Observations of RAF - SiC Single Crystals by Synchrotron X-ray Topography

Silicon carbide (SiC) is one of the promising semiconductor materials for next generation ultralow-loss and high-power electrical devices. However, SiC crystals still have a large number of crystal defects. One type of defect is macroscopic, such as micropipes and small-angle boundaries, and another type is elementary dislocations and stacking faults which are microscopic defects. It has already been reported that the former may adversely affect the electrical characteristics of SiC devices. Recently, the latter defects have also been suggested to be similarly harmful [1]. These defects have so far prevented the realization of high-efficiency, reliable electronic devices with SiC. An improvement of crystal quality is found to be indispensable for the realization of practical SiC devices.

We reported a method [2], the RAF (repeated a-face) growth process, designed to reduce the number of crystal defects in SiC single crystals. The aim of this research is to evaluate the crystal quality of RAF-SiC substrates by synchrotron X-ray topography. The identification of the types of crystal defects is important for the realization of practical SiC devices. X-ray topography is known to be the most effective nondestructive technique for large-area evaluation of defects in single crystals.

We used two in-house-fabricated 4H-SiC (0001) wafers as specimens. One is an ultrahigh-grade substrate, 4H-SiC (0001), 8 degrees off-axis, 2 inches in diameter, manufactured by the RAF process. The other is a conventional-grade substrate, 4H-SiC (0001), on-axis, 1.2 inches in diameter.

The synchrotron X-ray topography experiments were conducted at the second experimental hutch at beamline **BL20B2** [3,4]. In the experimental hutch, we can employ the horizontal-wide and monochromatic X-ray beam because of the distance from the bending magnet light source to the experimental hutch is as long as 200 m. Furthermore, the beamline is highly suitable for the X-ray topography experiment because the spatial distribution of the X-ray intensity is homogeneous. We performed topographic observations by means of the surface-sensitive method, which is the Berg-Barrett arrangement with a small glancing angle of 1 degree. The energy of the X-ray was tuned to 11.94 and 9.86 keV for the RAF substrate and for the conventional substrate, respectively, in order to obtain topographs using asymmetric reflection of $11\bar{2}8$ while maintaining the glancing angle of 1 degree. The X-ray penetration depths from the sample surface are estimated to be about 4 μm, and 2 μm, respectively. The topographs were recorded on nuclear plates at a high resolution.

The two topographs of SiC substrates, obtained by continuous scan of glancing angle, are shown in Fig. 1. Figure 1(a) shows that the crystal quality of the RAF

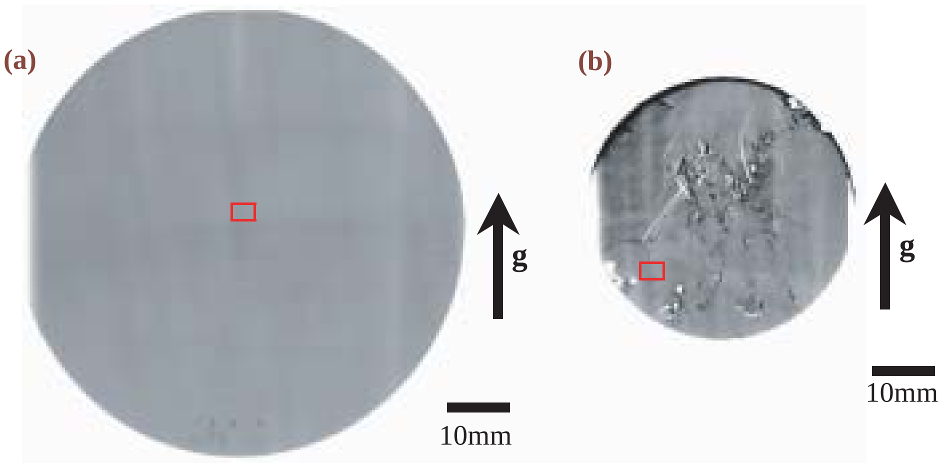

Fig. 1. X-ray topographs of the RAF SiC substrate **(a)** and the conventional substrate **(b)**, taken with the asymmetric reflection. The arrow indicates the diffraction vector **g** [2].

