The INSTITUTE for ENERGY EFFICIENCY

Science and Technology for an Efficient Energy Future

John Bowers
Director, IEE
bowers@iee.ucsb.edu
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<tr>
<td>9:30 AM</td>
<td>Welcoming Address &amp; Institute for Energy Efficiency Overview</td>
<td>John Bowers, UCSB</td>
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<td>10:00 AM</td>
<td>Introductory Remarks</td>
<td>Chancellor Yang, UCSB</td>
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<td>Sustainable Energy: Solar Power’s Transition into a Mainstream Generation Resource</td>
<td>Mahesh Mogiaia, First Solar</td>
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<td>Efficiency charge storage with battery-supercapacitor hybrids</td>
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<td><strong>Break</strong></td>
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<td>3:20 PM</td>
<td>Global environmental assessment of low-carbon technologies</td>
<td>Sangwoon Seh, UCSB</td>
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<td>Lifecycle of PV-battery microgrids</td>
<td>Roland Geyer, UCSB</td>
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<td>Photo- and Electrochemical Water Treatment and Mining</td>
<td>Chong Liu, Stanford</td>
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<td>High efficiency data center optical interconnects</td>
<td>Gers Kucuyan, HPE</td>
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Who Are We?

- A multi-disciplinary, cross-campus Institute
- 50 faculty, 180 graduate and post-doctoral students
- Researching technologies for efficient energy use, generation and storage
- 6 “Solution Groups”
Per Capita Electricity Consumption
The Impacts of increased energy consumption

- Economic stress
- Geopolitical instability
- Food shortages
- Climate Change
Lighting

Lighting consumes 22% of all US electricity.

Widespread adoption of LED lighting can reduce lighting energy use by 46% by 2030.
Accomplishments:
• Shuji Nakamura received 2014 Nobel Prize for inventing the blue LED
• Discovered why LED efficiency “droops” at high current levels
• Developed laser diode lighting: more efficient than LED lighting for high brightness applications
  – (e.g. streetlamps, car headlights)

Head:
Steve DenBaars
denbaars@engineering.ucsb.edu
Over 10% of all US electricity is lost through power conversion inefficiencies.
Accomplishment:

• Developed GaN technology that can eliminate over 50% of the losses sustained during power conversion
  – Being commercialized by startup Transphorm

Umesh Mishra
mishra@ece.ucsb.edu

Head:
John Bowers
bowers@ece.ucsb.edu
Electronics & Photonics

The power required for IO is often 40% of the total
The chip IO capacity (<10 Tb/s) is often a severe constraint.
Solution: 2.5 and 3D stacking
Photonics can reduce the IO power by 80%
Photonics can increase the capacity to 10 Tb/s per pin
Accomplishment:

- Heterogeneous integration of photonics and electronics
- Photonics on 200 mm and 300 mm wafers
- Transferred to Intel, Hewlett Packard, Aurrion
- High Q (100 Million) and integrated sensors for power lines, oil/gas (temperature, current, LIDAR (automotive))

John Bowers
bowers@ece.ucsb.edu
Buildings consume 72% of all US electricity.

Existing building control systems are manually operated and produce too many data points for an operator to effectively manage.
Accomplishment:

• Developed algorithms to quickly analyze large volumes of sensor feedback and identify key “pressure points” to optimize building efficiency
  – Being deployed by startup Ecorithm

Head:
Igor Mezic
mezic@engineering.ucsb.edu
Computing

Data centers consume 2% of global energy.

Data is predicted to increase 1000x by 2025, but computing efficiency is only expected to increase by 25x.
Accomplishments:

• Developed a “barely alive” server state, with the potential to reduce energy use by 20–25% when servers are on standby

• Developed memory system designs that extend the lifetime of high-efficiency resistive memory devices by 490%
  – Using resistive memory will reduce data center energy use by 15-25%

Head:
Rich Wolski
rich@cs.ucsb.edu
Renewables offer opportunities to diversify power generation and capture waste heat.

