Electrical potentials of mono-crystalline silicon solar cells by off-axis electron holography

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Electric potentials affect the phase of the electron wave in the TEM, and hence they can be analyzed from a phase image, reconstructed from a hologram [1]. An example is shown in Fig.1. Today, application of holography to silicon semiconductors is far advanced in that, e.g., measurements of the pn-voltages and dopant profiles in various materials have already been reported [2,3,4,5,6] also in-situ experiments with biasing [6,7].

Photovoltaic energy is the most promising future energy source. Therefore, strong efforts are made to increase their efficiency-to-price ratio. New technologies and materials are being involved in the production, such as amorphous rather than monocrystalline materials, which do not need highly sophisticated techniques or equipment. But increasing the efficiency needs an exhaustive comprehension of the different phenomena involved in their performance, such as role of defects, doping concentrations, and potentials.

Holographic analysis of the potential structure in amorphous or polycrystalline material is made very difficult by the peculiarly arising dynamic phase shifting effects between and within the grains, such as variations of mean inner potential, thickness, orientation, and interfaces. These undesirable phase modulations can easily be much stronger than the desirable one occurring from doping. Therefore we try to apply in-situ methods changing the parameters we are interested in. The idea of biasing or illuminating the sample is to separate the pn-potential, the inner potential and preparation artifacts, to obtain unique and quantitative information about built-in potentials.

In this work, we start with developing the method of mapping in-situ time-modulated electrostatic two-dimensional potentials in FIB-prepared monocrystalline silicon solar cells. For this purpose we constructed two holders, one providing two contacts for electrical biasing following the idea of ref. [4], and the second one allowing the in-situ illumination of the sample. Furthermore, we developed a special sample preparation because silicon solar cells do not have the pn-junction localized close to the surface; this FIB-preparation described in fig. 2 gives access to $200\mu m$ below the top contact, preserving the surface for biasing or illumination. The proposed preparation has the advantages of uniform thickness, enough robustness to handle, and large area to contact or to illuminate, which are fundamental for static [7] and for in-situ holographic experiments. Complete description of the designs and constructions will be given.

All potentials are quantitatively compared with 3D simulations, and effects over these potentials coming from the sample preparation, e.g. germanium implantation, dead layers and transitions layers, are analyzed as well.

The holographic TEM measurements were accomplished using a CM200 ST/Lorentz Philips TEM in Lorentz mode.

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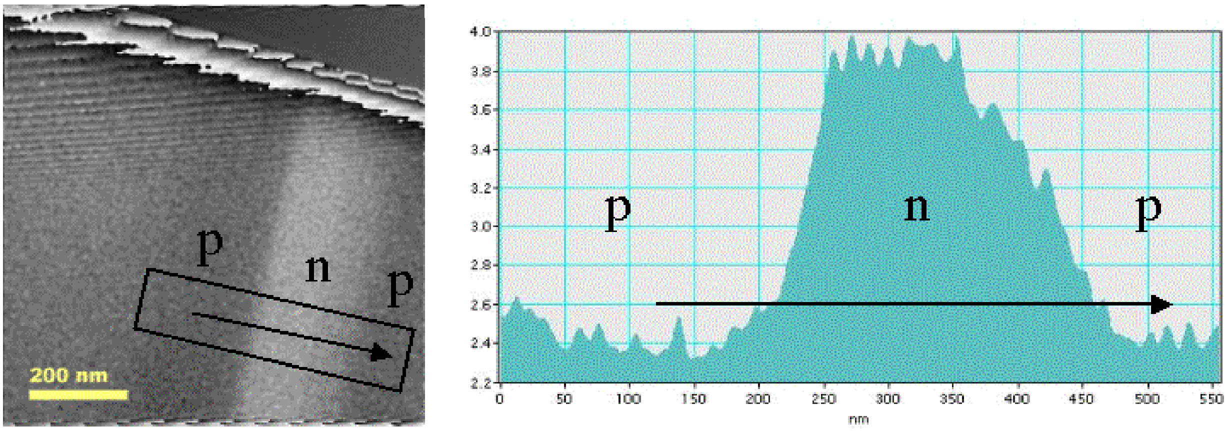

Figure 1. Left: Phase image of a p-n-p junction in silicon.
Right: Phase profile for determination of potential distribution across junctions.

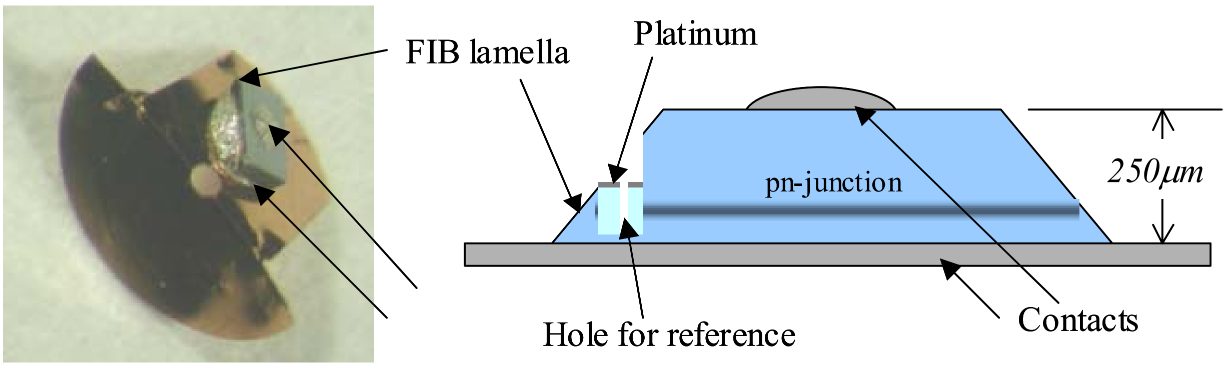

Figure 2. Sample preparation for biasing in-situ experiments.
Left: traditional sample preparation for biasing pn-junctions.
Right: modification of this preparation to access the pn-junction.

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