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A setup for studying stability and degradation of polymer solar cells

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Abstract

A detailed description of a setup for studying ageing of polymer devices is presented. The system offers individual control of the environmental factors (oxygen, humidity, atmosphere, temperature and light intensity) causing the degradation of organic devices. The system was developed for accurate control of the conditions and data collection of photovoltaic (PV) parameters for organic solar cells during long-term testing. The atmosphere chamber can operate under vacuum conditions without temperature control. It is designed for operation at an internal gas pressure of around 1 atm. It is further equipped for isotopic labeling experiments of the internal atmosphere ($^{18}O_2$ and $H_2{}^{18}O$) such that degradation mechanisms can be studied using TOF-SIMS as a chemical probe. Experiments on both "accelerated" (by applying thermal stress to the devices) and "long-term" lifetime measurements of traditional organic bulk heterojunction solar cell devices have been realized while controlling the environmental conditions. As an example of use of the setup we determined the acceleration factor for standard bulk heterojunction devices based on ITO/PEDOT:PSS/P3HT-[60]PCBM/Al when operated under an ambient atmosphere and under an inert atmosphere at temperatures of 25, 43, 63 and 83 °C. Different values for the acceleration factor were found depending on the atmosphere used and further our results suggest that the acceleration factor may change in time as different degradation mechanisms may dominate at different times during the device life.

Keywords: Stability; Degradation; Accelerated testing; Multiple processes; Setup; Instrumentation

1. Introduction

The field of polymer solar cells is still in a state of rapid development and has been reviewed several times [1–8]. The efficiency has reached 5% for simple bulk heterojunction cells [9,10] and 6.5% for tandem cells [11], while theoretical predictions suggest that it should be possible to obtain 10% [12,13]. The short operational stability and lifetime still remain one of the key issues of polymer PVs [14]. Significant improvement of stability and increase of lifetimes up to scales that could comply with industrial standards are essential requirements for further progress and commercialization of organic solar cell devices.

The ageing phenomenon in the organic solar cells occurs due to the combined influence of environmental factors, such as light, temperature, oxygen, humidity and intrinsic factors such as the constituents of the device. A number of scenarios have been proposed to describe the degradation processes [15–26] mainly using TOF-SIMS [20–26]. As yet, however, there is no general rule as to what mechanisms take place for any given device disposition and each case must still be studied in detail and while some basic mechanisms have been identified the overall scheme still remains unclear. In order to produce devices with good stability, it is necessary to thoroughly understand the decay mechanisms taking place in the cells. The effect of each of the aforementioned environmental components must be understood and mapped in order to prevent or sufficiently slow down the processes that they result in. Therefore, it is essential to develop an efficient procedure for accurate stability measurements of organic solar cell devices, while controlling all the affecting parameters individually. Methods, standards and equipment for studying inorganic solar cells were developed in the mid-1980s along with standardized measurement procedures of power conversion efficiency through a massive series of publications and standards [27–37] that later have been adapted for power

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conversion efficiency measurements of organic solar cells [38–40]. From this point of view one may ask why there is any need for a description of an apparatus for doing essentially the same with the exception that the solar cell is a polymer or an organic-based device. To answer this question we point to the fact that polymer and organic PVs differ from the inorganic technologies in the way they break down as detailed in this issue [14]. Inorganic solar cells are nearly all intrinsically stable from a chemical point of view and the materials will withstand illumination under intense sunlight in the ambient atmosphere indefinitely. Organic and polymer materials do not have this ability and will degrade over time. From this point of view the degradation of PV devices based on inorganic and organic materials share only some of the mechanisms associated with degradation (i.e. mechanical, encapsulant, electrical connections) but they do not share the internal instability of the material that organics have. As a result organic solar cells require special techniques for studying degradation and stability [14,20–26].

