Scanning Defect Diagnostics in Multicrystalline Silicon for Solar Cells

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ABSTRACT

Non-contact metrology of point and extended crystal defects is detrimental for electronic quality upgrading in multicrystalline silicon (mc-Si) for state-of-the-art photovoltaic application. We report here on scanning lifetime, photoluminescence (PL) and electron beam induced current (EBIC) mapping of defects limiting a performance of solar cells and located in regions with high recombination activity. By comparing PL mapping with the distribution of dislocations using PVSCAN system, we present experimental evidence that intensive room-temperature 0.8eV "defect" PL band corresponds to electrically active dislocation networks. At 4.2K a characteristic quartet of the dislocation D-lines is observed. One of these dislocation lines, D1, can be tracked as temperature increased and linked to the 0.8eV band. We also found using temperature dependent EBIC that the defect PL band originates at dislocations with low level of impurity contamination.

1. Introduction

Vigorous growth in the photovoltaic market over the past decade has been predominantly driven by advances in crystalline silicon technology. Multi-crystalline silicon (mc-Si), which can be produced by ribbon or block-casting techniques, can meet both a low-cost production and a high efficiency requirement for solar cells. Since mc-Si wafers are inhomogeneous, this motivated development of mapping techniques to track recombination activity of defects across entire wafer and solar cell. We report here on PL, total dislocation and EBIC mapping of recombination centers in high recombination regions of mc-Si wafers. This approach allows monitoring of electrically active dislocations contaminated with point defect precipitates at room temperature.

2. Samples and Methods

Materials used in this study were full-size 4"x4" boron doped mc-Si wafers grown by EFG technique. Some wafers were subjected to various steps of solar cell processing. The details on PL and PVSCAN systems were published elsewhere [1].

3. Results and Discussion

Inhomogeneity in electronics properties of mc-Si wafers gives rise to distinct high and low lifetime regions. In the regions with high value of the lifetime, the PL spectrum at room temperature consists of the band-to-band line with the maximum at 1.09eV. On the contrary, regions with reduced minority carrier lifetime exhibit additionally an intensive "defect" PL band with the maximum at about 0.8eV as shown in Fig. 1a. Recombination properties of the 0.8eV band were described in Ref. [1].

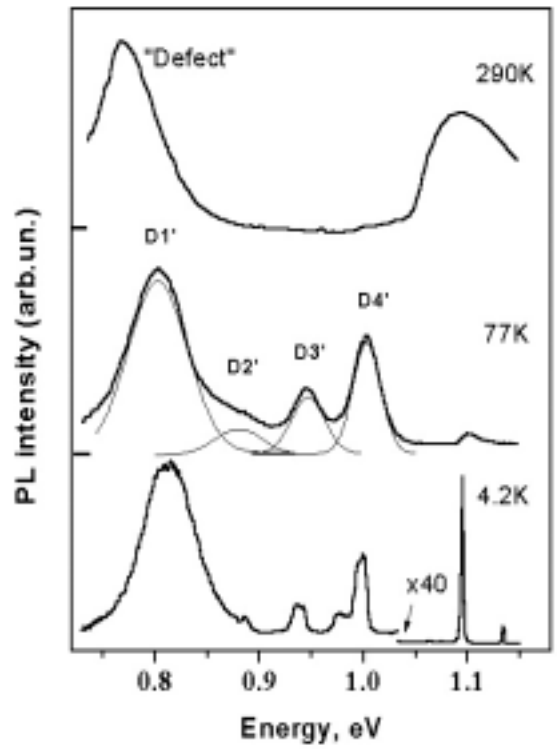

Fig.1 Temperature dependence of PL in EFG wafers.

The intensity of the defect band is highly inhomogeneous across the wafer. We measured PL mapping of both PL bands and observed a distinctive reverse correlation of two maps. The regions with high band-to-band PL shows negligible defect luminescence, and opposite, strong defect band is observed in regions with reduced band-to-band peak. In Figure 2a we present room temperature PL map of the defect PL intensity. The light areas correspond to high PL intensity.

To assess a possible origin of the defect band we performed PL spectroscopy at low temperature. At 77K, rich spectral features are now observed at energies below 1.05eV. Two bands appear at 0.95eV and 1.00eV. At lower energies, the PL spectrum shows the defect maximum at 0.80eV with a barely resolved additional band as a shoulder. This band was identified with defect maximum at room temperature. At 4.2K, the band-to-band emission is

replaced with exciton lines dominated by the TO-phonon replica of the boron bound exciton at 1.093eV. Along with the increasing in intensity between 77 and 4.2K, the PL bands below 1.05eV are now much narrower (~10meV) and exhibit additional sub-bands. The only exception is the 0.8eV band, which retains a large half-width of ~60meV down to 4.2K.

