EFRC: CENTER FOR EXCITONICS (CE)

UPDATED: AUGUST 2016

AWARDS: $19.0M (August 2009 – July 2014); $14.8M (August 2014 – July 2018)	
WEBSITES: http://science.energy.gov/bes/efrc/centers/ce/; http://www.rle.mit.edu/excitonics/	
TEAM: **Massachusetts Institute of Technology (Lead)**: Marc Baldo (Director), Mark Bathe, Moungi Bawendi, Vladimir Bulovic, Mircea Dinca, Dirk Englund, Pablo Jarillo-Herrero, Jing Kong, Leonid Levitov, Ju Li, Keith Nelson, Gabriella Schlau-Cohen, Will Tisdale, Troy Van Voorhis, Adam Willard; **MIT Lincoln Laboratory**: Eric Dauler; **Harvard University**: Alan Aspuru-Guzik; **Brookhaven National Laboratory**: Charles Black, Eric Stach	

SCIENTIFIC MISSION AND APPROACH

CE's mission is to supersede traditional electronics with devices that use excitonics to mediate the flow of energy. Excitons are nanoscale packets of energy that are characteristic of low-cost materials for solar cells and solid state lighting. Conventional materials require long range order and few defects, however excitons can survive in materials like organic molecules, quantum dots and wires, or 2D crystals that have shorter-range order. The room temperature synthesis of these more disordered materials significantly lowers manufacturing costs. CE aims to increase the efficiency of solar cells, and to develop new materials and structures for high brightness solid state lighting. The research is divided into three teams:

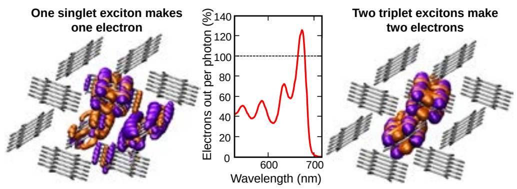
Team 1: Multiexciton Physics and Applications: Seeks to understand and master the dynamics of localized excitons in small molecules and quantum dots for solid state lighting and solar cell applications.

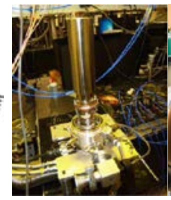
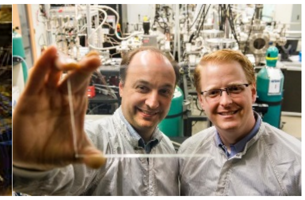
Team 2: Excitonic Antennas and Quantum Transport: Inspired by photosynthesis, study delocalized excited states in molecular assemblies known as excitonic antennas to understand how to protect excitons from long range disorder.

Team 3: Two dimensional Excitonic Crystals: Synthesize and understand the excitonic properties of 2D transition metal dichalcogenides, promising materials for solid state lighting at high brightness.

SELECTED SCIENTIFIC ACCOMPLISHMENTS

- Used singlet exciton fission to generate multiple carriers in a solar cell at an efficiency of > 1.26 electrons per photon, exceeding the unity limit in conventional electronic materials.
- In conventional nanocrystalline semiconductors, extensive single molecule spectroscopy showed that excitation of secondary electrons must out-compete rapid thermalization losses. However, in molecules, CE demonstrated that these losses are spin disallowed, meaning that exciton fission can be almost perfectly efficient.
- The first demonstration of quantum process tomography on a molecular excitonic system. Experiments unambiguously demonstrated 150 fs coherences and subpicosecond populations transfer between the inner and outer walls of a J-aggregate nanotube, an analogue to a chlorosome.
- The first single-particle spectroscopy of quantum dots in the infrared, an achievement that was made possible by the unique capabilities of CE's superconducting nanowire single photon detectors.
- Realized a hundredfold increase in efficiency of infrared quantum dot-LEDs through improved synthesis and device engineering.
- Developed nano- and atomic-scale methods to visualize exciton transport and annihilation; used the tools to diagnose why droop (low brightness) occurs in quantum dot-based LEDs.



CE research, from left: Unlike electrons, excitons can be split. CE used singlet exciton fission in pentacene to generate at least 1.26 electrons per photon; Superconducting nanowire single photon detector; Vladimir Bulovic and Miles Barrr, co-founders of Ubiquitous Energy, show a transparent solar cell that harvests invisible ultraviolet and near-infrared light into electricity.

