# Optics and Photonics for Advanced Energy Technology

## Topical Meeting

**Sponsored by OSA and MIT Center for Integrated Photonics Systems**
**Co-Sponsored by MIT Energy Initiative**

**Technical Conference: June 24-25, 2009**
Massachusetts Institute of Technology
MIT Center for Integrated Photonic Systems
Cambridge, Massachusetts, USA

Postdeadline Submission Deadline: June 9, 2009 (12:00 p.m. noon EDT; 16.00 GMT)
Pre-Registration Deadline: June 10, 2009
Information on Housing and Hotel Reservations can be found on the CIPS housing webpage.

### 2009 Meeting Chairs

Rajeev Ram, *MIT, USA*
Vladimir Bulovic, *MIT, USA*
Fred Leonberger, *MIT, USA*

### About Optics and Photonics for Advanced Energy Technology

The MIT Center for Integrated Photonic Systems (CIPS) and OSA present an exciting new meeting on the rapidly expanding roles of optics and photonics in energy generation and conservation. A major objective of the meeting is to provide an interactive forum to generate discussion among researchers and practitioners, across the energy value chain. Three key energy topics will be covered–solar, solid state lighting and energy-source development and efficiency–and the meeting will include a focus on optical systems and design. The meeting will showcase the development and deployment of these energy technologies including barriers and opportunities to accelerate the impact of optics and photonics in this growing field. Program highlights feature three keynote speakers who are leaders in the energy field spanning the technology, public policy and finance arenas. The MIT Energy Initiative, a major campus-wide program, is a co-sponsor of the meeting.

### Topics to Be Covered

- Solar
  - Photovoltaics and solar thermal
  - Advanced materials and devices, including nanostructures
  - Manufacturing technology
  - Diagnostics
  - Concentrators
  - Optical Systems
- Solid State Lighting
  - Materials and devices, including organics and other advanced materials
  - Smart lighting technologies
- Energy-Source Development and Efficiency
  - Fiber optic sensors for conventional and renewable energy sources (e.g., use in wind turbines, smart electric-power grids and oil exploration/extraction)
  - Optics for enabling chemical- and biological-based energy generation and storage

## Sponsors

*Co-Sponsor*:

# About Optics and Photonics for Advanced Energy Technology

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OSA The Optical Society

CiPS AT MIT

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MITei MIT Energy Initiative

# Program Committee

## Program Chairs

Rajeev Ram, *MIT, USA*
Vladimir Bulovic, *MIT, USA*
Fred Leonberger, *MIT, USA*

## Committee Members

Marc Baldo, *MIT, USA*
Tonio Buonassisi, *MIT, USA*
Shanhui Fan, *Stanford Univ., USA*
Alan Kost, *Univ. of Arizona, USA*
Peter Peumans, *Stanford Univ., USA*

# Special Events

## Reception and Dinner

*Wednesday, June 24, 2009, 6:30 p.m.-8:30 p.m.*
*MIT Faculty Club*

Join us on Wednesday, June 24 for a reception and dinner at the MIT Faculty Club, located on the Charles River providing great views of the nearby Boston skyline. The dinner speaker, Jeff Adams from Goldman Sachs, USA, will be giving a talk titled, “Wall Street Perspective on the Alternative Energy Sector” focusing on the finance and investment view of optics and alternative energy from a leading investment bank.

## Additional Conference Information

**Meals**
All meals, including breakfast and lunch and the Wednesday dinner, are included in your conference registration fee. See the program book for locations and times.

**Poster Sessions**
The poster sessions on Wednesday and Thursday include many posters from MIT graduate students. This is a great opportunity for attendees to learn about students’ research and meet and greet with the next generation of optical scientists.

# Invited Speakers

### Keynote Speakers

**Solar Energy Prospects**, John M. Deutch
**Solar Photovoltaics Technology: The Revolution Begins**, Lawrence L. Kazmerski
**Wall Street Perspective on the Alternative Energy Sector**, Jeffrey D. Adams

## Plenary Speakers

**WA1, Solar Energy Prospects**
John M. Deutch
*Institute Professor, MIT, USA, and former US Undersecretary of Energy*

**Abstract:** Electro optical technology is the key element for transformation of sunlight to heat, electricity, or fuels. Successful innovation, requires integration into a system designed for a particular application. The criteria for success include cost, and environmental benefit, as well as technical performance. However the absence of clear government policies adds additional uncertainty to design choices and comparison between different approaches. Despite these challenges it is sure that solar will become a dominant source of energy in the future -- when and how much cannot be predicted today.

**Biography:** John Deutch is an Institute Professor at the Massachusetts Institute of Technology. Mr. Deutch has been a member of the MIT faculty since 1970, and has served as Chairman of the Department of Chemistry, Dean of Science, and Provost. Mr. Deutch has published over 160 technical publications in physical chemistry, as well as numerous publications on technology, energy, international security, and public policy issues.

John Deutch served as Director of Central Intelligence from May 1995-December 1996. From 1994-1995, he served as Deputy Secretary of Defense and served as Undersecretary of Defense for Acquisition and Technology from 1993-1994. John Deutch has also served as Director of Energy Research (1977-1979), Acting Assistant Secretary for Energy Technology (1979), and Undersecretary (1979-80) in the United States Department of Energy.

In addition, John Deutch has served on the President's Nuclear Safety Oversight Committee (1980-81); the President's Commission on Strategic Forces (1983); the White House Science Council (1985-89); the President's Intelligence Advisory Board (1990-93); the President's Commission on Aviation Safety and Security (1996); the President's Commission on Reducing and Protecting Government Secrecy (1996-1997); and as Chairman of the Commission to Assess the Organization of the Federal Government to Combat the Proliferation of Weapons of Mass Destruction (1998-99). He was a member of the President's Committee of Advisors on Science and Technology (1997-2001). He received the Aspen Strategy Group Leadership Award in 2004 and was the Phi Beta Kappa "Orator" at Harvard University, 2005. He is a member of the National Petroleum Council John Deutch serves as director for the following publicly held companies: Cheniere Energy, Citigroup, and Raytheon. He is a trustee of the Center for American Progress, the Museum of Fine Arts, Boston, Resources for the Future, and a life trustee the Urban Institute.

