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Observation of Deep Levels and Their Hole Capture Behavior in p-type 4H-SiC Epilayers with and without Electron Irradiation

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Abstract

This paper reports deep levels in p-type 4H-SiC epilayers with and without electron irradiation by the current deep level transient spectroscopy. We also estimated time constants of hole capture by deep levels and discussed possibility that the deep levels behave as recombination centers.

1. Introduction

To fabricate power electronics systems handling very high power, power devices with high breakdown voltage and high current density are required. Silicon carbide (SiC) bipolar devices are considered as candidates of such power devices [1]. p-type SiC is a key material for development of bipolar SiC devices, and for any bipolar devices, control of the carrier lifetime in epilayers is strongly important [2-5]. However, studies for deep levels which affect the carrier lifetime in p-type 4H-SiC have been rarely reported. Therefore, in this study, we observed deep levels and analyzed their hole capture behavior in p-type 4H-SiC epilayers.

2. Experiments

Samples used in this study were the same samples as reported in ref. 6 and cut from an Al-doped p-type epilayer grown on 8°-off (0001) Si-face B doped bulk p-type 4H-SiC. We cut the epilayer to several pieces. One of the pieces was employed in the as-grown condition (As-grown). Other pieces were irradiated with 160 keV electrons. This electron energy displaces only carbon atoms but not silicon atoms in SiC. The electron doses were either 10^{16} cm^{-2} (10^{16} irradiated) or 10^{17} cm^{-2} (10^{17} irradiated). We formed Schottky and ohmic contacts on the samples, and performed current deep level transient spectroscopy (I-DLTS).

3. Results and discussion

I-DLTS spectra for the samples are shown in Fig. 1. As-grown shows three deep levels labeled as as-1, as-2 and as-3. On the other hand, 10^{16} irradiated shows deep levels labeled as e16-1, e16-2 and e16-3, while 10^{17} irradiated shows deep levels labeled as e17-1, e17-2 and e17-3. Although we also performed I-DLTS measurements up to 600 K, no deep level is observed at above room temperature. Activation energies *Ea* for the deep levels estimated from the Arrhenius plot are also shown in Fig. 1, but *Ea* for some deep levels are not estimated because of small peak heights. There is no deep level whose peak height increases with the electron doses. If we observe a deep level corresponding to the carbon vacancy or interstitial, its peak height should increase with the electron doses. Therefore, the observed deep levels in the samples after the electron irradiation would not originate from carbon vacancy or interstitial but originate from carbon-related complex defects.

We also estimated capture cross sections for the deep levels by I-DLTS measurements with various injection pulse widths. Figure 2 shows DLTS spectra with the various pulse widths for As-grown. The peak heights increase with increase of the pulse width. From this peak heights dependence on the pulse width, we obtained capture cross section at the peak temperatures σ_T. We also obtained capture cross sections at the infinite temperature σ_∞ from the Arrhenius plot. The obtained σ_T, σ_∞ and other trap parameters are listed in Table I.

From the obtained σ_T and σ_∞, by interpolation, we can estimate capture cross sections at room temperature $\sigma_{300K.}$ Then using σ_{300K} and trap concentration N_T estimated from the I-DLTS spectra, we can calculate time constants of hole capture by the deep levels at room temperature. We compared the calculated time constants with carrier lifetimes in a high injection condition reported in ref. 6 (we use 1/e lifetime which is carrier decay time from a peak to 1/e). Figure 3 shows the time constant of hole capture by the deep levels along with the 1/e lifetimes for the samples. Carrier lifetimes in the epilayer bulk should be approximately a sum of the time constants of hole and electron captures by a recombination center in the high injection condition. Therefore, if the time constant of hole capture by a certain deep level is larger than the 1/e lifetime, the deep level should not be a dominant recombination center. As shown in Fig. 3, because the time constants of hole capture by the observed deep levels are smaller than the 1/e lifetimes, these deep levels possibly behave as the recombination center.

