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Electroluminescence as characterization tool for polymer solar cells and modules

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Abstract

We show that laterally resolved luminescence detection is a highly versatile measurement technique for the characterization of polymer solar cells and modules. Besides lock-in thermography also luminescence imaging is highly suitable for quality control of processing steps, especially the control of homogeneous layer deposition and the proper lateral function of polymer solar cells and modules, by identification of local defects. Furthermore the application of luminescence imaging allows discrimination between active layer and organic/electrode-interface degradation in stability experiments. By correlation with photovoltaic parameters important conclusions can be drawn with respect to the specific degradation mechanism. For quantitative interpretation of such electroluminescence images, we propose an equivalent circuit model in which local solar cells are interconnected by resistors representing the sheet resistance of the transparent electrode. In combination with the laterally resolved measurement of electroluminescence, the application of this model allows calculation of local photovoltaic parameters and quantification of the lateral current and voltage distribution.

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1. Introduction

Laterally resolved luminescence detection with high-resolution cameras is a highly versatile method for solar cell characterization. Initially applied to silicon solar cells, luminescence imaging allows for

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monitoring of the lateral distribution of minority-charge-carrier lifetime or diffusion length [1,2] and quasi-external series resistance [3]. Also for polymer based thin film solar cells the usability of luminescence imaging is highly versatile [4,5,6]. The currently best developed material system for polymer solar cells consists of a semiconducting polymer:fullerene composite such as poly-(3-hexylthiophene) (P3HT) and substituted methanofullerenes like [6,6]-phenyl-C₆₁-butyric acid methyl ester (PCBM) [7]. During the last few years also considerable higher power conversion efficiencies, recently exceeding 8%, have been achieved [8,9,10]. However, the lifetime of such devices plays a key role for the market entry as commercial products [11,12]. Since organic materials are very frail to chemical reactions with the ambient environment [13], especially with water and oxygen [14], the lifetime of unsealed devices is limited and therefore hermetical sealing and intrinsically more stable materials are required. We have shown recently that luminescence imaging, especially the combination of electroluminescence and photoluminescence imaging (ELI and PLI) yields valuable information about the local performance and allows investigating the degradation of the photovoltaic devices [4,15]. The non-invasive nature of this method allows time-resolved measurements of one and the same device stressed under continuous aging. Furthermore with ELI the injection and thus the electrode-organic interface, whereas with PLI the integrity of the organic semiconductor is tested, allowing the discrimination between active layer photooxidation and degradation of the cathode and the electrode/organic-interface [15]. For the continuative market entry along with improved quality control during the production of polymer solar modules, fast methods for the detection of defects are needed. Luminescence imaging has the potential for fast laterally resolved characterization within a few seconds. For the quantitative interpretation of electroluminescence images, we propose a Micro-Diode-Model (MDM) that is corresponding to the solar cell architecture and includes description of a semitransparent electrode with limited electrical conductivity. Operation in the series resistance limited regime leads to voltage losses over the length of the solar cell, causing inhomogeneous electroluminescence patterns. Furthermore the electroluminescence emission can be used for calculation of the local current and voltage distribution, which allows e.g. characterization of the sheet resistance of the semitransparent electrode.

2. Experimental

We applied luminescence imaging to P3HT:PCBM bulk heterojunction solar cells, with the active layer sandwiched between poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate)/Indium Tin Oxide (PEDOT:PSS/ITO) and Aluminium electrodes (compare with Fig. 1a). Details of the device preparation are described elsewhere [7]. The method of luminescence imaging is based on the detection of luminescence radiation with a silicon charge-coupled-device (Si-CCD) camera as sketched in Fig. 1b. For electroluminescence imaging (ELI) a constant current at positive driving voltage was applied to the device under test. Thereby charge carriers were injected into the device resulting in a current flow of charges of both sign within the active layer, ultimately leading to radiative recombination with certain but small probability. For studying photoluminescence imaging (PLI) the devices were excited with a green solid-state diode emitting at 525 nm, leading to efficient photon absorption and exciton formation within the P3HT with subsequent radiative decay. To block the excitation light a cut-off filter was placed in front of the Si-CCD. Due to the efficient photoinduced charge transfer between P3HT and PCBM the photoluminescence was of low intensity as well. As the overall luminescence intensities are relatively small, the whole setup was placed into a light blocking housing.

For stability and degradation investigations, unsealed photovoltaic devices were aged in a controlled manner in a home-built stability setup that enables periodic in-situ IV-characterization. The stability setup consists of a high power illumination source (400W HQI-lamp), under which up to 40 solar cells can be placed. The solar cells were electrically connected to a computer-controlled source-measure-unit, and periodic IV-characterizations were sequentially performed on each solar cell by multiplexing.

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