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Characterization of Bulk Heterojunction Solar Cells by Spectroscopic Ellipsometry

Final Report

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This is a final report on the research activity performed at LIOS – Linz Institute of Organic Solar Cells, hosted by Prof. Niyazi Serdar SARICIFTCI, in the period January 11, 2010 - January 25, 2010.

The experimental work has consisted in the realization of a series of organic bulk heterojunction solar cells based on a P3HT:PCBM active layer fully in a inert atmosphere (integrated glove box system comprising a spin coater and a metal thermal evaporator) and of another series fully in air, with different realization parameters. All the realized samples have been electrically characterized (current-voltage characteristic in dark and under 1 sun). Selected devices have been encapsulated for future characterization.

The goals were:

- to realize and characterize organic solar cells for my Master Thesis activity;
- to find the best electrode configuration for subsequent spectroscopic ellipsometric characterization of the full device under operation;
- to test a simple and fast encapsulation process suitable for spectroscopic ellipsometric characterization of the device.

My stay in LIOS has been very fruitful. Moreover I had the opportunity to gain new skills and competences that I could use in my future scientific activity. The team in Linz provide me a great and enjoing working atmosphere, supporting me during my experiments.

I would like to thanks ESF for the accepted grant and the detailed report about the experimental results will be presented in the next pages.

Best Regards,

Andrea Perulli

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I. INTRODUCTION

Conducting polymers are of great topical interest. They have found applications in the design and development of thin, light-weight, flexible and low-cost electronic devices.

Extensive research is being done on organic light emitting diodes, solar cells, display devices, transistors, lasers and sensors. Solar cells are among the best technological alternatives to today's conventional energy sources and are the solution to the energy crisis. Their cost-effectiveness and easy processing have attracted the attention of researchers towards the development of organic photovoltaic (OPV) devices. There has been very fast progress in the performance of organic solar cells and an efficiency of ~6.5% has been achieved in a P3HT:PCBM system. Although these devices are sensitive to oxygen and moisture, their protection from ambient will hopefully lead to an acceptably long life. An outdoor working lifetime of more than 10000 h has been reported by a number of authors. Further improvement in the performance needs understanding of the physics behind the operation of these devices. Despite the rapid progress of organic devices towards commercial applications, device modelling is of prime importance in understanding the physics behind the operation of these devices. The device modelling is useful for example for the prediction of charge transport properties of the devices and facilitates better device design [1].

Besides the improvement in power conversion efficiency there are still some aspects that have not been fully studied: one important parameter to be studied is the optical behaviour of the real device under real operation condition and the effect on these parameters of ageing of the device realized in standard atmosphere condition (not protected from oxygen and moisture). It is well known that oxygen and moisture exposure of the device results in a fast degradation, and the effect of such an exposure has been studied by monitoring parameters like efficiency, fill factor, short circuit current, series resistance [2, 3]. Here were are going to monitor what happens to the complex index of refraction of the layers (PEDOT:PSS and active layer) after oxygen and moisture exposure.

In the following sections the preliminary results from this activity will be showed.

II. EXPERIMENT

Several P3HT:PCBM bulk heterojunction solar cells have been realized following the structure glass/indium tin oxide/PEDOT:PSS/P3HT:PCBM/top electrode, both fully in a inert atmosphere (named GB samples) and room condition (A samples). The glove box system that allows for the realization of the GB samples is composed by two interconnected glove boxes from MBraun, inside that there are a metal evaporator system from Leybold and a spin coater.

First step for realization of cells was been the etching of a thin layer of indium tin oxide (ITO), after that a thin layer of PEDOT:PSS from Bayer has been spin coated on top of the ITO, in order to pattern the bottom electrode surface.

Subsequently a thin layer of P3HT:PCBM blend has been spin coated from 1:0.8 weight ratio chlorobenzene solution filtered by a 0.45 μm PTFE siringe filter. P3HT has been bought from Rieke Metals and PCBM from Solenne bv. Starting from the P3HT:PCBM layer deposition for the GB samples performed in glove box, these samples were always kept in inert atmosphere.

