Characterization of Dissociated Threading Edge Dislocation Formed in 4H-SiC by Transmission Electron Microscopy

Y. Sugawara[1], Y. Yao[1], Y. Ishikawa[1], K. Danno[2], H. Suzuki[2], T. Bessho[2], S. Yamaguchi[3], K. Nishikawa[3] and Y. Ikuhara[1, 4]

[1] Japan Fine Ceramics Center, 2-4-1 Mutsuno, Atsuta-ku, Nagoya 456-8587, Japan
[2] Toyota Motor Corporation, 1200 Mishuku, Susono, Shizuoka 410-1193, Japan
[3] Toyota Central Research and Development Laboratories Incorporated, Nagakute, Aichi 480-1192, Japan
[4] The University of Tokyo, 2-11-16 Yayoi, Bunkyo-ku, Tokyo 113-8656, Japan

SiC single crystal has fundamentally superior physical properties. However, deterioration of its properties is caused by various lattice defects (e.g., threading dislocation (TD), basal plane dislocation (BPD), stacking fault (SF), etc.) formed in the crystal. Therefore, it has been an important issue decreasing these killer defects drastically. In order to decrease the defects, it is essential to accurately understand each defect structures and to clarify the formation mechanisms of the killer defects.

Recently, dislocation conversion from threading screw dislocation (TSD: Burgers vector $\boldsymbol{b}$=<0001>) to four frank type SFs which has $\boldsymbol{b}$=(c/4)<0001> is confirmed [1]. Similarly, it is proved that the existence not only the TDs with simple Burgers vectors ($\boldsymbol{b}$=n<0001> (n=1, 2, …) or $\boldsymbol{b}$=(a/3)<11$\bar{2}$0>), but also the threading mixed dislocation with both components (c+a dislocation) in hexagonal SiC [2], [3], [4].

On the other hand, it is widely accepted that the BPD with $\boldsymbol{b}$=(a/3)<11$\bar{2}$0> is extended as the 30° partial dislocation (PD) pairs $\boldsymbol{b}_1$=(a/3)<10$\bar{1}$0> and $\boldsymbol{b}_2$=(a/3)<01$\bar{1}$0> on basal plane. S. Chung et al. [5] have observed an extended BPD constricts before convert to a threading edge dislocation (TED) near the substrate/epilayer interface. However, the dislocation conversion mechanism between TED and BPD which was extended to the PD pair in the hexagonal SiC crystal has not been clarified. By taking account of the frequent conversion between TED and BPD in the hexagonal SiC crystal, the possibility of the TED dissociation remains as suggested by J. W. Yang et al [6].

A 4H-SiC single crystal was used for characterizing the dislocation structure. Firstly, an X-ray topographic image was obtained by grazing-incidence synchrotron monochromatic-beam X-ray topography (SMBXT) using $\bar{1}\bar{1}$28 diffraction. SMBXT was carried out at BL08B2 in SPring-8. The X-ray energy of the monochromatic beam was 9.53 keV and the angle between the incident beam and the substrate surface was ～ 3°. Topographic images were recorded on an industrial X-ray film. After that, etch pits were formed on the 4H-SiC surface by molten KOH etching with Na_2O_2 additive (KN etching) at 510 °C to identify the dislocation position [4]. On the basis of the SMBXT image and an optical micrograph after KN etching, a small hexagonal pit currently interpreted as a TED was selected for the observation target. Focused ion beam microsampling technique [4] was then applied to prepare the TEM cross-sectional specimen for extracting the core area of the small hexagonal pit. The dislocation structure was characterized by weak-beam dark-field (WBDF) method [4] using JEOL JEM-2010DM transmission electron microscope.

Dark-field images taken under the $\boldsymbol{g}$/3$\boldsymbol{g}$ weak-beam condition ($\boldsymbol{g}$: reciprocal lattice vector) of the TD which exists below the small hexagonal pit were shown in Fig. 1. The

g vectors of Fig. 1(a) and (b) are $\boldsymbol{g}=\bar{1}2\bar{1}0$ and $\boldsymbol{g}=000\bar{4}$, respectively. The dislocation contrast of the TD is clearly seen in Fig. 1(a). On the other hand, the contrast has disappeared in Fig. 1(b). Thus, it is considered that the Burgers vector of the TD has $[\bar{1}2\bar{1}0]$ or $[1\bar{2}10]$ component, but it has no <0001> component.

