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THERMAL ISSUES IN THE DESIGN OF PV DEVICES: FOCUS ON THE CASE OF NANOSCALE-GAP THERMOPHOTOVOLTAIC CELLS

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EXTENDED ABSTRACT. When designing high efficiency photovoltaic (PV) devices, the main objectives are almost always to decrease the optical and electrical losses. Thermal issues have so far been overlooked or considered after the design of the cell by using cooling systems that maintain the cell at some acceptable temperature. Actually, the radiative, electric and thermal mechanisms happening in PV systems are deeply intertwined. Therefore, solving them together considering in detail the thermal impacts - including radiative transfer - may lead to the discovery of new optimizations for the design of PV devices.

Recently, our groups have started the development of simulation tools to explore the thermal impacts on the performances of photovoltaic cells. In addition to the usual description of the optical and electrical phenomena, the thermal phenomena are considered so that the heat sources are properly calculated and the equilibrium temperature of the cell can be estimated. This work was initiated in the case of standard crystalline silicon (cSi) PV cells [1], because the required properties and their dependence on temperature are well known. The corresponding code (named TASC-1D-cSi, for Thermal Analysis of Solar Cells) is used to show that harvesting more light does not systematically increase the generated electrical power since a rise of the thermal sources can frustrate it [2]. To illustrate this statement, Figure 1 depicts the variation of the maximum output electrical power as a function of the Anti-Reflection Coating (ARC) thickness in the case of a cSi PV cell. In usual optimizations, the cell temperature is prescribed at 25°C (STC), and the optimum ARC thickness is found to be 80 nm. But under real operating conditions, i.e. in a given set of thermal conditions (outdoor temperature of 25°C, heat transfer coefficients between the cell and the surroundings of 4 and 0 W m^{-2} K^{-1} at the front and rear surfaces, respectively), the optimum ARC thickness is shifted to larger values (89 nm). This shift corresponds to the compromise between the maximization of optical generation of electrical charges, the minimization of the recombination of these charges, and the minimization of the total heat source. Including a thermal optimization leads in this case to a gain of 0.5% in maximum electrical output power. Even though the simulation tool still lacks a number of features such as the modeling of the encapsulation, this example suggests that thermal criteria could be beneficial to the design of PV cells. Other possible optimizations of cell characteristics are possible, as well as potential extensions to other cases such as Concentrated PV cells or plasmonics for PV devices. In this presentation, we focus on nanoscale-gap (or near-field) thermophotovoltaic devices.

In thermophotovoltaic (TPV) systems, thermal radiation emitted by heat sources (radiators) different from the sun (e.g. furnaces) is used for generation of electrical power. By separating the radiator and the TPV cell by a sub-Wien's wavelength vacuum gap, tunneling of evanescent waves can significantly improve the electrical power output of TPV systems [3]. These systems are called nanoscale-gap TPV (nano-TPV) devices. Among the important questions that need to be addressed before providing a full proof of concept, the thermal issues are very critical. To demonstrate this, we consider a bulk radiator (tungsten, T_0 = 2000 K) and a TPV cell ($In_{0.18}Ga_{0.82}Sb$, bandgap of 0.56 eV at 300 K), separated by a sub-wavelength vacuum gap of length d. The TPV cell consists of a single P-N junction, where the thicknesses of the P-doped and N-doped regions are given by t_p = 0.4 µm and t_n = 10 µm. Since various thermal sources will be the cause of the strong heating up of the TPV cell, a thermal management system is required to try to maintain the P-N junction close to room temperature. The cooling system is modeled as a convective boundary condition with a fixed external temperature (T_∞ = 293 K) and a heat transfer coefficient (h). The performances of the nano-TPV device are evaluated by solving the coupled near-field thermal radiation, charge and heat transport equations [4]. The analysis of the performances as a function of the distance between the radiator and the TPV cell and of the cooling conditions reveals (Figure 2): i. a clear near-field enhancement of the maximum output electrical power which reaches up to 12 times the far-field value if the cell is maintained at room temperature ($h=\infty$); ii. a drop of this near-field beneficial effect if the cell is not cooled properly (even with h=5000 or 2000 $Wm^{-2}K^{-1}$). These results suggest unambiguously that without any thermal design, the concept of nanoscale-gap TPV cell is likely to lose its relevance.

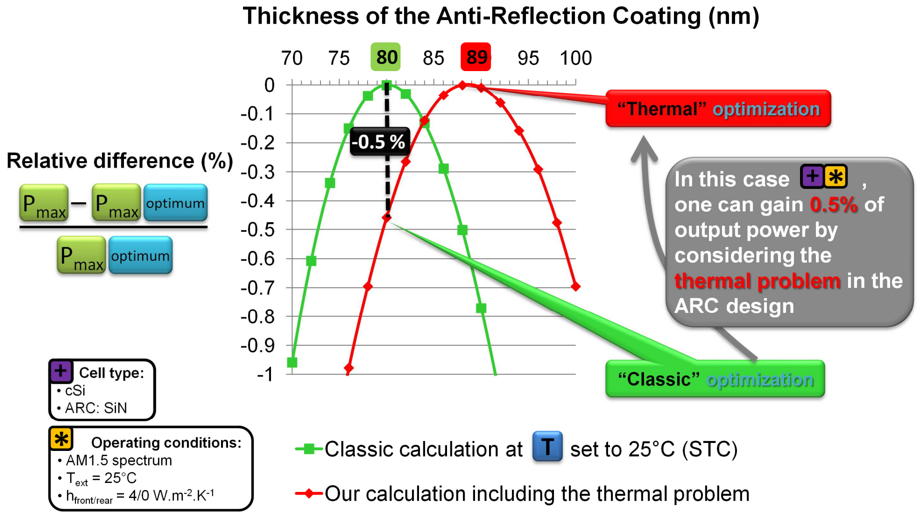

Figure 1. Thermal optimization of the Anti-Reflection Coating (SiN) thickness of a cSi solar cell

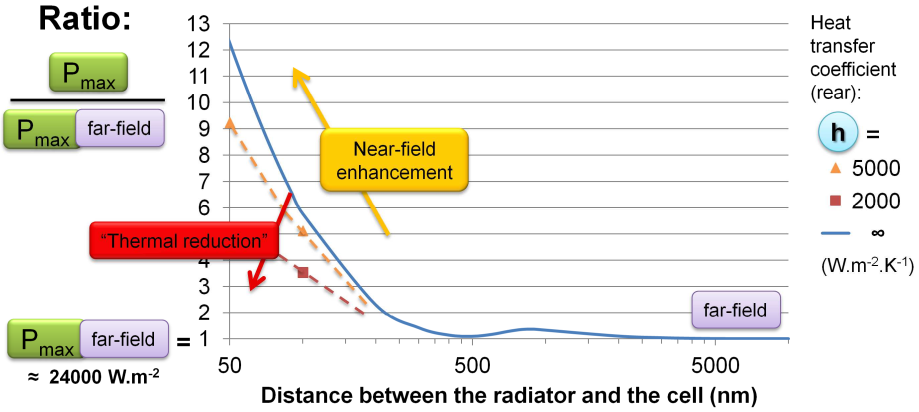

Figure 2. Near-field enhancement of the output electrical power as a function of the distance between the radiator and the TPV cell and its drop when a non-ideal cooling system is considered

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