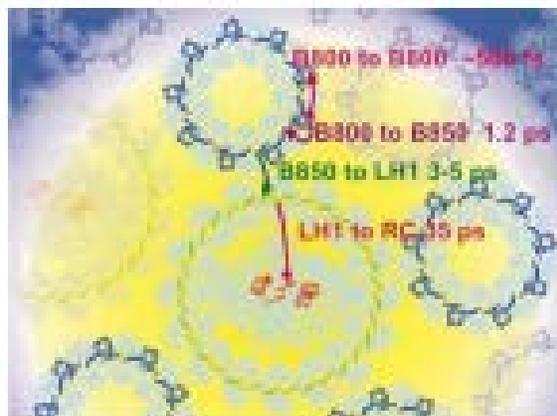


**Center for Excitonics (CE)**  
**EFRC Director: Marc Baldo**  
**Lead Institution: Massachusetts Institute of Technology**

**Mission Statement:** *To understand the transport of charge carriers in synthetic disordered systems, which hold promise as new materials for conversion of solar energy to electricity and electrical energy storage.*

Excitons are the crucial intermediate for energy transduction in low cost, disordered semiconductors. In this center, we seek to supersede traditional electronics with devices that use excitons to mediate the flow of energy. The problem with conventional electronic devices is that they are difficult to manufacture; their constituent materials require very high levels of order and achieving such low entropy in a semiconductor requires expensive and energy intensive fabrication. For example, the energy payback time for a crystalline silicon solar cell is on the order of 2 years, and at current manufacturing growth rates, it is expected to take at least 20 years to produce enough silicon-based solar cells to make a significant impact on the world energy supply. Similarly, epitaxial growth constraints are likely to limit solid state lighting sources to a small fraction of the overall demand for lighting.

There is an alternate approach that is more suitable for large scale production. We will use materials with only short-range order. Such *nanostructured* materials are compositions of nano-engineered elements such as organic molecules, polymers, or quantum dots and wires, in films bound together by weak van der Waals bonds. These materials are characterized by *excitons* that are *localized* within the ordered nanostructures. Due to localization of the excited states, the optical properties of the films are relatively immune to longer-range structural defects and disorder in the bulk. And in contrast with the painstaking growth requirements of conventional semi-conductors, weak van der Waals bonds allow nanostructured semiconductors to be readily deposited on a variety of materials at room temperature.



**Figure 1.** An excitonic circuit in photosynthesis. Like our nanostructured devices, photosynthesis exploits excitons and exhibits much larger levels of long range disorder than conventional solar cells. Image: Sundstrom, *et al.* J. Phys. Chem. B **103**, 2327 (1999).

Our efforts are divided into four working groups, each containing between three and five faculty devoted to key scientific problems confronting the development of more efficient solar cells and solid state lighting.

**(i) Coherence and disorder**

The aim of this working group is to understand exciton transport in locally organized materials. Our first model system is photosynthetic antennas. Photosynthesis is an excitonic system that has been optimized for more than 2 billion years. What can it tell us that is fundamental about controlling the transport of excitons? Our second model system is J-aggregates, where we perform theory and experiments. J-aggregates are self-assembled semicrystalline structures that are relevant to practical

organic solar cell materials. Here, the key questions are: What controls exciton formation in these structures? How big are the excitons? Do they spread out over multiple molecules? And what is the role of disorder? In both model systems, we also address the role of coherence. One of the most exciting research directions at present is the suggestion that phase coherence in the initial life of the exciton might help its transport within photosynthetic structures. We are pursuing this direction with the development of a 2D Fourier Transform Spectroscopy tool with a unique ability to quickly reconfigure multiple beams using a spatial light modulator.

**(ii) Semiconductor Nanocrystals**

Semiconductor nanocrystals are the perfect example of energy localized into excitons by material design. In this group, we seek to understand exciton dynamics in semiconductor nanocrystals using multiexciton spectroscopy and photonic interrogation of single quantum dots in the visible and infrared. Two key fundamental problems are addressed in studies of single quantum dots. First, what is the origin of ‘blinking’? This is the phenomenon where a single dot mysteriously and transiently turns off, and is no longer able to emit light. Is it still observed in the infrared? Second, what is the efficiency of multiple exciton generation in the infrared? By generating more than one charge per incident photon, this process could increase solar efficiencies beyond the single junction limit. Interrogating individual nanocrystals is a challenging task due to the inherently small optical cross section. We are pursuing two approaches to this problem. First, we are developing superconducting nanowire single photon detectors (SNSPDs). Second, we are building photonic nanostructures to collect photons for single nanocrystals. To complete our efforts, we are examining the dynamics of quantum dot films in electroluminescent structures. What are the efficiency losses in these devices? How can they be operated at very high brightness?

**(iii) Solar Antennas**

This working group seeks to use excitonics to collect, concentrate, and wavelength-convert sunlight for single junction solar cells, thereby increasing their efficiencies beyond conventional limits (>30%). Key topics for this team are: singlet exciton fission and solar-powered lasers for coherent upconversion.

**(iv) Solid State Lighting**

This working group combines excitons with photons to form ‘exciton polaritons’ - new states of matter and energy. The combination of excitons and photons has important new properties that may be exploited in new classes of energy conversion devices, especially ultralow threshold lasers that may be the foundation of future solid state lighting.

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