

Charge carrier lifetime measurements in organic solar cells: A comparative study of experimental techniques

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Charge carriers photo-excited into higher energy excited states do not have an infinite lifetime: they relax back to the lowest energy state either radiatively or non-radiatively. In organic solar cell materials this relaxation occurs through a series of competing pathways and may involve a large number of charged or neutral intermediates. Charge carrier lifetime determines the maximum concentration of photogenerated charges stored within the solar cell under illumination, therefore has a major impact on the open circuit voltage. At conditions other than V_{oc} , charge recombination, characterized by charge carrier lifetime τ , competes with charge extraction, characterized by the transit time t_{tr} . Efficient charge extraction requires lifetimes significantly larger than the transit times, which in turn will limit the maximum thickness of the photovoltaic material. For the above reasons, charge carrier lifetime is one of the most important parameters from both a fundamental and practical point of view. Due to the various competing charge recombination reactions and the disordered state of the charge transporting sites leading to dispersion, the determination of charge carrier lifetime under operational conditions on operational devices is challenging. It requires a combination of experimental techniques and a critical comparison of the results performed on the same samples.

In this presentation, through specific examples I will review a range of time-resolved optical and electrical experimental techniques. First, open-circuit voltage limiting charge recombination reactions are compared in porphyrin dye-sensitised TiO_2 solar cells and commercially available ruthenium complexes.¹ Furthermore, the effect of TiO_2 particle size and crystallinity,² dye structure³ and surface treatment⁴ will be briefly discussed.

P-type dye-sensitised solar cells, which use photoinduced hole injection from a dye into the valence band of an inorganic oxide, work in reverse to conventional n-type dye-sensitised solar cells. Although the concept of p-type sensitization has been demonstrated a decade ago, the efficiency was limited to $< 1\%$ until very recently. A series of new dyes have been developed⁵ with internal quantum efficiency now comparable to their n-type analogs. Using transient absorption spectroscopy, we have attributed this to the significantly longer lifetime of the dye anion on the surface of nanostructured NiO. This enables the fabrication of efficient tandem DSSCs, where the open circuit voltage is determined by the Fermi level difference in the n-type and p-type semiconductor and not influenced by the electrochemical potential of redox mediator.

On the dye regeneration side, multiple wavelength, nanosecond transient absorption measurements are used to determine the charge regeneration efficiency in solid-state dye-sensitised solar cells using various amounts of photo-deposited PEDOT hole conductors.⁶

In the last part of the presentation, various charge extraction techniques will be demonstrated to study charge recombination in bulk heterojunction solar cells based on thiophene

dendrimer/PCBM heterojunctions.⁷ Charge extraction using a nanosecond switch, charge extraction by a delayed voltage pulse and transient absorption measurements will be compared.

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