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ScienceDirect
Energy Procedia 55 (2014) 469 – 477
Energy Procedia

4th International Conference on Silicon Photovoltaics, SiliconPV 2014

Cracks in solar cell metallization leading to module power loss under mechanical loads

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Abstract

We investigate the mechanisms leading to electrically insulated cell parts in a photovoltaic module under mechanical load. For this we measure the resistances across a crack in a laminated solar cell during bending that is typical in the field. The cracks in the solar cell are detected with electroluminescence imaging. The resistance over the aluminum paste increases continuously by negligible 30 mΩ whereas the front finger resistance increases by 15.4 kΩ stepwise. This difference is the result of the higher ductility of the aluminum paste in comparison to the front finger metallization. We associate the steps in the front finger resistance measurement to breakage of single fingers with an equivalent circuit model. Furthermore we found that a silicon crack widths lower 2 µm has no influence on the resistances. Crack widths higher than 7 µm leads to a complete front finger interruption. We determine that the specific resistance of such a crack causes nearly 100% of the power loss, which is caused by a completely electrically insulating crack in a photovoltaic module.

Peer-review under responsibility of the scientific committee of the SiliconPV 2014 conference

Keywords: metallization; power loss; mechanical loads; crack width

1. Introduction

During their lifetime, photovoltaic (PV) modules are frequently exposed to mechanical loads like transport shocks, transport vibrations [1], installation loads [2], wind and snow loads. Some of these mechanical loads lead to visual defects in the module glass or the frame, but most of the damage is due to cracks in the silicon wafer of the

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Peer-review under responsibility of the scientific committee of the SiliconPV 2014 conference
doi:10.1016/j.egypro.2014.08.011

solar cells which are not visible to the human eye. Cracks in silicon wafer material of the solar cells typically lead to only 0 % to 2.5 % power loss in standard PV modules with 60 cells [3] as long as no cell part is insulated from the bus bar by the crack. This change of power is within the uncertainty of a power measurement and therefore the damage is often not detected. However, after 15 years in the field, cells within PV modules show many insulated parts as a result of cell cracks. These cell cracks, in combination with Ethylene-vinyl acetate (EVA) browning and delamination, lead to a power loss of up to 20 % in a study by Schulze et al. with more than 250 PV modules [4]. Thus the cracks in the silicon wafer proceed to the cell metallization and insulate cell parts from the bus bar. The question is, which main processes cause the insulation in the cell metallization. The knowledge of these processes would help to assess and avoid the power loss due to cell cracks. In this work we analyze the impact of repeated mechanical loading (cycling) - comparable to wind and snow loads in the field - to the cell metallization in a mini PV module on a microscopic scale.

2. Measurements

2.1. Setup

Fig. 1 (a) shows a sketch of the 3 line bending (3LB) setup which we use to stress our mini laminate. The center positions of the bearing rolls have a distance of 9 cm and all rolls have a diameter of 1 cm. Our mini laminate has an area of 2×10 cm^2 and a 2.9 mm thick toughened float glass, 0.84 mm thick EVA double layer and 0.3 mm thick back sheet, with a 2×6.4 cm^2 part of a standard screen printed solar cell (~ 0.19 mm multi crystalline silicon and ~ 0.05 mm aluminum paste) embedded in the EVA, shown in Fig. 1 (b). This cell part consists of two 2 cm long bus bars and 9 silver fingers on the front side and full area aluminum paste on the rear side with the exception of two silver pads. In this study, we investigate the influence of cracks that form in the metal pastes, as a result of cracking in the silicon material, and we do not consider the origin of the silicon cracks. Therefore, we measure only the electrical resistance of the metal pastes following mechanical deformation. To produce a crack in the silicon material we lower the mechanical strength of the silicon by a laser perforation between the front fingers without damaging the metal pastes (1.7 mm long, 40 µm width and ~ 160 µm depth). This corresponds to possible preliminary damage of a solar cell. To additionally increase the stress on the solar cell we apply a 2 mm long and wide part of an interconnector between a front finger close to the edge and the glass, which corresponds to a bus bar. We contact each bus bar and each silver pad with a single copper ribbon (interconnector) by soldering. We guide the interconnectors through the back sheet of the mini laminate at a distance of ~ 0.3 cm from the 2 cm long edges. During bending roll displacement (d_{Br}) we measure the resistance of the front (total uncertainty = ±20 mΩ) and rear (±5 mΩ) side respectively with a four point resistance measurement (4PP) as shown in Fig. 1 (a) with digital multimeters 195A from Keithley (~ 1.7 mA measurement current). Our mini laminate has more than 14 cm of interconnectors for each contact outside the laminate. We correct the measured resistance values for the circuit fractions, which are outside the mini laminate and sum up all measurement uncertainties to calculate the total uncertainty (from Keithley multimeters and resistance offset measurements from circuit fractions outside of the mini laminate).