Standard test conditions have been proposed for accurate indoor determination of the power conversion efficiency of organic solar cell devices [38–40], which allow for an evaluation of the cells in a comparable manner. However, it is technically complicated to characterize the cells within a longer period, if the lifetimes extend far beyond a month. One of the proposed partial solutions is long-term out-door testing of the cells under real sun [41] which includes the effect of nighttime and different weather conditions. As such this gives essential information on how the solar cell would perform under real conditions. In our case the aim is to correlate the observed degradation to the well-defined conditions of the experiment (light intensity, atmosphere, etc.) and from this point of view the demand for reliable weather conditions in the particular region are too extreme and in-door measurements using accelerated conditions are best suited. Accelerated lifetime measurements have been reported [42,43] and simply involve the application of a certain stress to the cells that accelerates the decay processes inside the device. The prediction of an operational lifetime under normal conditions can ideally be predicted from the accelerated data and the acceleration factor assuming that it is constant. The acceleration factor may vary depending on the type of the material and conditions.

In this article we describe a setup that allows for controlled and accurate long-term stability measurements of organic PV devices. This easy-to-use setup consists of an atmospheric chamber (AC) (manufactured at the National Laboratory for Sustainable Energy) and apparatus for recording the decay of PV parameters. A full description of the AC that allows for creating specific environmental conditions during the testing process is given. A few words are devoted to installation of samples inside the chamber and realization of periodic lifetime measurements under certain ambient conditions. Additionally, to demonstrate the use of the apparatus we compare results of both accelerated and normal lifetime measurements for traditional polymer bulk heterojunction solar cells maintained under ambient or inert environmental conditions using the AC setup. The rates of degradation for the devices maintained under different conditions were used to estimate acceleration factors and the results are discussed.

2. Experimental

2.1. Description of the experimental setup

The general experimental setup is shown in Fig. 1. Up to two devices under investigation are placed in an AC beneath the sun simulator and connected to a source measure unit (SMU) through a multiplexing system (*vide supra*) to obtain diode characteristics at intervals. The intensity of the flux from the sun simulator is measured using a precision pyranometer (Eppley Laboratories) in conjunction with irradiance measurements using an optical spectrum analyzer (AvaSpec 2048 from Avantes) to ensure that the conditions approach AM1.5G. The solar simulator is Class AAA with the exception of the wavelength range 700–800 nm where it is Class AAB with respect to non-uniformity, temporal instability and spectral match. It is not possible to fit the pyranometer inside the chamber and therefore Hamamatsu S1133 KG5 filtered photodiodes were employed inside the chamber (see our website www.risoe.dk/solarcells for a routine solar simulator calibration). We have not corrected for mismatch in the data reported as the purpose is not accurate determination of the device efficiency but rather the relative degradation of the performance. It is however possible with the setup presented here and the standard method that has been

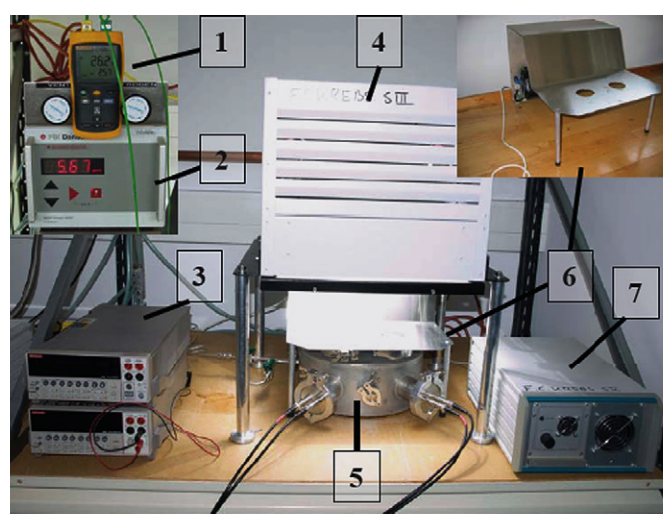

Fig. 1. *IV* testing setup: digital thermometer—to monitor the data of the thermocouples (1), O_2 Analyzer MAP Check 9000 (PBI Dansensor) (2), Keithley 2400 Sourcemeter and Keithley 2000 Multimeter—to transfer the *IV* data to PC (3), solar simulator (KHS Solar Constant 575) (4), atmospheric chamber (5), metal screen—to protect the chamber from overheating (also shown as an inset in the upper right corner) (6), power supply for solar simulator (7).