*B.A. - History and Economics, Amherst College*
*B.S. - Chemical Engineering, MIT*
*Ph.D. - Physical Chemistry, MIT*

**ThA1, Solar Photovoltaics Technology: The Revolution Begins**
Lawrence L. Kazmerski

*Executive Director, Science and Technology Partnerships, Natl. Renewable Energy Lab, USA*

**Abstract:** The prospects of current and coming solar-photovoltaic (PV) technologies are envisioned, arguing this solar-electricity source is at a *tipping point* in the complex worldwide energy outlook. The co-requirements for policy and technology investments are strongly supported. The emphasis of this presentation is on R&D advances (cell, materials, and module options), with indications of the limitations and strengths of crystalline (Si and GaAs) and thin-film (a-Si:H, Si, Cu(In,Ga)(Se,S)2, CdTe). The contributions and technological pathways for *now and near-term* technologies (silicon, III-Vs, and thin films) and status and forecasts for *next-generation* PV (organics, nanotechnologies, non-conventional junction approaches) are evaluated. Recent advances in concentrators with efficiencies headed toward 50%, new directions for thin films *(20% and beyond)*, and materials/device technology issues are discussed in terms of technology progress. Insights into technical and other investments needed to *tip* photovoltaics to its next level of contribution as a significant clean-energy partner in the world energy portfolio. The need for R&D accelerating the now and imminent *(evolutionary)* technologies balanced with work in mid-term *(disruptive)* approaches is highlighted. Moreover, technology progress and ownership for next generation solar PV mandates a balanced investment in research on *longer-term* (the revolution needs *revolutionary* approaches to sustain itself) technologies (quantum dots, multi-multijunctions, intermediate-band concepts, nanotubes, bio-inspired, thermophotonics, solar hydrogen. . . ) having high-risk, but extremely high performance and cost returns for our next generations of energy consumers. Issues relating to manufacturing are explored—especially with the requirements for the next-generation technologies. This presentation provides insights (some irreverent) into how this technology has developed—and where we can expect to be by this mid-21st century.

**Biography:** Lawrence L. Kazmerski is Executive Director, Science and Technology Partnerships at the National Renewable Energy Laboratory, Golden, Colorado—having served as Director of the *National Center for Photovoltaics* for the period 1999-2008. He received his B.S.E.E. in 1967, M.S.E.E. in 1968, and his Ph.D. degree in electrical engineering in 1970—all from the University of Notre Dame. He served in a postdoctoral position at the University of Notre Dame Radiation Research Laboratory (Atomic Energy Commission), January through August 1971, and was on the electrical engineering faculty of the University of Maine before coming to SERI (NREL) in 1977. His research at Maine included NSF- and ERDA-funded work in thin-film photovoltaics and the report of the *first* thin-film copper-indium-diselenide (CIS) solar cell. He was SERI's first staff member in photovoltaics, hired specifically to establish efforts in the characterization of photovoltaic materials and devices; he led NREL efforts in measurements and characterization for more than 20 years. He has held *adjunct professorships* at the University of Colorado, Colorado School of Mines, and the University of Denver. Dr. Kazmerski has published over 320 journal papers in the areas of solar cells, thin films, semiconductor materials and devices, surface and interface analysis, molecular beam epitaxy, semiconductor defects, scanning probe microscopy, nanoscale technology, high-temperature superconductivity, solar and photovoltaics technologies, and solar hydrogen. He has authored or edited four books, and serves on the editorial board of several journals—and he has more than 160 invited presentations at international conferences, workshops, and seminars. He was co-founder and editor of the journal *SOLAR CELLS*, published by Elsevier-Sequoia (1979-1991). Kazmerski is Editor-in-Chief of the Elsevier journal, *Renewable and Sustainable Energy Reviews*. He has four R&D 100 Awards. He is active in the IEEE, AVS, MRS, APS, ISES, and ASES. Kazmerski was the recipient of the Peter Mark Memorial Award of the AVS in 1981 and IEEE William R. Cherry Award in 1993. He has received several international recognitions for his work in solar photovoltaics. Kazmerski is a *Fellow* of the Institute of Electrical and Electronics Engineers (IEEE), a *Fellow* of the American Physical Society (APS), a *Fellow* of the AVS, and a *Fellow* of the International Energy Foundation (IEF). His is a *Distinguished Lecturer* of the AVS (1999-present). In 2000, Kazmerski was recognized as a Honorary Member of the AVS for his contributions to science and the Society. Kazmerski was elected as a member of the *National Academy of Engineering* in 2005. He received the World PV Award from the international PV communities representing the Europe, Asia-Pacific, and the U.S. for outstanding leadership and contributions to the worldwide advancement of photovoltaic science and technology in 2006. In September 2006, he was recognized with the *Nelson W. Taylor Award for Materials Science* by Penn State University. He received the 2007 Karl W. Böer Medalist for contributions to solar energy, and he is the recipient of the 2008 ASES Charles Greeley Abbot Award *for outstanding leadership and scientific excellence in the research and development of photovoltaics*. Recently, Kazmerski was inducted into the *Environmental Hall of Fame* in the Field of Solar Energy (Photovoltaics Technology). In December 2008, he was the United Kingdom ISES *David Hall Memorial Lecturer* for his contributions to international photovoltaic R&D. Kazmerski is Visiting Professor of Solar Energy at the University of Southampton in the U.K., and in January 2009, he was elected as *Honorary Professor* at Strömstad Academy in Sweden.

## Dinner Speaker

**WE1, Wall Street Perspective on the Alternative Energy Sector**
Jeffrey D. Adams
*Goldman Sachs, USA*

**Abstract:** A high level review of the trends and outlook for solar and LED technologies, and the investor environment, sentiment, and capital availability for energy companies.

