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Enabling stress determination on alkaline textured silicon using Raman spectroscopy

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Abstract

Confocal micro-Raman spectroscopy allows for spatially resolved measurements of the phonon energy in silicon, which is correlated to mechanical stress. Mechanical stress is a tensorial quantity. For the confocal measurement geometry and certain crystal orientations approximations have been derived in the past which correlate the shift of the Raman frequency to a scalar stress value. For optimization of mono-crystalline solar cell manufacturing steps the determination of induced mechanical stress from the top view perspective is desirable. However, this method is so far restricted to planar wafers or cross sections. we find that the anti-reflection surface texture strongly affects the measurement result. To enable quantitative stress determination of alkaline textured silicon a suited measurement procedure is investigated using 3-point bended solar cell segments. Preceding elasticity test revealed Young's module and allowed a prediction of maximum stress values for any bending radius. We propose a measurement procedure which yields an observable shift of the Raman frequency proportional to the induced stress. We state the requirements for determination of a calibration factor to quantify stress on any alkaline textured solar cell. Adapting the conversion factors allows calibrated measurements for textures with different average pyramid heights. By varying the numerical aperture and the focus setting even changes of the induced stress within the texture pyramids are resolved.

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Keywords: Solar Cells; Surface texture; Confocal Microscopy; Raman Spectroscopy; Mechanical Stress

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1. Introduction

Residual mechanical stress harms the lifetime of silicon solar cells. Stress induced while solar cell manufacturing can cause cracks or detachment of contacts and interconnects [1, 2]. For the optimization of processing steps that likely induce stress, such as front side metallization, soldering or lamination, measuring the induced stress is desirable [3]. Confocal Raman spectroscopy proofed to be a suitable method for analyzing local stress [4–6]. The Raman frequency quantifies the energy difference of photons before and after inelastic scattering. For crystalline materials this frequency corresponds to the energy of the phonon absorbed or emitted in the scattering process. Mechanical stress changes the phonon energy and causes a corresponding shift in the Raman frequency [7]. A priori the Raman signal is dependent on crystal orientation and can be represented by a tensor. In a confocal experimental set up the signal can be approximated by a scalar value which allows introducing calibration factors to convert shifts of the Raman frequency to magnitude of stress. For different oriented planar surfaces such calibration factors have been published [8, 9]. For non-destructive measurements during solar cell processing the stress distribution needs to be determined from the top view perspective. Mono crystalline solar cells usually feature an alkaline textured surface to increase plight absorption. For stress determination on pyramid textured silicon, so far neither a calibration factor, nor a satisfying measurement technique was proposed. As many examples show, there is a straight-forward way to determine the calibration factor [8]: Measuring the Raman shift for varying defined external loads and comparing it to calculated stress distributions. In this study a 3 point bending test is chosen, since it represents a well-defined experimental situation which can be described analytically. On the basis of this model possibilities and constraints for calibrated Raman-measurements from alkaline textured surfaces are examined.

2. Measurement set-up and 3-point bending

All examinations were done on alkaline textured mono crystalline cz solar cells. Texture solar cells are cut into segments of 1 x 8 cm². The elastic parameters of all used wafer and solar cell samples were determined using a Zwick material testing machine. By simultaneous measurement of deflection s and applied force F Young's modulum E is calculated considering the distance of the bending blocks l, the width b and the thickness d of the bended sample according to equation (1) that can be found in any standard work of elastic theory [10]. For the Raman investigation we calculated the expected maximum stress at the vertex by using the bending radius r. As illustrated in Figure 1, r was evaluated using a photograph of the 3 point bending set up and fitting the coordinates of the cross-section with a circular function. In this way the maximum tensile stress in the bending vertex could be determined using equation (2). This way proofed to be more precise (relative error of 3%) than the measurement of the deflection.

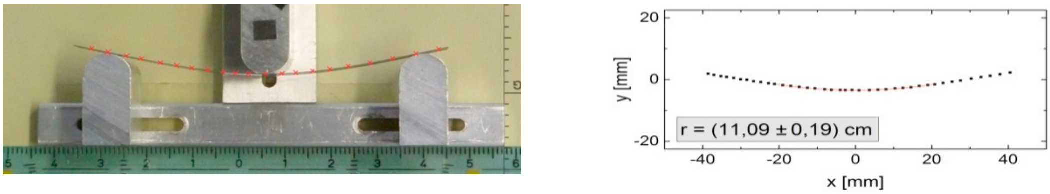

Fig. 1. The bending radius is determined by extracting the cross-section coordinates and fitting the bow at the vertex with a circular function.

$$E = \frac{F \cdot l^3}{d^3 \cdot b \cdot s} \tag{1}$$

$$\sigma_{max} = \frac{E \cdot d}{2\,r} \tag{2}$$

The Raman measurements are performed using a 532 nm excitation laser (penetration depth in silicon ~1 µm) and a confocal laser microscope (set up described in [5]). The spot size was about 0.5 µm and the laser power was set to 1 mW. The 3 point tester was constructed in a way that it allowed Raman examination from the top- and cross-