

Simulation and test of metastability of  
a-Si/ $\mu$ c-Si solar modules under outdoor  
conditions

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# Abstract

This dissertation presents the work for analyzing outdoor-characterization of tandem solar modules of amorphous silicon (a-Si) and microcrystalline silicon ( $\mu$ c-Si) solar modules. Due to the Staebler Wronski effect (light-induced degradation and its temperature dependent annealing) the observation, monitoring and the simulation of the electrical performance pose challenges that have not been solved yet: "For many thin-film modules, no long-term data are available." (Status 2016/10/14) [1, p. 43]. And if long term data are available, the modules are not produced anymore. This work improves the possibilities for the simulation of long-term data with the diode model under different climatic regions.

For simulation of the metastability effects of thin film solar cells it is necessary to determine every parameter of the diode model under several climate environmental conditions. By determination of the variation of every parameter, it is possible to transmit this for other climatic regions. The most important parameters are the serial resistance, the parallel resistance, the photo current, the diode (diode factor and saturation current) and the recombination current. The solar modules observed under outdoor conditions are a

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single-junction amorphous module, an amorphous/microcrystalline tandem module and a monocrystalline module for comparison reasons.

The saturation current represents the behavior of the diode. This is why it can be applied to the dangling bonds caused by the Staebler-Wronski effect. The dangling bonds behavior is analyzed and transposed to other climatic conditions, so that this simulation gives predictions about the performance and metastability of a-Si and  $\mu$ c-Si solar cells under different climatic conditions.

For this simulation the photo current and the spectral response need to be determined under outdoor condition. In this work a method is presented, how it can be calculated without direct measurements by measured temperature and irradiation data and the parameters of the diode model.

# Zusammenfassung

Diese Dissertation stellt die Arbeit zur Analyse von im Freien gemessenen Tandem-Solarmodulen aus amorphen (a-Si) und mikrokristallinen Solarzellen vor. Durch den Staebler-Wronski-Effekt (lichtinduzierte Degradation und temperaturabhängige Ausheilung) stellen Beobachtung, Überwachung und Simulation der elektrischen Performance eine Herausforderung dar, die noch nicht gelöst ist: "Für viele Dünnschichtmodule sind keine Langzeitdaten verfügbar." (Stand 2016/10/14) [1, S. 43]. Sobald die Langzeitdaten verfügbar sind, werden diese Module nicht mehr erhältlich. Diese Arbeit verbessert die Möglichkeiten zur Simulation von Langzeitdaten für das Diodenmodell in verschiedenen Klimazonen. Für die Simulation der Metastabilitätseffekte von Dünnschicht-Solarzellen ist es notwendig, jeden Parameter des Diodenmodells unter mehreren Umgebungsvariablen zu bestimmen. Durch die Bestimmung der Variation jedes Parameters ist es möglich, diese für andere Klimazonen zu übertragen. Die wichtigsten Parameter sind der Serienwiderstand, Parallelwiderstand, der Photostrom, die Diode (Diodenfaktor und Sättigungsstrom) und der Rekombinationsstrom. Die untersuchten Solarmodule unter realen Außenbedingungen sind ein amorphes single-junction Silizium

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Solarmodul, ein amorphes / mikrokristallines Tandem-Solarmodul und ein monokristallines Solarmodul aus Vergleichsgründen.

Der Sättigungsstrom repräsentiert das Verhalten der Diode. Deshalb kann dieser übertragen werden auf die durch den Staebler-Wronski-Effekt verursachten ungesättigten elektronische Bindungen. Das Verhalten der ungesättigten Elektronen-Bindungen wird analysiert und auf andere klimatische Bedingungen übertragen, so dass diese Simulation Aussagen über die Leistungsfähigkeit und als Funktion der Zeit von a-Si- und  $\mu$ -c-Si-Solarzellen unter verschiedenen klimatischen Bedingungen geben kann. Für diese Simulation müssen der Photostrom und das Spektralverhalten unter Außenbedingungen bestimmt werden. In dieser Arbeit wird zusätzlich ein Verfahren vorgestellt, wie dieses ohne direkte Messungen berechnet werden kann aus den gemessenen Temperatur- und Einstrahlungsdaten sowie mit Hilfe der Parameter des Dioden-Ersatzschaltbildes.

# Motivation

The light-induced degradation at its temperature-dependent recovery by annealing [2] in amorphous and microcrystalline silicon solar cells is determined through long (up to 1000 hours) measurements at constant 50°C cell temperature [3].

To verify the samples for different climatic regions under laboratory conditions, the measurements need to be repeated for other temperatures [4]. The consequent efficiency could change by up to 5% depending on the operating and degradation temperatures [5]. This condition could lead for tandem solar cells to current mismatching in the cells [6]. Given this condition, identifying the degradations of different silicon-based solar cells inside of micromorph solar modules is important for examining and simulating the cells [7]. Doing so will make it possible to transfer this metastability to different climatic regions and to optimize the solar cells, also for other tandem solar cell concepts like Perovskite /c-Si solar cells this is helpful [8].