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Invited review

Ultrafast and fast charge separation processes in real dye-sensitized solar cells

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ABSTRACT

The increasing global energy consumption and the simultaneous non-renewable resources depletion with their rising contamination levels, make the present energy scenario unsustainable. Among all the renewable energies, the sun's energy through its direct conversion into electricity is one of the best alternatives. In particular, since 1991 dye-sensitized solar cells (DSSCs) have attracted considerable interest from the scientific and commercial communities due to their promising characteristics as solar light converters. Nevertheless, even though there have been many efforts to increase the photoconversion efficiency through the photovoltaic parameters improvement using novel materials and device construction approaches, the efficiency and stability are still open challenges. On this regard, several approaches and techniques are being used to analyze the dependence of the overall efficiency on these parameters. In particular, the fast and ultrafast time-resolved spectroscopy techniques have provided advances towards unraveling the rate constants and quantum yields of the individual processes taking place in sensitized films in air as well as in complete DSSCs. Thus, the aim of this review is to discuss the main recent findings and the importance of the application of these techniques to understand why certain complete DSSC configurations have been more successful than others in terms of good sunlight conversion efficiencies, as well as to draw the basic guidelines on how to make further improvements in DSSCs. We firmly believe that new advances in this research area using ultrafast laser-based spectroscopy will not only help to discover fundamental and yet unknown information about these devices, but will also have impact on related topics like photocatalysis and photonics, supporting both technologies' development and contributing to the growth of the fundamental knowledge on interactions among photons, electrons and materials.

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Cristina Martin received her Bachelor degree in Chemistry from the University Complutense of Madrid (UCM) in 2009. In 2010, she got her Master's degree at the University of Castilla-la Mancha (UCLM), and in 2014, she obtained her PhD degree (under the supervision of Prof. Abderrazzak Douhal and Dr. Boiko Cohen) in Nanoscience and Nanotechnology at the same University. After that, she was a postdoctoral student in the same group and recently she moved to Belgium as FWO Fellow in Prof. Johan Hofkens' group at KU Leuven. Her research interest is focused on the application of different time-resolved and single-molecule spectroscopic tools in order to understand fast and ultrafast processes in materials science.

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1. Introduction and state of the art

Nowadays, energy is involved in the provision of every kind of goods and service, which in conjunction with a rising population and a heavy industrialization; make essential a steady and reliable energy supply [1]. Therefore, the global energy consumption, which is projected to reach 27 TW per year in 2040 [1], in addition to the menacing depletion of the non-renewable sources and their rising extraction costs [2], make unsustainable the present energy scenario of using fossil fuels [1,3]. Fortunately, considerable attention is being paid to the production, storage and distribution of energy originated from (unlimited) renewable sources [4–6], among which the Sun's energy has been identified as an efficient source of the key technologies to shift from fossil fuels to a decarbonized energy supply strategy. This statement is mainly based on two reasons: (1) the amount of energy produced by the Sun in 1 h is higher than the current worldwide yearly consumption (12 TW) [7]; and (2) the feasibility to directly transforming this energy into electricity (one of the most used kinds of energy due to its versatility and ease of transportation).

In 1954, Chaplin, Fuller and Pearson gave birth to the called "first generation" of solar devices [8], and a great interest was raised throughout the scientific and related commercial communities. Nevertheless, although a lot of efforts have been made to increase the conversion efficiency and reduce the final devices cost by using different device construction approaches (known as the "second" and "third generation" of solar cells [9,10]) sunlight energy conversion into electricity still presents scientific and technological challenges. In spite of this, this process does not present any problem for Nature, where over billions of years plants and bacteria are using sunlight as their primary energy source to produce and

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