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Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 59-60
8-10 November, 2011

Photoacoustic Characterization of Semi-Insulating 6H-SiC Single Crystal Irradiated by Electron

電子線照射した半絶縁性 6H-SiC 単結晶の光音響分光法による評価

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1. Introduction

Single crystalline SiC is expected as a power device, because of high breakdown electric field (3 MV/cm: 6H-SiC) and high saturated drift velocity (1.9×10^7 cm/s: 6H-SiC) [1)]. Also thermal conductivity (4.9 W/cmK: 6H-SiC) of SiC[1)] is promising as the substrate of the GaN high frequency high power device. Moreover, SiC has a superior radiation resistivity because it has a wide band gap (3.0 eV: 6H-SiC) [1)] and the large bond dissociation energy（435 kJ/mol）[2)]. SiC has a large advantage of downsizing, lightening and life-time extending for the entire system, for the devices used in high radiation environment such as the space and the surrounding of nuclear reactor.

It is necessary to evaluate the effects of radiation, for example, electron radiation for practical use. Many researchers have used photoluminescence (PL) as an evaluating method for the influence of the electron irradiation.[3)] However, PL cannot detect non-luminescent transition. To detect nonradiative transition in materials, photoacoustic spectroscopy (PAS) is the most effective method. In this study, we investigated electron irradiated 6H-SiC single crystal by PAS.

2. Experiments

Semi-insulating 6H-SiC single crystal substrates supplied from SiXON Ltd. were grown by the modified Lely method, and they were cut into the size of $5\times5\times0.5$ mm^3 perpendicular to [0001] axis. The both surfaces of the samples were mirror-polished. The electron irradiation at 1 MeV was carried out at Japan Atomic Energy Agency (JAEA), Takasaki. The samples were irradiated with electrons at fluences between 1×10^{16} and 5×10^{17} /cm^2, at a rate of 7.78×10^{12} /cm^2・sec. The fluences correspond to the irradiation of one year in the Van Allen belt. Samples were put on a water-cooled copper plate during electron irradiation to avoid temperature increase. Thus, the sample temperature was kept about 317 – 323 K in the experiment.

All samples were measured by ultraviotet-visible (UV-vis) transmittance spectroscopy and PAS. **Figure 1** shows a schematic diagram of the gas-microphone PAS system. The monochromatized light from Xe lump was used for incident light. The modulation frequency was 20 Hz. To improve the S/N ratio, we use an optically thin but thermally thick fused quartz cup and a total reflection mirror to remove the effect of scattered light.[4)] Similar PA experiments were carried out for the single crystal lithium niobate ($LiNbO_3$:LN) irradiated under the same condition.[5)] The change of the PA spectra of 6H-SiC by the electron irradiation is much smaller, because 6H-SiC has a higher resistance against the electron radiation than LN. Therefore, to emphasize the difference of PA spectra, we normalized all spectra by the PA spectra of non-irradiated sample.

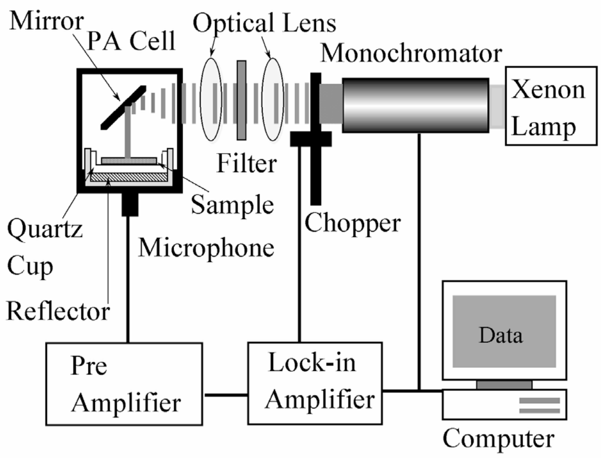

Fig. 1. Schematic diagram of the experiment for PAS

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3. Results and Discussion

The shape of transmittance spectra of the samples below the fluence of $1 \times 10^{17}/cm^2$ shows no difference compared with that of non-irradiated sample, though the broad but small peak around 600 nm appeared in sample of $5 \times 10^{17}/cm^2$ fluence.