**Biography:** Jeff is a managing director in the Technology, Media and Telecommunications group in the Investment Banking Division and focuses on a broad range of technology clients. He is head of the Renewable and Alternative Energy team covering venture capitalists and emerging growth companies and was formerly co-head of the global Semiconductor team. Jeff has worked in technology investment banking for 14 years and became a managing director in 2002. Jeff earned a B.S. in Chemical Engineering from The Ohio State University in 1987 and an M.B.A. from The Anderson School at UCLA in 1993.

## Invited Speakers

### Solar

**WD1, Solar Economics**, Ardeth Barnhardt; *Univ. of Arizona, USA*
**WD2, Organic Materials for Solar Photovoltaics**, Mark E. Thompson[1], M. Dolores Perez[1], Carsten Borek[1], Peter I. Djurovich[1], Richard R. Lunt[2], Stephen R. Forrest[2]; *[1]Univ. of Southern California, USA, [2]Univ. of Michigan, USA*
**WD3, Nanoporous "Black Silicon" by a Nanocatalyzed Etch: Photovoltaic Anti-Reflection and Simple Physics from a Graded-Density Surface Layer**, Howard Branz, Hao-Chih Yuan, Vernon E. Yost, Paul Stradins, Matthes R. Page; *Natl. Renewable Energy Lab, USA*
**WD4, What Photons Tell Us about Solar Cells: Imaging Diagnostic Techniques**, Martin Kasemann[1], Johannes A. Giesecke[1], Wolfram Kwapil[1], Bernhard Michl[1], Marco Seeland[2], Harald Hoppe[2], Wilhelm Warta[1]; *[1]Fraunhofer Inst. for Solar Energy Systems, Germany, [2]Technical Univ. of Illmenau, Germany*
**WD5, Light Management in Photovoltaic Modules**, Dan Doble; *Fraunhofer Ctr. for Sustainable Energy Systems, USA*
**WD6, Optical Aspects of Linear Fresnel Reflector Design**, David Mills; *Ausra, Inc., USA*
**WD7, Focusing on the Optics**, Narkis Shatz[1], John Bortz[1], Roland Winston[2]; *[1]Science Applications Intl. Corp., USA, [2]Univ. of California at Merced, USA*
**WD8, Beating the Optical Liouville Theorem**, Roland Winston; *Univ. of California at Merced, USA*
**ThD1, Thin Film PV: The Pathway to Grid Parity**, Benny Buller, David Eaglesham; *First Solar, USA*
**ThD2, A MEMS Wafer Expansion Approach to Microconcentrator Silicon Solar Cells**, Peter Peumans; *Stanford Univ., USA*
**ThD4, Luminescent Solar Concentrators**, Marc Baldo; *MIT, USA*
**ThD5, Nanowires as Solar Cells and Nanoelectronic Power Sources**, Charlie Lieber. Thomas Kempa; *Harvard Univ., USA*

### Solid-State Lighting

**WB1, Energy Implications of Solid-State Lighting Technology**, E. Fred Schubert, Jong Kyu Kim; *Rensselaer Polytechnic Inst., USA*
**WB2, Advanced LEDs**, Matthew A. Stough; *Osram Sylvania, USA*
**WB3, Solid-State Lighting Technology**, Anil Duggal; *GE Global Res., USA*
**WB4, Flexible Solid-State Lighting**, Brian D'Andrade, Alex Kattamis; *Exponent Inc., USA*

## Energy-Source Development and Efficiency

**ThB1, Optical Current Sensors for Electric Power Grid Modernization**, Allen H. Rose, Jim Blake; *Areva T&D Inc., USA*
**ThB2, Downhole Fluid Analysis: The Key to Unraveling Reservoir Complexities**, Oliver Mullins; *Schulumberger Technology Corp., USA*
**ThB4, Optical Gas Sensors for Energy Applications**, Alexis Mendez; *MCH Engineering, LLC, USA*
**ThB5, Fiber-Optic Sensor for Advanced Wind Energy Generation: Structural Monitoring and Pitch Control**, Kevin Hsu[1], Alan Turner[2]; *[1]Micron Optics, Inc., USA, [2]MCH Engineering, LLC, USA*
**ThB7, New Opportunities for Direct Light-to-Fuel Energy Conversion**, Yogesh Surendranath, Matthew W. Kanan, Daniel G. Nocera; *MIT, USA*

## Agenda of Sessions

| **Wednesday, June 24, 2009** | | |
|---|---|---|
| **8:00 a.m.** | **Registration Open** | *Wong Lobby* |
| **8:30 a.m.–9:00 a.m.** | **Breakfast** | *Wong Lobby* |
| **9:00 a.m.–10:00 a.m.** | **WA • Welcome and Plenary Session I** | *Wong Auditorium* |
| **10:00 a.m.–10:30 a.m.** | **Break** | *Wong Lobby* |
| **10:30 a.m.–12:25 p.m.** | **WB • Solid-State Lighting** | *Wong Auditorium* |
| **12:30 p.m.–1:30 p.m.** | **Lunch** | *Morss Hall* |
| **1:30 p.m.–2:30 p.m.** | **WC • Poster Session I** | *Morss Hall* |
| **2:30 p.m.–5:50 p.m.** | **WD • Solar I** | *Wong Auditorium* |
| **6:00 p.m.–9:00 p.m.** | **WE • Reception & Dinner (Speaker)** | *MIT Faculty Club* |

| **Thursday, June 25, 2009** | | |
|---|---|---|
| **8:00 a.m.** | **Registration Open** | *Wong Lobby* |
| **8:30 a.m.–9:00 a.m.** | **Breakfast** | *Wong Lobby* |
| **9:00 a.m.–9:45 a.m.** | **ThA • Plenary Session II** | *Wong Auditorium* |
| **9:45 a.m.–10:15 a.m.** | **Break** | *Wong Lobby* |
| **10:15 a.m.–12:50 p.m.** | **ThB • Energy Development** | *Wong Auditorium* |
| **12:50 p.m.–1:45 p.m.** | **Lunch** | *Morss Hall* |
| **1:45 p.m.–2:45 p.m.** | **ThC • Poster Session II** | *Morss Hall* |
| **2:45 p.m.–5:20 p.m.** | **ThD • Solar II** | *Wong Auditorium* |
| **5:20 p.m.–6:00 p.m.** | **ThE • Postdeadline Papers** | *Wong Auditorium* |

