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Surface potential investigation on interdigitated back contact solar cells by Scanning Electron Microscopy and Kelvin Probe Force Microscopy: Effect of electrical bias

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ABSTRACT

Both Kelvin Probe Force Microscopy and Scanning Electron Microscopy enable assessment of the effect of electrical bias on the surface potential of the layers of a solar cell. We report on a comprehensive comparison of surface potential measurements on an interdigitated back contact solar cell using these two techniques. Measurements under different values of electrical biases are performed on and between the metallic contacts. They show a good agreement between the surface potential obtained with Kelvin Probe Force Microscopy and the Scanning Electron Microscopy signal. In order to provide an accurate comparison, the scanned areas are adjacent to each other and accurate repositioning is achieved thanks to a nano-indentation between the contacts. We show that measurements under reverse bias are of interest to locate nano-defects and measurements under forward bias are relevant to identify local series resistance issues. We suggest that a setup combining Scanning Electron Microscopy and Kelvin Probe Force Microscopy under different values of the electrical bias should be valuable since the former is a high throughput technique enabling measurements on large scan areas, while the latter is a quantitative, low noise, and unintrusive local technique.

1. Introduction

Interdigitated back contact (IBC) solar cells are a promising design to reach high conversion efficiencies. In this architecture, both p and n contacts are positioned on the rear side of the cell with the shape of two interdigitated combs. This design avoids reflection losses on the front side of the cell, contrary to the case of traditional solar cells. The latest crystalline silicon solar cells showing the record efficiencies belong to IBC family. For instance, Sunpower has recently presented 25% efficient industrially feasible solar cells [1] and Kaneka has announced a 26.33% laboratory world record [2] using this design. In order to approach the theoretical limit of 29% efficiency for crystalline silicon solar cells [3] remaining losses have to be reduced. Among them, electrical losses mainly come from local series resistance due to poor local contacts and long current paths [4]. In this perspective, the investigation of series resistance and electrical defects at the nanoscale becomes of interest to localize the areas of power losses in IBC solar cells. Local series resistances cause surface potential drops that can be monitored with several characterization techniques. In this work, we focus on two of them: Kelvin Probe Force Microscopy (KPFM) and Scanning Electron Microscopy (SEM).

KPFM is a scanning probe microscopy technique that measures the surface potential of a sample by monitoring the amplitude of the AFM cantilever operated in tapping mode. KPFM has proven to be an effective tool to investigate the electrical behavior of solar cells at the nanoscale. For instance, measurements on the cross-section of solar cells have enabled monitoring the effect of illumination [5] and electrical bias [6] on the PN junction properties of solar cells.

SEM is an electron microscopy technique that is routinely used to study the surface topography of materials at the nanoscale. However, it

Abbreviations: AFM, Atomic Force Microscopy; a-Si, H: hydrogenated amorphous silicon; IBC, Interdigitated Back Contact Solar Cell; ITO, Indium Tin Oxide; J(V), current density – voltage; KPFM, Kelvin Probe Force Microscopy; SE, Secondary Electrons; SEM, Scanning Electron Microscopy

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has been known for more than five decades that SEM images are also sensitive to surface potential and enable to detect doping contrasts [7]. In particular, doping contrast imaging in low acceleration voltage SEM is a well-known technique used for wafer inspection [8]. Recently, some theoretical works have provided explanations to this sensitivity and achieved quantitative surface potential measurements with low voltage SEM that could be compared with KPFM [9]. Moreover, other studies have shown the influence of the electrical bias on SEM measurements of PN junctions of different materials [10,11].

Recently, studies comparing SEM and KPFM on the cross-section of solar cells under different values of electrical bias have been carried out and showed a good agreement, enabling to discuss the assets of each technique [12]. The interpretation of cross-section measurements can be challenging because of surface states and the fact that cross-section preparation is intrusive and may degrade the electrical properties locally.

In this article, we compare SEM and KPFM measurements performed on and between the metallic contacts of an IBC heterojunction solar cell under different values of electrical bias. Because of the design of IBC solar cells, no intrusive preparation process is required for this measurement. We show that SEM and KPFM measurements of surface potential are consistent. SEM enables fast and large scale measurements and KPFM enables quantitative and unintrusive local measurements.

2. Material and methods

2.1. Interdigitated back contact solar cell structure

The IBC solar cell was fabricated at IMEC. The architecture of the cell is depicted in Fig. 1. It is a silicon heterojunction solar cell with an energy conversion efficiency of 19.1%, a short circuit current density of 40.3 mA cm^{-2}, an open circuit voltage of 705 mV, and a fill factor of 67.3%. The series resistance was 2 Ω cm^2. The n-type float-zone wafer has a resistivity of 2.8 Ω cm. The front side of the cell was textured using wet etching leading to random pyramids, followed by the deposition of passivation and antireflective films. The backside was not textured, but directly coated by an intrinsic hydrogenated amorphous silicon layer (a-Si:H). Afterwards, n^+ doped a-Si:H and p^+ doped a-Si:H layers were deposited side by side, forming respectively the n^+ a-Si:H and the p^+ a-Si:H stripe regions. The thickness of the intrinsic/ n^+ a-Si:H stack is around 30 nm and that of the intrinsic/ p^+ a-Si:H stack is around 17 nm. Finally, indium tin oxide (ITO) and copper were deposited both on the p^+ a-Si:H and n^+ a-Si:H regions in with a distance of 80 µm between each finger.