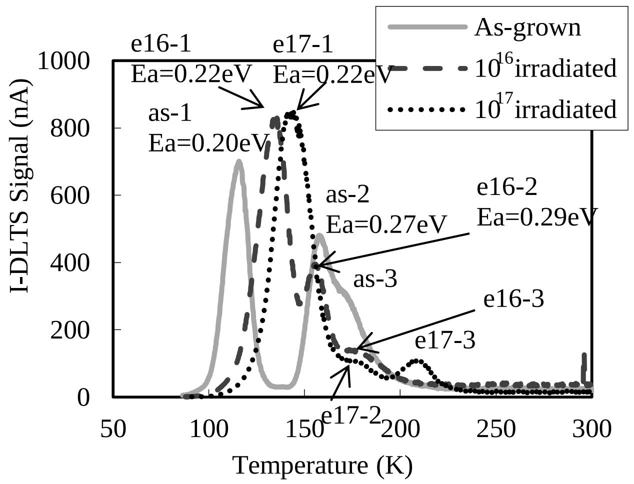

Fig. 1 I-DLTS spectra for the samples (an emission time constant at a peak temperature is 0.9 ms).

Table I. Trap parameters for the observed deep levels.

Label	*Nt* (cm^{-3})	*Ea* (eV)	σ_∞ (cm^2)	σ_T (cm^2)
as-1	1.7×10^{17}	0.20	3.5×10^{-15}	2.4×10^{-18}
as-2	1.0×10^{17}	0.27	1.6×10^{-14}	1.3×10^{-19}
e16-1	1.9×10^{17}	0.22	5.6×10^{-15}	4.6×10^{-19}
e16-2	8.4×10^{16}	0.29	8.6×10^{-14}	9.5×10^{-20}
e17-1	3.2×10^{17}	0.22	7.5×10^{-16}	7.3×10^{-20}

4. Conclusions

We observed deep levels in p-type 4H-SiC epilayers with and without the electron irradiation. We found that deep levels observed after the electron irradiation should originate from carbon-related complex defects. We also found that all deep levels observed in the samples would behave as recombination centers. Thus we consider that deep level introduction by the electron irradiation is effective to decrease the carrier lifetime.

Acknowledgements

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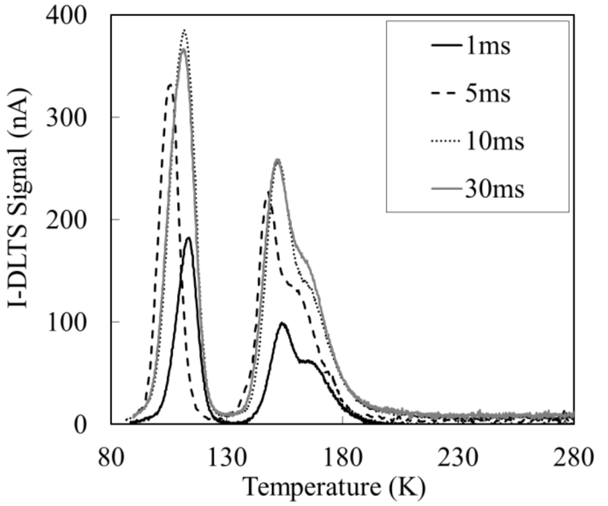

Fig. 2 I-DLTS spectra with various injection pulse widths for As-grown. (an emission time constant at a peak temperature is 4 ms).

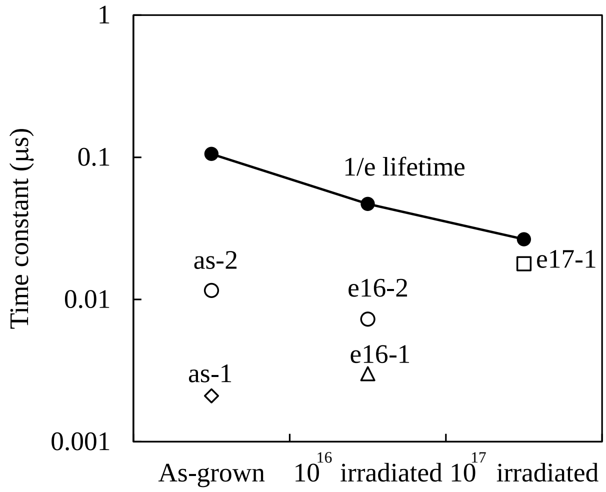

Fig. 3 1/e lifetimes for the samples and time constants of hole capture by observed deep levels.