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Investigating metal-semiconductor contacts in solar cells using magnetic field imaging

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While solar cells and modules are already a mature technology in mass production, contacting schemes are constantly evolving and currently multi busbar/multi wire contacting systems are being developed. During the development and the production of such technologies, it is critical to optimize and to systematically monitor their performance.

In this paper, we find that different contacting fault types can be identified by inducing specific current flow patterns through the contacts of a single side of a solar cell and measuring the resultant 2D magnetic field image.

Additionally, we explore the use of circuit network modelling in conjunction with these magnetic field images to gain further insights about the contacting faults and in particular to determine relevant contacting parameters like contact and sheet resistance for the investigated structures.

Introduction and Background

The focus of this paper is the assessment of solar cell contacting structures using magnetic field (MF) imaging. MF imaging is a characterisation technique where the magnetic field on the surface of a solar cell is monitored while the cell is driven in different operating conditions. From the 2-dimensional (2D) MF maps generated by such a measurement 2D maps of current vectors within the solar cell can be approximated (thin-layer approximation) [1]. Such current maps are used in conjunction with electronic circuit network modelling to study contacting structures.

Traditionally, solar cell contacting schemes are studied using transmission line measurements (TLM) with specifically designed contact structures [2]. From such TLMs the contact resistance R_c between metal and semiconductor (Ω-cm^2) and sheet resistance R_{sheet} (in $\Omega/\square$) of the semiconductor sheet can be determined.

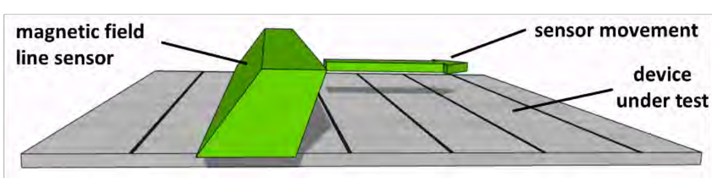

Figure. 1. Schematic of magnetic field line-scanning set-up used to measure 2D magnetic field maps of Bx, By, and Bz on solar cells.

This paper presents a method using MF imaging that allows investigating solar cell contacting structures without the need for creating specific test structures. It can also be used in the case of finite busbar/contacting wire resistance R_w which renders the regular TLM method unviable.

Example: Measurements and modelling of a multi-wire contacting scheme

Magnetic field images of solar cells can readily reveal many types of defects. In particular, defects significantly altering the current flows in solar cells can be identified, such as strong shunts, missing solder connections or broken grid fingers. However, more insights can be gained when metal-semiconductor structures on solar cells are modelled using a suitable circuit simulation program such as LT SPICE (the package used in this work).

For this paper we prepared an aluminium screen-printed rear of a multiwire solar cell with a wire spacing of 8 mm (18 wires in total). In an initial test we injected current on one side of a single wire and extracted the current at the other side of the same wire. We found that the current did not stay confined to the contacted wire but instead distributed over the rear surface of the solar cell in a characteristic pattern (this will be shown at the conference).

We then tested a measurement configuration whereby the current was injected in one wire of the rear metallization and extracted at another wire (4 cm away) on the same side of the solar cell. The resulting magnetic fields B_x and B_y are displayed in Fig. 2 (a) and (b), respectively. The resulting magnetic field (and hence current flow patterns) indicates a characteristic current distribution for this contacting scheme whereby most current flows horizontally close to the injection/extraction points but there is also significant current flowing further away from the current injection/extraction.

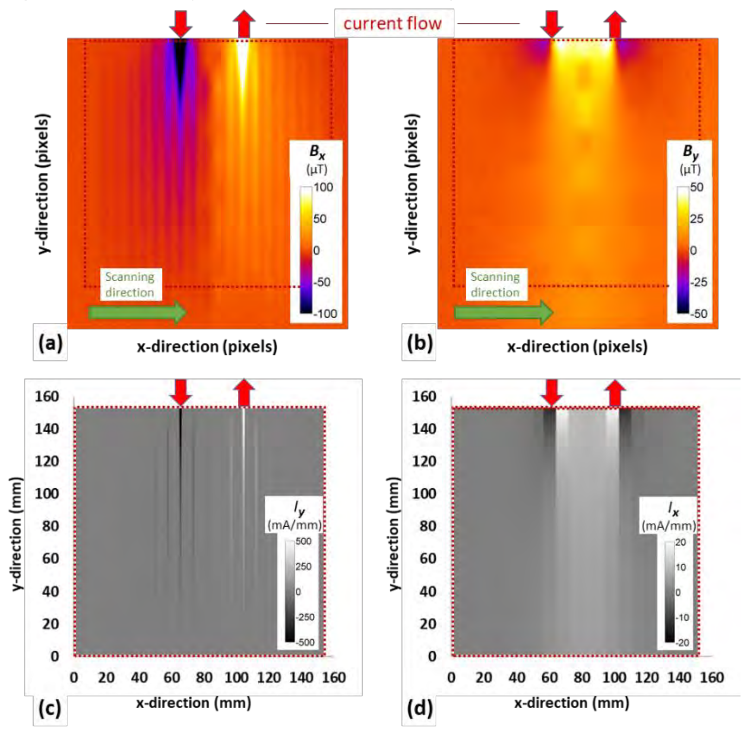

Figure 2. Magnetic field measurement (a) B_x and (b) B_y of a cell with multi-wire contacting scheme when current is injected and extracted on one side with a spacing of 5 wires apart (see arrows). Quantitative electronic network simulation of the current flows (c) in y-direction and (d) in x-direction for the same current flow configuration.

We modelled these current flows using a resistive grid pattern (Fig. 2 (c) and (d)) with 1 mm grid resolution (~ 25,000 nodes) using the circuit simulating software LT SPICE. When using resistance values (i) $R_w = 0.25\ \Omega/m$, (ii) $R_c = 50\ m\Omega\text{-}m$ and $R_{sheet} = 10\ \mu\Omega/\square$ the current flow patterns and the MF images look approximately identical.

Conclusions

Magnetic field images of solar cells can readily reveal many types of defects. Furthermore, using electronic circuit network modelling it is possible to gain additional insights and even to determine characteristic metal-semiconductor parameters that would otherwise necessitate the preparation of samples with specifically designed contacting structures.