high injection condition for 4H-SiC. The origins of loss of the proportionality of the microwave reflectivity are not only due to the large conductivity change reported in Ref. 2 but also due to decrease of the mobility by the electron-hole scattering. Impacts of the electron-hole scattering should be considered in the design of the bipolar devices, and thus this result will help the development of bipolar SiC devices.

Acknowledgements

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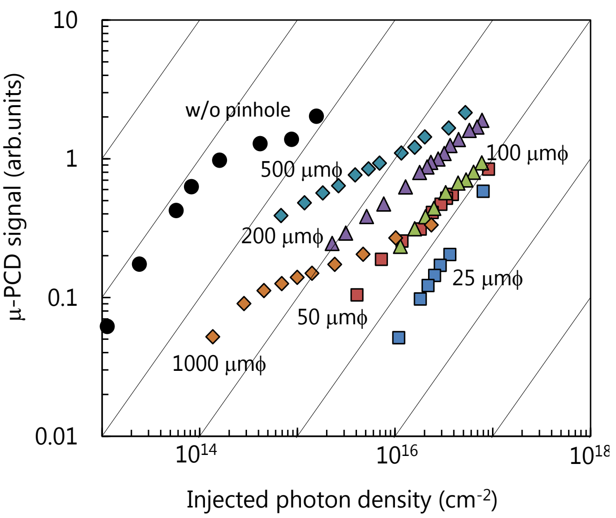

Fig. 1 Dependence of the peak μ-PCD signal on the injected photon density for the Si-face of the sample excited by the 355 nm laser through the pinholes. The slopes of the diagonal lines indicate the proportionality.

References

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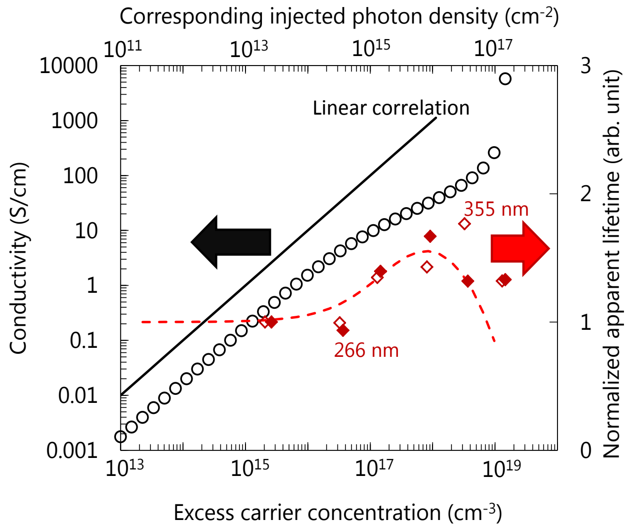

Fig. 2 Dependence of the conductivity (the circles) and the normalized 1/e lifetime (the dashed line) on the excess carrier concentration considering the electron-hole scattering [3]. The rhombuses are plots for the experimental 1/e lifetimes. The upper horizontal axis indicates the corresponding injected photon density to the excess carrier concentration.

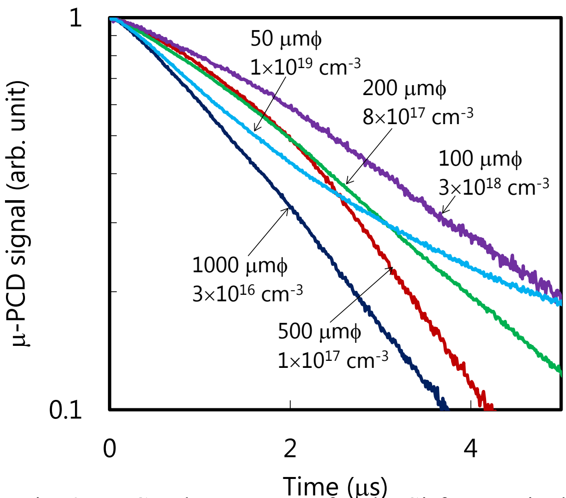

Fig. 3 μ-PCD decay curves for the Si-face excited by 355 nm through the pinholes. Approximate excess carrier concentrations are also shown for the each decay.