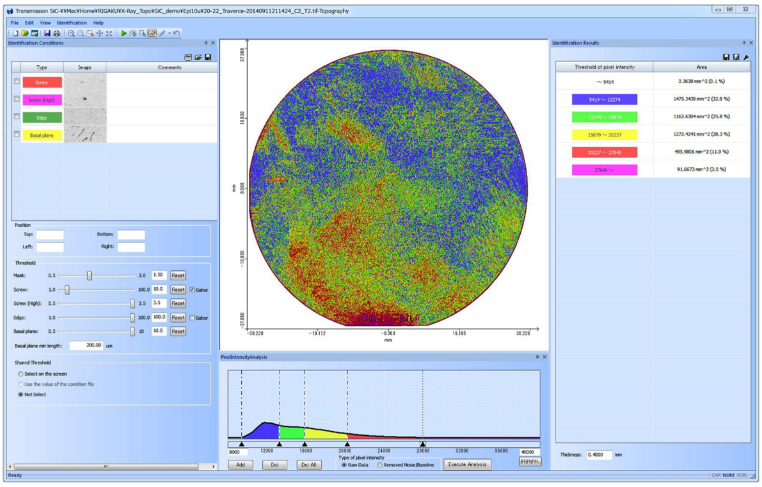
Automated dislocation evaluation software for X-ray topography images

Topography Analysis



1. Introduction

X-ray topography is a powerful technique for evaluating crystal defects such as dislocations, stacking faults, scratches, and so on. High–performance electronics devices such as microprocessors, solid-state memories, imaging processors are fabricated on dislocation-free Si single crystal wafers. However, device fabrication processes often induce dislocations in the Si wafers that can affect the device's performance. Because X-ray topography can evaluate these crystal defects efficiently, it plays an important role in the Si industry. Recently, composite semiconductors—for example, SiC-based materials—have been highlighted due to their higher band gap energies and higher breakdown voltages, features superior to those of Si for achieving higher-efficiency power devices. These devices are sought to improve the utilization efficiency of electric energy and reduce carbon dioxide emissions in order to prevent global warming. Although a lot of effort has been devoted to developing growth technology for achieving low-dislocation density crystals, even the highest quality crystals still have many dislocations, in the range of hundreds to thousands per cm^2. These dislocations can degrade the device's performance. Therefore, quantitative measurement of the dislocation density is crucial for controlling fabrication yields and improving device reliabilities. Recently, a high-resolution and high-speed X-ray topography measurement instrument called XRTmicron has been released that allows users to acquire high-quality topography digital images[(1)]. New software that analyzes the obtained digital topography images to count dislocations and identify their types has been developed. In this note, the operation of the software will be introduced.

2. Dislocation of SiC crystal

Figure 1 shows a typical transmission topography image of a (0001) SiC wafer taken using the $2\bar{2}02$ reflection. Three types of dislocations can be recognized

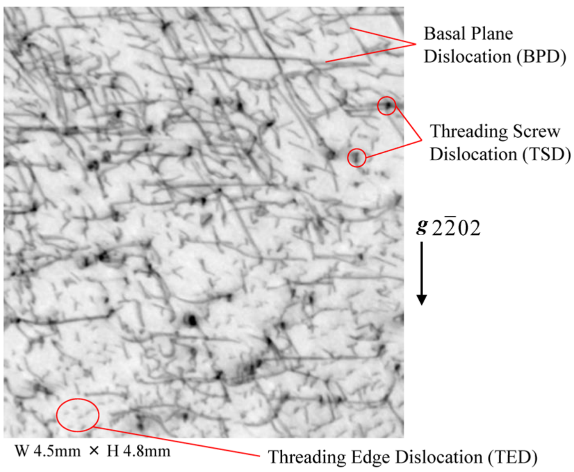


Fig. 1. Transmission topography image taken by $2\bar{2}02$ reflection for a SiC wafer. Threading screw, threading edge, and basal plane dislocations are clearly recognizable.