**Wong Lobby/Auditorium -Building E51 (Tang Center )**
**Morss Hall- Building 50 ( Walker Memorial)**
**MIT Faculty Club - Building E-52 (Sloan)**

## Optics and Photonics for Advanced Energy Technology Abstracts

### •Wednesday, June 24, 2009•

*Wong Lobby*
**8:00 a.m.**
**Registration Open**

*Wong Lobby*
**8:30 a.m.–9:00 a.m.**
**Breakfast**

### WA • Welcome and Plenary Session I

*Wong Auditorium*
**9:00 a.m.–10:00 a.m.**
*Rajeev J. Ram; MIT, USA, Presider*

**WA1 • 9:00 a.m.** **Invited**
**Solar Photovoltaics Technology: The Revolution Begins,** *Lawrence L. Kazmerski; Natl. Ctr. for Photovoltaics, Natl. Renewable Energy Lab, USA.* The prospects of solar-photovoltaic (PV) technologies are envisioned, arguing this electricity source is at a *tipping point* in the complex, worldwide energy outlook. The emphasis of this presentation is on R&D advances, providing insights into how PV has developed and where we can expect to be by mid-21st century.

*Wong Lobby*
**10:00 a.m.–10:30 a.m.**
**Break**

### WB • Solid-State Lighting

*Wong Auditorium*
**10:30 a.m.–12:25 p.m.**
*Marc Baldo; MIT, USA, Presider*

**WB1 • 10:30 a.m.** **Invited**
**Energy Implications of Solid-State Lighting Technology,** *E. Fred Schubert, Jong Kyu Kim; Rensselaer Polytechnic Inst., USA.* The efficient yet highly controllable generation of light can be accomplished by light-emitting diodes that can have a 20 times greater efficiency than incandescent light sources. Implications on energy, environment, and finances will be discussed.

**WB2 • 10:55 a.m.** **Invited**
**Advanced LEDs,** *Matthew A. Stough; Osram Sylvania, USA.* Light Emitting Diodes (LEDs) are the new tungsten filament of the lighting world. Advances in the optical performance, geometric configuration, and availability of type place the LED at the forefront of modern lighting product designs.

**WB3 • 11:20 a.m.** **Invited**
**Solid-State Lighting Technology,** *Anil Duggal; GE Global Res., USA.* In this talk the vision of LED and OLED based solid state lighting will be introduced and the technical efforts at GE aimed at enabling a low cost OLED lighting technology will be discussed.

**WB4 • 11:45 a.m.** **Invited**
**Flexible Solid-State Lighting,** *Brian D'Andrade, Alex Kattamis; Exponent Inc., USA.* Steel foil tolerance to high temperature processing, dimensional stability, chemical resistance, low moisture and oxygen permeability are characteristics that in combination with top emission organic LEDs are needed for flexible solid state lighting sources.

**WB5 • 12:10 p.m.**
**Ultrathin Metal Transparent Electrodes for Lighting and Photovoltaic Applications,** *Dhriti Sundar Ghosh[1], Danny Krautz[1], Stephanie Cheylan[1], Valerio Pruneri[1,2]; [1]ICFO- Inst. of Photonic Sciences, Spain, [2]ICREA- Inst. Catalana de Recerca i Estudis Avançats, Spain.* Transparent electrodes based on ultrathin metal films are realized, whose transparency is high compared to ITO in UV and IR and similar in visible region. Performance of an OLED is demonstrated as a potential application.

*Morss Hall*
**12:30 p.m.–1:30 p.m.**
**Lunch**

### WC • Poster Session I

*Morss Hall*
**1:30 p.m.–2:30 p.m.**

**WC1**
**Array of Plasmonic Nanoparticles Enabling Light Coupling and Guiding in Solar Systems: A Theoretical Analysis,** *Shabnam Ghadarghadr, Hossein Mosallaei; Northeastern Univ., USA.* This paper demonstrates a novel approach for enhancing energy coupling into thin-layered solar cells enabled by depositing non-periodic arrays of plasmonic nanoparticles. Theoretical models are developed to characterize the structure and determine novel physical performance.

**WC2**
**Stochastic Resonance Enhanced Imaging for Defect Location in Silicon Solar Cells,** *Janice A. Hudgings, Kevin D. McCarthy; Alenas Imaging Inc., USA.* We describe the use of stochastic resonance enhanced thermoreflectance imaging for characterizing and locating defects including shunts and microcracks in multicrystalline silicon solar cells.

**WC3**
**Increasing Fused Silica Transmission for Solar Applications with Improved Optics Manufacturing Techniques,** *Joseph Spilman, Alan Gould, Tobias Nitzsche, Jonathan Watson, Andrew Haefner, Robert Wiederhold, Jessica DeGroote Nelson; Optimax Systems Inc., USA.* Fused silica's broad transmission spectrum makes it desirable for solar concentrator optics. A four-phase project is underway to create an optical manufacturing process that ensures maximized optical transmission for fused silica.

**WC4**
**Absorption Enhancement in Organic Photovoltaic Devices Based on Surface Plasmon-Polariton Effects,** *Yifen Liu, Jaeyoun Kim; Iowa State Univ., USA.* We propose to enhance the photovoltaic effect using an Au grating electrode which induces surface plasmon-polaritons (SPPs) propagating along the active layer/bottom electrode interface and hence increases the interaction length without increasing the actual thickness.

