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Analysis of Lattice Distortion in Multicrystalline Silicon for Photovoltaic Cells by Synchrotron X-ray Diffraction

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1 Introduction

Photovoltaic (PV) cells promise to provide sustainable clean energy, since they directly convert solar energy into electricity. Approximately half of current PV cells are fabricated from cast multicrystalline silicon (mc-Si), because of its good balance between high conversion efficiency and low production cost. However, further improvements are required, such as a reduction of carrier recombination centers and thinning of the mc-Si wafers to reduce the cost of electricity.

The conversion efficiency of a mc-Si PV cell is usually a few percent lower than that of one based on monocrystalline Si, mainly due to the existence of grain boundaries (GBs). Many studies have been undertaken to clarify the electrical properties of GBs [1]. In these studies, electron backscattering diffraction (EBSD) was commonly used to map the grain orientation, with a typical accuracy of less than 1~2°. However, precise grain orientation maps are essential for an improved understanding of the electrical nature of the GBs.

Mc-Si contains residual lattice strain generated during inhomogeneous crystallization, which adversely affects the strength of the mc-Si wafers and can sometimes cause breakage during wafer slicing and device fabrication. The correlation between residual stress and electrical properties has been discussed [2, 3]. He et al. reported a correlation between residual stress, photoluminescence, and surface photovoltage [2], while Chen et al. claimed that the strain did not directly affect the electrical activity [3]. Therefore, imaging of the strain distribution in mc-Si is important for research and development aimed at reducing fabrication costs and improving conversion efficiency.

In this study, we demonstrate the use of synchrotron x-ray diffraction for the imaging of lattice distortion in mc-Si.

2 Experiment

The mc-Si materials used in this study were cut from high-purity large-grain mc-Si ingots, which were grown by a multistage solidification method [4]. Atomic absorption spectrophotometry revealed that most metallic impurities, except Fe, were below the detection limit. The Fe concentration was approximately 5×10^{12} cm^{-3}.

Monochromatic x-ray topographs were taken at BL15C of Photon Factory (PF) in Tsukuba, Japan. X-rays were monochromatized to 12.4 keV with a Si(111) double-crystal monochromator. The reflections in Bragg case were employed, and the diffracted x-rays were observed using an x-ray CCD detector with a pixel size of 6×6 μm^2. The sample images observed by the CCD detector were distorted, depending on the direction of the diffracted x-rays, and were manually corrected according to orientation maps obtained from EBSD measurements. For the strain measurements, a Si analyzer crystal was placed in front of the CCD detector to allow the observation of only x-rays diffracted in a certain direction, and to estimate the strain from the scattering angle.

3 Results and Discussion

Monochromatic x-ray topography is very sensitive to lattice distortion. In the monochromatic x-ray topography, the bending of the lattice was extracted from the rotation angle of the sample, and the strain was estimated from the rotation angle of the analyzer crystal. Figure 1 shows the the strain and bending maps, respectively.

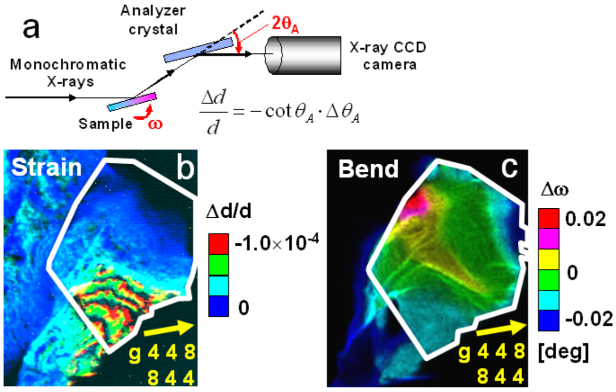

Fig. 1: (a) Experimental setup for monochromatic x-ray topography. (b) and (c) show the strain and bending maps, respectively.

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