Understanding Charge Carrier Dynamics in Solar Cell Materials using Time Resolved Terahertz Spectroscopy

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***Abstract*—The need for developing highly efficient solar cell devices have never been so pressing until recently when the urgency of using renewable energy sources becomes more evident. There are several promising technologies being explored by many groups with the sole purpose of optimizing harvesting sunlight and converting it to useful electricity. These include, but not limited to, dye- and quantum dot-sensitized, bulk heterojunction organic, inorganic nanowires, and very recently perovskite-based solar cells. In this talk, charge carrier dynamics of an assortment of solar cell technologies probed using time-resolved terahertz spectroscopy will be presented. Electron injection, mobility, charge carrier lifetime and recombination dynamics will be discussed.**

I. INTRODUCTION

THE terahertz (THz) regime contains useful information on the conductivity of materials in the nanoscopic length scales. When used as probe of charge transport after photoexcitation, these far-infrared waves could help reveal charge carrier behavior from subpicosecond to nanosecond timescale. Upon above-band gap optical excitation, electron and hole pairs are generated in the conduction and valence bands of the material, respectively. This results in a change of conductivity of the material, from the ground state (σ(f)) to the photo-induced, or transient conductivity (Δσ(f)). The conductivity normalized to the excitation density, en_{exc}, is the primary result of time-resolved THz spectroscopy (TRTS) experiment and expressed as:

$$\xi x\mu(f) = .\frac{\Delta\sigma(f)}{n_{exc}e_0}(cm^2V^{-1}s^{-1})$$

where e is the elementary charge, n_{exc} the excitation density and ζ is quantum yield. The signal size of transient THz photoconductivity per photon absorbed gives the average mobility μ(f) per charge carrier, while its rise and/or decay could reflect charge transfer, lifetime and recombination dynamics of photogenerated charges.

II. RESULTS

Shown in Figure 1 is the early time THz kinetics of different solar cell materials normalized to 1. For bulk heterojunction materials, i.e. APFO:PCBM and TQ1:PCBM, an instrument limited rise is followed by a fast few picosecond decay. The rise is assigned to photogeneration of charges while the decay is due to charge pair annihilation brought about very high excitation density [1,2]. The rise time in the THz photoconductivity signal for CdSe quantum dot (QD) and perovskite $CH_3NH_3PbI_3$ attached to TiO_2 appears to be slower than those of the organic-based materials. We note that since the response of the set-up is within the same timescale, interpretation of this rise is not straightforward. On one hand, the rise in CdSe/TiO_2 is followed by an almost constant signal. This is interpreted as electron injection to TiO_2 since non-attached CdSe showed fast decay at this timescale (details is found in Ref. 3). On the other hand, perovskite $CH_3NH_3PbI_3/TiO_2$ kinetics represents the hole left in the perovskite since electrons are injected in TiO_2 with very small signal (0.1 cm^2/Vs) compared to the estimated hole mobility of 7.5 cm^2/Vs. Finally, for InP NWs, the generation of charge carriers is also instrument limited. Details can be found in Ref. 5.

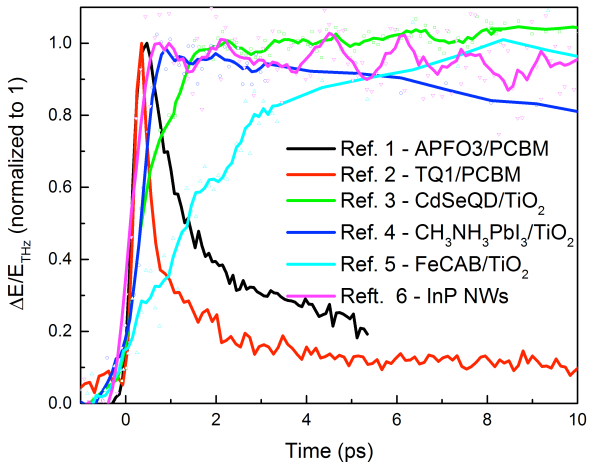

Fig. 2. Early time THz photoconductivity kinetics of different solar cells materials showing characteristic times of photogeneration and charge injection.

Discussion of the recombination dynamics and the use of other optical spectroscopy techniques to understand the charge carrier behavior in the ultrafast regime will be presented in this keynote lecture.

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