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Thin-film silicon solar cell and module analysis by electroluminescence

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Abstract

Electroluminescence is a fast and reliable method for defect characterization of thin-film silicon large area modules. At forward bias, the injected carriers recombine via defect states in the p-i-n structure but only the radiating portion is detected by a means of a detector array. For these investigations, it is mainly assumed that the EL-signal is proportional to the local current density (J). We will present a detailed analysis of thin-film silicon modules and the circumstances will be discussed under which the simple approach with the EL-signal proportional to the current density is not valid.

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Keywords: electroluminescence; solar cell; thin-film silicon

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1. Introduction

In recent years large area inspection tools such as electroluminescence (EL) and infrared lock-in thermography have become increasingly important for module analysis and defect detection [1-3]. In particular electroluminescence is used for in-line inspection and quality control, due to the fast response in comparison to infrared lock-in thermography. EL spectroscopy is an established technology for in-line micro crack detection of c-Si cells and a

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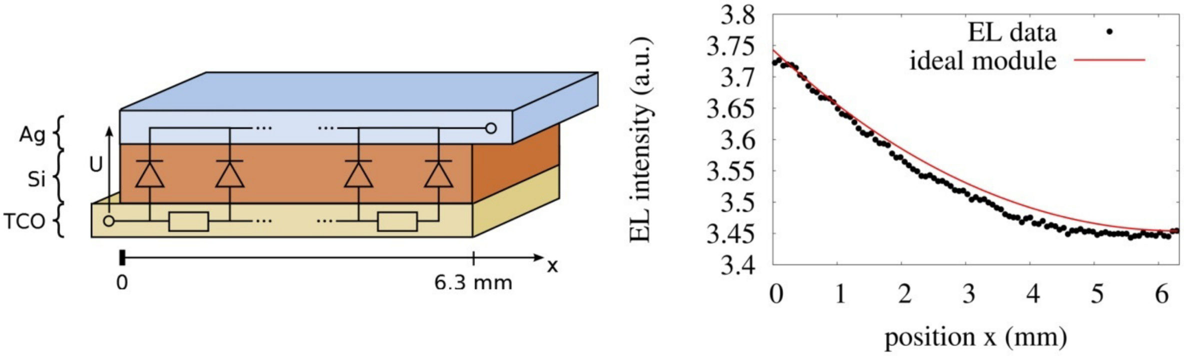

Fig. 1. Sketch of an equivalent circuit of a cell stripe within a series connected thin-film module (left) and comparison of a measured (EL-data) and simulated (ideal module) EL-signal (right) based on the equivalent circuit.

detailed understanding of derived parameters as e.g. local lifetime and local series resistance already exists [4,5]. In the area of thin-film silicon photovoltaic the application of EL is mainly limited to error recognition of short circuits caused by laser scribing errors of the integrated series connection or deposition faults. At forward bias, injected electron and hole pairs at the contacts recombine mainly in the i-layer of the p-i-n structure but only the radiating portion yields to the EL-signal. For these investigations, it is mainly assumed that the EL-signal is proportional to the local current density (J). However, also the local dependent lifetime of carriers generated within a thin-film silicon module can have a major influence on the detected EL signal. In this work, we will discuss circumstances under which the assumption of a local homogeneous lifetime within a cell stripe of a module is not valid. Based on a detailed analysis a simple measurement procedure is proposed enabling the identification of local defects introduced by undesired inclusions.

2. Results and discussion

We have investigated single amorphous and microcrystalline silicon small area modules and a-Si:H/μc-Si:H tandem cell structures both deposited by large area equipment (>1m^2) and have classified different kinds of defects originating from locally based short circuits, laser scribing error and coating faults. A general finding of thin-film silicon modules with a metal back contact is an inhomogeneous EL-signal within a cell stripe as shown Fig. 1 (right). At the positive terminal side ($x = 0$) a higher intensity of the EL-signal is observed in comparison to the negative terminal side. This finding can be explained by the influence of the TCO resistance. Based on a simple equivalent circuit the local current density within a cell stripe of a thin-film silicon module can be calculated (Fig. 1, left side). The model describes the active areas by an infinite small region consisting of a diode and a resistance. The resistance takes into account the ohmic losses of the transparent conductive oxide (TCO). The thin film diode is characterized by the diode quality factor n, which lies in the range of 1.4-1.7 and the reverse bias saturation current. For simplicity the ohmic resistance of the metal back contact is neglected, since the conductivity of the Ag back contact is several orders of magnitude higher than the conductivity of the TCO. Assuming that the EL signal of an ideal (laterally homogeneous) thin-film silicon module is proportional to the local current density, the measured EL signal can reproduced by the simulations (Fig.1, right side) with a good agreement. The ohmic losses of the TCO results in a voltage drop at the infinite small regions. Consequently, the voltage at the thin-film diode decreases with increasing position (x) and the dark current density of the local diode decreases. With decreasing TCO conductivity or increasing total current density the negative slope of the curve (EL intensity versus position) is more pronounced.

However for real devices the signal can be affected significantly by a laterally inhomogeneous density of states (DOS) in the amorphous silicon based layers. One class of defects with lateral inhomogeneous lifetime distribution in a-Si:H based devices shows a strong spectral dependence and leads to hot spots (Fig. 2). The bright local EL-signal (observed with a c-Si CCD) disappears when a cut off filter of 1.42 eV is used. On the other hand bright locally induced hot spots can be observed using no or a cut-on filter at 1.18 eV. Due to the different transmittance of