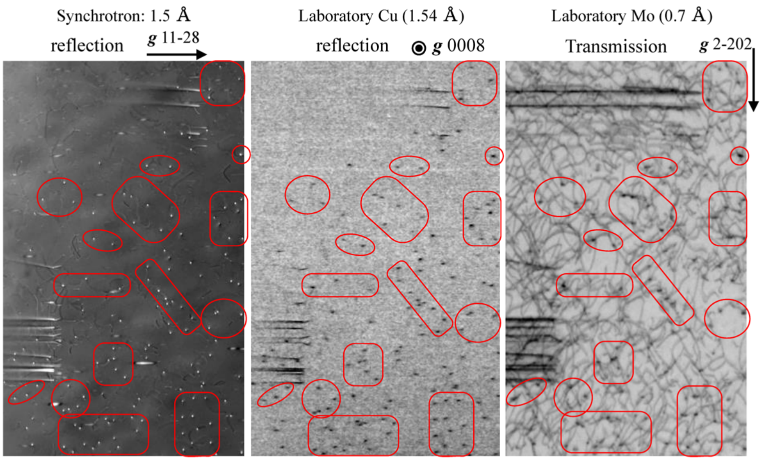


Fig. 2. Comparison of synchrotron reflection, laboratory reflection, and laboratory transmission topography images of the same area. TSDs are detected identically in the synchrotron and laboratory reflection topography images. The transmission topography image includes several BPDs inside the wafer and the TSDs correspond well with the other experiments.

in this image. Large strong dots indicate threading screw dislocations (TSD), which are directed along the *c*-axis and are accompanied by large strain fields around the dislocation core. Its Burgers vector is $n\boldsymbol{c}\langle 0001\rangle$ $(n=1, 2)$. Basal plane dislocations (BPD) are extended in the (0001) plane and appear as long lines in this topography image. Weak dots and short lines are classified as threading edge dislocations (TED), which are elongated along the *c*-axis as were the TSDs. However, TED accompanies a smaller strain field due to its smaller Burgers vector $\boldsymbol{a}/3\langle 11\bar{2}0\rangle$ compared to that of TSD, making weak dots in the topography image. We have confirmed the identification of the above described three types of dislocations by comparing the topography images with those taken at a synchrotron facility. Synchrotron topography is known as the standard method for identification of dislocations[2]. Figure 2 shows the comparison of topography images taken by synchrotron and laboratory sources, respectively. Although the dislocation image taken at the synchrotron is much clearer than that taken with the laboratory system, almost identical TSD results are obtained at the synchrotron as with laboratory Cu reflection topography. In the transmission topography image, there are a lot of BPDs and some TSDs that are unclear or missing. However, more than 80% of TSDs can be detected using transmission geometry. In addition, clearly detected BPDs are known to affect device performance; therefore, reliable quantitative detection of BPDs is a crucial function.

3. Dislocation analysis software for SiC crystals

Rigaku's new X-ray topography system enables us to acquire high-resolution digital image data, which is of sufficient quality to identify dislocation types TSD, TED, and BPD in SiC crystals,. Then, automated identification software was developed. It can not only identify dislocation types, but also count the numbers of TSDs, TEDs, and BPDs. However, counting BPDs is not