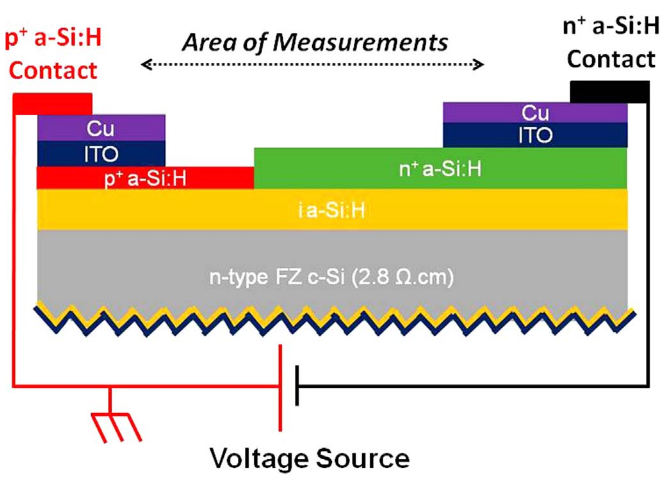

Fig. 1. Schematic of the IBC solar cell connected to the voltage source. The Cu/ITO/p^+a-Si:H contact is grounded and the Cu/ITO/n^+a-Si:H contact is biased. SEM and KPFM measurements are performed on and between the contacts.

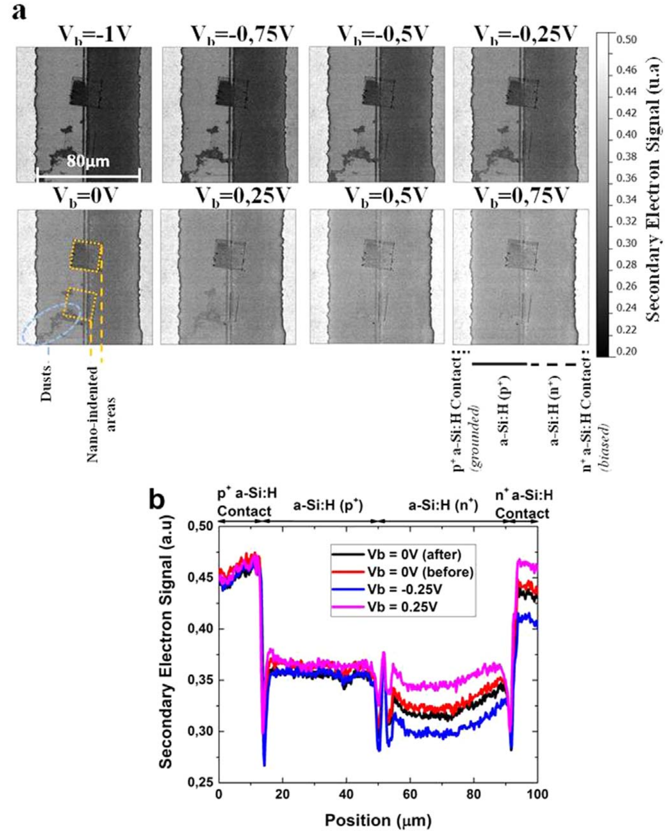

Fig. 2. (a) SEM images of the IBC solar cell under various values of the applied voltage bias in the range between -1 V and 0.75 V with steps of 0.25 V. On the left, the Cu/ITO/p^+ a-Si:H contact is grounded and on the right, the Cu/ITO/n^+ a-Si:H contact is biased. (b) SEM profiles for electrical bias equal to -0.25 V, 0.25 V and 0 V before and after the set of measurements. The degradation after one set of measurements is negligible compared to changes associated with the applied voltage bias of 0.25 V.

2.2. Setup and measurement timeline

Previous studies have shown that measurements on distant areas of solar cells could lead to uncertainties [12]. In order to make more accurate interpretations, SEM and KPFM measurements have to be performed on adjacent areas of the IBC solar cells. In order to identify easily the area of interest, we used AFM to perform nano-indentation between the fingers of the solar cell. For this purpose, we used a stiff AFM cantilever with a spring constant of 40 N m^{-1} and we performed two scans in AFM contact mode with a strength of around 10 µN. The nano-indentation array can be seen in Fig. 2.a. It is composed of two squares of 20 µm side separated by a distance of 20 µm.

After nano-indentation, the IBC solar cell was cleaned using acetone and ethanol, and SEM measurements were performed under an electrical bias. In contrast to cross-section investigations, no intrusive preparation process (e.g. cleavage or polishing) was required [12]. KPFM measurements under the electrical bias were carried out on a region adjacent to the SEM measurement (< 5 µm distance) in order to avoid the influence of local defects between areas of measurements or possible carbon contamination.

For both SEM and KPFM, measurements were performed at different values of the electrical bias (in the range from -1 V to 0.75 V) applied between the Cu/ITO/p^+ a-Si:H and the Cu/ITO/n^+ a-Si:H contacts. The voltage step was 0.25 V. For all measurements, the Cu/ITO/p^+ a-Si:H contact was grounded. Measurements were performed on and between the contacts, as shown in Fig. 1. In both setups, J(V) curves were measured and compared to the J(V) curves obtained under a solar simulator, in order to investigate the series resistances related to each setup. From these curves, we estimated the series