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Photoluminescence of Dislocations in 4H-SiC Epitaxial Layers

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1. Introduction

Ultra-high-voltage SiC-IGBTs with a breakdown voltage of higher than 10kV are expected to realize low-loss and small-sized power conversion equipment for the next generation power transmission system. A high density of dislocations, including basal plane dislocations (BPDs), threading edge dislocations (TEDs) and threading screw dislocations (TSDs) exist in SiC substrates and epitaxial layers, and they can influence the SiC power device performance.

Photoluminescence (PL) imaging technique is a non-destructive technique with a high spatial resolution to detect dislocations in semiconductor materials [1]. Liu et al. reported their PL spectral analysis of the TEDs, TSDs and BPDs in SiC epilayers. In this paper, we compare the PL images of dislocations in SiC epilayers with synchrotron X-ray topography images and discuss discrimination of the dislocations in the PL technique.

2. Experimental procedure

We used 4H-SiC epilayers with a doping concentration of $<1\text{x}10^{14}$ cm^{-3} as the specimens. The epilayers were grown on Si-face 4H-SiC *n*-type conductive substrates with an off-cut angle of 8°. Grazing incidence synchrotron reflection X-ray topography was performed with $\boldsymbol{g}$=11-28 and λ=1.541 Å at SPring-8. Figure 1 shows a schematic of the setup of PL measurements. The 363.8 nm line of a cw Ar laser was used as the excitation light for PL imaging. The PL images ware detected using a cooled CCD camera attached to a optical microscope. The PL spectrum analysis of the dislocations was carried out using the optical band-pass filters with a FWHM of ±5-7 nm attached to the microscope. In the case of low temperature PL measurement, the sample stage was cooled by the liquid-nitrogen.

3. Results and discussion

Figure 2 shows a X-ray topography image and PL images taken at room temperature and 78 K for the same region in a 4H-SiC epilayer. The epilayer thickness is ~140 μm. In the X-ray topography image [Fig. 2(a)], the TEDs and TSDs exhibit short segment of bright contrast and relatively large circular bright contrast, respectively [2]. The PL images were taken with a band-pass filter at 900±5 nm. In a comparison of the X ray topography image and the PL images, one to one correlations are confirmed between the topography defect contrast of TEDs and TSDs and the bright spots in PL images. We obtain relatively clear dislocation images in room temperature PL measurements than low temperature measurements.

In the room temperature PL image [Fig. 2(b)], we found bright spots with different sizes. From a comparison with the X-ray topography image, it is confirmed that TSDs exhibit a relatively large PL spot (labeled L), while TEDs exhibit medium-size (labeled M) or small-size (short segment, labeled S) PL spots. Through the Burgers vector analysis of TEDs for the X-ray topography images [3], we found that the difference in the PL spot size (medium or small size) of TEDs originates in the direction of Burgers vector [labeled A or B in Fig. 2(a)]. The TEDs with a Burgers vector having the two of the six directions, which towards 60° or 120° counterclockwise rotation from the step flow [11-20] direction, correspond to medium-size PL spots. On the other hand, the other four types of TEDs are found to correspond with small size PL spots.

Figure 3 shows PL spectra of TSDs and TEDs. The PL spectra of TSDs are found to have a peak at around 800 nm in the room temperature measurements and around 850 nm in the low temperature measurements [Fig. 3(a) and (b)], although we notice that spectrum shape and peak wavelength can vary slightly for different TSDs. The PL spectra of the TEDs show broad spectra at a range higher than 700 nm in room temperature measurements, while the spectra becomes to have a sharp rise in low temperature measurements at 78 K, as shown in Fig. 3(c) and (d).

3. Summary

PL images and spectra of TSDs and TEDs were obtained at room temperature and 78K and compared with synchrotron X-ray topography images. It was confirmed that discrimination of TSDs and TEDs is possible by analysis of PL spot size in the imaging technique and of PL spectrum of the dislocations in an infrared region. We also found that the difference in the PL spot size for TEDs originates from the direction of the Burgers vector.

