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Effects of Focused-Ion-Beam Processing on Local Electrical Measurements of Inorganic Solar Cells

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Quantitative determination of electronic properties at high spatial resolution is crucial for the development of high-efficiency solar cells. Electron beam induced current (EBIC) is a powerful technique in which electron-hole pairs are created in proximity to an exposed surface, and the carrier collection efficiency is measured as a function of excitation position [1]. Cross-sections of device are often created by focused ion beams (FIB) due to the flexibility of the patterning and milling processes. However, the irradiating Ga ions of the FIB fabrication may introduce unintended artifacts, affecting local electronic properties. In this study, we investigate the impact of the FIB process observed in EBIC measurements and two-dimensional finite element simulations.

Figure 1 (a) shows a cross-sectional scanning electron microscopy (SEM) image of a cleaved single crystalline (c-Si) solar cell, where a part of the exposed area was prepared using Ga ion beams. The FIB milling was performed at the acceleration voltage of 30 keV and the beam current of 2.5 nA. A series of EBIC data was obtained at different electron beam voltages and beam currents to examine the depth and carrier injection level dependence inside the depletion region and away from the p-n junction (Figure 2a). The bright contrast in the EBIC images (Figure 1, b to d) indicates high carrier collection probability, arising from the strong electric field at the depletion region. However, the brightness of the FIB milled area is much lower than that of the cleaved area. This difference appears to be prominent in the low energy EBIC images (< 10 keV), where the carrier dynamics *(i.e.,* generation and collection) occur closed to the surface having an unintended Ga implanted layer [2].

Quantitative analysis suggests that the FIB milling process would cause over 50% reduction of the EBIC efficiency near the surface at the *p-n* junction. The EBIC collection efficiency (eEBIC) is defined as the ratio of collected current to the total generated carriers. The value of eEBIC is expected to be 100 % at a well-defined, strong electric field region [3]. A series of EBIC line scans at different acceleration voltages were obtained on the cleaved sample (Figure 2b) and the FIB milled sample. The eEBIC at the *p-n* junction were calculated by the measured highest current in the EBIC line scans divided by the estimated generated carriers [4], shown in Figure 2c. The eEBIC of the FIB processed device increases with the higher electron beam voltages. The size of the carrier generation bulb increases with the acceleration beam voltage, creating the electron-hole pairs into the bulk away from the damaged layer. 2D modeling is underway to gain better understanding the carrier dynamics. These results will provide important information about the effects of FIB processing of various types of photovoltaic devices including CdTe and CIGS solar cells.

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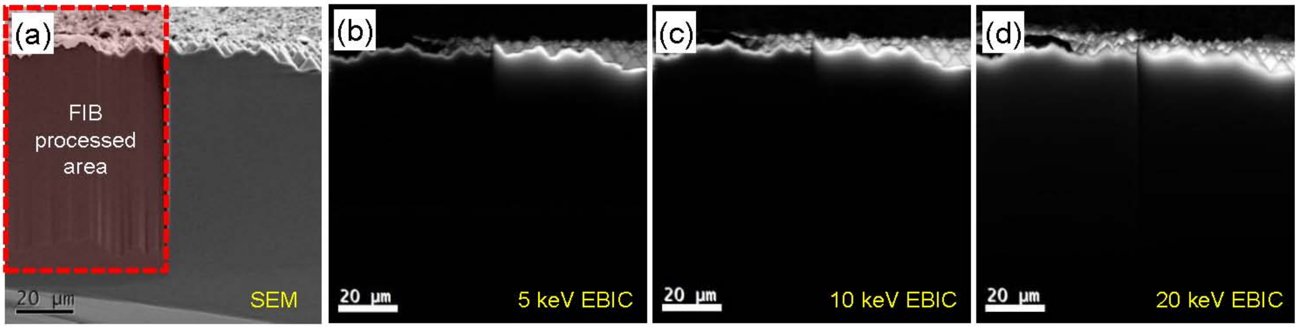

Figure 1. Cross-sectional SEM image (a) of a c-Si solar cell, where a part of the exposed area was prepared using Ga ion beams. The FIB milling was performed at the acceleration voltage of 30 keV and the beam current of 2.5 nA. A series of EBIC images at 5 keV (b), 10 keV (c), and 20 keV (d). Bright contrast indicates a high carrier collection efficiency.

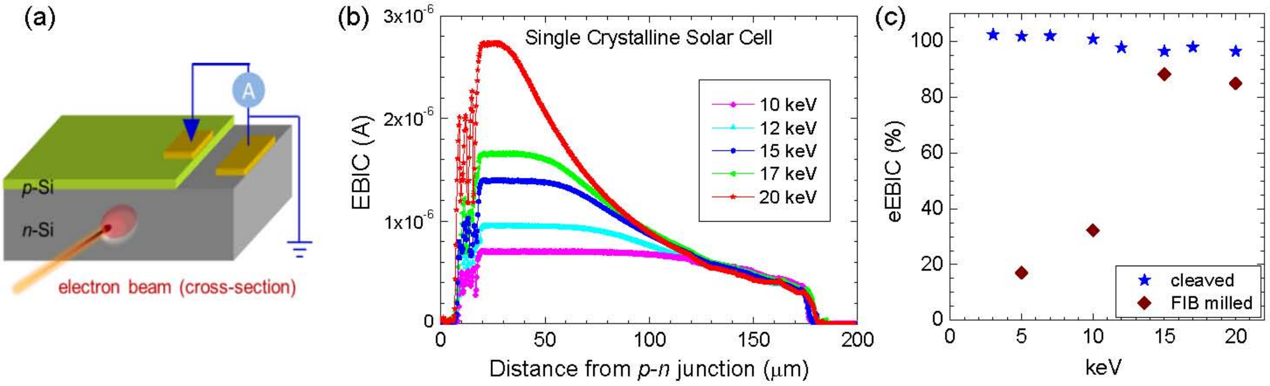

Figure 2. (a) Schematic of cross-section EBIC measurement. (b) A series of line scans of a cleaved c-Si solar cell. The highest current at each EBIC line scan was used for calculating EBIC efficiency. (c) EBIC efficiency (eEBIC) at the *p-n* junction of the cleaved and the FIB milled devices at different acceleration voltages.

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