INTERFACE ANALYSIS TECHNIQUES ON NANOSCALE DIMENSION IN FLEXIBLE SOLAR CELLS

Schwarz, R. Ayouchi, C. Casteleiro
Instituto Superior Técnico, Departamento de Física, Av. Rovisco Pais 1, P-1049-001, Lisboa, Portugal
G.M. Junior, M. Ribeiro, P. Alpuim
University of Minho, Department of Physics, P-4800-058 Guimarães, Portugal

Basic idea: This work concerns the study of interface properties in thin film devices on a nanometer depth scale. Several analysis techniques are employed and correlated:

- photocapacitance spectroscopy [1],
- stress measurement at the interface,
- interface recombination by steady-state and transient grating techniques (SSPG, TG),
- photoluminescence (PL), and
- correlation between interface light scattering and the open-circuit voltage V_{oc}.

As a typical example we consider a tandem structure of an amorphous silicon based thin film solar cell consisting of nano-structured ZnO window layer, followed by a p-i-n a-Si:H solar cell deposited at the amorphous-to-microcrystalline transition (polymorphous), and terminating in a hydrogenated microcrystalline silicon bottom p-i-n cell. The three regions are tailored for best performance in the UV, visible, and IR spectral range, respectively. The whole structure is deposited on a flexible polymeric substrate [2].

Techniques: The flexible substrate is critical in two respects: first, the surface roughness of the ZnO contact layer (including ZnO quantum dots as shown in Fig. 1) which is helpful for improving the solar cell efficiency through light scattering may be responsible for creation of detrimental interface trap states. Secondly, a flexible substrate imposes mechanical constraints on the contact layer that may deteriorate the quality of its interface to the semiconductor film. Photocapacitance spectroscopy is sensitive to non-radiative recombination introduced by additional interface states and to the local electric field distribution near the heterostructure interface. Cells will be inserted in a four-point bending jig and their I-V characteristics under fixed illumination will be recorded as a function of the applied bending moment that will induce strain in a controlled manner in the devices. The degradation of solar cell performance, reflected in its V_{oc}, I_{sc} and fill factor values, will be studied as a function of the number of load-unload cycles applied in the four-point bending geometry. Comparison of photocapacitance measurement results performed before and after mechanical stressing of the device will elucidate about the extent of the damage in the interface ZnO/a-Si:H caused by strain [3].

Technology: We have previously used photocapacitance spectroscopy to study the local defect creation in irradiated amorphous silicon-based p-i-n detectors [1]. Here we extend this technique to study thin film solar cells deposited on ZnO-coated flexible substrates (PI and PEN). The p-i-n structures were deposited by RF-PECVD and HW-CVD at particularly low substrate temperature

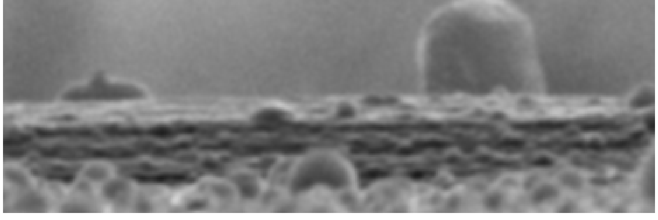

Figure 1: ZnO quantum dot on catalytic Au layer

of 150 ˚C. Hydrogen dilution was varied between 50 and 98 %. One of the contact layers used was polycrystalline ZnO prepared from sintered oxide targets by pulsed laser deposition (PLD). The photocapacitance measurements were done under HeNe laser illumination at a modulation frequency up to 1 MHz, as a function of voltage bias, and under different white light bias conditions. Enhanced recombination is seen by both the reduction of the photocapacitance signal and by faster capacitance decay in pulsed mode. The spatial resolution under focused laser light is limited ultimately by lateral carrier diffusion.

Scientific relevance: The analysis with photocapacitance spectroscopy has several innovative aspects: First, it is an alternative to the usual laser-beam-induced photocurrent measurements (LBIC) to study solar cell quality. Secondly, the technique is sensitive to both interface defects and interface electric field profiles between the ZnO contact layer and the p-i-n solar cell structure. Finally, by scanning a focused laser beam across the cell we obtain a topological image of defect regions of the solar cell.
The 4-point bending technique allows the application of pure bending to the specimen under study, if it is placed between the two inner loading points. It is possible to apply tractile of compressive strain just by placing the device in the convex or concave surface upon bending. The effect on solar cell performance of the cracks that will develop perpendicular to the substrate and through the solar cell thickness under positive strain and the eventual recover of device performance under negative strain will be measured. The combination of this technique with the photocapacitance spectroscopy will allow to assess the relative importance of the mechanically damage in the bulk of the device and in the interface with ZnO.

Conclusions: Spectrally and spatially resolved photocapacitance measurements, stress measurement at heterointerface, the correlation between interface recombination, open-circuit voltage and photoluminescence yield give a comprehensive picture of the interface quality between a conductive transparent oxide layer and a thin film solar cell. As an example we studied a typical solar cell structure composed of ZnO/a-Si:H on polymer substrate. A lateral spatial resolution of a few tens of microns is achieved when scanning across the cell surface. The depth resolution obtained by wavelength selection is of nanometer scale in the interface region.

References:

[1] C. Casteleiro, R. Schwarz, A. Maçarico, J. Martins, M. Vieira, F. Wuensch, M. Kunst, E. Morgado, P. Stallinga, H. Gomes, "*Spatially-Resolved Photocapacitance Measurements to Study Defects in a-Si:H Based p-i-n Particle Detectors*", to be published in Thin Solid Films (2008).

[2] S.A. Filonovich, P. Alpuim, L. Rebouta, J.-E. Bourée, Y. M. Soro, "*Amorphous and nanocrystalline silicon solar sells deposited by HWCVD and rf-PECVD on plastic substrates at 150ºC*", Journal of Non-Crystalline Solids, in print (2008).

[3] P. Alpuim, S. Lanceros-Mendez, V. Sencadas, M. Andrade, S.A. Filonovich, "*Piezo-Resistive Properties Of Nanocrystalline Silicon Thin Films Deposited On Plastic Substrates By Radio-Frequency And Hot-Wire Chemical Vapor Deposition*", Thin Solid Films, 515 (19), 7658 (2007).