Five different type of cathodes (top electrode) have been used for different devices: LiF/Al and Al samples have been used as reference cells. The ultrathin Al, the Al/Ag and the Ag samples have been realized specifically for subsequent spectroscopic ellipsometry experiments. Each sample comprises three separate cells with active areas of about 0.007 cm^2.

The total number of realized samples is:

- GB LiF/Al: 9 samples;
- GB Al: 5 samples;
- GB Al (10 nm): 2 samples;
- GB Ag: 4 samples;
- A LiF/Al: 18 samples;
- A Al: 5 samples;
- A Al/Ag: 2 samples;

The measure of Current-Voltage characteristics have been realized by a computer controlled Keithley 236: respectively inside the glove box system for GB samples, and at room condition for A samples.

Samples that showed good behavior during these measure have been encapsulated by thermal evaporation of 300 nm LiF layer onto the top electrodes followed by spin coating of a two components epoxy resin from CORE, resulting in a thin epoxy resin covering layer; the whole sample surface has been covered except for two thin stripes allowing the electrical connection of the devices to the external load. A similar process has been previously tested for Organic Light Emitting Diode [4] and here we are testing the quality of such thin encapsulation for solar cell devices.

III. RESULTS AND BRIEF DISCUSSION

We have realized the ultrathin Al, the Al/Ag and the Ag cathode on some samples for subsequent study by spectroscopic ellipsometry. We have choosen these configuration because it is necessary that the top electrode (which is in the side from where the light beam from the ellipsometer comes) is transparent enough, on the contrary the spectroscopic ellipsometric measurement of the active layer would be impossible to achieve. First we have realized the ultrathin Al and the Ag electrode samples, but these devices were all clearly shortcutted. We have tried then with the Al (7nm)/ Ag (33nm) finding that these devices worked. After the first I-V measurement test, these devices have been encapsulated for successive measurement in air.

All the working devices (both GB and A series) have been continously electrically characterized as a function of time (simple ageing characterization) at steps of about 24 h for 10 days.

I-V characteristic of five of these cells with different top contact are reported in Fig. 1 V_{oc} and then also the fill factor (FF) for these devices are very low if compared with the corresponding values for the GB series reference cells.

Ageing of four of these cells are reported in Fig 2,3,4,5 where we note the decreasing of FF and respectively series resistance increasing during the days.

Finally are showed in Fig. 6,7 the variation during 7 days of series resistance (R_s), obtained from the plot of the gradient of the I-V characteristic by calculating the inverse of the value obtained for zero V_{oc}, of two devices with 7 nm of Al followed by 33 nm of Ag as top metal contact. These samples are compose of three cells (named respectively “left”, “centre”, “right” cell).

From these experiments it has been possible to select the devices to be tested also in the University of Salento under real ambient condition: this step is in progress in Lecce - Italy.

Secondly, the effect on the performance of the cells of the encapsulation process is being currently tested, both with on going I-V characterization in air and with the previously described R_s extraction procedure. From preliminary results we can argue that this encapsulation process did not negatively influence the performance of the device

IV. CONCLUSIONS AND PLANNED EXPERIMENTS/PUBLICATIONS

Several sets of bulk heterojunction solar cells have been realized and characterized with different parameterization. These cells have been tested and compared taking as references the standard realized devices with LiF/Al as top electrode. The acquired data are currently being analised.

With this laboratory activity in LIOS, I had the possibility to be trained in the field of organic photovoltaics research activity.

