PERFORMANCE AND LIFETIME OF TANDEM ORGANIC SOLAR CELLS

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1) Context / Study motivation

The field of organic photovoltaics (OPVs) has progressed quite significantly in the last ten years for their potential as an affordable energy technology. OPV modules are lightweight, translucent, can be fabricated on flexible plastic substrates and by all-solution process. In spite of all of these advantages, OPV technology is limited by its quite low efficiency and its short lifetime in comparison to Si technology.
Tandem architectures are a strategy that could permit an efficiency increase up to 15%[1] for organic solar cell technology. They consist of a stack of two organic solar cells having complementary absorption spectra. This strategy has already demonstrated its effectiveness by achieving efficiencies up to 10.6%[2] and 10.8%[3]. However, the augmentation of the number of layers has, as a consequence, increased the risk of reducing the lifetime of the cell due to the ageing phenomena present at the interfaces[4].

2) Description of approach and techniques

After having selected two optically complementary active materials with a low overlapping absorption spectra, an optimization of both materials in single cells has been performed by varying different parameters as the donor:acceptor ratio, the solvent, the interface materials, etc.
Thereafter, the fabrication of tandem solar cells, which consist of the stack of the two previously optimized single cells, has been made. Both subcells are connected in series thanks to an intermediate layer. This configuration has, as consequence, to respect the Kirschoff's Law :

$$V_{OC_{Tandem}} = V_{oc\,HBG} + V_{oc\,LBG}$$
$$J_{sc_{Tandem}} = J_{sc_{min}}(HBG{:}LBG)$$

In those conditions, an optical simulation tool has been necessary to determine the optimal parameters of thicknesses of both active layers to obtain the highest performance. This tool allowed us to achieve efficiency close to 7%. However, in order to study the impact of the higher number of interfaces on the tandem cell and their influences, we decided to investigate two High Band Gap active materials, *HBG1* and *HBG2*, and one Low Band Gap material, *LBG1* (see figure 1). In this condition, we were able to study the degradation of two tandem configuration HBG1:$PC_{60}BM$/LBG1:$PC_{70}BM$ and HBG2:$IC_{60}BA$/LBG1:$PC_{70}BM$.Those systems allow us to determine, in addition to the influence of the interface material, the influence of the HBG in the tandem cell.

To study of the intrinsic degradation mechanisms, we exposed the interface materials, the active materials, the single and tandem solar cells under continuous illumination 100mW/cm² in N_2 atmosphere and room temperature and followed the evolution of the different parameters. We used Impedance Spectroscopy (IS), External Quantum Efficiency (EQE) and Intensity-Voltage curves (IV) for the complete devices, Scanning Kelvin Probe (SKP) for the interface materials and UV-Visible spectra together with Steady-State Photocarrier Grating (SSPG) for the active material.
These work showed different profiles of degradation depending of the active material and the architecture used.

3) Results / Conclusions / Perspectives

Firstly, we can observe that among the single cells, those based on HBG2:$IC_{60}BA$ are the most stable. We denote losses of 10% after 500H of illumination against 45% for the cells based on HBG1 and a working limited at 50h for the LBG1:$PC_{70}BM$.

Secondly, when single cells are integrated in tandem architecture, the short lifetime of LBG1:$PC_{70}BM$ single cells have a low influence on the lifetime of the tandem cells and still work after, at least, 250h of continuous illumination.
And thirdly, we can observe that the tandem cells composed with HBG2:$IC_{60}BA$ are more stable, with 2,5% of losses after 250H, than those with HBG1:$PC_{60}BM$ with 55% of losses (see Figure 2).

To start, we focused our work on the HBG1:PCBM single cell degradation. The evolution of the parameters obtained by IV Curves (figure 3) shows a decreasing of the Jsc and the FF (-12% for both) between 0h and 24h hours of illumination. The SKP measurements showed a stable behavior of the interface materials alone. The EQE measurements of the HBG1:PCBM (figure 4) show a decreasing of the quantum efficiency between 380 and 550nm during the first 24 hours. The following of the absorption spectra (figure 5) of the HBG1:PCBM demonstrates a modification at 320nm corresponding to a dimerization[5] of the acceptor molecule, the PCBM which can be the origin of this decreasing of the *Jsc* and *FF* parameters.
The same work will be made with all active material and architecture to understand why the LBG1:$PC_{70}BM$ short lifetime in single has a low influence on the lifetime of both tandem cells based on HBG1 and HBG2.

