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Carrier Diffusion Waves in Electronic Solids used in Clean Energy Technologies

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Abstract

Photocarriers in semiconductors excited by modulated laser sources give rise to charge diffusion waves that can be used to study and characterize the electronic transport properties of materials and devices. In this talk the concept of carrier diffusion waves (CDW) will be introduced for continuousband semiconductors (e.g. Si); and of hopping diffusion waves in nanolayers (e.g. colloidal quantum dot (CQD) excitonic ensembles). The fundamental transport equations describing these coherent oscillations will be presented with focus on the key CDW parameters: wavenumber, diffusivity, drift velocity, mobility, diffusion length and surface/interface diffusion currents determined by recombination velocities and flux transfer coefficients [1,2].

In continuous-band materials CDW transport is limited by band-to-band recombination and band-todefect state decays with relaxation times controlled by bandgap defect and impurity state trap densities interacting with the free carrier bandedges through thermal emission and capture rates. The CDW concept has given rise to dynamic material and device diagnostic methodologies, specifically the dynamic, spectrally-gated photoluminescence-based modalities photocarrier radiometry (PCR) [3] and its imaging analog, lock-in carrierography (LIC) [4]. Examples of PCR and LIC applications to the measurement and imaging of diffusion-wave parameters in micro- and opto-electronic materials and devices will be discussed.

In discrete-particle nanolayers (CQD ensembles, in particular), very recent formulations of the hopping CDW theory [5,6] leading to physical insights into diffusion and drift mechanisms in bandenergy-equivalent structures consisting of CQD will be presented with focus on how excitonic and/or dissociated carrier hopping diffusion determines anomalous S-shaped current-voltage characteristics of state-of-the-art nanolayered solar cells. The effects of the presence of electrodes in photovoltaic solar-cell device quality will be identified by means of ultra-high-frequency LIC images revealing compromises in carrier diffusivities and diffusion lengths at the contract-nanolayer interface.

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