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[3] Kenji Kawano, Roberto Pacios, Dmitry Poplavskyy, Jenny Nelson, Donald D.C. Bradley, James R. Durrant, Sol. Energy Mater. Sol. Cells 90, 3520 (2006);

[4] Jian-Ji Huang, Yan-Kuin Su, Ming-Hua Chang, Tsung-Eong Hsieh, Bohr-Ran Huang, Shun-Hsi Wang, Wen-Ray Chen, Yu-Sheng Tsai, Huai-En Hsieh, Mark O. Liu, Fuh-Shyang Juang, Jpn. J. Appl. Phys., 5676 (2008).

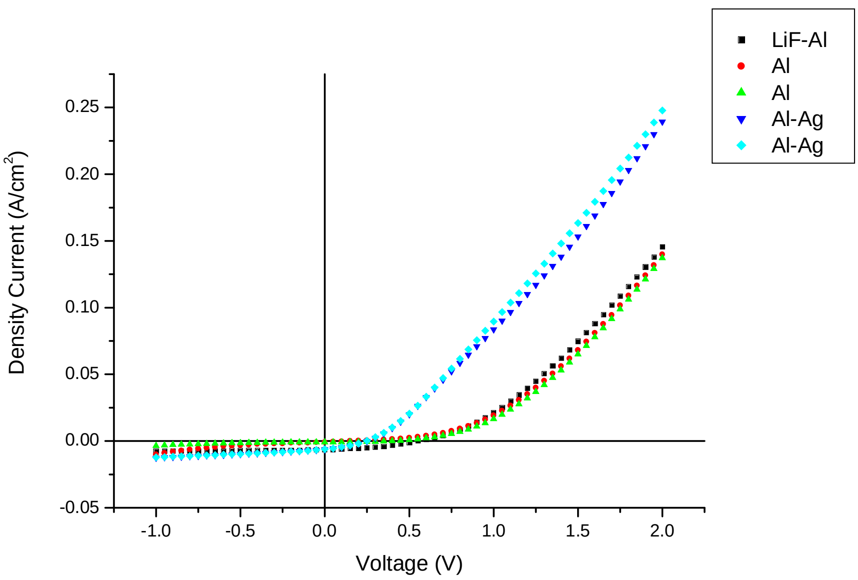

Fig. 1 Current-Voltage characteristic of five samples (A series) with LiF-Al, Al, Al-Ag top metal

