Concept of a Split Tandem Photovoltaic Window

Marc Jobin, Cédric Pellodi

hepia, University of Applied Sciences HES-SO, 1202 Genève, SWITZERLAND

***Abstract* — We present a concept of a split tandem photovoltaic window, where the larger wavelengths solar radiations are sent towards horizontal silicon solar cells while short wavelength solar radiations are directed on transparent large band gap solar cells, either dye-sensitized or organic solar cells (DSSC and OSC respectively). We first evaluate the expected enhancement in them of conversion efficiency and then describe the construction of a mini module of this window.**

***Index Terms* — Building integrated photovoltaic (BIPV), tandem cell, organic solar cell (OSC), dye-sensitized solar cell (DSSC).**

I. MOTIVATION

A large scientific and commercial effort has been devoted in the last decade to achieve and promote energy efficient buildings, targeting toward net zero energy buildings [1]. In this view, photovoltaic (PV) windows play a central role, both in terms of thermal insulation and in terms of direct energy production. So far, the market is still dominated by opaque standard silicon based PV cells partially covering surface of the window. However, transparent or semi-transparent (either neutral density or colored) PV windows can be achieved with thin films PV cells or more recent PV technologies such as dye-sensitized solar cells (DSSC) [2] and organic solar cells (OPV) [3].

Both DSSC and OPV are large band-gap solar cells, offering then potentially an enhanced conversion efficiency provided a tandem strategy is used : the blue-green radiations have to reach the transparent large band gap cells while the yellow-red part of the spectrum should reach the opaque small band gap silicon solar cell. But in contrary to standard tandem PV cells where the two cells are superposed, we need, for the window application, to physically split the incident radiations according to their wavelength. Apart from the windows application, the idea to split the solar radiation and to send it to several separated photovoltaic cells with various band gaps is also proposed for high efficiency photovoltaics cells [4].

II. DESIGN AND FABRICATION OF THE PHOTOVOLTAIC WINDOW

A. Window design

The principle of the split tandem PV window is shown in Fig. 1. The solar spectrum entering the window is split with a wavelength dependent filter. The 600-1100nm wavelengths are sent towards an opaque silicon PV cell, which is positioned horizontally in order that the global transparency of the window is affected only by the thickness of the cell. In our case this thickness is 300um, bus this can be reduced to a few microns with thin film a-Si technology. The short incoming wavelengths are not affected by the filter and hit a transparent PV cell, either DSSC or an organic cell.

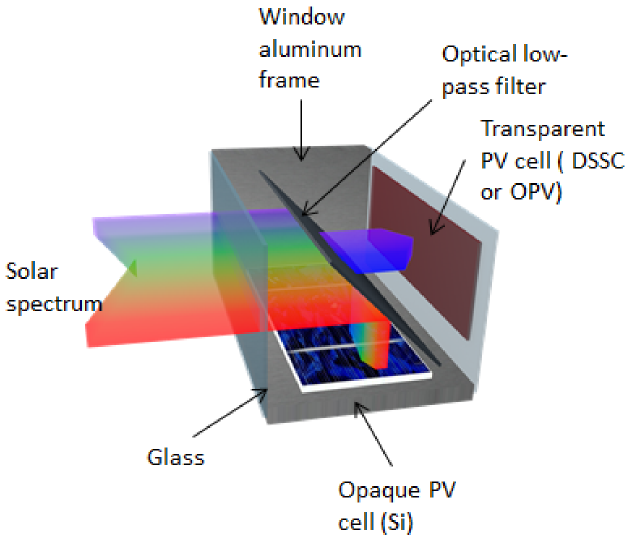

Fig. 1. Principle and design of the split tandem photovoltaic window.

The expected improvement of the total energy conversion efficiency of the split tandem cell compared to individual cells can be illustrated by the plot of the internal quantum efficiency (IQE), as shown in Fig. 2. The Si technology (1.1eV bandgap) is more efficient at long wavelengths, as most of the energy of short wavelength photons is lost in thermalization. In the other hand, large band gap PV cells (as DSSC represented here with a bandgap of 1.8eV) are unable to extract any energy from a large portion of the solar irradiation, as no absorption occurs. The potential improvement of the split tandem window compared to a standard Si cell is shown in the figure (arrow).

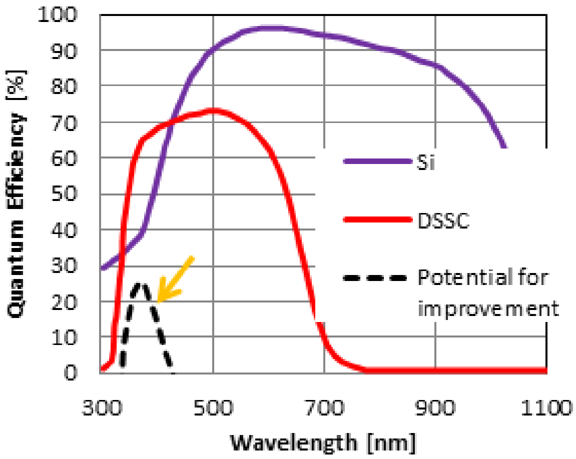

Fig. 2. Expected quantum efficiency of the split cell and potential improvement compared to a standard Si cell.

