Final Publishable Summary Report

The DIELECTRIC PV project pursued the development of advanced light trapping structures, for application in thin film silicon solar cells, employing wavelength-sized photonic features. It consisted in a multidisciplinary research plan which involved theoretical and experimental activities executed in the facilities of the host center CENIMAT-i3N within FCT-UNL.

The project has generated much interest in the host center and attracted the collaboration of other researchers which have assisted and complemented the scientific activities that were initially planned. Consequently, new promising research lines have sprouted in CENIMAT from this work, which are now being developed by other PhD and Post-doc researchers.

In the framework of DIELECTRIC PV, the following important scientific deliverables have been attained: 9 publications in peer-reviewed international journals, 1 publication in the proceedings of a peer-reviewed conference, 1 book chapter, 1 publication in a national journal, 9 presentations in international conferences (2 invited talks + 2 oral + 5 visual presentations).

Description of the work performed and main results achieved

The project is structured in 3 main parts, as detailed in section B1.2 of the proposal, whose developments and key achievements are briefly described below:

1) *Computational Modeling* – In-depth optimization studies were performed using a numerical FDTD software (*Lumerical Solutions*) which provided not only the optimal conditions for the best performing dielectric-based photonic elements, but also analyzed in detail the physical mechanisms caused by such elements that allow substantial light absorption enhancement in thin film PV devices. Therefore, the envisaged project objectives for the simulation activities have been outstandingly fulfilled as testified by the related high-impact deliverables, being the most relevant the article published in *Nano Energy* (impact factor of 12, see graphical abstract in Fig. 1). Furthermore, the project surpassed its initial objectives regarding the modeling activities, as additional photonic structures have been explored based on plasmonic metal nanoparticles which were shown to lead to complementary light trapping action for the longer wavelengths (near-infrared range). These were shown to be promising structures for the rear part of the solar cells, which can be combined with the dielectric-based features proposed in the project that are implemented on the cells' front.

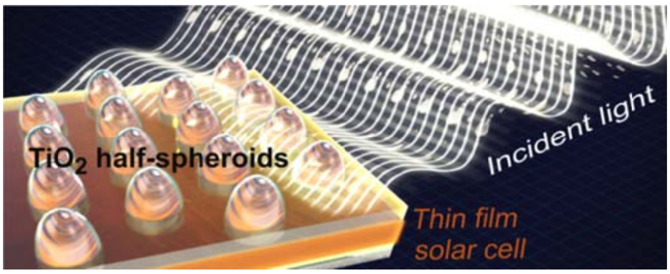

Figure 1: Illustrative graphical abstract image of the article entitled: *Design of optimized wave-optical spheroidal nano-structures for photonic-enhanced solar cells* [**M. J. Mendes et al., Nano Energy, Vol. 26, 2016**], published in the framework of the DIELECTRIC PV project.

***2) Nanofabrication work* –** The objectives planned for the experimental work have been fulfilled as the researcher was able to develop an advanced process based on colloidal lithography to pattern the arrays of wavelength-sized photonic elements of the front surface of any type of thin film solar cell. This allowed the engineering of high-index dielectric structures with high degree of uniformity and long-range order, having the nano/micro-scale dimensions indicated by the computational optimization studies of the previous activity.

***3) Device construction* –** Prior to the application of the light trapping structures, a considerable amount of work was performed in the development of thin film silicon (both hydrogenated amorphous, a-Si:H, and nanocrystalline, nc-Si:H) solar cells via PECVD (plasmaenhanced chemical vapour deposition). The aim was to attain reference devices with state-of-the-art performance in terms of efficiency (~8% was achieved) and electrical quality (standard values of fill factor and open-circuit voltage were achieved), that were used as the base structures where the photonic elements were applied. This work was assisted mainly by the technician (Tiago Mateus) of the host center expert in solar cell fabrication by PECVD, and other co-workers. Afterwards, different types of light trapping structures were implemented in the devices, composed both of the initially-proposed dielectric-based photonic elements but also of additional plasmonic-based structures that were computationally optimized in the same way. Both types of structures were shown to yield pronounced (~40%) current and efficiency enhancement in thin film Si cells, without deterioration of their electrical characteristics. Thus demonstrating the advantages of their applicability in thin film PV.

Other achievements

In addition to the aforementioned results, it is important to refer that a national project application was submitted to the past call of "FCT - Projectos IC&DT 2014", partially based on the ideas of the DIELECTRIC PV project and on the knowledge that has been gained since its start. This project application was accepted for funding by FCT (acronym: ALTALUZ, reference: PTDC/CTMENE/5125/2014, with an approved budget of 200k€). Within this FCT project, another researcher has been hired by the host center who is now working in close relation with Dr. Mendes in the continuation of the investigations initiated in this project.

Potential socio-economic impact and use

The key outcome of the project was the demonstration of highly-promising low-cost and industrial-compatible light trapping strategies that have the potential to strongly boost the optical absorption in any type of thin solar cell material, thereby enabling higher efficiency and allowing the cells' thickness reduction. Optically-thicker but physically-thinner PV devices imply cheaper and faster fabrication, and also improved flexibility which is important for roll-to-roll manufacturing and their application in bendable substrates (e.g. paper, polymers, tissues, etc.) aimed for consumer-oriented products (sun-powered intelligent packaging, wearable PV, portable electronics, building-integrated PV, light-powered internet-of-things, etc).

Apart from the well-known environmental benefits of solar electricity for the future of our society, the aforementioned novel PV applications allowed by photonic-enhanced thin-film cells can open many new opportunities for the PV energy market and for start-up companies and SMEs, enabling to bring EU to the forefront of PV R&D. The availability of solar power and its advantages as a renewable energy source make PV one of the most important technologies for addressing the present energy challenges. The global PV market (presently sized at 80 billion €) is projected to reach ~320 billion € by 2020, with 400 GW installed capacity. China is expected to be the leader by over 110 GW, followed by US and Japan. However, the technological step change allowed by the advanced photonic technology demonstrated in this project, for thin film solar cells, will contribute to offer an opportunity for EU PV industry to recover a leadership position with new affordable products for the global market and to promote investment and job creation in Europe in the crucial sector of green economy.

Additional information, website and contact details

The project results have been regularly communicated in a public website maintained by the researcher (https://sites.google.com/site/manuelmdm) which is announced in the website of the host center (www.cenimat.fct.unl.pt). For further information regarding the project please contact Prof. Isabel Ferreira (imf@fct.unl.pt) and/or Dr. Manuel J. Mendes (mj.mendes@fct.unl.pt).