Characterization of Organic Solar Cells

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Application Note

Introduction

Photovoltaic cells based on solution processable organic semiconductors have attracted remarkable interest as a possible alternative to silicon solar cells. The following key advantages of organic photovoltaic devices have been suggested:

- Low weight and flexibility
- Semitransparency
- New market opportunities e.g. wearable PV
- Significantly lower manufacturing costs
- Short energy payback times and low environmental impact during manufacturing and operations

This suggests that OPV has the potential to be a disruptive technology within the PV market. One of the main drawbacks of organic solar cells available today is their relatively low power conversion efficiency. While silicon-based modules with an efficiency >20% are commercially available, best lab-cell efficiencies in the range of 10% are reported for organic solar cells. In a manuscript published by W. Shockley and H. Queisser in 1961 [1], the efficiency limit of converting solar energy into electricity is described. Assuming ideal, linear photon absorption, only radiative recombination of charge carriers and perfect charge carrier collection, an ultimate power conversion efficiency of 32% was found when exposing the solar cell to air mass 1.5 solar radiation. A surprising consequence of the so called Shockley-Queisser Limit is that an ideal solar cell is also an ideal light emitting diode [2]. In 2007 U. Rau derived a reciprocity relation between the photovoltaic quantum efficiency and electroluminescence of solar cells. Especially the work by Rau illustrates the importance of photoluminescence and electroluminescence studies on solar cells.

Experimental Setup

Investigated organic solar cells were based on the following layer stack: glass (1 mm), indium tin oxide (100 nm), Clevios AI4083 (about 70 nm), organic semiconductor, aluminium. Devices were sealed using a UV-curable epoxy and a thin glass slide to avoid oxidation of the aluminium top contact.
The setup for measuring the photo- and electroluminescence is shown in Figure 1. Solar cells are excited using a tuneable super-continuum light source or charge carrier are injected into the solar cell by applying an external voltage using a source meter unit. Photons emitted by the solar cell are collected and coupled into the spectrograph (Andor Shamrock SR-303i-B) using two off-axis parabolic metal mirrors. The spectrograph is equipped with two gratings with 300 lines per mm and 800 nm and 1250 nm blaze. A CDD camera (Andor iDus DU420A-OE) and an InGaAs detector array (Andor iDus DU490A-1.7) are attached to the exits of the spectrograph.

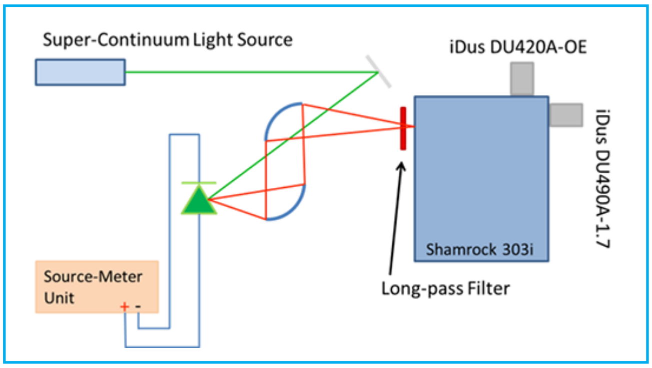

Figure 1: Schematic diagram of the experimental setup

A set of high performance optical long pass filters are used to cut-off excitation stray light and to avoid second order effects.

Experimental results and discussion

In Figure 2 electroluminescence spectra measured on a photodiode comprising a photoactive layer made of the fullerene derivative [6,6]-Phenyl C61 butyric acid methyl ester (PCBM) are shown. Spectra were recorded at different forward-bias voltages.

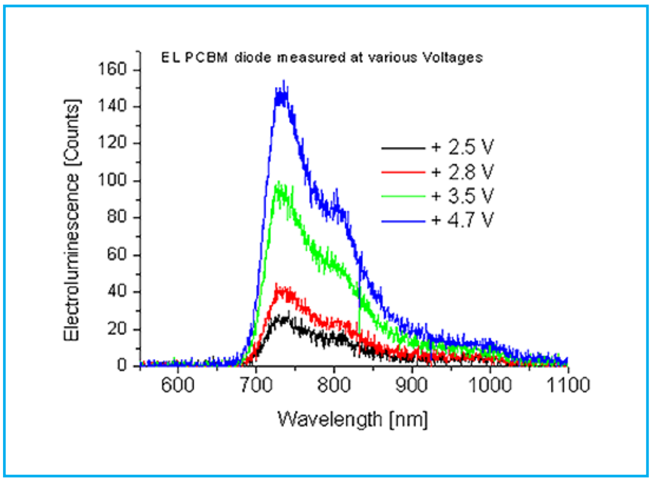

Figure 2: Electroluminescence of a PCBM photodiode

In Figure 3 the electroluminescence of an organic solar cell with an absorber layer made of a mixture of poly-3-hexyl-thiophene (P3HT) and PCBM is shown.

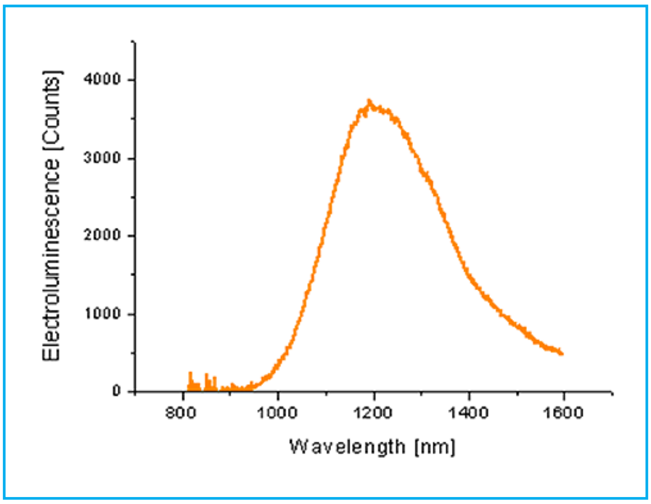

Figure 3: Electroluminescence of a P3HT/PCBM photodiode.

This spectrum was recorded using the InGaAs detector array. Very long (>1 sec) integrations times and very large injection currents into the solar cell were required to record this spectrum.

In Figure 4 the photoluminescence and the electroluminescence of a high performance organic solar cell is shown.

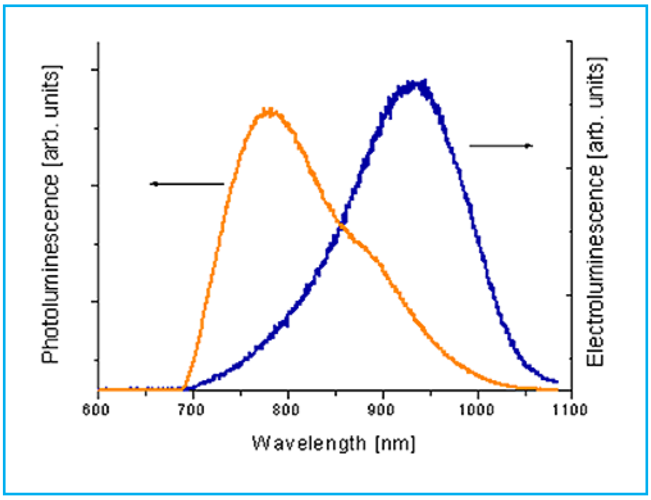

Figure 4: Photo- and Electroluminescence of a high performance organic solar cell.

The two spectra are very different suggesting that the emission results from the recombination of different species. It is generally accepted that the low energy emission which is dominating the electroluminescence spectrum is coming from the recombination of charge transfer states while the photoluminescence is dominated by the recombination of excitons.

The photo- and electroluminescence quantum efficiency of high performance organic solar cells is found to be very low and sensitive equipment is required for their characterization. This low radiative recombination quantum yield may be one of the key limitations of the power conversion efficiency of organic solar cells.

References

[1] W. Shockley, H. J. Queisser, J. Appl. Phys. 32 (1961) 510.
[2] M. A. Green, J. Zhao, A. Wang, P. J. Reece, M. Gal, Nature 412 (2001) 805.

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