B. PV cells fabrication

The silicon solar cell is built from a *p*-doped Si wafer on which a spin coated solution containing phosphorus is deposited (spin-on dopant). The *p*-type dopant (P) is incorporated in the wafer thy thermal diffusion [5], with the help of a gas-controlled tubular furnace. The solvent evaporated coated wafer is then heated is during 120 min at 1’000°C, and then slowly cooled.

The DSSC cell is built from dye sensitized titania nanoparticles, and we mainly followed the procedure given in Ref [6]. Organic solar cells (OPV) have the ITO/PEDOT:PSS/P3HT:Al architecture and synthetized as described in a previous work [7,8]. In both case (DSSC and OPV), each layer was controlled (thickness and structure) by Atomic Force Microscopy (AFM) and with our home made Interferometric Optical Microscopy (IOM) [9].

C. Filter

We have used a commercial dichroic filter mounted in a rotary stage integrated in the window : this allows to choose the relative incidence angle of the solar radiation and, as a consequence, the splitting of the transmitted/reflective spectra. The effective splitting of the solar irradiance (as measured with a “AAA” AM 1.5 solar simulator) as a function of the filter angle is shown in Fig. 4. We then see that we will be able to choose the cut-off wavelength that will be optimally tuned to the quantum efficiencies of the solar cells.

To reduce the fabrication cost of the window, we plan to make our own optical pass-band filter by sol-gel deposition, with six alternated TiO_2/SiO_2 layers.

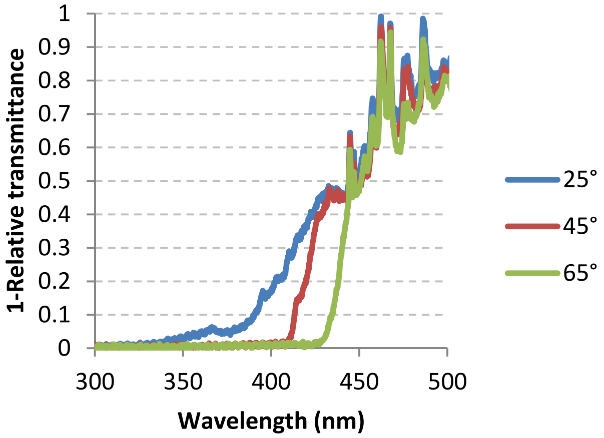

Fig. 3. Transmittance of AM1.5 illumination through the filter as a function of the filter angle.

D. Window integration

As a demonstrator, we have built a small window with an aluminum frame as shown in Fig. 4. The two solar cells and the filter have been assembled in a nitrogen glove box and the front window is sealed with butyl. This is standard in the window industry, but we did not use any water absorber.

The filter is mounted on a rotary stage to allow for the choice of the angle relative to the solar radiation direction. This will allow for the optimization of this angle and for the study of the efficiency as a function of the time during the day.

Fig. 4. Picture of the mini window.

III. PERFORMANCES

The internal and external quantum efficiency (IQE and EQE respectively) have been measured for the various transparent photovoltaic cells. Fig. 5 shows the normalized EQE of DSSC and OSC we have built and integrated into the windows module. On top of the PV performances themselves, the choice of the technology can also be directed by the final desired aspect (mainly colors) of the window.

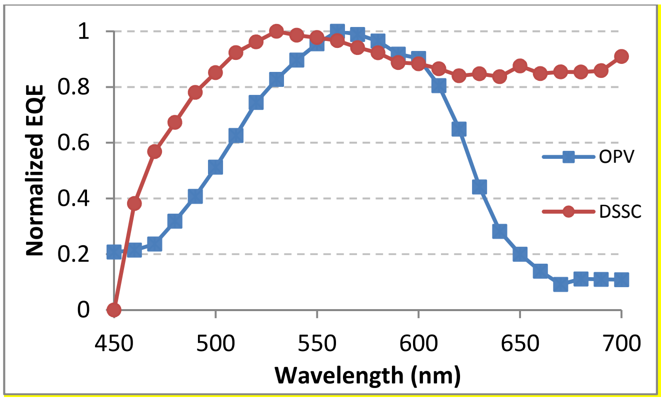

Fig. 5. Relative EQE of DSSC and OSC used for the split window.

Once the PV cells will be optimized and integrated onto the mini window, the energy conversion efficiency (ECE) will be measured in standard condition (1000W/m^2 with a AAA solar simulator). In order to maximize the performance, the filter angle relative to the solar radiation will be optimize, as well as the relative area of the cells, in order to have the same current for the Si and the transparent cell. Finally, the thermal performance of the window will be measured and compared to both standard and other PV windows available on the market.

ACKNOWLEDGEMENT

This work is partially funded by the “EnergyDistrict - ED2050” program from HES-SO (University of Applied Sciences and Art of Western Switzerland”.

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