Fig. 2 is a magnified image of Fig. 1(a). Two TDs close to 10nm projection distance are observed in the dark-field image of $\boldsymbol{g}=\bar{1}2\bar{1}0$. If the dislocation pair which has the Burgers vector of an opposite sign is close to each other, it will be annihilate. However, existing of the pair of proximate dislocations, strongly suggested that the dislocation pair is dissociated TED includes the displacement component of the $[\bar{1}2\bar{1}0]$ or $[1\bar{2}10]$ directions.

The authors thank Dr. Kazushi Yokoyama of Hyogo STA and Mr. Yoshiharu Hirose of TCRDL for their help in the topographic observation. The synchrotron radiation experiments were performed at BL08B2 of SPring-8 with the approval of the Japan Synchrotron Radiation Research Institute (JASRI, Proposal No. 2009B3322).

References

[1] H. Tsuchida, M. Ito, I. Kamata and M. Nagano, Phys. Status Solidi B, **246**, 1553 (2009).
[2] D. Nakamura, S. Yamaguchi, I. Gunjishima, Y. Hirose and T. Kimoto, J. Crystal Growth, **304**, 57 (2007).
[3] H. Yamaguchi and H. Matsuhata, J. Electron. Mater., **39**, 715 (2010).
[4] Y. Sugawara, M. Nakamori, Y. Yao, Y. Ishikawa, K. Danno, H. Suzuki, T. Bessho, S. Yamaguchi, K. Nishikawa and Y. Ikuhara, Appl. Phys. Express, **5**, 081301 (2012).
[5] S. Chung, V. Wheeler, R. Myers-Ward, C. R. Eddy, D. K. Gaskill, P. Wu, Y. N. Picard and M. Skowronski, J. Appl. Phys., 109, 094906 (2011).
[6] J. W. Yang and P. Pirouz, J. Mater. Res., **8**, 2902 (1993).

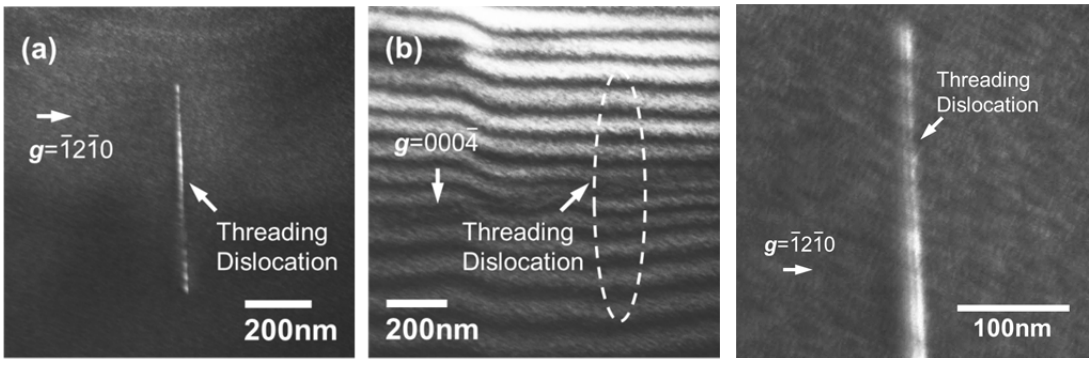

Fig. 1 Dark-field images under the ***g***/3***g*** weak-beam condition of the threading dislocation which exists below the small hexagonal pit. (a) $\boldsymbol{g}=\bar{1}2\bar{1}0$, (b) $\boldsymbol{g}=000\bar{4}$.

Fig. 2 An enlarged image of Fig. 1(a). A dissociated dislocation pair was observed on $\boldsymbol{g}=\bar{1}2\bar{1}0$ weak-beam condition.