PhD THESIS DEFENSE: Photonic based approaches to overcome intrinsic losses in organic solar cells

FRANCISCO GUMARO BERNAL TEXCA

November 29, 2024

11:00 to 12:00

Elements Room

The large dependence on fossil fuels led to a severe environmental crisis, evident in the acceleration of climate change caused by the greenhouse effect. This unsustainable model has led to a reassessment of our energy infrastructure, which has initiated a shift towards more sustainable energy sources. Renewable energy sources, such as wind, hydro, and particularly solar, provide a more sustainable alternative. Solar energy, which can be transformed into electrical energy by photovoltaic (PV) cells, is notable for its abundant availability and minimal environmental impact. However, intrinsic fundamental losses in solar energy conversion limit the power conversion efficiency (PCE) of single-junction planar geometry solar cell devices to 33.1%, as described by the Shockley-Queisser detailed balance model. In this thesis, we address the study of two fundamental losses limiting the maximum efficiency achievable by planar-geometry single-junction solar cells. We consider the approach on organic solar cell (OSC)s because they offer significant benefits over traditional inorganic-based cells. OSCs, made from carbon-based materials, can be flexible, integrable, lightweight, and potentially less costly to produce. These qualities make OSCs a promising innovation for incorporating solar power into a wider range of applications, advancing the pursuit of a cleaner, more sustainable energy future. The thesis is organized into four main chapters. In Chapter 1 we discuss global energy demand and positioning solar energy as a sustainable alternative. It also covers a discussion on the intrinsic losses leading to the fundamental limits in solar energy conversion. Chapter 1 also provides an overview of the state-of-the-art OSCs, including the properties of organic semiconductor materials and device photophysics, and concludes with a justification for the research developed and described in the rest of the thesis. Chapter 2 focuses on mitigating transmission and thermalization losses by employing a tandem strategy. To overcome some of the limitations of the two-terminal configuration, we develop a four-terminal tandem structure composed of a transparent front and an opaque back cell, thus enhancing fabrication feasibility and overall performance. Chapters 3 and 4 delve into Boltzmann losses linked to a mismatch between the absorption and emission cones that directly impact the maximum achievable open-circuit voltage (Voc). In Chapter 3, we investigate the mechanisms governing the quasi-Fermi level splitting (QFLS) dynamics in OSCs. Our study identifies direct radiative recombination and recombination via trapping states as the two primary competing processes controlling the QFLS in PM6:Y6 solar cells. We propose a strategy to passivate trap states, leading to a reduction in mid-gap trap states density and, consequently, an increase in Voc. We highlight the role played by radiative recombination in regulating the final Voc of such PM6:Y6 solar cell. Chapter 4 builds on these findings by leveraging the emitted photons to experimentally demonstrate an Voc enhancement through the restriction of photon emission, thereby reducing Boltzmann losses. We demonstrate that using a two-optical resonance cavity configuration, we can obtain a reduction in the mismatch between the absorption and emission cones in OSCs. We experimentally demonstrate a solely optical-based Voc increase larger than 30 mV. In summary, the findings in the present thesis establish an optical-based path to increase Voc and the performance of the solar cells and eventually surpass the Shockley-Queisser PCE limit for planar-geometry single-junction solar cells.

Friday November 29, 11:00 h. ICFO Elements Room
Thesis Director: Prof. Dr. Jordi Martorell
Hosted by: Prof. Dr. Jordi Martorell