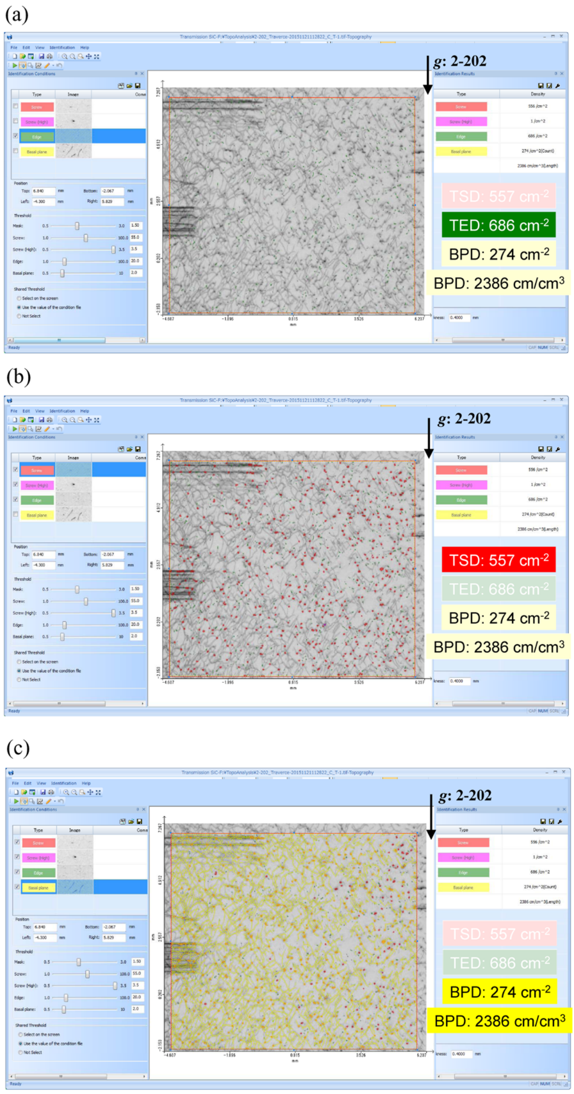


Fig. 3. Software display for the detection of dislocations for (a) TEDs, (b) TSDs, and (c) BPDs.

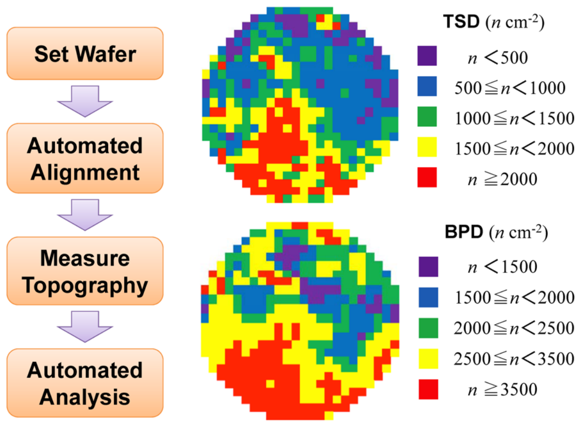


Fig. 4. Flow chart demonstrating an automated topography measurement and analysis (left) and the results of wafer mapping for TSD and BPD (right).

appropriate for transmission topography, because BPDs are connected, making networks. Therefore, a function measuring the lengths of BPDs has also been developed. How the software operates is shown in Fig. 3(a), (b), and (c), which identify TEDs, TSDs, and BPDs, respectively. The resultant dislocation density is indicated as number/area in units of cm^{-2}. The length of a BPD is converted to a dislocation density by calculating length/(area×thickness) in units of cm/cm^3. The software contains a field where the wafer thickness can be entered by the user. In order to avoid misdetection due to noise in the image, the user can control the threshold of the lower detection limit for each dislocation type.

4. Whole wafer mapping of the dislocations

For quality and yields control for SiC devices, dislocation densities should be one of the key parameters. Therefore, wafer mapping of dislocation densities is strongly recommended. Combination of a topography measurement system and the dislocation analysis software can achieve automated wafer mapping of dislocations. The user can select the size of the unit area, make a whole wafer map as shown in Fig. 4 and compare device performance at each point.

X-ray topography has long been used for evaluating the crystal quality of wafers. However, very few specialists can interpret the observed topography images, so they were never used for quality and production control. Rigaku's automated topography measurement and analysis system makes it possible to utilize this analysis for the quality control of production wafers. The developed dislocation analysis software can be easily modified for other crystals, such as Si, GaN, Al_2O_3, others. Those software enhancements will be released in the near future.

References

(1) K. Omote: *Rigaku Journal (English version)*, **29** (2013), 1–8.

(2) H. Tsuchida, I. Kamarta and M. Nagano: *J. Cryst. Growth*, **310** (2008), 757–765.