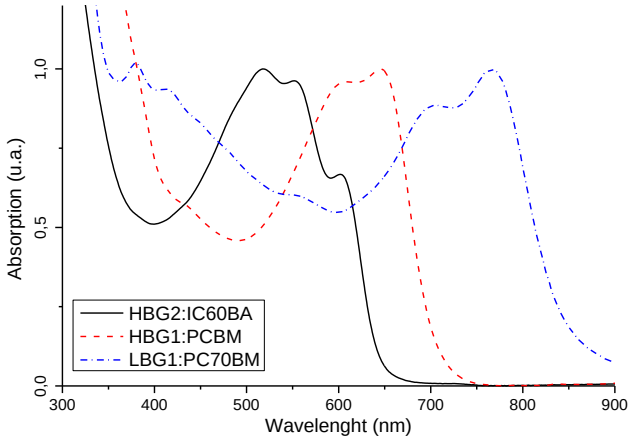

Figure 1: Absorption spectra of the active materials with their respective acceptor material.

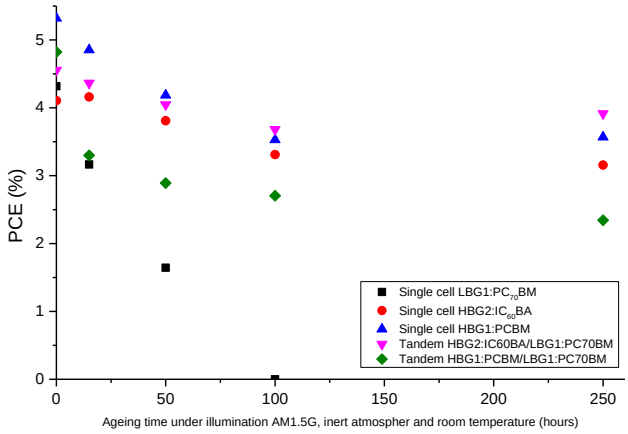

Figure 2. Evolution of the efficiency of the single and tandem solar cells under continuous illumination AM1.5G, inert atmosphere and room temperature.

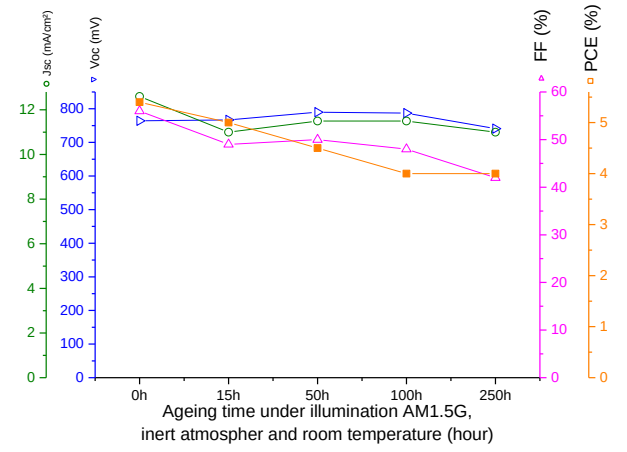

Figure 3. Evolution of the parameters of the single HBG1:PCBM under illumination AM1.5G, inert atmosphere and room temperature.

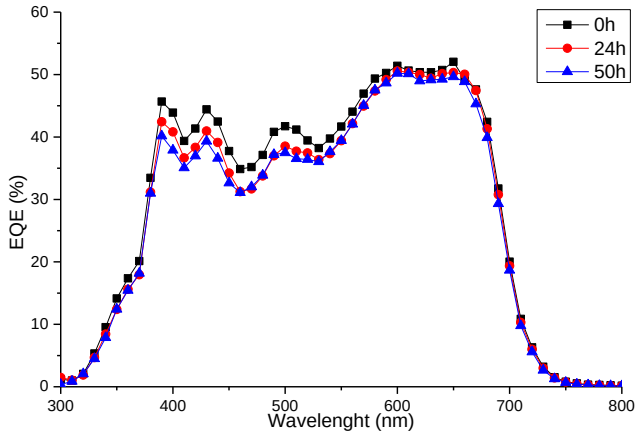

Figure 4. EQE of the HBG1:PCBM single cell at t0 and after 24h and 50h of AM1.5G illumination, inert atmosphere and room temperature.

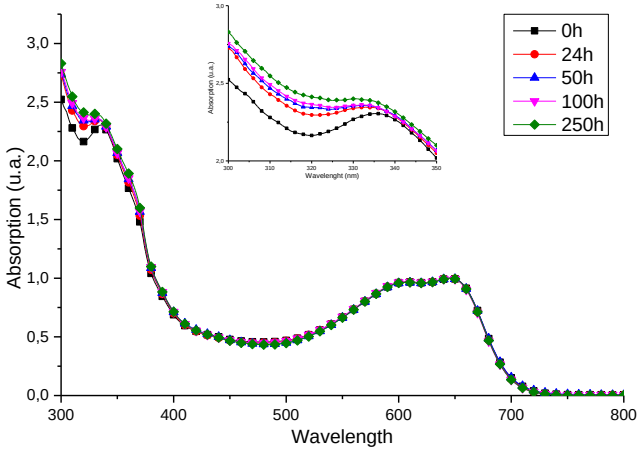

Figure 5. Absorption spectra of the single cell HBG1:PCBM under illumination AM1.5G, inert atmosphere and room temperature.

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