SSLS EFRC
SOLID-STATE LIGHTING SCIENCE
ENERGY FRONTIER RESEARCH CENTER

SAND2012-0976P

Solid-State Lighting

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Advanced Materials Sciences Dept.

February 13, 2011

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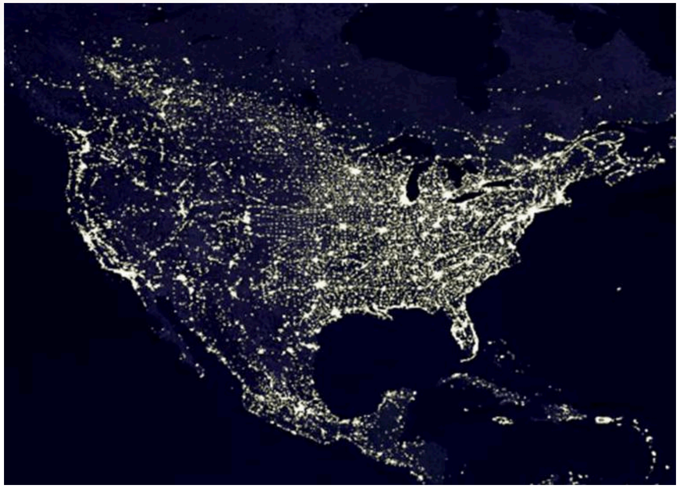
Outline of Presentation

- Introduction to solid-state lighting
- Development of Sandia’s SSL program
- Where we are today
  - Solid-State Lighting Science EFRC

Why Solid-State Lighting Matters



- ~22% of electricity consumption is used for lighting
- Lighting is one of the most ***inefficient*** energy technologies in buildings → opportunity!
- 2012 DOE projections:
  - 36% adoption by 2020
  - 74% adoption by 2030

➢ decrease electricity consumed by lighting by ~46%

Efficiencies of energy technologies in buildings:

Heating: 70 - 80%
Elect. motors: 85 - 95%
Fluorescent: 20-25%
Incandescent: ~3-5%

US DOE target: 50%
"Ultra-efficient" SSL*: ≥ 70%

Projected Year 2030 Savings	US
Electricity used (TW-hr)	300/year
$ spent on Electricity	$30B/year
Electricity generating capacity (GW)	50
Carbon emissions (Mtons/year)	210

1999-2001: Sandia helps catalyze national Interest in SSL

THE CASE FOR A NATIONAL RESEARCH PROGRAM ON SEMICONDUCTOR LIGHTING[1,2]

Roland Haitz and Fred Kish, Hewlett-Packard Company, Palo Alto, CA 94304
Jeff Tsao and Jeff Nelson, Sandia National Laboratories, Albuquerque, NM 87185-0601

EXECUTIVE SUMMARY

Dramatic changes are unfolding in lighting technology. Semiconductor light emitting diodes (LEDs), until recently used mainly as simple indicator lamps in electronics and toys, have become as bright and efficient as incandescent bulbs, at nearly all visible wavelengths. They have already begun to displace incandescent bulbs in many applications, particularly those requiring durability, compactness, cool operation and/or directionality (e.g., traffic, automotive, display, and architectural/directed-area lighting).

Further major improvements in this technology are believed achievable. Recently, external electrical-to-optical energy conversion efficiencies exceeding 50% have been achieved in infrared light emitting devices. If similar efficiencies are achieved in the visible, the result would be the holy grail of lighting: a 200*lm/W* white light source two times more efficient than fluorescent lamps, and ten times more efficient than incandescent lamps.

This new white light source would change the way we live, and the way we consume energy. The worldwide amount of electricity consumed by lighting would decrease by more than 50%, and total worldwide consumption of electricity would decrease by more than 10%. The global savings would be more than 1,000*TWh/yr* of electricity at a value of about US$100B/year, along with the approximately 200 million tons of carbon emissions created during the generation of that electricity. Moreover, more than 125*GW* of electricity generating capacity would be freed for other uses or would not need to be created, a savings of over US$50B of construction cost.