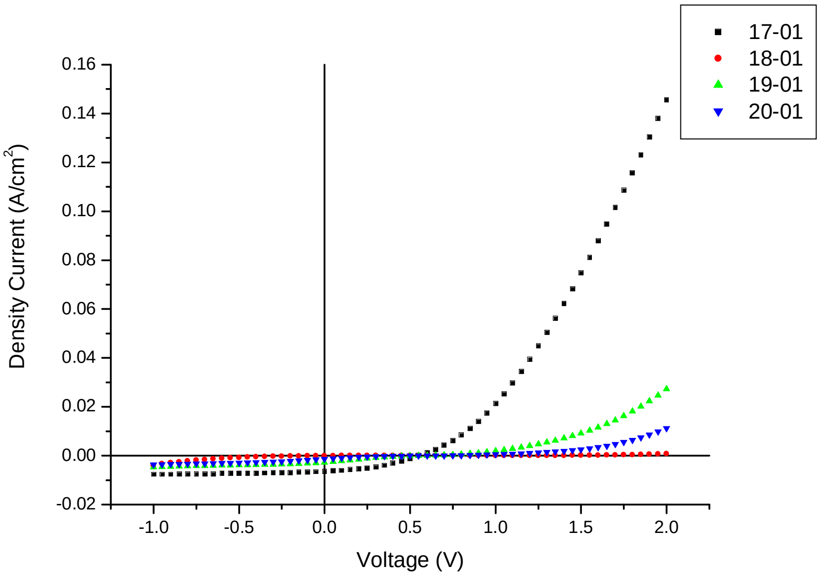

Fig. 2 Ageing of a sample with LiF-Al top metal contact

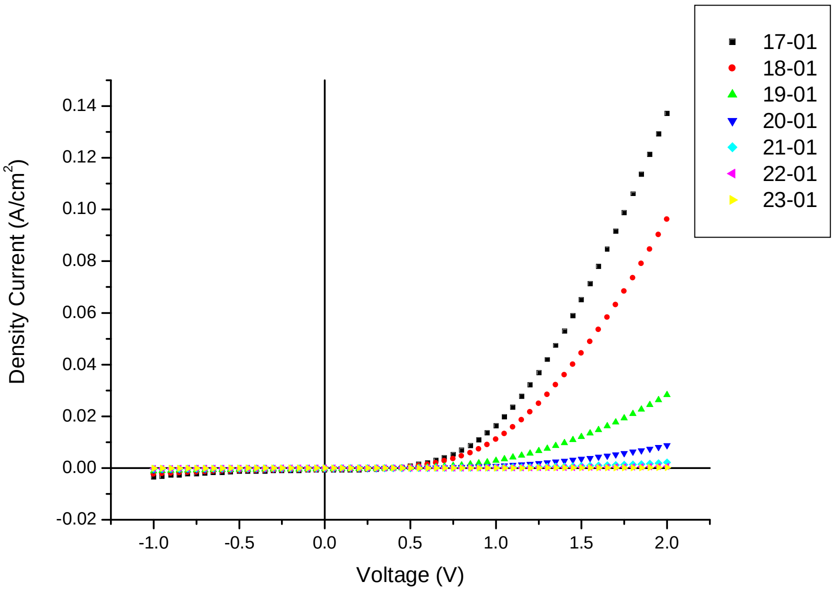

Figura 3 Ageing of a sample with Al top metal contact

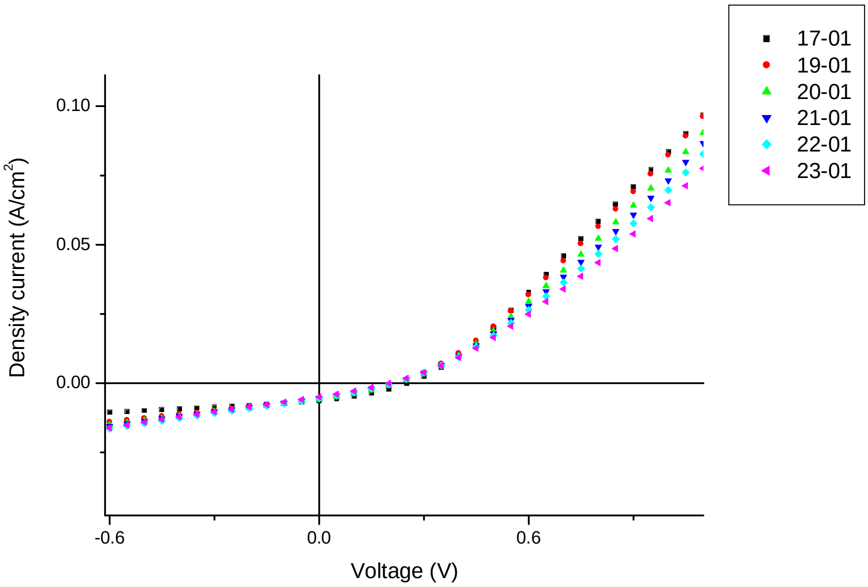

Fig. 4 Ageing of a sample with Ag-Al top metal contact

