Light-Material Interactions in Energy Conversion (LMI)
EFRC Director: Ralph Nuzzo
Lead Institution: California Institute of Technology
Start Date: August 2009

Mission Statement: *To tailor the morphology, complex dielectric structure, and electronic properties of matter so as to sculpt the flow of sunlight and heat, enabling light conversion to electrical energy with unprecedented efficiency.*

The Light-Material Interactions in Energy Conversion Energy Frontier Research Center (LMI-EFRC) is a national resource for fundamental optical principles and photonic design used for solar energy conversion. This Center is a foundational partnership between scientific world leaders in optical properties of matter, internationally recognized experts in photovoltaic energy conversion, and innovators in the design and fabrication of novel electronic and photonic materials. The Center features a team of researchers spanning Caltech, Harvard, Lawrence Berkeley National Laboratory, Stanford, and University of Illinois at Urbana-Champaign. In its renewal phase, the LMI-EFRC is comprehensively addressing new opportunities for very high efficiency solar energy conversion, making scientific discoveries that enable the efficient utilization of the entire visible and infrared solar resource.

Objectives for 2014-2018

The overarching objective of the LMI is to develop fundamental principles and new photonic materials and structures that can yield advances in ultrahigh solar conversion efficiency. Specifically, we aim to:

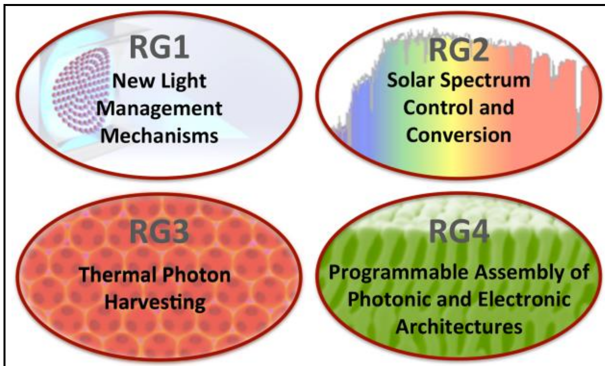
- Identify new mechanisms, materials, and enabling structures for the control and exploitation of light-material interactions along with predictive mathematical methods for their inverse design.
- Design photonic principles and fully integrated structures delivering unprecedented capabilities for control and conversion of the solar spectrum to greatly enhance photovoltaic efficiency.
- Establish fundamental principles for the utilization and control of thermal photonics with a holistic view of both the emitter and absorber, and discover new structures and materials that enable efficient and useful forms of energy conversion.
- Develop advanced materials and fabrication methods for the programmable assembly of electronic and photonic architectures in arbitrary form factors that enable more efficient electron transport, photon capture, optical power flow and dispersion in devices that harness passive and actively controlled light-matter interactions.

Selected Accomplishments to Date

- Discovered new principles of photon emission to maximize photovoltaic conversion efficiencies, providing the foundations of current world record single, dual, and quadruple-junction solar cells.
- Designed photonic crystals with record performance, demonstrating the first optoelectronically active 3D photonic crystal LED and selective thermal emitters with unprecedented stability.
- Advanced quantum dot materials and new principles of photonic design enabling luminescent solar concentrators with record concentration ratios and levels of performance.
- Developed assembly schemes and interface materials for quadruple junction, four terminal solar cells with efficiencies of 44% at concentrations of 1000 suns.
- Developed light-driven material synthesis processes that enable energy conversion materials to develop their own complex architectures in response to illumination conditions.
- Established mathematical methods that enable the design and optimization of photonic structures for light-trapping, spectrum-splitting, and control of near-field thermal emission.
- Identified light-matter interaction principles and synthesis methods impacting the companies Alta Devices, Caelux, Semprius, MC10, and Electroninks Inc, all co-founded by LMI investigators.

Center Research Team and Scientific Organization

The Center is organized scientifically into four research groups (RGs) that address scientific themes related to light-matter interactions, with each team spanning multiple institutional partners and designed to address our four-year scientific objectives.



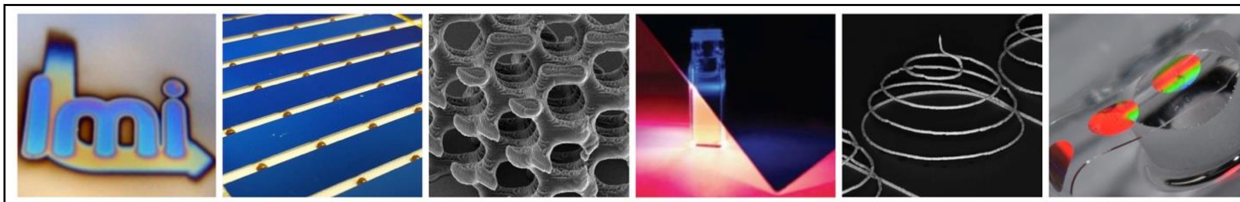
Research groups of the LMI-EFRC.

<u>RG1 New Light Management Mechanisms</u>: Exploring new mechanisms and metaphotonic structures for controlling and usefully mediating light-material interactions along with predictive mathematical methods for their inverse design. RG1 is a theoretically motivated effort to develop building block components and optical mechanisms connecting to RG2, RG3, and RG4.

<u>RG2 Solar Spectrum Control and Conversion</u>: Designing photonic principles and fully integrated structures delivering unprecedented capabilities for control and conversion of the solar spectrum to greatly enhance photovoltaic efficiency.

<u>RG3 Thermal Photon Harvesting</u>: Establishing fundamental principles for the utilization and control of thermal photonics, and discovering new structures and materials that enable efficient and useful forms of energy conversion.

<u>RG4 Programmable Assembly of Photonic and Electronic Architectures</u>: Developing powerful new methods for programmable assembly of photonic, electronic, and optoelectronic architectures that yield both materials and device specific elements of enhanced performance.



Representative LMI research efforts, from left: refractive index design via porous Si etching; concentrating photovoltaics capturing diffuse and direct irradiance; gyroid photonic crystal fabricated by two-photon lithography; photonic mirror and quantum dot design for luminescent solar concentrators; printed conductive Ag microstructures; conformal metafilm of Si nanoposts.

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