IMPACT

- **Ubiquitous Energy**, co-founded by Bulovic in 2011, is developing the world's first truly transparent solar technology. The solar cells, first investigated at MIT as part of the CE EFRC, achieve transparency by selectively transmitting visible light, while harvesting invisible ultraviolet and near-infrared light into electricity. Ubiquitous Energy's mission is to eliminate the battery life limitations of mobile devices and power smart glass for buildings. It has won numerous awards, including NSF SBIR/STTR awards and the 2015 Display Week Innovation Award, and has a pilot plant in CA. http://www.ubiquitous-energy.com/
- **Photon Spot Inc.**, founded in 2009, specializes in superconducting nanowire single-photon detectors, their applications, and sub-Kelvin cryogenic systems. Photon Spot evaluated CE research on super-conducting nanowire single-photon detectors for their business. http://www.photonspot.com/
- CE research accomplishments have been the basis for over $8M in follow-on funding.

PUBLICATIONS AND INTELLECTUAL PROPERTY

As of May 2016, CE had published 202 peer-reviewed publications cited over 5,800 times and filed 31 disclosures, 21 US patent applications, and 12 foreign patent applications. Four patents have been issued and 2 disclosure and patent applications licensed. A selection of highly cited papers are:

- Shirasaki, Y., Supran, G., Bawendi, M. & Bulovic, V. Emergence of colloidal quantum-dot light-emitting technologies. *Nature Photonics* **7**, 13-23, doi:10.1038/NPHOTON.2012.328 (2013). [**404 citations**]
- Congreve, D. et al. External Quantum Efficiency Above 100% in a Singlet-Exciton-Fission-Based Organic Photovoltaic Cell. *Science* **340**, 334-337, doi:10.1126/science.1232994 (2013). [**225 citations**]
- Gan, X. et al. Chip-integrated ultrafast graphene photodetector with high responsivity. *Nature Photonics* **7**, 883-887, doi:10.1038/nphoton.2013.253 (2013). [**221 citations**]
- Shustova, N. B., McCarthy, B. D. & Dinca, M. Turn-On Fluorescence in Tetraphenylethylene-Based Metal-Organic Frameworks: An Alternative to Aggregation-Induced Emission. *Journal of the American Chemical Society* **133**, 20126-20129, doi:10.1021/ja209327q (2011). [**180 citations**]
- Seo, K. et al. Multicolored Vertical Silicon Nanowires. *Nano Letters* **11**, 1851-1856, doi:10.1021/nl200201b (2011). [**162 citations**]
- Zhao, J., Nair, G., Fisher, B. & Bawendi, M. Challenge to the Charging Model of Semiconductor-Nanocrystal Fluorescence Intermittency from Off-State Quantum Yields and Multiexciton Blinking. *Physical Review Letters* **104**, doi:10.1103/PhysRevLett.104.157403 (2010). [**144 citations**]
- Shustova, N. B., Cozzolino, A. F., Reineke, S., Baldo, M. & Dinca, M. Selective Turn-On Ammonia Sensing Enabled by High-Temperature Fluorescence in Metal-Organic Frameworks with Open Metal Sites. *Journal of the American Chemical Society* **135**, 13326-13329, doi:10.1021/ja407778a (2013). [**136 citations**]
- Wang, K. *et al*. Trapping and rotating nanoparticles using a plasmonic nano-tweezer with an integrated heat sink. *Nature Communications* **2**, doi:10.1038/ncomms1480 (2011). [**121 citations**]
- Nair, G., Chang, L., Geyer, S. & Bawendi, M. Perspective on the Prospects of a Carrier Multiplication Nanocrystal Solar Cell. *Nano Letters* **11**, 2145-2151, doi:10.1021/nl200798x (2011). [**119 citations**]
- Shim, S., Rebentrost, P., Valleau, S. & Aspuru-Guzik, A. Atomistic Study of the Long-Lived Quantum Coherences in the Fenna-Matthews-Olson Complex. *Biophysical Journal* **102**, 649-660, doi:10.1016/j.bpj.2011.12.021 (2012). [**112 citations**]