Inferring Dislocation Recombination Strength in Multicrystalline Silicon *via* Etch Pit Geometry Analysis

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Motivation

Dislocation clusters are known to decrease minority carrier diffusion length and limit solar cell performance.^[1-3]

Recombination strength (Γ) of dislocation clusters can vary by orders of magnitude within the same wafer, presumably due to oxide precipitates or metal-impurity decoration at dislocations.^[4-6]

We explore the root cause of variations among different dislocation clusters by combining surface and bulk characterization techniques.

We propose a facile method to assess the relative recombination strength of dislocation clusters by analyzing etch pit surface geometry.

Characterization

Cluster Selection and Electrical Characterization

A *p*-type mc-Si wafer, from a directionally-solidified boron-doped ingot (1 Ω -cm) was processed into a solar cell.

Figure 1. (a) Internal Quantum Efficiency (IQE) map from LBIC measurement. (b) Dislocation etch pit map of mc-Si sample containing five clusters. (c) Recombination strength values calculated using the extended Donolato theory.

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Surface Characterization

Etch pit geometry approximated by elliptical shapes.

Eccentricity values fitted between 0 (circle) to 1 (elongated ellipse) with a MATLAB algorithm. (Fig. 2)

Figure 2. Selected dislocation etch pit regions from Cluster A and E with fitted elliptical shape, and their eccentricity values. Herein, a value of 0 corresponds to a perfect circle and 1 to an elongated ellipse.

Bulk Characterization

Metal decoration in dislocations from clusters A, C, and E were analyzed *via* synchrotron-based micro X-Ray Fluorescence (μ -XRF) technique.

Grain orientation and microstructure were analyzed by Electron Backscatter Diffraction (EBSD) and Transmission Electron Microscopy (TEM), respectively.

Results and Discussions

Figure 3. (a) Variation in eccentricity values within each dislocation cluster as a function of recombination activity. The variation is defined as the range between the 5th and 95th percentile of the data. (b) Frequency distribution of eccentricity values corresponding to clusters A through E. In both (a) and (b), the color indicates the crystal orientation of the grain in which the cluster is located.

From μ -XRF, no metal-rich particles were found on cluster A (lowest Γ); only clusters C, and E (higher Γ) showed presence of Cu-rich particles. (Fig. 4)

Figure 4. μ -XRF maps of selected etch pits from clusters A, C, and E. Dark regions in the Si channel correspond to dislocation etch pits. Cu channel in cluster A shows no fluorescence signal above noise floor.

TEM images show a higher degree of interaction and disorder in dislocation line segments. (Fig. 5)

Figure 5. (a-e) Micrographs of dislocation etch pits. (b-d) TEM images of dislocations found in cluster A. (f-h) TEM images of dislocations in cluster E. Variation in line direction, curvature, length and dislocation interaction is evident in cluster E.

Conclusions

The variation in eccentricity values of dislocation etch pits can be used as a proxy to determine relative recombination strength of dislocation clusters.

This proxy is based on the correlation between etch-pit eccentricity variation, and the degree of order and disorder of dislocation line vectors through the bulk.

The framework proposed herein resembles the frameworks for grain boundaries, where impurity decoration is enhanced at defects with higher degree of core-structure disorder (higher Σ values) the Coincident Site Lattice (CSL) model.^[9,10]

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