Acknowledgements

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References

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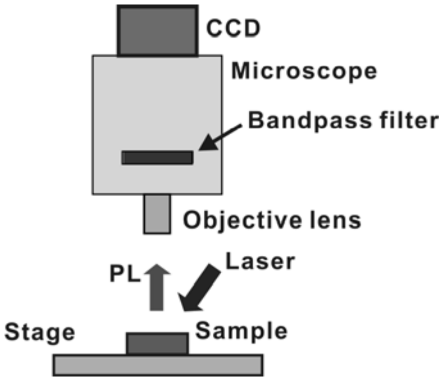

Figure 1. Schematic drawing of the experimental setup of PL measurements.

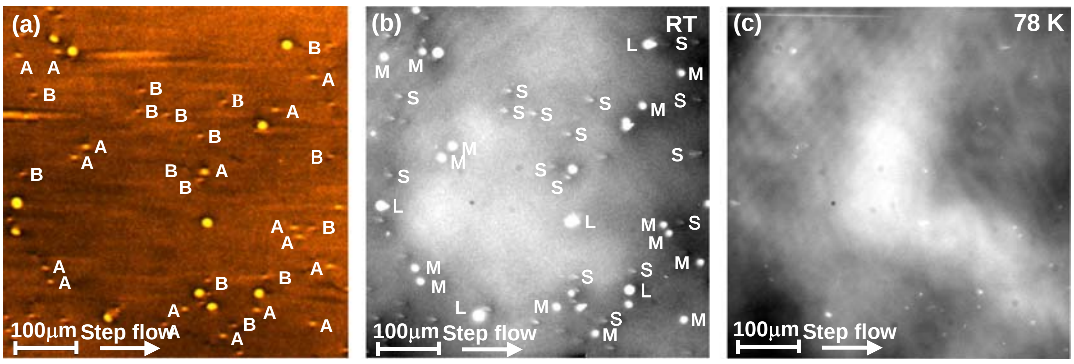

Figure 2. (a) Grazing incidence synchrotron reflection X-ray topography image (g=11-28). The labels A and B indicate Type-A and Type-B TEDs, respectively. (b) PL images taken with a band-pass filter at 900±5 nm at (b) RT and (c) 78K. The labels L, M and S in (b) indicate large spots, medium spots and small spots, respectively.

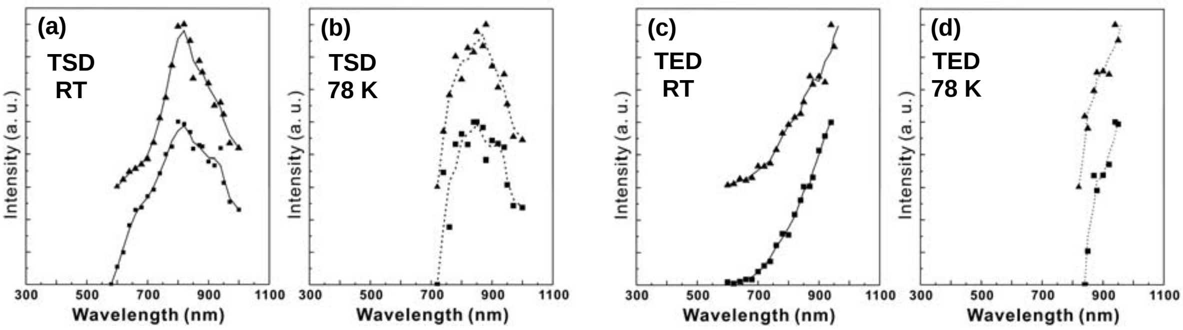

Figure 3. PL spectra of (a) TSDs at RT, (b) TSDs at 78 K, (c) TEDs at RT and (d) TEDs at 78K.