A numerical deconvolution of the 77K PL spectrum in the range of 0.72eV to 1.05eV revealed four Gaussian peaks assigned as D1'to D4'. A set of four similar PL lines, known as D1 to D4, with very close energies to those seen here, was previously observed and studied in detail in plastically deformed Cz and float-zone Si single crystals [2]. These bands are attributed to dislocations.

Mapping of a total dislocation density was performed using scanning light scattering technique. In Figures 2 and 3 we illustrate a correlation of the defect PL band and dislocation density in the same EFG wafer. This result is consistent with data on cast mc-Si [1]. Areas with high dislocation density typically contribute to intensive defect band luminescence. To check further an assumption on dislocation origin of the defect band, we compared the band-to-band and defect band PL distributions in EFG wafer with recombination activity measured on the same wafer by temperature dependent EBIC [3]. Regions with high recombination activity of dislocations are clearly identified on high-resolution EBIC maps. In this PL/EBIC study, it became clear that the defect PL is associated with dislocations with moderate degree of impurity contamination. In fact, recombination activity of dislocations strongly depends on both metal impurity contamination and temperature. According to the model developed in Ref. [4], a moderate contamination level is exhibited as a reduction of EBIC contrast at high temperature compared to 77K. This is exactly a case of 0.8eV PL band defects. If the contamination level is too low ("clear" dislocation) or too high (dislocation decorated by metal silicate precipitates) the defect PL band luminescence is vanished. However, a relatively low contamination level of dislocations, in the order of 10 impurity atoms per micron of the dislocation length produces distinguishable defect band luminescence.

This project demonstrates a utility of the spectroscopic room-temperature PL mapping to monitor electrically active dislocations at various contamination levels of precipitated defects.

4. Acknowledgement. This work was supported by NREL subcontract ACQ-9-29639-03. We thank Juris Kalejs for helpful discussion.

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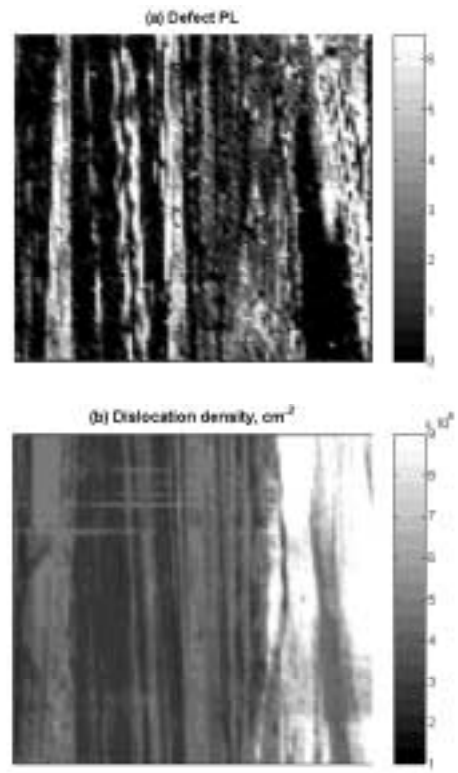

Fig. 2 Mapping of defect band (a) and dislocation density (b) in EFG wafer

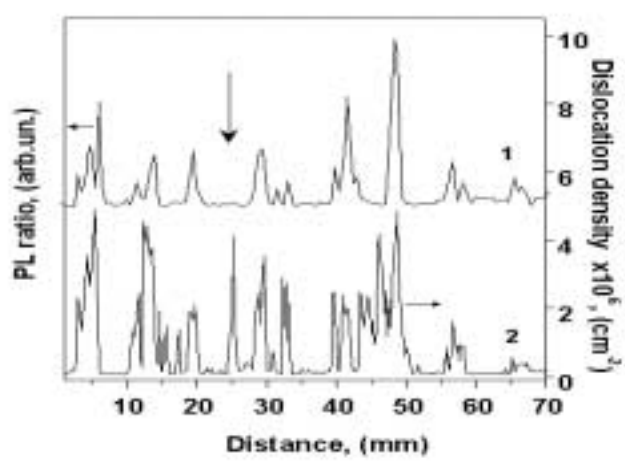

Fig.3 Line scans of the defect PL and dislocation density.