Theme 2: materials for energy

People involved:

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Projects: ANR Blanc GENESE (2014-2018), PHC ORCHID (2015-2016), Labex EMC3 COTRA (2017-2018), Qatar National Research Funds (2016-2020), RIN LUMIERE (2018-2020), RIN REFEREE (2018-2021), 1 PHC BARRANDE (2020-2022), Projet de Prématuration Cocot (2020-2021)

The research axis of **materials for energy** arises since the last evaluation period, where first results on down conversion in silicon oxy-nitride layer for increase of photovoltaic (PV) conversion were already presented. This theme related to **frequency conversion** for PV is now increased by more advanced research on photoconversion (down-shifting and conversion, up-conversion) by rare earth dopants in silicon based material as well as by the development of new In-free TCO. New subjects connected to material for energy system arise as the optical **Heat management** through development of heterostructures performing radiative cooling, with potential application in energetic system.

Frequency conversion.

The expertise acquired in thin films based on Si doped with rare earths for materials for photonics has naturally led to the emergence of a new theme dealing with the management of light in energy systems. Among energy systems, photovoltaic conversion was our first domain of interest. After the demonstration of the mechanism of down conversion (DC) in such donor-acceptor system [Y.-T. An et al., *Advanced Optical Materia*l, 2013], we have explored further this topic through the PhD thesis of L. Dumont, the ANR Genese project and PHC Orchid project by Tb^{3+}/Yb^{3+} co-doping Silicon nitride layer. We investigated and optimized the fabrication process, in order to maximize the down-conversion process in three kinds of host matrices SiO_x, SiO_xN_y, SiN_x. We have also explored a supplementary process called downshifting (DS) by doping the SiN_x host matrix with Tb^{3+} ions [L. Dumont et al., Solar Energy Materials & Solar Cells, 2016 and 2017]. Thanks to optical spectroscopies and modeling, we were able in all these studies to determine their conversion efficiency and to estimate the improvement that would generate our DC and DS layers. Following this success, we have investigated the implementation of frequency conversion layers on silicon solar cell. Based on the encouraging conversion results, we modified an existing solar cell by replacing the antireflection layer by a frequency conversion antireflection layer. In this way, we changed in a very slight way the process of PV cell manufacturing for demonstrating the applicability of our concept. For this purpose, we put our efforts in working on the antireflective nitride layer constituting a Si solar Cell that we doped with the couple of RE ions Tb^{3+}/Yb^{3+}. We have first demonstrated the gain in PV conversion efficiency thanks to Lab's solar cell produced by our partner IEMN (Lille) within the ANR Genese framework. The comparison between the cell with the antireflective layer alone (SiN_x) and that doped with the couple of RE ions Tb^{3+}: Yb^{3+} has revealed an increase in the efficiency of the cell of 1.4 times that demonstrates the existence of a DC layer effect. A network of Ag nanoparticles has also been developed to enhance the efficiency of the cell, and we found an increase of the photocurrent by a factor 5 with the non-modified antireflective layer which is promising for the DC layer [E. Elmi et al., *Nanotechnology*, 2018]. These results have led us to test our DS and DC layers on industrial cell, thanks to an international collaboration with the National Dong Hwa University (Taiwan) as well as with the industrial partner E-Ton Solar Tech Co., we have used our conversion frequency layers on Si industrial cell provided by the company. Several approaches were made in order to improve the process and try to overcome the critical point of the passivation. Anyway, by using the Sinton method measurement, a gain of 1.3% of the efficiency has been evidenced with the use of our DC layer [L. Dumont et al, Progress in PV, 2019; I.-S. Yu et al., Journal of Rare Earth, 2019].

More recently, within a collaboration managed by CRISMAT Lab through the Labex project COTRA (2017-2018), and RIN PLDSurf (2019-2022), NIMPH Team has involved itself in a new type of oxide thin film. It concerns a new promising generation of TCO with a greater transparency and a higher density of current carriers with respect to previous TCO generation. This new generation of TCO could be therefore useful in energy conversion system such as PV or PEC where the limited carrier density may limit the current extraction. The potential replacement is the $SrVO_3$ that combines the transparency in the visible range and a good electrical conductivity. In August 2020 a patent has been accepted. A "Projet de Prématuration" named Cocot (CRISMAT) has begun in June 2020, supported by the CNRS for 18 months to help on the development of this patent. NIMPH team is involved in optical measurements and ALD depositions.

Heat management.

The development of thin film heterostructures for daytime radiative cooling is a new topic that has emerged in the team thanks to support from CNRS Peps Energy, Labex EMC3 Daycool and RIN REFEREE. This topic aim at developing heterostructures that act simultaneously as a solar irradiance reflector and a thermal emitter in mid infrared spectral range in the so called atmospheric transparent windows. In certain regime of high reflectance and high emittance, this device may act as a coupler to a cold heat sink the space above atmosphere. We estimate that this kind of device could radiate about $100W/m^2$ in the outer space and therefore acts as a new brick for thermal energy system such as for example thermal management of building. We have developed an original algorithm to design such a structure based on evolutionary method and material and optical modeling. We have thus with the help of our algorithm built several heterostructures with high cooling performance. Since one of the main points to succeed in the fabrication of such a "cooling film" is the accurate control of the thickness, we have designed and bought a new sputtering machine with optical monitoring. It is not possible to give more details of the system since a demand of patent is currently in discussion with the CNRS.