More efficient energy storage is a critical challenge.
Accomplishments:

• Developed a new class of nanostructured materials that efficiently convert waste heat directly into electricity

• Developed a new class of organic molecules for cheap, flexible, transparent and lightweight solar cells, setting a new efficiency record

• Developing a hybrid battery / capacitor: for higher power, faster charging times, and longer lifetime than lithium ion batteries

Head:
Gui Bazan
bazan@chem.ucsb.edu
Integration of new technologies into the marketplace requires an understanding of not just technical, but also environmental and resource issues.
Accomplishments:

• Helped to author major UN studies assessing the sustainability of:
  – 1) low-carbon energy technologies and
  – 2) energy efficiency technologies

• Developing an online tool enabling companies to evaluate the life-cycle impacts of chemicals at an early stage of product development

Head:
Sangwon Suh
suh@bren.ucsb.edu
Industry Partners Program

Benefits:

• Concierge campus visits to meet with faculty and explore research
• Opportunities to engage in energy-related research projects
• Personalized campus recruitment events
• Quarterly reports of energy-related technologies available for licensing
• Invitations to UCSB events
• … and more

Contact:
Roger Helkey
helkey@iee.ucsb.edu

John Bowers
bowers@iee.ucsb.edu
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The Energy Efficient Photonics Revolution

John Bowers

*Director, Institute for Energy Efficiency*

**Collaborators**

**UCSB:** Dan Blumenthal, Larry Coldren, Clint Schow, Rich Wolski

**Intel:** Richard Jones,

**Aurrion:** Eric Hall, Alex Fang, Greg Fish

**Hewlett Packard:** Di Liang, Marco Fiorentino, Raymond G. Beausoleil
Lighting
- A $1 LED light bulb 20x more efficient than an incandescent bulb

Electronics and Photonics
- Wireless and optical technologies for super-high-performance communications

Computing
- A new Moore’s Law for more energy-efficient computing

Buildings and Design
- Economically viable zero net-energy building systems

Production and Storage
- Solar cells with double efficiency at one-tenth the cost

Economics and Policy
- Worldwide energy efficiency policy direction, measurements and standards
Outline

• The Problem: Fast growing Internet and increasing power requirements. Power hungry interconnects
• The Solution: Highly integrated photonics
• The low cost solution: Highly integrated photonics on silicon
• The Impact: Lower power, higher capacity data centers, supercomputers, microprocessors.
How do we get to Terabit Optical Ethernet?

100G standards being commercialized – 200G and 400G are next – then onto Terabit

Complex, highly integrated circuits are needed
Value of Photonic Integration: Size, Weight and Power Reduction

100 Gb/s Transmit

100 Gb/s Receive

Infinera 100 Gb/s Solution Receive 100 Gb/s Transmit
• **Mission Statement:**
  - To lead the way in a new roadmap for multi Tbps Optical Ethernet
  - Create new energy efficient photonic integrated technologies

http://iee.ucsb.edu/toec
Reconfigurable Network-on-Silicon

- BUS-ring network on chip with flexible configuration
- WDM signal routing enabled by broadband switch fabric

Over 300 active units (48 DFB, 93 EAM, 67 PD)
Over 120 passive units (7 AWG, 1X15 MZI switch)
Heterogeneously-integrated 2.5 Tbps WDM Network-on-Chip

Zhang et al. Optica (2016)

320 (8×40) Gbps per transceiver node
2.56 Tbps (8×320 Gbps) for the whole photonic circuit.

1×8 (De)Mux

Broadband MZI switch array
28 Gbps

40 Gbps
The Path to Tera-scale Data Rates

Today: 12.5 Gbps x 4 = 50Gbps

25 Gbps x 4 = 100Gbps

Scale UP

Scale OUT

12.5 Gbps x 8 = 100Gbps

Scale up AND out

Next Generation Optical USB
Every computer, SAN, Display, …
The coal sector’s descent happened remarkably fast. Peabody is the fifth and largest US coal producer to enter bankruptcy in the last year.
If solar energy grows over the next five years like it did in the last fifteen, it will account for a quarter of global power generation. With the rapid advance in electric vehicle technology, the energy field is changing rapidly.