substrate is very homogeneous. Very few macroscopic or microscopic defects are seen in the enlarged image of the topograph (Fig. 2(a)). On the other hand, as shown in Fig. 1(b), the conventional substrate has many macroscopic defects, such as micropipes and small-angle boundaries. Many microscopic defects can also be seen in Fig. 2(b). In this enlarged topograph, two different kinds of dislocations are observable: screw dislocations and basal plane dislocations. The dots correspond to the screw dislocations running almost parallel to the c-axis, i.e., perpendicular to the sample surface. The basal plane dislocations, the dislocation lines of which lie in the basal plane, have the white or black arch-shaped features, and form dislocation networks. In Fig. 2(b), more basal plane dislocations are observed, although the observation depth for the RAF substrate is shallower than that for the conventional substrate. Clearly, the crystal quality of the RAF substrate is much better than that of the conventional substrate.

In summary, synchrotron X-ray topography has revealed that the RAF method can yield ultrahigh-quality SiC single crystals. The macroscopic defects can be eliminated completely and the microscopic defects can be reduced considerably. Consequently, these substrates will promote the development of high-power SiC devices and the reduction of energy losses of the resulting electrical systems.

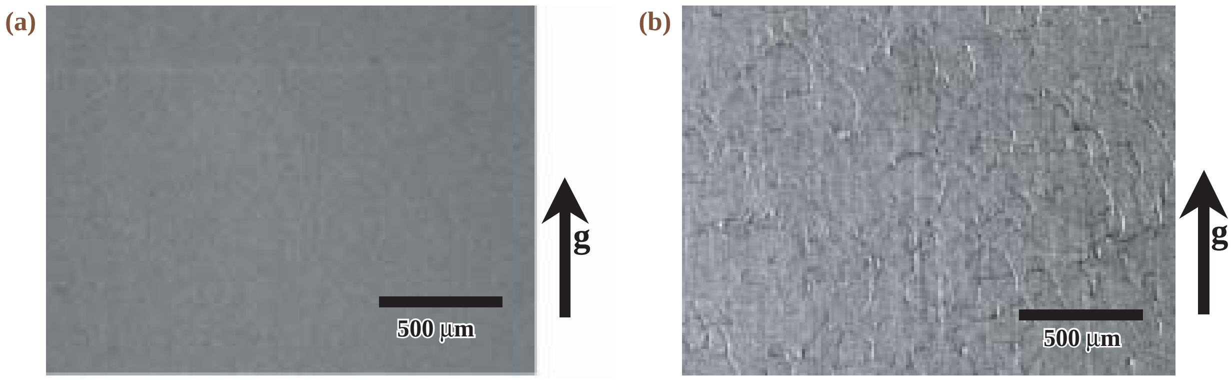

Fig. 2. The enlarged images of the regions indicated in Fig. 1. The arrow indicates the diffraction vector **g** [2].

Satoshi Yamaguchi*, Daisuke Nakamura and Yoshiharu Hirose

Toyota Central R&D Laboratories, Inc.

*E-mail: e1238@mosk.tytlabs.co.jp

References

[1] P.G. Neudeck *et al.*: Solid State Electronics **42** (1998) 2157.
[2] *D. Nakamura, I. Gunjishima, S. Yamaguchi, T. Ito, A. Okamoto, H. Kondo, S. Onda and K. Takatori: Nature **430** (2004) 1009.*
[3] Y. Chikaura *et al.*: J. Phys. D: Appl. Phys. **34** (2001) A158.
[4] S. Kawado *et al.*: SPring-8 Research Frontiers **1999/2000** (2001) 89.