**WC5**
**Nanoscale Investigation of Collodial Quantum Dot/Organic Semiconductor Interfaces,** *Matthew J. Panzer, Polina O. Anikeeva, Jonathan E. Halpert, Moungi G. Bawendi, Vladimir Bulovic; MIT, USA.* We examine several methods for preparing bilayers of colloidal quantum dots (QDs) and hole-transporting organic semiconductor thin films. Controlling the degree of interpenetration between these two materials at the nanoscale may enhance our understanding of QD-based optoelectronic device performance.

**WC6**
**Colloidally-Synthesized Nanocrystal LEDs Using Metal Oxide Thin Films,** *Vanessa Wood, Matthew Panzer, Jean-Michel Caruge, Jonathan Halpert, Moungi Bawendi, Vladimir Bulovic; MIT, USA.* We present methods for integrating colloidally synthesized nanocrystals (NCs) and metal oxide thin films into functional, air-stable devices. We demonstrate metal oxide and NC light emitting devices and use them to study the mechanisms for electrical excitation of NCs.

**WC7**
**Synchrotron-Based Investigation of Metal Impurity Diffusion in Silicon Solar Cell Materials,** *David Fenning, Steve Hudelson, Joseph Sullivan, Sarah Bernardis, Mariana Bertoni, Bonna Newman, Tonio Buonassisi; MIT, USA.* This presentation details synchrotron-based diffusion experiments investigating the impact of high-temperature processing on the distribution of transition metal impurities in the bulk crystal and along grain boundaries in silicon solar cell materials.

**WC8**
**Synchrotron-Based X-Ray Absorption Spectroscopy Applied to Novel Silicon Solar Cell Material,** *Bonna Newman, Joseph Sullivan, Matthew Marcus, Sirine Fakra, Mark Winkler, Renee Sher, Tonio Buonassisi; MIT, USA.* After doping silicon well above the solubility limit with selenium atoms using femto-second laser pulses, we observe strong absorption of photons below the band gap of silicon. This enhanced absorption allows the possibility of increasing the photocurrent and the efficiency of silicon solar cells. We use synchrotron-based X-ray absorption spectroscopy to probe the chemical state of selenium to understand the material's unique absorption properties.

**WC9**
**Earth-Abundant Materials for High-Efficiency Heterojunction Thin Film Solar Cells,** *Yun Seog Lee, Mariana Bertoni, Tonio Buonassisi; MIT, USA.* We investigate materials for thin film solar cells that can meet tens of terawatts level deployment potential. As one of the candidates, cuprous oxide (Cu2O) is synthesized and characterized optically and electronically.

**WC10**
**Annealing of Dislocations in Multicrystalline Silicon Solar Cell Material,** *Mariana Bertoni, Clémence Colin, Tonio Buonassisi; MIT, USA.* We propose and demonstrate a method to remove performance-limiting dislocations from multicrystalline silicon solar cell material. High temperature annealing procedures, inspired in the well known treatment of metals, show dislocation density reductions of >95%.

**WC11**
**Monolithic Integration of Non-Nitride Green Light Emitting Devices on Si Substrates,** *M. J. Mori, S. T. Boles, E. A. Fitzgerald; MIT, USA.* We present a novel pathway towards the development of high-efficiency AlInGaP, InGaP and AlInP light emitting devices. Virtual substrates with tunable lattice constants on Si or GaAs serve as a thermodynamically stable platform which has numerous advantages over existing nitride-based technology.

## WD • Solar I

*Wong Auditorium*
**2:30 p.m.–5:50 p.m.**
*Peter Peumans; Stanford Univ., USA, Presider*

**WD1 • 2:30 p.m.** **Invited**
**Solar Economics,** *Ardeth Barnhardt; Univ. of Arizona, USA.* Abstract not available.

**WD2 • 2:55 p.m. Invited**

**Organic Materials for Solar Photovoltaics,** *Mark E. Thompson[1], M. Dolores Perez[1], Carsten Borek[1], Peter I. Djurovich[1], Richard R. Lunt[2], Stephen R. Forrest[2]; [1]Univ. of Southern California, USA, [2]Univ. of Michigan, USA.* Metalloporphyrins and subphthalocyanines make excellent donor/acceptor materials in OPVs, some with high open circuit voltages (Voc). The properties of these devices and model for understanding the origin of Voc for OPVs will be presented.

**WD3 • 3:20 p.m. Invited**

**Nanoporous "Black Silicon" by a Nanocatalyzed Etch: Photovoltaic Anti-Reflection and Simple Physics from a Graded-Density Surface Layer,** *Howard M. Branz, Hao-Chih Yuan, Vernon E. Yost, Paul Stradins, Matthew R. Page; Natl. Renewable Energy Lab, USA.* We fabricate nanoporous "black-silicon" surfaces by a low-cost nanocatalyzed liquid etch and find an exponential decay of reflectance versus the wavelength-scaled density grade depth. Using this surface in place of conventional anti-reflection coating, we have fabricated confirmed 16.8%-efficient silicon solar cells.

**WD4 • 3:45 p.m. Invited**

**What Photons Tell Us about Solar Cells: Imaging Diagnostic Techniques,** *Martin Kasemann[1], Johannes A. Giesecke[1], Wolfram Kwapil[1], Bernhard Michl[1], Marco Seeland[2], Harald Hoppe[2], Wilhelm Warta[1]; [1]Fraunhofer Inst. for Solar Energy Systems, Germany, [2]Technichal Univ. of Illmenau, Germany.* We demonstrate that luminescence, heat radiation, dislocation luminescence, and junction-breakdown radiation allows to measure and detect local series resistances, hot-spots, junction breakdown, bulk-, surface-, grain-boundary recombination, degradation and contamination in silicon and/or polymer solar cells.

**WD5 • 4:10 p.m. Invited**

**Light Management in Photovoltaic Modules,** *Dan Doble; Fraunhofer Ctr. for Sustainable Energy Systems, USA.* In the future, it may be that the most significant innovations in anti-reflection will be those that can be manufactured on a massive scale at a significantly reduced cost.