Bringing about such revolutionary improvements in performance will require a concerted national effort, of the order $0.5B over ten years, tackling a broad set of issues in semiconductor lighting technology. The effort would also require harnessing the most advanced high-technology companies, the best national laboratory resources, and the most creative university researchers in this area.

Fire — Candles and Lamps — Bulbs and Tubes — Semiconductors

[1] This white paper was first presented publicly at the 1999 Optoelectronics Industry Development Association (OIDA) forum in Washington DC on October 6, 1999.

[2] Revision B:03/30/1999

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II

107TH CONGRESS
1ST SESSION

S. 1166

To establish the Next Generation Lighting Initiative at the Department of Energy, and for other purposes.

IN THE SENATE OF THE UNITED STATES

JULY 11, 2001

Mr. BINGAMAN (for himself and Mr. DEWINE) introduced the following bill; which was read twice and referred to the Committee on Energy and Natural Resources

A BILL

To establish the Next Generation Lighting Initiative at the Department of Energy, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as "Next Generation Lighting Initiative Act".

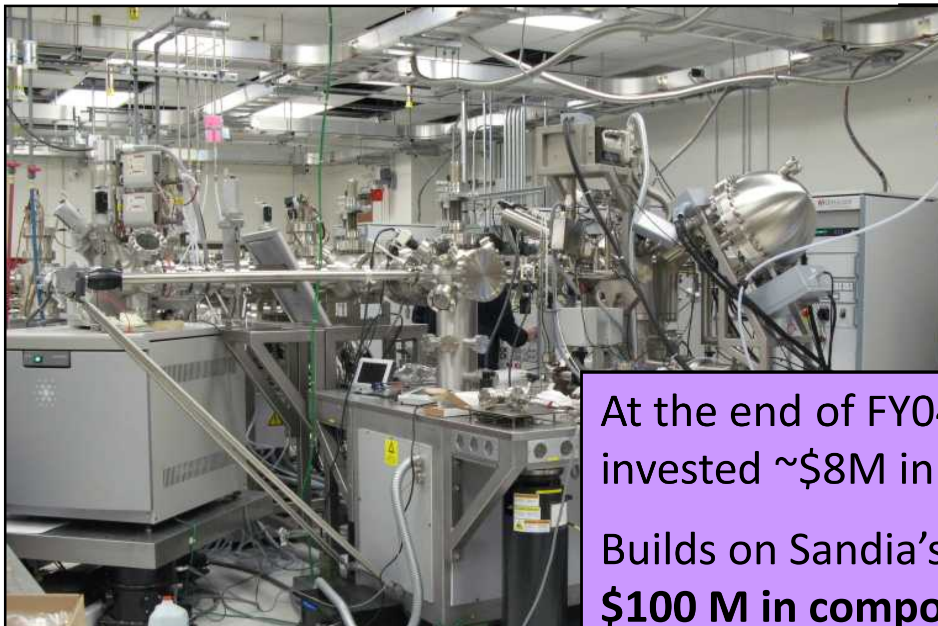
SEC. 2. FINDING.

Congress finds that it is in the economic and energy security interests of the United States to encourage the development of white light emitting diodes by providing financial assistance to firms, or a consortium of firms, and

We started "A Revolution in Lighting:" Sandia's Grand Challenge LDRD (2000)

Goals of the Grand Challenge LDRD (Laboratory Directed R&D) Project:

