PhD Thesis Defense PAOLA MANTILLA PEREZ ?Multi-Junction Thin Films Solar Cells for an Optimal Light Harvesting?

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Organic Nanostructured Photovoltaics

ICFO-The Institute of Photonic Sciences

Thin film photovoltaics encompass a group of technologies able to harvest light within only a few microns thickness. The reduced thickness allows a low cost of manufacture while making the films flexible and adaptable to different surfaces. This, combined with their low weight, positioned thin film solar cells as ideal candidates for building integrated photovoltaics. For the latter, organic solar cells can provide a high quality semi-transparency that closely mimics the aesthetics of standard windows. Indeed, some unique features of organic solar cells make them the optimal solution for applications where standard Si technology cannot be used. However, for large-scale electricity production where efficiency is, perhaps, the most determining factor, newer thin film technologies like perovskites solar cells may be a more adequate option. At the moment of writing this thesis, state of the art efficiencies of single junction perovskites nearly double that of the best single junction organic solar cell. A limitation found in both technologies, especially in organics and to a lesser degree in perovskites, is the low mobility of the carriers. This, together with other processing shortcomings in the organic absorbers and perovskites limit their thickness to 100-130 nm, and 500 - 600 nm, respectively. In summary, light management must be an essential ingredient when designing device architectures to achieve the optimal performance in the specific application being considered. In this thesis, in order to achieve an optimal light harvesting and therefore increase the performance of thin film solar cells, we take two approaches. On one hand, we increase the total thickness of the absorber material used in the device without increasing the thickness of the single active material layer and, on the other hand, we combine complementary absorbers to cover a wider portion of the solar spectra. These approaches pose the double challenge of finding the optimal electromagnetic field distribution within a complicated multilayer structure containing two or more active layers, while at the same time implementing an effective charge collection or recombination in the intermediate layers connecting two adjacent sub-cells. In the case of OSC, we consider multi-junction cells where the same active material is used in all the junctions. This can be implemented by fabricating structures where the active layer thickness in each sub-cell does not exceed the 100 nm. For other types of thin film solar cells, we consider configurations using complementary absorbers. In both cases, but particularly in the former one, a systematic approach to optimize light absorption is needed. In order to obtain such optimal configurations, we implement an inverse integration approach combined with a transfer matrix calculation of the electric field. Furthermore, we develop several new approaches to optimize charge collection in the sub-cell interconnection layers which we apply to tandem, triple, 4-terminal and series-parallel configurations. The thesis has been organized into five chapters. Chapter 1 introduces concepts required for the development of the thesis work including the optical model. Chapter 2 describes the optical optimization and experimental implementation of current-matched multi-junction devices using PTB7:PC71BM, including applications. In order to profit from the advantage of electrically separated devices, Chapter 3 evaluates different types of 4-terminal architectures using PTB7:PC71BM and PTB7-Th:PC71BM. In one of the architectures we establish a serial-connection between sub-cells while in other we leave the sub-cells completely independent. Chapter 4 theoretically proposes a novel monolithic architecture combining perovskites and CIGS which does not require current-matching. Finally, in Chapter 5, an in-depth study of the semi-transparent inner electrodes is given that include vacuum-based and solution-processed layers.

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Thesis Director: Prof . Dr. Jordi Martorell