

## P<sup>+</sup> DOPING ANALYSIS OF LASER FIRED CONTACTS BY RAMAN SPECTROSCOPY

J. Ebser, N. Brinkmann, Y. Schiele, A. Herguth, G. Hahn, B. Terheiden

University of Konstanz, Department of Physics, Box 676, 78457 Konstanz, Germany

Author for correspondence: Jan.Ebser@uni-konstanz.de, Tel.: +49 7531 88 4995, Fax: +49 7531 88 3895

**ABSTRACT:** Laser firing of contacts is a simple method to establish local rear contacts of silicon PERC (passivated emitter and rear contact) solar cells. The silicon bulk is contacted point-wise by Al driven by the laser through the rear dielectric layer. The Al is deposited on the full area by physical vapor deposition or screen-printing. Al and B, if the Al paste contains B additives, can thereby establish a p<sup>+</sup>-doped Si region below the Laser Fired Contact (LFC), which helps to lower carrier recombination because of the local back surface field and also to reduce contact resistance. In this work Raman spectroscopy is used to detect and investigate the p<sup>+</sup>-layer established by laser firing through screen-printed Al. Scanning Raman measurements allow spatially resolved determination of the free hole concentration in the contact area. In a line scan through a LFC, the step in doping concentration between the lowly doped bulk Si and the highly doped LFC area is clearly seen by a high local hole concentrations in the range of 10<sup>19</sup> cm<sup>-3</sup> in the LFC region. This shows that scanning Raman spectroscopy is a useful method for the microscopic understanding of LFCs and optimization of the process parameters.

Keywords: Characterization, Metallization, Laser Processing, Doping

### 1 INTRODUCTION

Laser Fired Contacts (LFC) [1, 2] provide a simple method to establish local rear contacts of a silicon PERC (passivated emitter and rear contact) solar cell. In this process a full area aluminum layer (deposited by physical vapor deposition or screen-printing [3]) is contacted point-wise by laser spots through the rear passivation layer to the silicon bulk. Aluminum and boron, if the Al paste contains B additives, can thereby establish a p<sup>+</sup>-doped Si region below the LFC. This is desirable for a low contact resistance and reduced carrier recombination because of the formed local back surface field.

Improving, and therefore characterizing such local rear contact properties plays an important role to increase efficiency of silicon PERC solar cells. For this purpose various methods can be used for microscopic characterization of the contacts. Raman spectroscopy is in this context a method to measure p<sup>+</sup>-doping densities with high spatial resolution and less complexity compared to other techniques as for example secondary ion mass spectrometry (SIMS).

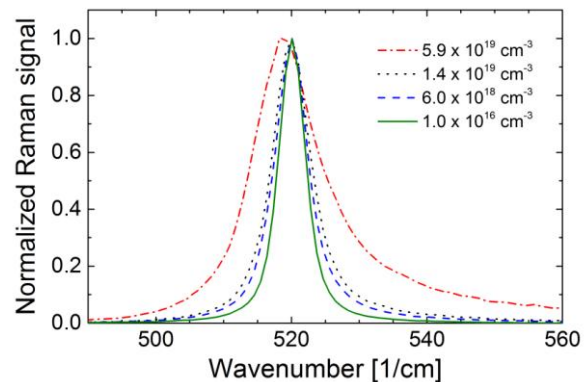
Applied to full area Al-alloyed rear layers of screen-printed Si solar cells, doping concentration measurement by Raman spectroscopy was already successfully demonstrated [4]. In this work, for the first time, Raman spectroscopy is investigated with regard to perform spatially resolved measurements of the highly doped p<sup>+</sup> layer below the LFCs. This application can therefore be a useful for the microscopic understanding and optimization of the LFC process parameters.

