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An electric model of cracked solar cells accounting for distributed damage caused by crack interaction

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Abstract

Electric models based on a distributed series resistance along the grid line can be used to predict the current through the thickness of the Silicon solar cell, as well as the current and the voltage along the grid line. In the presence of a crack intersecting a finger, a localized electrical resistance dependent on the crack opening has to be introduced in that intersection point. In the present study, a refinement of these electric models is proposed by introducing a sheet resistance dependent on the amount of damage induced by cracks in the surrounding material. The proposed model is successfully validated in reference to experimental data on mono-crystalline Silicon solar cells with cracks artificially created by Vickers indentation, providing an insight into the electric degradation mechanisms caused by crack interaction phenomena.

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Keywords: One dimenstional electric model; Distributed damag; Vickers indentation; Cracks; Mono-crystalline Silicon

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1. Introduction

In the last few years, the durability of photovoltaic (PV) modules emerged as an important issue to be debated by the scientific community [1-3]. International organizations and agencies are interested in the interpretation of laboratory and field degradation data of PV modules coming from different producers and installed in different climate zones [4]. For this reason, the understanding of the possible sources of losses in the energy production and the quantification of the degradation of a PV system are fundamental issues to establish appropriate business plans accounting for maintenance costs considering warranties when the underperformance of PV modules are above the producers' specifics. In addition to this, the durability issue is expected to become even more relevant in the next few years due to the rapid development of building integrated PV systems. In this work, we focus our attention on the damage caused by cracks in monocrystalline Silicon solar cells. The effects of cracks on solar cells are manifold,

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including a linear decreasing of the short circuit current by increasing the inactive cell area [1,5,6] and an increase in the series resistance of the cell [2,7]. Potentially, if a crack crossing a finger (grid line) is sufficiently wide, an interruption of the electric flow to the busbars, or from the busbar in case of the electroluminescence (EL) test, may occur. In the present contribution, the one-dimensional model for the current distribution along a grid line in [8] is further generalized by considering not only the effect of cracks crossing the grid line as in [9], but also a distributed damaged region around the cracks. This is achieved by introducing a distributed resistance depending on the amount damage induced by cracks in the surrounding material. Experimental results are proposed to identify the model parameters and assess the important role of crack interaction on the introduced novel electric parameters.

2. Effect of cracks on the material proprieties of monocrystalline Silicon

Vickers micro-indentation is a suitable methodology to propagate cracks in Silicon solar cells that are similar to those induced by impacts [10, 11]. The typical shape of a Vickers indenter is a square-base diamond pyramid. The angle between opposite faces of the pyramid is 136°. This test is also called *diamond-pyramid hardness* (DPH) test, due to the shape of the indenter. The Vickers hardness provides a continuous scale of hardness, for a given load, from very soft metals with a DPH of 5 to extremely hard materials with a DPH of 1500 and, due to the geometric similarity of impressions made by the pyramid indenter, no matter their size, the DPH is independent of load [12].

After the insertion of cracks with this technique, nano-indentation tests have been performed in [11] to measure the material hardness in the surrounding region, showing a dependency of this material property on the distance from the main channel micro-crack, see the dots in Fig. 1, where H_{Si} denotes the hardness of the undamaged Silicon. This is the result of the pile up of dislocations in the surrounding material, of higher amplitude in the material region near the channel crack located at x=0. This experimental trend can be well fitted by an exponential decay of the type:

$$\frac{H}{H_{\mathrm{Si}}} = \frac{1}{\exp(x)^{a/H_{\min}} + 1} \tag{1}$$

where H_{Si}=10.5 GPa, $H_{\min}$=7.1 GPa, and a=0.4, see the solid line in Fig. 1.

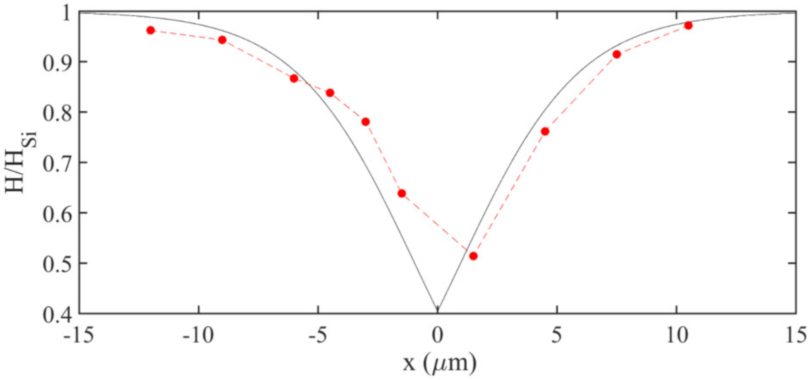

Fig. 1. Profile of the hardness near the channel crack located at x=0 (experimental data from [11], fitted by an exponential decay in Eq. (1) by the present authors, shown with solid line).

3. A one-dimensional electric model for monocrystalline Silicon cells with distributed damage

Under the assumption of an ideal semiconductor, which has homogeneous properties everywhere in the plane of the solar cell, the two-diode electric model proposed in [8] has been generalized in [9, 13] by considering a localized crack resistance dependent on crack opening. In this section, that electric model is further generalized in case of distributed damage in the Silicon solar cell surrounding the main channel cracks. The improved electric model