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A round robin study of flexible large-area roll-to-roll processed polymer solar cell modules

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ABSTRACT

A round robin for the performance of roll-to-roll coated flexible large-area polymer solar-cell modules involving 18 different laboratories in Northern America, Europe and Middle East is presented. The study involved the performance measurement of the devices at one location (Risø DTU) followed by transportation to a participating laboratory for performance measurement and return to the starting location (Risø DTU) for re-measurement of the performance. It was found possible to package polymer solar-cell modules using a flexible plastic barrier material in such a manner that degradation of the

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devices played a relatively small role in the experiment that has taken place over 4 months. The method of transportation followed both air-mail and surface-mail paths.

1. Introduction

Polymer solar cells [1–3] are a relatively recent photovoltaic (PV) technology that is believed to convincingly address the problem of reducing manufacturing cost which as a result can be expected to make a dramatic improvement in the cost factors for PV-generated power. The main reason for this lies in the ability to manufacture polymer solar cells under much more humble conditions (low temperature, no vacuum) than traditional PV technologies with a relatively small investment in capital equipment. Low temperature, solution coating and fast processing on flexible plastic substrates should enable a very low manufacturing cost which has not been fully confirmed. One study has detailed the cost of processing and shown that low-cost manufacturing of polymer solar cells is possible but materials costs must be reduced significantly to reach ultimate cost goals of 20 cents per watt [4]. The power conversion efficiency has demonstrated a consistent increase over the past 10 years and currently in excess of 6% can be obtained [5] and the current NREL certified record is 6.4% for a Konarka single junction polymer solar cell. In order to be useful as a technology it should be possible to prepare the devices using the high-speed methods with both reasonable performance and stability [3]. Since each of the properties required for successful implementation of the technology has been demonstrated individually it may seem trivial to find a materials combination and device geometry where these properties are observed at the same time. However, it has proven rather difficult to unify this into a single device. In the traditional 1st and 2nd generation photovoltaics it has been customary for decades to share devices and perform studies known as round robins (RR) or inter-laboratory studies (ILS) [6–13]. Within the realm of polymer photovoltaics devices have rarely been shared and few examples exist where devices have been deliberately transported between laboratories [14,15]. The only well-documented examples include the certification of efficiency and measurement of record devices at a reference laboratory (e.g. NREL, AIST, Frauenhofer ISE) to support the claims of high performance [5,16]. The main reason for this can be ascribed to the relatively poor stability that polymer solar cells have exhibited to date. Degradation can at worst be so rapid that transportation would be impossible without complete degradation of the device [1]. This has made it difficult to compare results between laboratories and it has become customary not to think of sharing cells and measurements. An additional problem that has arisen is some inconsistencies in reported data that possibly could have been avoided if it had been possible to get a second opinion from one or more collegial laboratories. This has resulted in some debate [17–20]. The RR (or ILS) has traditionally been employed to serve the purpose of transporting the same reference devices and calibration equipment such that a very high level of agreement on measurement conditions and measured data is achieved. This was excellently demonstrated in the 1980s and 1990s by many laboratories [6–11]. RR and ILS can also be more humbly applied to test whether it is at all possible to share devices for a given technology.

In this study we show that it is possible to encapsulate flexible polymer solar-cell devices in such a way that RR and ILS are possible. We discuss some of the requirements to the polymer solar-cell device that will need to be fulfilled before RR and ILS can be performed with the high level of quality that is currently customary within the field of 1st and 2nd generation photovoltaics.

2. Experimental

2.1. Device preparation and handling

The devices were prepared following the method described in the literature except that full roll-to-roll processing was employed in all steps such that also the final silver electrode was printed using a roll-to-roll process [21]. Briefly, the device was prepared starting from a commercially available 130-μm-thick PET substrate with an overlayer of ITO having a nominal sheet resistivity of 60 Ω square^{-1}. The desired ITO pattern was developed by screen printing and UV curing an etch resist with the desired pattern followed by etching, stripping, washing and drying. A zinc oxide nanoparticle layer was then applied by a modified slot-die coating procedure [22] followed by deposition of P3HT-PCBM and PEDOT:PSS layers using the same method. The devices were completed by screen-printing silver paste. The layered architecture of the device was thus PET-ITO-ZnO-P3HT:PCBM-PEDOT:PSS-Ag paste. Single cells as well as 2, 3 and 8 serially connected devices were prepared. The modules with 8 serially connected devices were employed in this study. The devices were labelled according to the position they had on the roll. A photograph of the typical device is shown from the backside in Fig. 1.

2.2. Device encapsulation

After drying a 25-μm-thick PET protective layer was laminated on top of the active stack in the device. This layer served the purpose of protecting the active layer during handling. The thin PET had little barrier properties. The devices in this form were

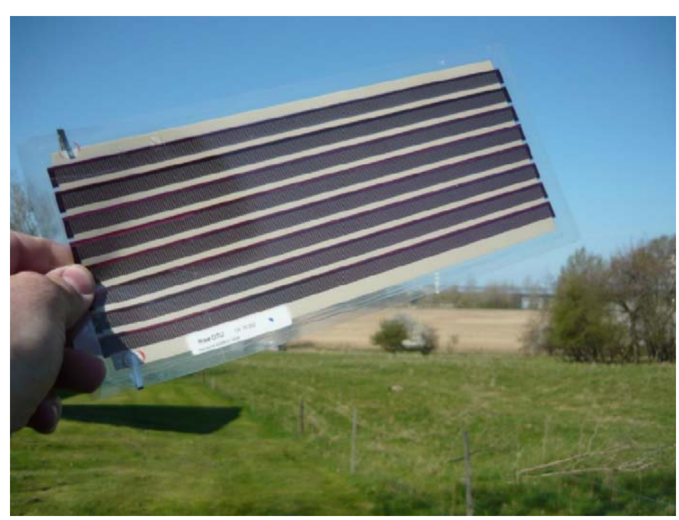

Fig. 1. The modules employed in this study as seen from the back side. The module comprises 8 serially connected devices.