IEE Partners: Jim Dehlsen on Wind Power (GE and UTC) and Ecomerit Jim Nelson on Solar Power (Solar3D, now SunWorks)
New Research Awards

“Tools and Metrics for REMADE” (DOE-EERE via RIT)
S. SUH, R. GEYER

“Increased Energy Efficiency via Programmable Irrigation and Fertigation” (PowWow/CEC)
R. GEYER

“PINE: Photonic Integrated enabled Network architecture for Energy Efficient datacenters” (ARPA-E via Columbia)
J. BOWERS
PINE: Photonic Integrated Enabled Network architecture for Energy Efficient datacenters

$9.8M  Columbia, UCSB, AIM, Cisco, Micron

PINE architecture: Flexible Topology Through Optical Bandwidth Steering

Node Cluster

Modest-radix SiP switches

SIP based off-module IO

DC Node:
- Multi Chip Modules (MCM)s with deeply integrated Silicon Photonic interfaces

Packet Switching MCM

Compute MCM

HBM MCM

NVRAM MCM

Supports many topologies in between

High connectivity between clusters (all to all)

High bandwidth between cluster pairs
Szilagyi Energy Breakthrough Fellowships

• Intended as seed funding for continuing graduate student new energy breakthrough ideas leading to potential commercialization.

• Designed to recognize "out of the box" thinking and are intended to provide fellows with an opportunity to explore energy breakthrough ideas that they otherwise could not explore.

• Awarded to one student per academic year beginning in Fall 2017, providing $25K in discretionary funds to be used solely in support of proposed research project.

*The Szilagyi Energy Breakthrough Fellowships are made possible through the generous support of Gary and Tammy Szilagyi.*
Mr. Jiahao Kang:
Research: “2D Materials and Devices for Ultra-Energy-Efficient Electronics”
Group: Electronics & Photronics, Department: Electrical & Computer Engineering

Ms. Megan Butala:
Research “Materials chemistry approach to next-generation energy storage”
Group: Production & Storage, Department: Materials
Holbrook Fellows 2016-17

Mr. George Tzimpragos:
Research “Energy Efficiency with Heterogeneous Computing”
Group: Computing, Department: Computer Science

Mr. Andrew Netherton:
Research: “High-Capacity High-Radix Optical Switch for Data Center & HPC Applications”
Group: Electronics & Photonics, Department: Electrical & Computer Engineering

Four new students chosen and recruited last month

Ms. Nicole Michenfelder-Shauser:
Group: Energy Storage, Department: Materials

Mr. Yun Zhao:
Research: “Projects on energy-efficient mobile computing”
Group: Computing, Department: Electrical & Computer Science
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<td>Conjugated Polymers in Redox Active Devices: Electrochromism and Charge Storage as Case Studies</td>
<td>John R. Reynolds</td>
<td>Oct 13, 2016</td>
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<td>Sources of Shockley-Read-Hall Recombination in III-Nitrides</td>
<td>Cyrus Dreyer</td>
<td>Oct 20, 2016</td>
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<td>CASIS (Center for the Advancement of Science in Space) and International Space Station National Lab: Research in Space for Earth Benefits</td>
<td>Dr. C. Randy Giles</td>
<td>Nov 8, 2016</td>
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<td>Of Devices and Droplets: Evaporative Structuring of Solution-Processed Semiconducting Polymer Blends</td>
<td>Jasper Michels</td>
<td>Dec 1, 2016</td>
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<td>Optofluidic Integration of Hollow-Core Waveguides for Chip-Based Biomolecule Analysis</td>
<td>Holger Schmidt</td>
<td>Dec 15, 2016</td>
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<td>Compliant III-V on (001) Si Substrates for Direct Laser Growth</td>
<td>Kei May Lau</td>
<td>Jan 5, 2017</td>
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<td>Entrainment Models for Wind Farms and Other Canopies, Enabling An Ideal Limit for Wind Farm Performance</td>
<td>Paolo Luzzatto-Fegiz</td>
<td>Jan 19, 2017</td>
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<td>Disorder-Order Transitions In (\pi-)-Conjugated Polymers</td>
<td>Anna Köhler</td>
<td>Feb 2, 2017</td>
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More-Than-Moore With Integrated Silicon-Photonics
Speaker: Vladimir Stojanovic
ESB 1001 / Mar 30, 2017

Nano Research at the University of Duisburg-Essen: An Overview
Speaker: Tobias Teckentrup
Elings 1601 / Mar 1, 2017

Manipulating Light with Nano-photonics on Silicon
Speaker: Connie Chang-Hasnain
ESB 2001 / Apr 20, 2017

Transportation Energy - What is Best?
Speaker: Mark Delucchi
ESB 2001 / Apr 27, 2017
The information disclosed herein and during the AFRL site visit is Proprietary and strictly for the purpose of allowing the AFRL team to evaluate the proposal. It is not for dissemination outside of that purpose.
American Institute for Manufacturing integrated Photonics

- **VISION:** Establish a technology, business and education framework for industry, government and academia to accelerate the transition of integrated photonic solutions from innovation to manufacturing-ready deployment in systems spanning commercial and defense applications.

- **MISSION:** Create a national institute supporting the end-to-end integrated photonics manufacturing ecosystem in the U.S. by expanding upon a highly successful public-private partnership model with open-access to world-class shared-use resources and capabilities.
Albany campus: 4 Silicon Fabs—all can handle 300 mm wafers. The main one is 42,000 square feet (4 times UCSB clean room)

UCSB IEE is the lead for the West Coast
Atomic Clocks on a Chip

The CORES platform would enable optical frequency synthesis on a chip

- Reduction in footprint by >1000x compared to state-of-the-art
- Power consumption reduced by 1000x
- Ubiquitous optical frequency synthesis enabling a wide range of applications
**DODOS Team**

**UCSB**

**John Bowers**, PI: Heterogeneous integration on silicon

**Luke Theogarajan**: Low-power CMOS design and integration with photonics

**Dan Blumenthal**: Low-loss silicon nitride waveguides on silicon

**Caltech**

**Kerry Vahala**: Ultrahigh-Q whispering gallery mode resonator design

**Tobias Kippenberg**: Low power SN ring resonator octave generation

**NIST**

**Scott Diddams, Nate Newbury, Scott Papp and Kartik Srinivasan**: Leaders in optical synthesis and first demonstrated many of the key concepts and systems for self-referenced frequency combs

**University of Virginia**

**Andreas Beling and Steven Bowers**: High power photo-detectors and stabilization of microwave oscillators.

**Transitions to military systems**

**Greg Fish and Erik Norberg**

Leading company in heterogeneous integration on silicon

**Transitions to commercial systems, including test and measurements**
“TomKat UC Carbon Neutrality Project”

This project will facilitate and manage a set of project teams aimed at developing solutions to the most challenging aspects of the UC Carbon Neutrality Initiative. Each project will consist of a highly collaborative team of faculty, students, and staff from a wide range of disciplines at ten UC campuses and its three affiliated national laboratories. The outcomes of the work of these project teams will include economic and technical analysis of emerging technologies and systems, meta-analysis and synthesis of existing data to develop shared information resources, strategic roadmaps for the campuses, policy analysis and recommendations, field trials, and prototypes of emerging technologies.

- **Project Director:** Dave Auston
- **Donor:** TomKat Foundation
- **Partners:** National Center for Ecological Analysis and Synthesis (NCEAS), The Bren School of Environmental Science & Management, and The Applied Working Group of the UC Global Climate Leadership Council (ARWG).
- 18 months, $300K
“High Efficiency Quantum-Dot Photonic Integrated Circuit Technology Epitaxially Grown on Silicon”

To develop a technology for scaling high efficiency datacenter and supercomputer photonics to 300 mm wafers at low cost with high performance. Successful development of the proposed technology can solve the bandwidth capacity bottleneck of electronic chips and reduce the power necessary for interconnecting ICs, addressing a major impending need for high volume, low power, low cost silicon photonic optical interconnects for data centers, supercomputers and fiber to the home (FTTH).

- **PIs**: John Bowers, Art Gossard
- **Agency**: ARPA-E (DOE)
- 36 months, $1.9M
“Chip-scale Optical Resonator Enabled Synthesizer (CORES)”

A fundamental program of research and development to implement direct digital synthesis of optical frequencies in a single integrated chip-scale package. The outcome of this work will be a revolutionary Chip-scale Optical Resonator Enabled Synthesizer (CORES) that provides a laser output with programmable optical frequency resolution of one part in $10^{14}$ across 50 nm of bandwidth centered at 1500 nm.

- **PIs:** John Bowers, Luke Theogarajan, Dan Blumenthal
- **Agency:** DOD Advanced Research Projects Agency (DARPA)
- **Subcontracts:** Univ. of Virginia, Caltech, EPFL, Aurrion
- **Other Partners:** NIST *(direct funded)*
- **42 months, $11M**
“Irrigation Optimization and Well Pump Monitoring Leveraging Smart Meter Data”

The overall objective of this project is to demonstrate energy efficiency farming practices and a scalable well pump monitoring solution on more than 1,000 acres of farmland. Unlike existing solutions that require hardware installations, this platform leverages existing smart meter data from power utilities to measure groundwater extraction and integrates other data sources into a user-friendly software tool to assist growers to optimize irrigation. By using this platform, farms will be able to reduce energy and water consumption while maintaining or improving crop yields.

