ハイパフォーマンス多結晶シリコンにおける粒界 3 重点と転位発生の相関

Correlation of GB triple junctions with dislocation generation in high-performance mc-Si

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[Introduction] From a viewpoint of cost effectiveness, more than 50% of commercial solar cells are fabricated with multicrystalline silicon (mc-Si), grown via high-throughput directional solidification at a low cost [1]. One important issue to fabricate high quality mc-Si solar cells is to control the dislocation clusters degrading the photovoltaic (PV) properties, that are frequently generated during the crystal growth. Even though the degree of dislocation generation in mc-Si would depend on the type of grain boundaries (GBs) [2], the generation sources have been hardly determined in commercial mc-Si ingots with complicated crystal structure. Recently, three-dimensional (3D) distribution of dislocation clusters is visualized in a high-performance mc-Si (hp-Si) ingot for commercial solar cells by photoluminescence (PL) image processing [3], and it is proposed that some triple junctions of GBs would be related to dislocation generation [4]. In the present work, we have examined the triple junctions to discuss the origin of the generation of dislocation clusters in terms of nanoscopic structural properties including the nature and distribution of GBs and dislocations, by using transmission electron microscopy (TEM) combined with PL image processing, electron back scattering diffraction (EBSD), and etch-pit techniques [5].

[Results & discussions] 3D micro-PL imaging combined with EBSD and etch pit analysis reveals that a dislocation cluster degrading the PV properties is generated nearby a junction of three GBs. Those dislocations are generated in a specific grain from the neighboring GB, accompanied with the movement of the triple junction. Occasionally, the atomic plane of the GB is sharply bent via the movement of the triple junction, supposedly due to micro-twins (composed of $\sum3\{111\}$ GBs) intersecting the GB nearby the triple junction, and a number of dislocation arrays are generated from the corners on the GB. Similar generation process is observed during multi-crystallization by the rotation of $\sum3^n$ GBs [5]. TEM reveals that the dislocation cluster is composed of bundles of low-angle GBs (LAGBs; composed of arrays of parallel dislocations expanding towards the growth direction) and honeycombed dislocation networks on a {111} plane. Most of the dislocations have the same Burgers vector parallel to the {111} plane, suggesting that those dislocations are generated in the same slip system. Some dislocations in a honeycombed dislocation networks would change their expansion direction forming LAGBs when the dislocations are tangled. The generation processes of the dislocations will be discussed in terms of the impact of micro-twins existing nearby triple junctions of GBs.

References: [1] C.W. Lan, *et al.*, Cryst. Eng. Comm. 18 (2016) 1474; [2] T. Iwata, I. Takahashi, and N. Usami, Jpn. J. Appl. Phys. 56 (2017) 075501; [3] Y. Hayama, *et al.*, Sol. Energy Mat. Sol. Cells 189 (2019) 239; [4] K. Tajima, *et al.*, 79th JSAP Fall Meeting (2018) 20a-133-2; [5] Y. Ohno, *et al.*, 66th JSAP Spring Meeting (2019) 9a-W611-1; [6] T. Kojima, *et al.*; 29th International Photovoltaic Science and Engineering Conference (2019).

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