**WD6 • 4:35 p.m. Invited**

**Optical Aspects of Linear Fresnel Reflector Design,** *David Mills; Ausra, Inc., USA.* A Linear Fresnel Reflector Solar Collector uses long tracking reflector rows to overlay reflected images of the sun upon a linear downward-facing thermal receiver for the generation of steam.

**WD7 • 5:00 p.m. Invited**

**Focusing on the Optics,** *Narkis Shatz[1], John Bortz[1], Roland Winston[2]; [1]Science Applications Intl. Corp., USA, [2]Univ. of California at Merced, USA.* The flux-transfer efficiency of nonimaging optical systems is limited by étendue conservation. For symmetric optical systems a more stringent limitation is imposed. A concentrating photovoltaic system comprises collection/concentration optics and a solar cell.

**WD8 • 5:25 p.m. Invited**

**Beating the Optical Liouville Theorem,** *Roland Winston; Univ. of California at Merced, USA.* It is well-known that conservation of phase-space volume or optical etendue leads to strict limits to concentration. Less well- known is the connection between entropy and etendue. Entropy has a logarithmic dependence on etendue in addition to the familiar linear dependence on heat. This trade-off permits, in principle, an exponential boost in concentration. Optical systems that make use of this possibility will be discussed.

**WE • Reception & Dinner (Speaker)**

*MIT Faculty Club*
**6:00 p.m.–9:00 p.m.**
*Fred Leonberger; MIT, USA, Presider*

**WE1 • 7:05 p.m. Invited**

**Wall Street Perspective on the Alternative Energy Sector,** *Jeff Adams; Goldman Sachs, USA.* A high level review of the trends and outlook for solar and LED technologies, and the investor environment, sentiment, and capital availability for energy companies.

## •Thursday, June 25, 2009•

*Wong Lobby*
**8:00 a.m.**
**Registration Open**

*Wong Lobby*
**8:30 a.m.–9:00 a.m.**
**Breakfast**

### ThA • Plenary Session II

*Wong Auditorium*
**9:00 a.m.–9:45 a.m.**
*Tonio Buonassissi; MIT, USA, Presider*

**ThA1 • 9:00 a.m.** **Invited**
**Solar Energy Prospects,** *John Deutch; MIT, USA.* Electro optical technology is the key element for transformation of sunlight to heat, electricity, or fuels. Successful innovation, requires integration into a system designed for a particular application. The criteria for success include cost, and environmental benefit, as well as technical performance. However the absence of clear government policies adds additional uncertainty to design choices and comparison between different approaches. Despite these challenges it is sure that solar will become a dominant source of energy in the future -- when and how much cannot be predicted today.

*Wong Lobby*
**9:45 a.m.–10:15 a.m.**
**Break**

### ThB • Energy Development

*Wong Auditorium*
**10:15 a.m.–12:50 p.m.**
*Alan Kost; Univ. of Arizona, USA, Presider*

**ThB1 • 10:15 a.m.** **Invited**
**Optical Current Sensors for Electric Power Grid Modernization,** *Allen H. Rose, Jim Blake; AREVA T&D Inc., USA.* Optical current transducers will advance the modernization of the power grid, because of the economic cost, environmental cost, safety, reliability, and metrology performance improvements they make to the measurement of current at high voltages.

**ThB2 • 10:40 a.m.** **Invited**
**Downhole Fluid Analysis: The Key to Unraveling Reservoir Complexities,** *Oliver Mullins; Schlumberger Technology Corp., USA.* Downhole fluid analysis (DFA) utilizing visible and near-infrared molecular spectroscopy is transforming the way the subsurface oil reservoirs are characterized. DFA is the key enabling technology to characterize the complexities of reservoir fluids and reservoir architecture greatly improving efficiency.

**ThB3 • 11:05 a.m.**
**Trace Gas Analyzers Based on Tunable Diode Laser Absorption Spectroscopy (TDLAS) for Energy Production, Transmission, and Storage,** *Mickey B. Frish, David M. Sonnenfroh; Physical Sciences Inc., USA.* This paper describes energy-related uses of TDLAS. Applications include improving the efficiency and quality of natural gas transmission, monitoring and verifying the fate of $CO_2$ at geological sequestration sites, and monitoring contaminants in hydrogen fuels.

**ThB4 • 11:20 a.m.** **Invited**
**Optical Gas Sensing in Energy Applications,** *Alexis Mendez; MCH Engineering, LLC, USA.* Optical gas sensing is an effective and practical tool for detection, assessment and localization of fugitive gas emissions, leaks and contaminants, such as hydrocarbons and $SF_6$, in chemical plants, refineries, power plants, and gas pipelines.

**ThB5 • 11:45 a.m.** **Invited**
**Fiber-Optic Sensor for Advanced Wind Energy Generation: Structural Monitoring and Pitch Control,** *Kevin Hsu[1], Alan Turner[1], Alexis Mendez[2]; [1]Micron Optics, Inc., USA, [2]MCH Engineering, LLC, USA.* Fiber Bragg grating sensing systems are deployed to optimize design, operation and maintenance of wind turbines from manufacturing to in-service operation. The multi-channel sensing network can monitor composite blades with 1μstrain repeatability at 1KHz rate.

**ThB6 • 12:10 p.m.**
**Tomographic Phase Imaging of Fuel Cell Systems,** *Laura Waller, Jungik Kim, Yang Shao-Horn, George Barbastathis; MIT, USA.* We extend our optical phase tomographic system for monitoring water content of fuel cell membranes *in situ*. Using interferometry at two angles, we tomographically reconstruct smooth distributions using a custom modified filtered backprojection algorithm.

**ThB7 • 12:35 p.m.** **Invited**
**New Opportunities for Direct Light-to-Fuel Energy Conversion,***Yogesh Surendranath, Matthew W. Kanan and Daniel G. Nocera: MIT, USA.* Recent discovery of a cobalt-phosphate water oxidation catalyst has opened new avenues for the development of efficient and robust water-splitting photoelectrodes. Insight into the catalyst's mechanism and properties that make it suitable for this application will be discussed.