- **UCSB PIs**: Roland Geyer, Chandra Krintz, Rich Wolski
- **Agency**: California Energy Commission via PowWow Energy, Inc.
- **Partners**: PowWow Energy, Inc. (prime), UC Davis
- **30 months, $416K**
“Chemical Life Cycle Collaborative (CLiCC)”

The primary objective of this collaborative is to develop, implement and disseminate an open-access, online tool for rapid and efficiency characterization of chemical life-cycle impacts. The CLiCC tool is being developed to evaluate life-cycle impacts for chemical and materials at an early stage of the chemical product development process, when the precise manufacturing routes and fates of the products are still uncertain.

- **PIs:** Sangwon Suh, Arturo Keller, Dave Auston, Mike Doherty, Ram Seshadri, Susannah Scott
- **Agency:** Environmental Protection Agency (EPA)
- **Duration:** 48 months, $4.8M
“Highly Powerful Capacitors Boosted with Both Anolyte and Catholyte”

To develop a technology to combine the technical advantages of both batteries and electrical double Layer Capacitors (EDLCs) into a single electrical storage device for electric vehicles (EVs). The approach is to mechanistically integrate battery reactions into the configuration of EDLCs to create a new energy device that can be charged in less than 2 minutes (compared to hours for batteries), meet or exceed the lifetime of EVs, and deliver much higher power density than any battery.

- **PIs**: Galen Stucky, Dave Auston
- **Agency**: DOE Advanced Research Projects Agency-Energy (ARPA-E)
- **Subcontracts**: Univ. of Oregon, OSU
- 36 months, $1.6M
“Energy Storage with Isothermal Gas Compression”

Based on previous UCSB work on high efficiency isothermal gas compressors, the project proposed a practical method of storing energy produced by electrical generation that is scalable from household to grid levels, does not use rare or expensive materials, is not electrochemical, and has essentially unlimited cycle life for the critical infrastructure components, has low maintenance and is extremely reliable. Further, this project will develop a demonstration-scale installation that will store and dispatch electrical energy imported from Southern California Edison and generated onsite by the campus’ future 5MW solar PV generating facility for grid stability and load management purposes, leveraging the campus’ existing Automated Demand Response (ADR) capability.

- **PI:** Philip Lubin
- **Agency:** Southern California Edison
- 60 months, $5M*

*pending official award*
The INSTITUTE for ENERGY EFFICIENCY

Science and Technology for an Efficient Energy Future
Roger Helkey, Associate Director

Helkey is a Senior Member of the IEEE, has published four book chapters, 40 journal papers, and has received 41 patents. He spent 15 years at Calient Networks, developing optical switching as a low-power alternative to electrical switching for data center and telecommunications applications. Helkey received his B.S. degree from Caltech and Ph.D. degree from UC Santa Barbara.

Institute for Energy Efficiency
- Provides scientific & organization leadership
- Manages industrial & technical relationships
- Contributes to fundraising
- Responsible for engagement & solicitation of industrial partners

AIM Photonics
- Manages west cost headquarters, including industrial & technical relationships
- Complex milestone & deliverable reports
- Technical presentations
- Business development activities
IEE Staff

Jane Kittle, 
*Business Officer*
- Oversight of departmental operations
- Financial & administrative management
- Contract & grant administration

Carolyn Meisner, 
*Contract & Grant Analyst*
- Contract & grant administration
- Academic personnel processes
- Visa application coordination

Katherine Grayson, 
*Personnel & Purchasing Analyst*
- Payroll & new hires
- Travel/entertainment payments
- Procurement coordination

Ceanna Bowman, *Event Coordinator*
- Seminars, lectures, & workshops
- Quarterly Newsletter
- Holbrook & Frenkel Fellowships

Jon Winterbottom, 
*Financial Coordinator*
- Payroll & new hires
- Travel/entertainment payments
- Procurement coordination
Megan Birney, President

Goal: Eliminate kerosene light along with its health, safety and CO2 problems

Result: High efficiency, compact light source

>70,000 lights shipped to 64 countries on 4 continents.

2000 lights shipped to Tsunami victims (Mitsubishi supported)

Looking at a Sustainable model. Paid for out of kerosene savings.

www.unite-to-light.org (501c3 organization)