Figure 2 shows the PA spectra where the PA signals were averaged 50 times at each wavelength to improve the S/N ratio. The broad peak around 375 nm of the PA spectra appeared in sample of the fluence of 5×10^{16} /cm^2 and 5×10^{17} /cm^2. Moreover, the other broad peak around 640 nm appeared at the fluence of 5×10^{17} /cm^2. To observe the spectrum between 600 and 670 nm in detail, PA signals were averaged 400 times at each wavelength (**Fig. 3**). The arrows in Fig. 3 indicate the common structures of the spectra for both samples, this comes from the energy levels in the band caused by the electron irradiation.

In the measurement of the transmittance spectra, a peak was observed in sample with the fluence of 5×10^{16} /cm^2, but it was very broad and small. On the other hand, we obtained the peaks in PA spectra with increasing electron fluence, which correspond to the defects generated by electron irradiation. These defects are considered Si-vacancy or related complex.

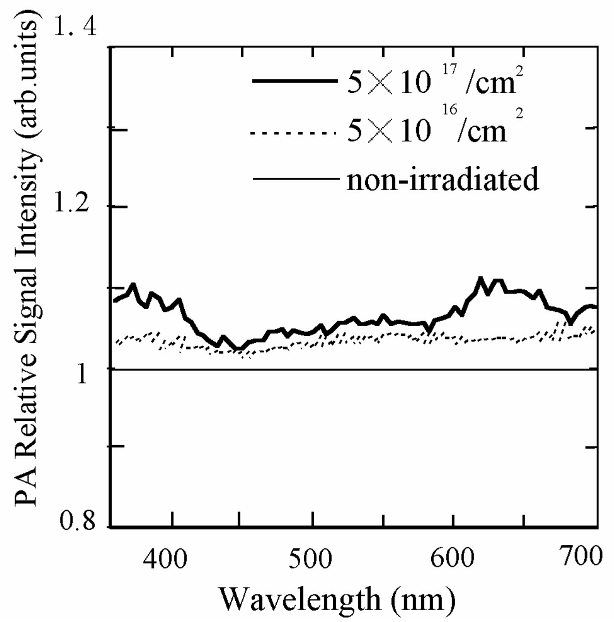

Fig. 2. The PA spectrum of electron irradiated 6H-SiC. All spectra are normalized by the PA spectra of non-irradiated sample.

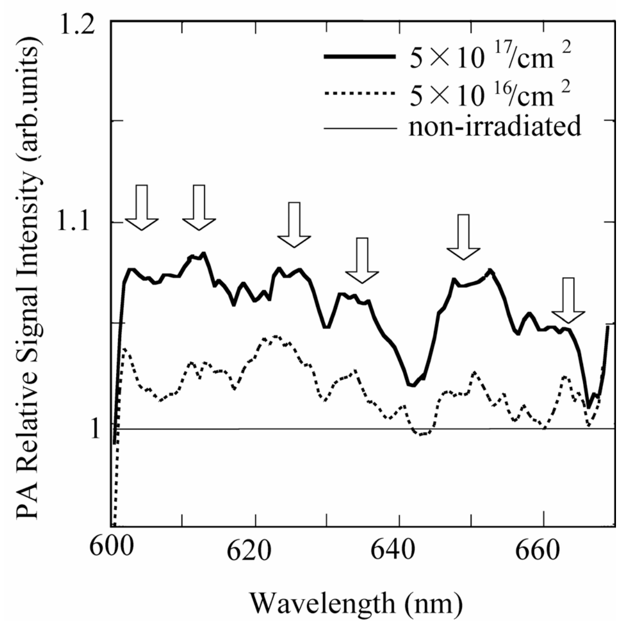

Fig. 3. The detail of the PA spectrum of electron irradiated 6H-SiC. All spectra are normalized by the PA spectra of non-irradiated sample.

4. Conclusion

It was difficult to detect the electron irradiation damage in SiC by using the conventional optical method, because SiC has higher radiation resistance compared with Si. We applied the photoacoustic spectroscopy (PAS) to know the non-radiative relaxation process and found the deep defect levels induced by the electron irradiation.

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