*Morss Hall*
**12:50 p.m.–1:45 p.m.**
**Lunch**

**ThC • Poster Session II**

*Morss Hall*
**1:45 p.m.–2:45 p.m.**

**ThC1**
**Photonic Crystal Fibre Sensor for High Temperature Energy Environment,** *Vittoria Finazzi[1], Joel Villatoro[1], Gianluca Coviello[1], Valerio Pruneri[1,2]; [1]ICFO- Inst. of Photonic Sciences, Spain, [2]ICREA – Inst. Catalana de Recerca i Estudis Avançats, Spain.* We present an integrated sensor for high temperature environments based on a photonic crystal fibre. Being all-silica it can measure parameters, such as strain, gas concentration and temperature up to the material softening point (>1000ºC).

**ThC2**
**Advanced Fiber Optic Condition Monitoring System for the Entire Wind Turbine Life Cycle,** *Vahid Sotoudeh, Behzad Moslehi, Richard Black; Intelligent Fiber Optic Systems Corp., USA.* IFOS demonstrates here its fiber-optic-based solution for wind turbine blade manufacturing monitoring and pre-installation inspection. The proposed sensing system is a wind turbine condition monitoring system (CMS) for blade, the gearbox, tower and generator monitoring.

**ThC3**
**Guided-Resonance Induced Absorption Enhancement in Silicon Nanowire Arrays for Photovoltaic Application,** *Chenxi Lin, Michelle L. Povinelli; Ming Hsieh Dept. of Electrical Engineering, Univ. of Southern California, USA.* We simulate the optical properties of silicon nanowire arrays using the transfer matrix method. Results reveal that guided resonances in nanowire arrays with proper size can greatly enhance the absorption of solar radiation.

**ThC4**
**Metallic Nanolens and III-V Nano-Optical Metamaterials Lenses for Subwavelength Imaging and Optoelectronics Applications,** *Bernard Didier F. Casse, Wentao T. Lu, Yongjian Huang, Srinivas Sridhar; Northeastern Univ., USA.* We report the experimental realization of a metallic nanolens for far-field subwavelength imaging and 3 innovative III-V nano-optical lenses based on negative-index phenomena for optoelectronics applications. This work was supported by AFRL and NSF.

**ThC5**
**Photonic Crystals for Improving Organic Solar Cell Efficiency,** *David Duché[1,2], Ludovic Escoubas[1,2], Jean-Jacques Simon[1,2], Philippe Torchio[1,2], Judikael Le Rouzo[1,2], Wilfried Vervisch[1,2], François Flory[2,3], Antoine Labeyrie[4,5], Jean-Louis Roumiguières[5]; [1]IM2NP Lab, Univ. Paul Cézanne, France, [2]CNRS, IM2NP (UMR 6242), Faculté des Sciences et Techniques de Saint Jérôme, France, [3]École Centrale Marseille, IM2NP, France, [4]College de France, France, [5]Irilab Co., France.* An improvement of the organic solar cells efficiency is theoretically demonstrated by nanostructuring the active layer in the shape of a photonic crystal. An original process allowing polymers nanostructuration is presented.

**ThC6**
**Towards Efficient Quantum Dot-Based Schottky Photovoltaic Cells,** *N. Zhao, T. P. Osedach, L. -y Chang, S. M. Geyer, M. Bawendi, V. Bulović; MIT, USA.* Schottky photovoltaic cells (PVs) based on PbS quantum dot films have recently attracted much research interest due to their ability to harvest solar energy at infrared wavelengths. By engineering the device structure and fabrication methods, we explore several important aspects that determine the performance of PbS QD-based Pvs.

**ThC7**
**Optimization of Thermophotovoltaic Systems Using Tungsten Photonic Crystal Structures,** *M. Araghchini, A. Yeng, M. Ghebrebrhan, Ivan Čelanović, J. Joannopoulos, G. S. Petrich, L. A. Kolodziejski; MIT, USA.* Thermophotovoltaic (TPV) systems convert heat into electricity. A basic thermophotovoltaic system consists of a thermal emitter and a photovoltaic (PV) diode. Although TPV conversion systems have advantages such as no moving parts, long lifetime and low maintenance, they suffer from low efficiency. In order to achieve high TPV efficiencies it is necessary to better match the emitted spectrum to the sensitivity spectrum of the PV diode. In this work spectral control is done via selective emission using tungsten photonic crystal.

**ThC8**
**Luminescent Solar Concentrators for Energy Harvesting in Displays,** *C. L. Mulder, H. Kim, C. Rotschild, M. A. Baldo; MIT, USA.* We propose to use linearly polarized luminescent concentrators to harvest energy in displays. The concentrator employs aligned dye molecules that redirect absorbed photons to solar cells in the frame of the display.

**ThC9**
**High Open-Circuit Voltage in Heterojunction Photovoltaics Using Printed Colloidal Quantum Dots as a Photosensitive Layer,** *Alexi C. Arango[1], Tim P. Osedach[1], Matthew J. Panzer[1], Vladimir Bulović[1], Scott M. Geyer[2], David C. Oertel[2], Moungi G. Bawendi[2]; [1]Dept. of Electrical Engineering and Computer Science, MIT, USA, [2]Dept. of Chemistry, MIT, USA.* We have successfully printed a thin film of colloidal cadmium selenide (CdSe) quantum dots onto a transparent organic semiconductor, forming a unique solar cell that generates more voltage than previously expected for donor/acceptor photovoltaics.

**ThC10**

**High Efficiency Organic Multilayer Photodetectors Based on Singlet Fission,** *Jiye Lee, Priya Jadhav, Marc Baldo; MIT, USA.* We aim to enhance the efficiency of an organic multilayer photodetector employing exciton fission process. Our device consists of ultrathin pentacene-fullerene alternating layers. The quantum efficiency enhancement from singlet fission was about 35%.