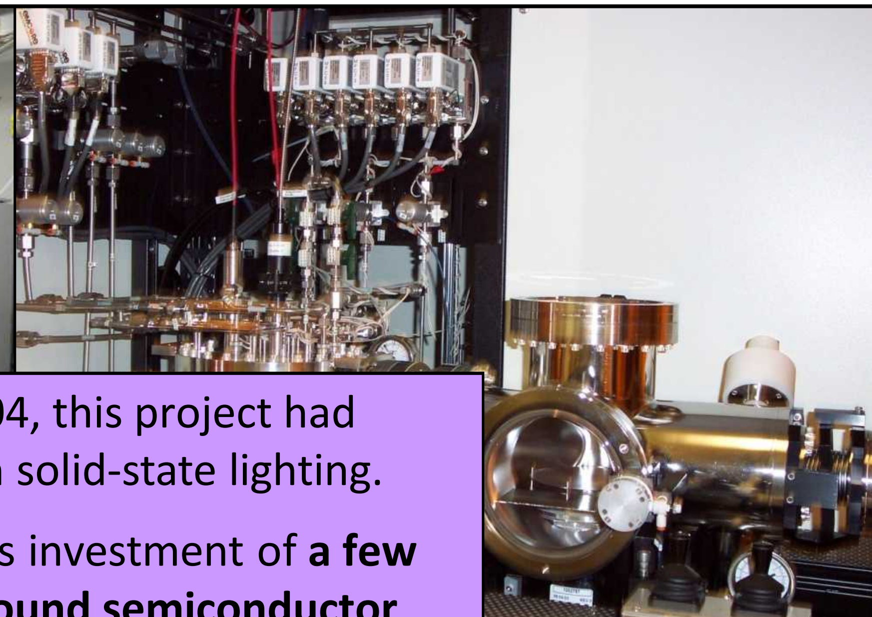
1. Help establish the fundamental science and technology base for SSL.
2. Develop the technology infrastructure of gallium nitride (GaN) material sciences for synergistic national security needs.



Advanced Nanotechnology Tool (ANT)

At the end of FY04, this project had invested ~$8M in solid-state lighting.

Builds on Sandia's investment of **a few $100 M in compound semiconductor technology** over the past two decades.



GaN MOCVD System

2004-DOE/Office of Energy Efficiency and Renewable Energy develops an SSL program

DOE/EERE Solid-State Lighting Program Goal

By 2025, develop advanced solid state lighting technologies that, compared to conventional lighting technologies, are much more energy efficient, longer lasting, and cost-competitive, by targeting a product system efficiency of 50 percent with lighting that accurately reproduces the sunlight spectrum.

http://www.ssl.energy.gov/

The Energy Policy Act of 2005 is supportive of increased SSL R&D

Subtitle A - Energy Efficiency

SEC. 912. NEXT GENERATION LIGHTING INITIATIVE

"The Secretary shall carry out a Next Generation Lighting Initiative in accordance with this section to support research, development, demonstration, and commercial application activities related to advanced solid-state lighting technologies based on white light emitting diodes."

Authorizes $50M/year for 2006 through 2013 (8 years)

Subtitle F: Science

SEC. 966. SOLID STATE LIGHTING

"The Secretary shall conduct a program of fundamental research on advanced solid state lighting in support of the Next Generation Lighting Initiative carried out under section 912."

Many externally funded, follow-on programs related to Solid-State Lighting

- 3 DARPA projects
- 1 DOE / Basic Energy Sciences project
- 1 DOE / Energy Efficiency Science Initiative
- 8 DOE / EERE SSL Core technology projects
- 1 DOE / EERE SSL Manufacturing project
- 5 DOE / EERE National Center for SSL Projects
- DOE / BES Energy Frontier Research Center (2009-2014)

- These include several large joint projects with UNM and Philips Lumileds
- Other partnerships with companies:
  Veeco, Inlustra, Kyma