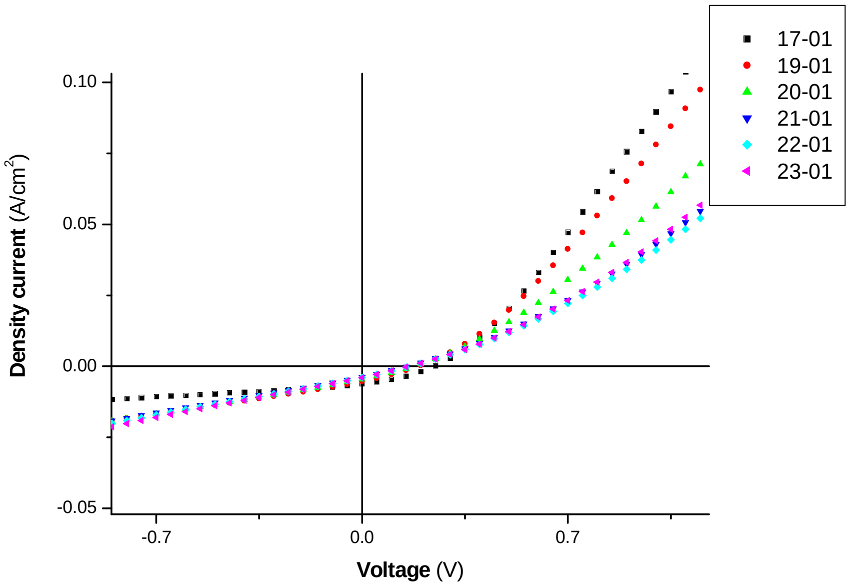

Figura 5 Ageing of a sample with Ag-Al top metal contact

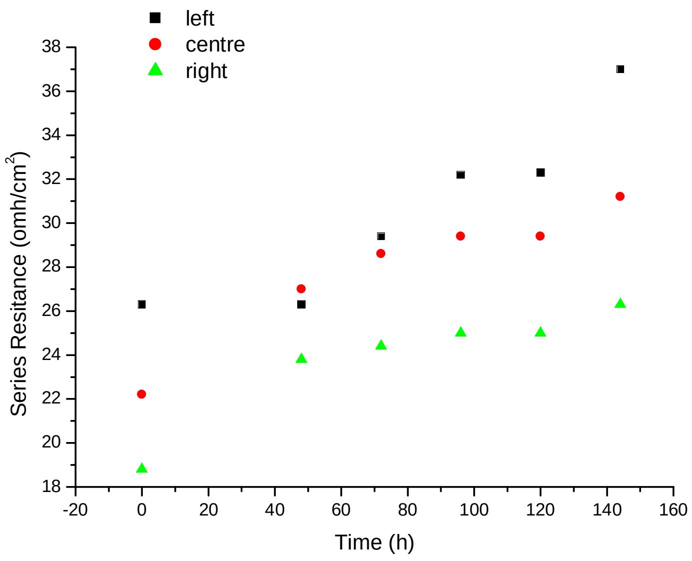

Fig. 6 Trend of series resistance during 7 days

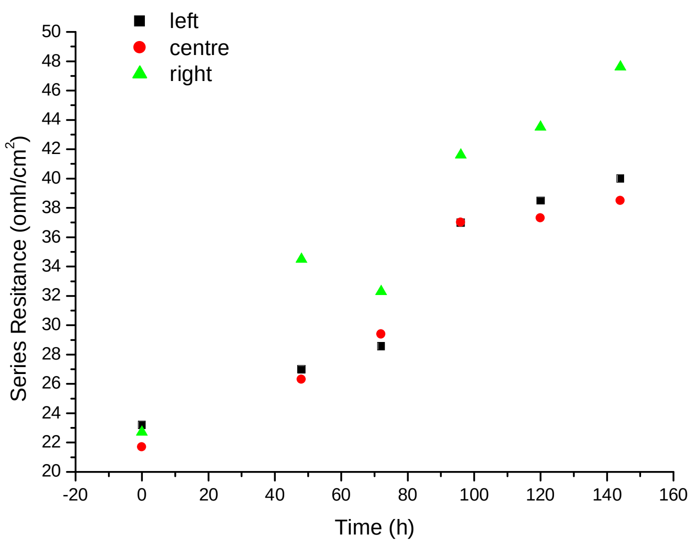

Fig. 7 Trend of series resistance during 7 days