UNIVERSITY OF CALIFORNIA, IRVINE

Department of Materials Science and Engineering

Exploiting Disordered Photonics for Light Trapping in Photoelectrochemical Energy Conversion Applications

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Abstract: Photoelectrochemical (PEC) solar energy conversion applications rely on chemical reactions drive n by photogenerated minority carriers (electrons or holes) at a semiconductor-liquid junction. The optical, electronic, and chemical transport processes characteristic of these PEC reacti ons occur on independent and generally disparate length scales. Fabricating electrodes with hierarchical structure can optimize the performance for each of these processes simultaneously. However, the optimal structure for one process is generally at odds for another. Our research focuses on disordered, hierarchically structured materials as the basis for PEC photo-electrodes. Disordered materials with dielectric contrast on the length scales of the wavelength of light can trap light in localized modes. The simplicity of the fabri-cation alone makes this approach a particularly attractive one for engineering light trapping into scalable photoelectrode structures. We have recently introduced an approach to synthesizing disordered colloidal composites (SiO_2 and polystyrene) and selectively removing the polystyrene spheres from the assembly. This allows us to fabricate defects in disordered or random assemblies of SiO_2 nanospheres to function as resonant optical cavities in disordered assembles of scatters called pho-tonic glasses. We have demonstrated that we can functionalize these structures with a thin semiconductor light absorber to improve the rate of PEC water oxidation, for example. This approach can also generate the multiscale structure necessary for uniting the many important transport length scales for PEC energy conversion into a single, simple material. In this talk, we will introduce our combined theoretical and experimental approach to building photoelectrodes based on disordered photonic scaffolds as a way to dramatically improve light absorption and quantum yield in thin-film semiconductors. One significant issue is that disordered materials can only be defined by ensemble or statistical parameters (pore diameter, scatterer diameter, relative volume fractions) rather than as precise structures, which re-sults in a real, physical variance intrinsic to the ensemble structure. Simulations of the ensemble properties (local light absorption, for example) require a large num-ber of examples for a given statistical configuration. We will describe our recent efforts to use machine learning to improve the computational efficiency of finite-difference time-domain simulations in ensembles of disordered photonic glasses. We will outline how these algorithmic predictions can be used to identify the most efficient ensemble configuration for a given semiconductor photoelectrode. Finally, we will discuss recent experimental photoelectrode constructions synthesized via atomic layer deposition and electrodeposition. We will conclude by considering methods to selectively functionalize the high-quality light-trapping defects via photo-electrodeposition.

Bio: Rob Coridan is an Assistant Professor in the Department of Chemistry and Biochemistry at the University of Arkansas. His group's research interests include de-veloping novel approaches to characterize and fabricate structured solar fuel materials. In addition to materials synthesis, they are also interested in the use of syn-chrotron x-ray scattering and machine learning to study the fundamental properties of these materials at the nanoscale. Prof. Coridan is the recipient of a Department of Energy Early Career Award (2019), a Sloan/RCSA Scialog Fellowship for Negative Emissions Science (2020), and is active in several NSF-funded collaborations. Prior to joining the University of Arkansas, Prof. Coridan earned his Ph.D. (2009) in Physics from the University of Illinois, Urba na-Champaign, where he studied the femto-second dynamics of liquid water with inelastic x-ray scattering under the supervision of Prof. Gerard Wong (now at UCLA). He was also a Postdoctoral Scholar in Chemistry (2010-2015) at the California Institute of Technology under the supervision of Prof. Nate Lewis.