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Development of a double-tilt stage-scanning sample holder for scanning confocal electron microscopy of single crystal samples

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On the analogy of confocal optical microscopy, confocal imaging in scanning transmission electron microscopy (STEM) would be one of the most promising techniques for performing high resolution 3D observation [1-9]. This technique is called scanning confocal electron microscopy (SCEM). The lateral resolution of SCEM is expected to be comparable with that of conventional STEM, e.g., a lateral atomic resolution is achievable. To perform SCEM, an incident electron probe is finely focused on the specimen by an illumination lens system and the probe is re-focused on a detector by an imaging lens system. By introducing a pinhole immediately before the detector, electrons coming from a specific depth in the specimen are collected to the detector through the pinhole and most of the other electrons from the out-of-focus depths are rejected by the pinhole. When scanning the incident beam to obtain SCEM images, the scanned beam must be de-scanned after the specimen to fix the beam position on the pinhole, because the pinhole is located in a real space.

The first SCEM experiment was performed by Zaluzec and his coworkers using a 300keV electron microscope equipped with the scan-descan system, and demonstrated that SCEM imaging operated at a bright field (BF) mode resulted in visualizing the inner structures of thick biological and semiconductor specimens with high amplitude contrast [1,2]. Their scan-descan type SCEM is not capable of 3D scanning because of the difficulty of Z directional descan. Recently we have developed a 3D stage-scanning system for SCEM to solve the problem of the beam scan-descan type [6]. Using the 3D stage-scanning system, the specimen can be scanned three-dimensionally to perform SCEM with a fixed electron optics configuration. Furthermore, we have found out that annular dark field (ADF) SCEM is capable of improvement of depth resolution [7]. It has been demonstrated that a carbon nano-coil and a carbon nano-horn on which metal nanoparticles were distributed were three-dimensionally reconstructed using ADF-SCEM [8,9]. However, this stage-scan system has only one tilt axis (X-tilt axis), and therefore an orientation of single crystal samples cannot be aligned parallel to an optical axis.

In the present work, we have developed a stage-scan sample holder with X- and Y-tilt axes (so-called double tilt type). As described in Ref.[6], a specimen stage part is supported with only tubular piezoelectric actuators. On the other hand, Y-tilt is carried out by tilting the specimen stage part through a Y-tilt driving mechanism including a driving shaft attached to the holder body. If the driving shaft is connected with the specimen stage part, the stage cannot be scanned smoothly. Therefore, as shown in Fig. 1, in our double-tilt stage-scanning sample holder, the Y-tilt mechanism on the stage is driven by the driving shaft through a clutch so that the shaft is connected with the stage only when Y-tilt is carried out. Otherwise, the stage is isolated from the shaft and the Y-tilt angle of the stage is maintained during 3D stage-scanning.

The performance test of the sample holder was performed in ADF-SCEM using a JEOL JEM-2100F (Cs=1.0mm) equipped with a pinhole and ADF apertures. The details of an experimental setup for ADF-SCEM were described in Refs. [7-9]. Figures 2(a) and 2(b) shows ADF-SCEM XY- and XZ-scanned images of a <110> Si single crystal. It is clear that the holder is capable of high-resolution XY-scan imaging.

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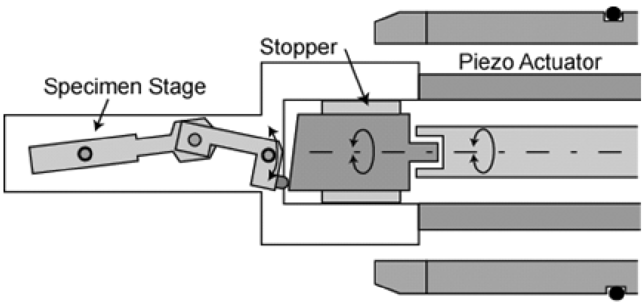

FIG. 1 Schematic drawing of a double-tilt stage-scanning sample holder.

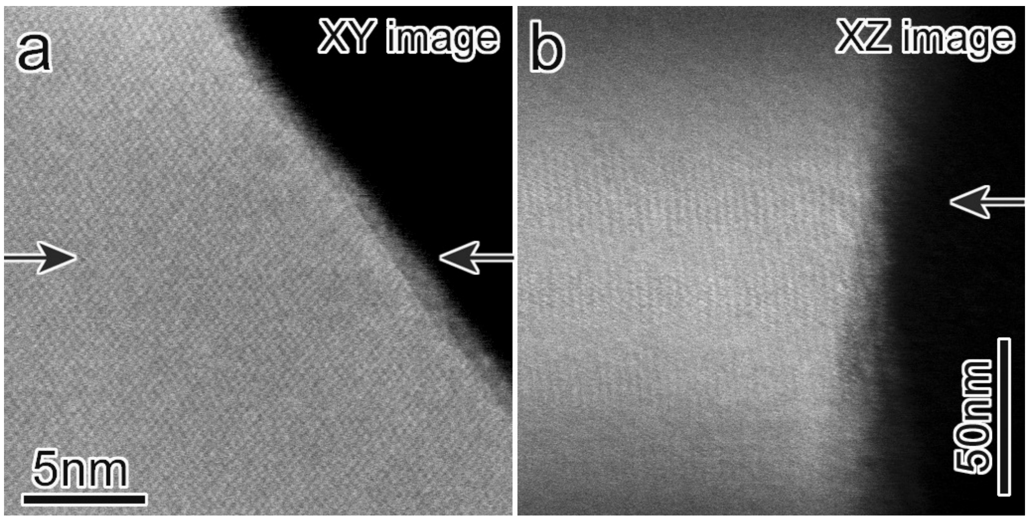

FIG. 2(a, b) ADF-SCEM XY- and XZ-scanned images of Si<011> taken using the developed double-tilt stage-scanning sample holder, respectively.