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Optical coherence tomography (OCT) as a 3-dimensional imaging technique for non-destructive testing of roll-to-roll coated polymer solar cells

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ABSTRACT

We have recently demonstrated the first application of optical coherence tomography (OCT) as a 3-dimensional (3D) imaging technique to visualize the internal structure of complete multilayered polymer solar cell modules (Thrane et al., Solar Energy Materials & Solar Cells **97**, 181-185 (2012)). The 3D imaging of complete polymer solar cells prepared by roll-to-roll coating was carried out using a high-resolution 1322nm OCT system having a 4.5 microns axial resolution and a 12 microns lateral resolution. It was possible to image the 3-dimensional structure of the entire solar cell that comprise UV-barrier, barrier material, adhesive, substrate and active solar cell multilayer structure. In addition, it was found that the OCT technique could be readily employed to identify coating defects in the functional layers, making it a potential technique to enable process control by real-time adjustment to the production process.

Keywords: 3-dimensional imaging, polymer solar cells, optical coherence tomography, defect identification, non-destructive

1. INTRODUCTION

The polymer solar cell presents a potentially very low cost photovoltaic (PV) technology that can be prepared as thin films by coating and printing techniques [1,2]. The performance in terms of power conversion efficiency and stability has increased steadily to levels that begin to compete with other thin film PV technologies. Currently, record power conversion efficiencies in the 8-9.5% range [3] and lifetimes of many thousands of hours [4-6] have been claimed. For non-destructive testing of these polymer solar cells there is still a need for 3D imaging techniques that cover the macroscopic regime (from microns to millimeters). They would obviously become very useful in the context of manufacture and production of polymer solar cells as information can be collected and processed while performing the roll-to-roll coating and printing of the polymer solar cell thus enabling process control by real time adjustment to the process.

Here, we will present the results of our recent study where optical coherence tomography [7] was used as a 3-dimensional imaging technique for polymer solar cells, and describe how the layered structure can be analyzed and coating errors can be identified [8].

2. EXPERIMENTAL RESULTS

The polymer solar cell investigated in this study was prepared according to the well known ProcessOne [9] as a module having 16 serially connected solar cells with dimensions 15 x 225 mm each. The entire module had an active area of 360 cm^2. Briefly, the module was prepared on a 175 micron PET substrate carrying a patterned layer of indium tin oxide (ITO) that formed the transparent bottom electrode. On top of the ITO, the layers in the active stack were subsequently coated, i.e, zinc oxide (electron transport layer), P3HT-PCBM (active layer), PEDOT:PSS (hole transport layer and semitransparent electrode) and finally a silver grid as the back electrode. The PET substrate and the active solar cell stack are sandwiched between adhesive, barrier, and UV-protective layers (see Figure 1) [8].

We investigated a common coating defect in the PEDOT:PSS layer which is a result of local dewetting during coating and initial drying. This leads to printing of the silver fingers directly onto the P3HT-PCBM active layer which lead to a short circuit. The coating error was identified in an optical image and clearly seen in a light beam induced current (LBIC) image as a region where the current production is very low or totally absent (not shown here) [8].

The OCT system used in this study has previously been described in detail [10]. It is a mobile fiber-based, 4 kHz (A-scan rate) time-domain, real-time OCT system. The lateral resolution has been increased to 12 microns. Furthermore, the light source used is now a superluminescent diode with 1322-nm center wavelength, a power of 19 mW (ex fiber), and a 3 dB-bandwidth of 108 nm corresponding to an axial resolution of 7.1 microns in air. Assuming an average refractive index (RI) of 1.575 for the solar cell (RI for PET [11]), the axial resolution in the solar cell is 4.5 microns.

Figure 1 shows an OCT cross-sectional view of the layered structure of the polymer solar cell with UV-protective layer, barrier, adhesive, substrate, and solar cell stack. Figure 2 shows a 3D OCT rendering of the region of the coating defect. The silver fingers printed directly on the P3HT-PCBM active layer are clearly seen.

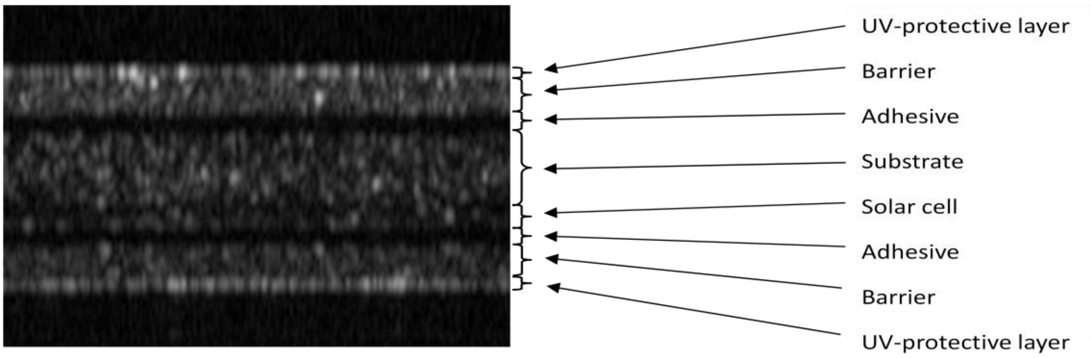

Figure 1: OCT cross-sectional view of the layered structure of the polymer solar cell with UV-protective layer, barrier, adhesive, substrate, and solar cell stack. The total thickness is 499 micrometer.

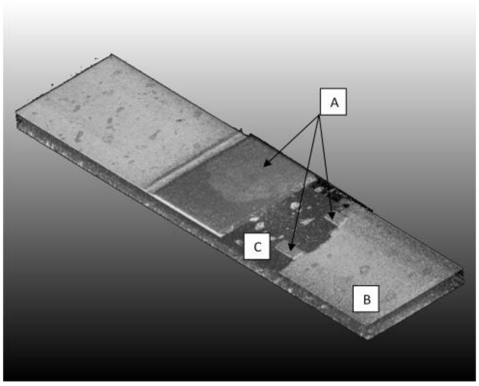

Figure 2: A 3D OCT rendering of the region of the coating defect. The scanned region is 2 mm wide and 10 mm long. A: silver, B: PEDOT:PSS, C: active layer.

3D OCT data may reveal spatial detail on defects such as micron sized particles that may be suspended in the device matrix. This could for instance reveal whether the particle impurity remains on the substrate (or is partially embedded in it), or it could allow one to conclude that the particle came from a particular processing step during preparation of one of the layers.

3. CONCLUSION

The OCT technique can be applied as a non-destructive technique to provide 3-dimensional information on the microscale of complete and encapsulated polymer solar cell modules. It was possible to rapidly extract cross-sections of entire modules comprising barrier layers, adhesive layers, substrate and electrodes, and in addition, OCT enabled the detection of a coating defect which was complemented by optical imaging and LBIC mapping.

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