Evaluation of crystal quality of TlBr semiconductor detector

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ABSTRACT

Thallium bromide (TlBr) is a semiconductor attractive for gamma-ray detectors and imagers. In order to realize a large size TlBr detectors, we should discuss crystal quality. As the crystal quality evaluation methods, we applied neutron Bragg-dip imaging, which is based on the neutron diffraction technique. We also compared the neutron Bragg-dip imaging and the electron backscatter diffraction image.

1 Introduction

Thallium bromide (TlBr) is one of the candidate materials of compound semiconductor gamma-ray detectors and imagers[1-3]. Since TlBr has high effective atomic number and high density, it is considered to be attractive for high-energy photon imagers. Recently, TlBr detectors have been shown a high mobility-lifetime product of electrons and holes. Consequently, a TlBr detector shows high energy resolution[2][3]. However, these excellent results were shown in relatively small crystal detectors. In order to realize a large size TlBr detector, we should discuss crystal quality and uniformity, which are considered to have a relation with carrier transport properties.

In order to evaluate a crystal quality of the TlBr, we apply a neutron and electron diffraction-based techniques. The former can analyze a deep region of bulky crystal. However, this technique can conduct only at the large neutron facility, such as J-PARC[4]. On the other hand, although the latter can analyze only on the surface, it can be conducted by a scanning electron microscope (SEM), which can easily be conducted compared with the neutron diffraction. As a neutron diffraction technique, the Bragg-dip imaging is a powerful tool to evaluate the single crystal quality[5]. We also apply the electron backscattering diffraction (EBSD) technique[6]. We compared the results obtained by the both techniques.

2 Experiments

As a semiconductor material for gamma-ray detectors, bulky crystal quality is important. However, the EBSD can observe only sample surface. Therefore, we first checked the crystal growth feature of TlBr in the current growth procedure. We prepared disk wafers successively cut from a TlBr single-crystal ingot. Figure 1 shows photographs of a TlBr crystal ingot and prepared disk wafers. For a comparison between the neutron Bragg-dip imaging and the EBSD, we also prepared another TlBr crystal wafer. The surface of the crystal wafer was polished for EBSD measurement. The thickness and diameter was 3 mm and 18 mm, respectively, for all the wafers.

We acquired the energy-resolved neutron imaging at the BL-22 beamline in the pulsed-neutron facility J-PARC. The neutron energy can be determined with the neutron time-of-flight method by using a time-resolving two-dimensional detector, boron μ-NID. For single crystals, Bragg-dip pattern could be shown in neutron transmission spectra. By analyzing these patterns, we can estimate crystal orientation, which is dominant along neutron path.

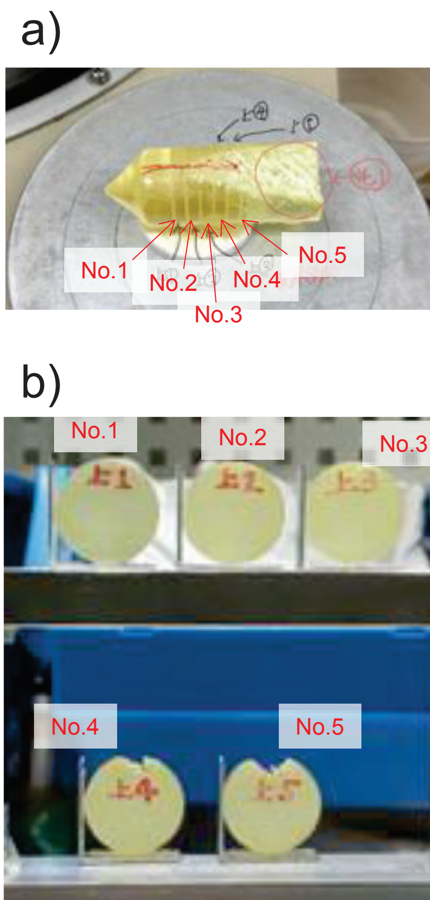

Fig. 1 Photographs of a) a TlBr crystal ingot and b) disk wafers successively cut from the ingot.

The EBSD analysis was conducted by using the SEM (Zeiss, ULTRA55) at the Ultramicroscopy Research Center, Kyushu University. By analyzing a backscattered electron patterns, crystal orientation distribution can be obtained as the inverse pole figure.