### 2 EXPERIMENTAL AND RESULTS

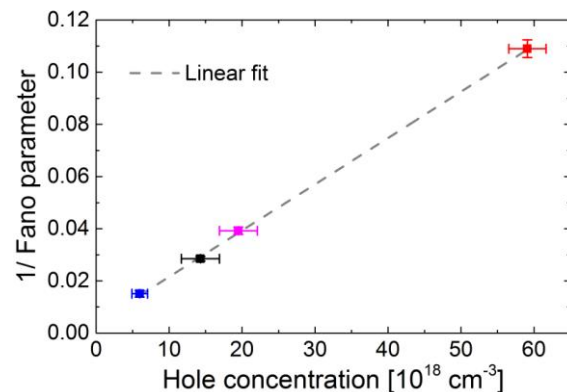
#### 2.1 Measurement technique

Raman measurements are performed with a commercial WITec alpha300 confocal Raman microscope. Measuring the back-scattered spectrum of Si results in a characteristic Raman-peak at wavenumber ~520 cm<sup>-1</sup> relative to the excitation. The shape of this peak changes with doping density (see Fig. 1). Instead of the Lorentzian distribution for undoped Si, the peak shape for highly doped Si is described by the Fano distribution with the Fano parameter  $q$  [4, 5, 6].  $1/q$

characterizes the peak asymmetry and is proportional to the free hole concentration.



**Figure 1:** Raman measurements of homogeneously B doped p-Si wafers showing the change in the shape of the peak with variation of doping density.



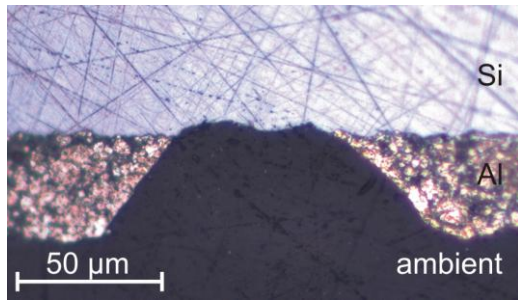
**Figure 2:** Fano evaluation of Raman measurements correlated to the hole concentration measured by ECV. Different highly B doped p-Si wafers (colors correspond to the curves in Fig. 1) and an alloyed Si sample (magenta, 2·10<sup>19</sup> cm<sup>-3</sup>) established by screen-printed paste containing Al and B are used.

To get absolute values of doping concentration, the calibration is performed by electrochemical capacitance-voltage (ECV) measurements of highly B doped Si wafers or full area Al-alloyed Si samples (see Fig. 2).

## 2.2 Sample preparation

To investigate the application of Raman spectroscopy to LFCs, NaOH etched Cz-Si samples (B doping density  $\sim 1 \cdot 10^{16} \text{ cm}^{-3}$ ) are prepared with a passivation layer of PECVD  $\text{SiN}_x\text{:H}$  and a screen-printed Al layer. A commercially available Al paste is used for this experiment. Many of these Al pastes also contain B to allow higher doping densities in the formed  $p^+$  region due to a higher solubility of B in Si compared to Al in Si. The higher doping thereby improves the surface passivation effect of the formed high-low junction below the LFC.

The samples are fired in a belt-furnace to form a laterally conducting Al layer. The  $\text{SiN}_x\text{:H}$  acts at the same time as a protection layer preventing contact formation between Al and Si. Then the LFCs are formed using a 1064 nm ns laser (Rofin Powerline 100D). Fig. 3 shows an optical microscope image of a LFC cross-section.