**ThC11**

**Solar Thermoelectric Generator for μ-Power Applications,** *Reja Amatya, R. J. Ram; MIT, USA.* Solar thermoelectric generator (STG) using cheap parabolic concentrator with high ZT modules can be a cost-effective alternative to solar photovoltaics for micro-power generation. Using novel thermoelectric materials, conversion efficiency of 5.5% can be achieved for a STG.

**ThC12**

**Polychromatic Diffractive Concentrators for Ultra-High Efficiency Photovoltaic Cells,** *Rajesh Menon; MIT, USA.* I will describe an approach to achieve energy-conversion efficiencies > 50% via a thin nanostructured optic that not only concentrates sunlight, but also separates and assigns the solar-spectral components to photovoltaic cells with matching bandgaps.

*Location*
**2:30 p.m.–2:45 p.m.**
**Break**

## ThD • Solar II

*Wong Auditorium*
**2:45 p.m.–5:20 p.m.**
**ThD • 2:45 p.m.**
*Vladmir Bulovic; MIT, USA, Presider*

**ThD1 • 2:45 p.m.** **Invited**

**Thin Film PV: The Pathway to Grid Parity,** *Benny Buller, David Eaglesham; First Solar Inc., USA.* First Solar is the global leader in PV module manufacturing, at <$1.00/W. Grid parity will require a module cost/W 30% lower. This talk will outline the pathway to $0.65/W and parity with fossil fuels.

**ThD2 • 3:10 p.m.** **Invited**

**A MEMS Wafer Expansion Approach to Microconcentrator Silicon Solar Cells,** *Peter Peumans; Stanford Univ., USA.* We developed an approach to expand a wafered solar cell into an array of miniature solar cells placed accurately on a low-cost substrate with integrated wiring that is then mated to low-cost molded optics.

**ThD3 • 3:35 p.m.** **Invited**

**Thin Film PV Design and Broadening Applications,** *Sam Palmer[1], Jeff Chapin[2]; [1]Konarka Technologies Inc., USA, [2]IDEO, USA.* Abstract not available.

**ThD4 • 4:00 p.m.** **Invited**

**Luminescent Solar Concentrators,** *Marc Baldo; MIT, USA.* Luminescent solar concentrators (LSCs) are planar waveguides containing an organic or inorganic dye and inorganic solar cells attached to the edges. Light is absorbed by the dye and reemitted into waveguide modes for collection by the solar cells.

**ThD5 • 4:25 p.m.** **Invited**

**Nanowires as Solar Cells and Nanoelectronic Power Sources,** *Charlie Lieber, Thomas Kempa; Harvard Univ., USA.* Studies of single nanowire photovoltaic cells elucidate the benefits of "bottom-up" nanoscale design, lead to fundamental and breakthrough device performance insights, and open new opportunities for next generation solar cells.

**ThD6 • 4:50 p.m.**

**Nanostructured Absorber and Emitter for Solar Thermo-Photovoltaics Exceeding the Shockley-Queisser Limit,** *Eden Rephaeli, Shanhui Fan; Stanford Univ., USA.* We present a tungsten-based nanostructured absorber and emitter pair designed for solar thermo-photovoltaic (STPV) applications. The pair enables STPV systems with efficiencies exceeding the Shockley-Queisser limit.

**ThD7 • 5:05 p.m.**

**A Silicon Metamaterial Demonstrating Low-Energy Carrier Generation and Multiplication,** *Zbigniew T. Kuznicki; Photonic Systems Lab, France.* New PV conversion mechanisms were observed in nanostructured Si produced by amorphizing ion-implantation and subsequent thermal treatment. Intense physical transformations of usual c-Si lead to *Si-metamaterials* and a *multistage conversion cycle*.

## ThE • Postdeadline Papers

*Wong Auditorium*
**5:20 p.m.–6:00 p.m.**
*Fred Leonberger; MIT, USA, Presider*

## Key to Authors and Presiders

(**Bold** denotes Presider or Presenting Author)

# Optics and Photonics for Advanced Energy Technology

## UPDATE SHEET

**Presenter Changes:**

WB2, **Advanced LEDs** will be presented by *Maria Anc; Osram Sylvania, USA*

# •Optics and Photonics for Advanced Energy Technology

# Postdeadline Paper Abstracts•

**ThE • Postdeadline Papers**

*Wong Auditorium*
**5:20 p.m.–5:56 p.m.**
*Fred Leonberger; MIT, USA, Presider*

**ThE1 • 5:20 p.m.**
**Chiral Fibers for Harsh Environments,** *Victor I. Kopp[1], Victor M. Churikov[1], Dan Neugroschl[1], Azriel Z. Genack[1,2]; [1]Chiral Photonics, Inc., USA, [2]Queens College of CUNY, USA.* Periodic Chiral fibers produced by twisting optical fibers can be fashioned from glasses selected for their robustness in harsh environments. For example, temperature sensors produced by twisting pure silica microstructured fiber operate beyond 1000 C.

**ThE2 • 5:32 p.m.**
**Nanostructured Solar Cells for Control of Exciton Recombination,** *Luat T. Vuong[1], Gregory Kozyreff[2], Jordi Martorell[1,3]; [1]ICFO-Inst. de Ciencies Fotoniques, Spain, [2]Optique Nonlinéaire Théorique, Univ. Libre de Bruxelles (ULB), Belgium, [3]Univ. Politècnica de Catalunya, Spain.* We calculate the position-dependent exciton lifetimes in a Schottky solar cell and demonstrate enhanced device performance due to inhibited spontaneous emission.

**ThE3 • 5:44 p.m.**
**SOFT OPTICS,** *Sheila Kennedy[1,2], Murat Mutlu[2]; [1]Kennedy and Violich Architecture, Ltd., USA, [2]MIT, USA.* SOFT OPTICS is an emergent field in design for light management where flexibility, weight reduction, affordability and low embodied energy in production are desirable. Applications include thin film, foil and textile solar concentrators and diffusers with applications in architectural façade systems, solar PV optimization and solid state lighting.

**Key to Authors and Presiders**
(**Bold** denotes Presenting Author or Presider)