3 Results and discussion

Figure 2 shows a crystal orientation map of the successive TlBr crystal wafers obtained with the neutron Bragg-dip imaging. The successive wafers show gradually changing orientation map patterns. From this result, we can consider that crystal grains are growing along the crystal ingot axis, which is parallel to the crystal solidification direction. In other words, crystal orientation remains nearly unchanged over short distance on the order of a few millimeters, which is approximately the thickness of the wafer. Therefore, the crystal orientation on the wafer surface is highly likely to show the orientation within the crystal wafer.

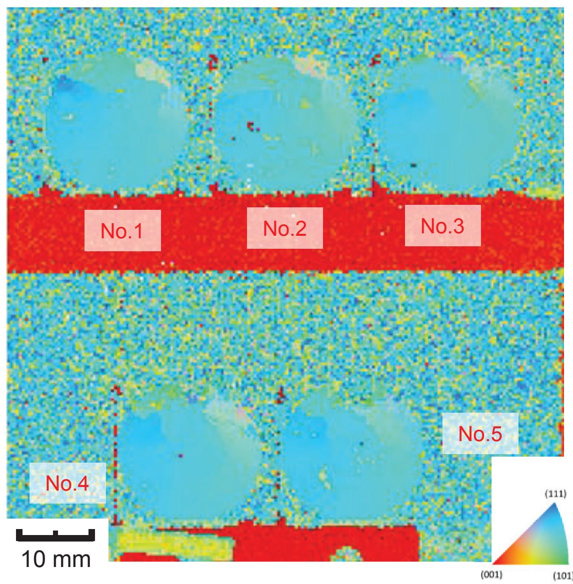

Fig. 2 Crystal orientation map of the TlBr wafers obtained with the neutron Bragg-dip imaging.

Figure 3 shows the crystal orientation maps of a TlBr crystal wafer obtained with the neutron Bragg-dip imaging and EBSD. Although the spatial resolution of the EBSD is better than that of the neutron Bragg-dip imaging, the both maps show similar patterns. The neutron Bragg-dip imaging can only be conducted at large neutron facilities, such as J-PARC, while the EBSD can easily be measured using the SEM, which is available in many laboratories. Consequently, we conclude that the EBSD is also a powerful tool for crystal quality evaluation of TlBr.

4 Conclusions

From neutron Bragg-dip imaging of disk wafers successively cut from the TlBr crystal ingot, we confirmed that crystal grains are growing along the ingot axis. As a result, the crystal orientation on the wafer surface is highly likely to show the orientation within the crystal wafer. The neutron Bragg-dip imaging and EBSD of the TlBr wafer can show almost the same information for TlBr crystals. We concluded that the EBSD can also be a powerful tool for crystal quality evaluation of TlBr.

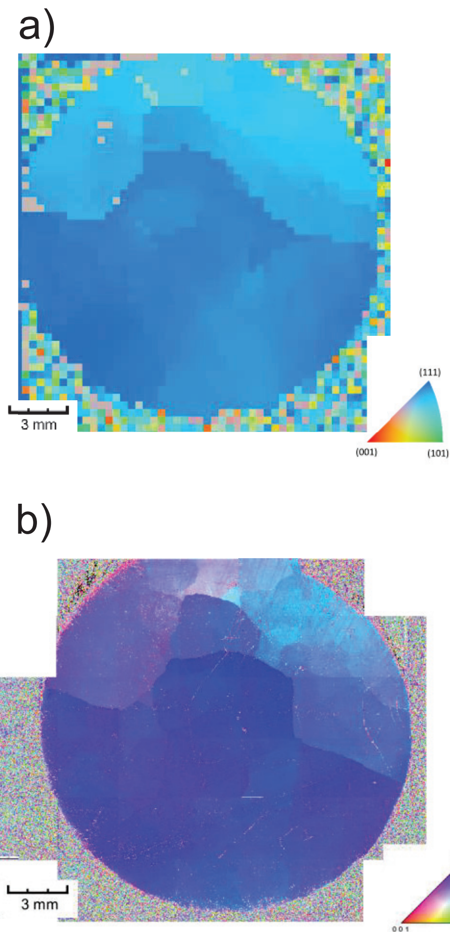

Fig. 3 Crystal orientation map of a TlBr wafer obtained with a) the neutron Bragg-dip imaging and b) EBSD.

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