Current Collaborations with Industry

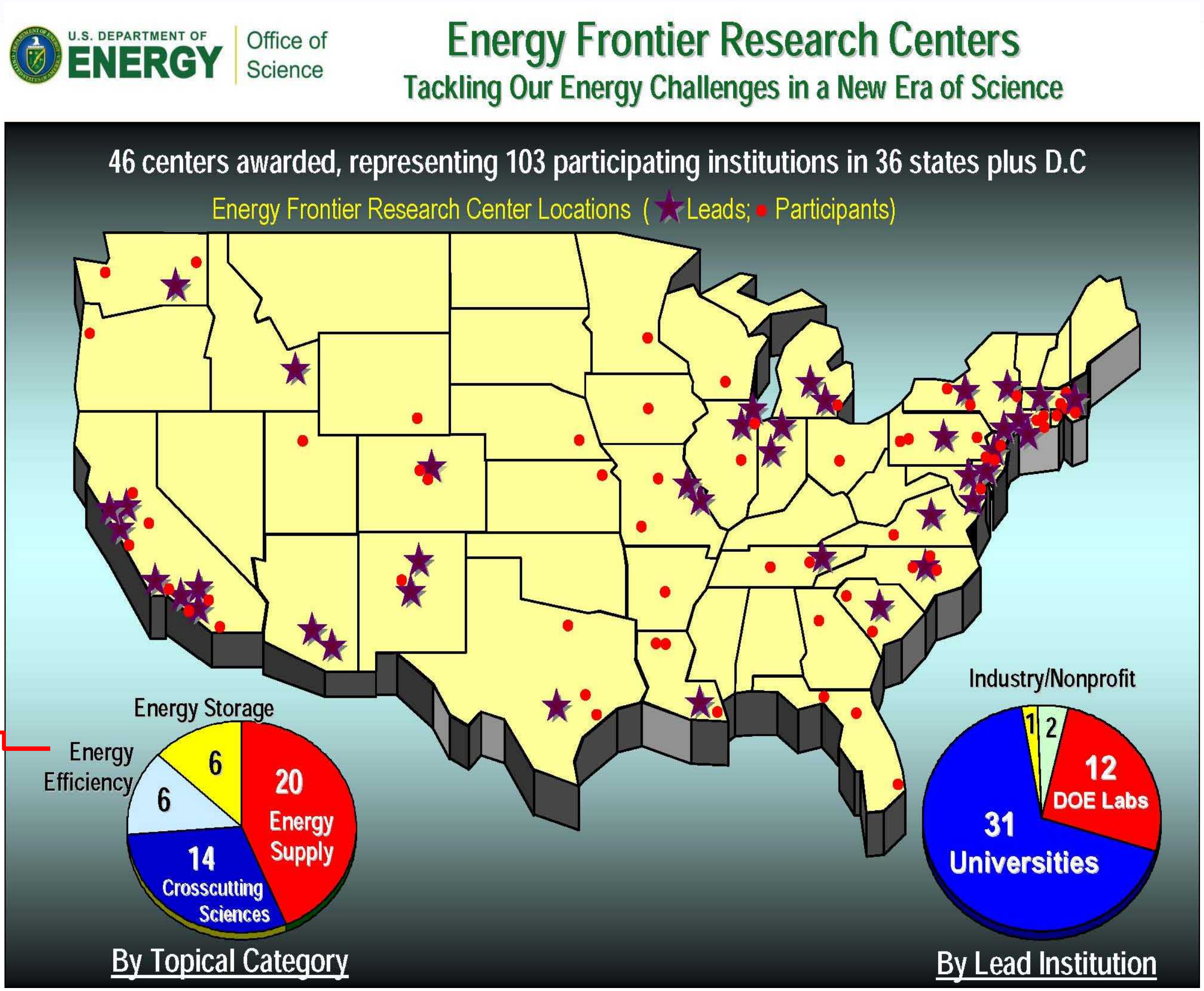
- Veeco / Philips Lumileds
  - EERE Advanced SSL Manufacturing Project "Implementation of Process-Simulation Tools and Temperature-Control Methods for High-Yield MOCVD Growth"
  - Goal: *A complementary set of high-resolution short-wavelength and infrared in-situ monitoring tools for accurate substrate temperature measurement and growth rate monitoring*
- Inlustra
  - EERE SSL Core Technology Project on "Semi-polar GaN Materials Technology for High IQE Green LEDs"
  - