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Loss analysis for laser separated solar cells

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Abstract

Half-cell modules are promising candidates for new innovative module designs as they offer major advantages. Modified connection schemes reduce the serial resistance losses yielding a higher overall module performance. The reduced size of the cells allows a more flexible module design that is needed for special applications such as implementations on curved surface. Furthermore, a better performance under partial shading can be achieved. However, these advantages lead to a benefit only if the losses induced by the cell separation process are negligible. In this work, we study the different sources of power reduction, i.e. increased shunting and recombination, for mono-crystalline and multi-crystalline silicon solar cells separated using different laser process parameters. It is shown that recombination plays the major role for an optimized laser separation process. Additionally we identify the laser scribing process as the major source of losses in comparison to the mechanical breaking.

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Keywords: laser; solar cells; loss analysis; electrical characterization

1. Introduction and motivation

It is well known that the series resistance losses of a PV-module can be reduced by implementing half-cells instead of full cells. While the series resistance contribution of the individual cells remains unchanged the losses in the connectors are reduced [1, 2, 3]. This can lead to an increased module performance of about $1\%_{rel} - 3\%_{rel}$. However, the cell separation process induces an additional process step accompanied by additional costs. Hence, half-cell modules will become a competitive alternative only if the cell separation process is performed such that the additionally induced electrical cell losses and mechanical damages are minimized [4].

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There are several cell-splitting technologies which are applicable to separate a full-cell into two half-cells. Among those, the laser scribing with subsequent mechanical breaking of the cells is rather cost efficient and results in small and controllable edge damages. Splitting a full-cell into half-cells leads to two additional sources of electrical cell losses. First, additional shunts along the new edge might be induced due to the laser treatment. These shunts are visible in the current-voltage characteristic as a decreased parallel resistance. Alternatively, lock-in-thermography can be employed to localize these shunts. Second, the additional surface of the new edge might lead to an increased carrier recombination. This is reflected as a change in the second saturation current, i.e. the J_{02} recombination contribution in the two diode model.

In this work, a number of batches of multi-Si and mono-Si solar cells has been prepared and separated into half-cells using laser scribing and mechanical breaking. The cells have been electrically characterized before the laser process, after the laser process and after the final cell separation. The cell parameters of the two-diode model that have been extracted from the current-voltage data indicate the quantitative contribution of the two major loss sources. We show that for an optimized laser separation process, it is not the shunting but the recombination that leads to the major losses. Furthermore, it is shown that the relative change in efficiency that is caused by the cell separation is similar for mono-crystalline cells and multi-crystalline cells. Finally, our results indicate that the laser scribing imposes a larger damage to the cell than the breaking. Therefore, the optimization of the laser process is a crucial step in the development of an industrial half-cell process.

2. Sample preparation and measurement approach

In our first experiment, we have compared two different cell types: multi-crystalline silicon solar cells and mono-crystalline silicon solar cells. We have analyzed commercially available cells from a mass production process. Two batches of 20 cells each have been selected for each cell type. Each of these batches has then been processed with an optimized laser process such that the damage due to the laser is minimal. On the other hand, the laser scribing has to be deep enough to ensure a clean breakage in the subsequent mechanical separation. For all experiments we used pulsed laser irradiation with a wavelength of 532 nm and pulse length of 10 ns. The pulse energy was about 230 µJ. Optimal results were obtained with a scribing speed of 15 mm/s. Scribing was done twice to reach the necessary scribe depth of about one third of the cell thickness.

All cells have been electrically characterized on a solar simulator before and after the cell separation. The cells were electrically contacted using 48 current pins and 3 voltage pins. The current-voltage-curves where analyzed and the two-diode-model parameters extracted. The focus of this first experiment has been on the identification of the major loss mechanism, i.e. decreasing R_p or increasing J_{02}, and on the comparison of mono- and multi-crystalline silicon cells. While the shunt resistance R_p has been obtained from the slope of the dark-I-V-curve at zero voltage the loss current J_{02} is determined by analyzing the I_{sc}-V_{oc}-curve.

Fig. 1: Full cell before laser scribing (left), full cell after laser scribing and before breaking (middle), and two half cells positioned on the measurement stage (right).

In our second experiment, the two individual steps of the cell separation, i.e. laser scribing and mechanical breaking, were investigated in more detail. Two batches of five solar cells have been prepared. The first batch has been subject to the cell separation. While leaving laser wavelength, pulse duration, and energy unchanged a modified