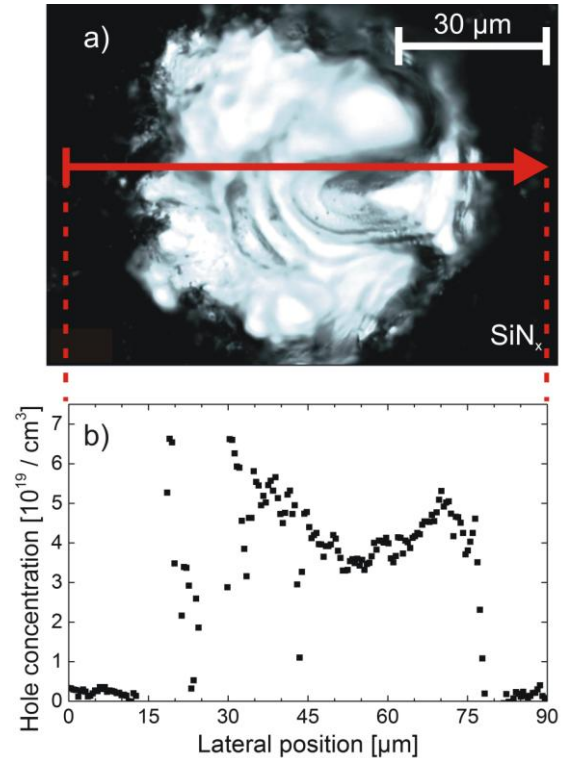
**Figure 3:** Optical microscope image of a polished contact cross-section after LFC process using screen-printed Al. The Al layer is completely ablated in the center so the actual contact is assumed to be located at the boundary region of the contact where Al is remaining.

## 2.3 Measurement and evaluation

For the Raman measurements the Al layer is etched-off in HCl solution. An excitation laser wavelength of 488 nm is used to get a signal from near the surface (excitation depth is  $\sim 0.8 \mu\text{m}$ ). The laser spot size is in the  $\mu\text{m}$  range and the automatic sample positioning stage allows mappings of specific areas as for example a high resolution line scan through one LFC as shown in Fig. 4a.

For data evaluation the Fano distribution is fitted to the (offset corrected and normalized) Si-Raman-peak of the spectrum of each measured point of the line scan. Then,  $1/q$  is correlated to the corresponding doping density from calibration via the ECV method resulting in a spatial distribution of the hole concentration (see Fig. 4b). The step in doping concentration at 18 and 78  $\mu\text{m}$  between the lowly B doped bulk Si and the highly doped LFC area is clearly recognizable. The determined values of the bulk Si are not considered reasonable because the well known bulk doping ( $\sim 1 \cdot 10^{16} \text{ cm}^{-3}$ ) is obviously far smaller and thus the determined values of around  $1 \cdot 10^{18} \text{ cm}^{-3}$  represent the detection limit for the used measurement technique and evaluation method. Furthermore, extrapolation over two orders of magnitude from the range of the ECV calibration data is not considered reliable.

It can be seen that the local hole concentration in the LFC region is increased up to values above  $6 \cdot 10^{19} \text{ cm}^{-3}$ . This value is well above the solubility limit of Al in Si, indicating that the used Al paste possibly contains B. In addition this Al concentration is higher than values of full area alloyed samples, perhaps caused by the different temperature profile of the laser process compared to the conventional contact firing in an infrared belt furnace. Another explanation could be that a laser-induced damage affects the measurement, leading to this very high value.



**Figure 4:** (a) Optical microscope image of a LFC after etching-off the Al layer with HCl. The dark surrounding is the remaining  $\text{SiN}_x\text{:H}$ -layer. The red arrow marks the Raman line scan. (b) Spatial distribution of the resulting hole concentration determined by Raman spectroscopy.

Furthermore, the LFC in this example shows a non-uniform doping distribution with lower hole concentration in the center of the contact area. This is perhaps caused by a non-uniform laser intensity profile used for LFC formation or inhomogeneities in the screen-printed Al layer thickness.

## 3 CONCLUSIONS

It could be demonstrated that Raman spectroscopy is applicable to the microscopic characterization of LFCs. The asymmetry of the Si-Raman-peak can be used to perform spatially resolved measurements of the Al doped  $p^+$  region below the contact.

In a line scan through a LFC, the step in doping concentration between the lowly B doped bulk Si and the highly doped LFC area can clearly be seen with high local hole concentrations in the range of  $10^{19} \text{ cm}^{-3}$  in the LFC region.

#### 4 ACKNOWLEDGEMENTS

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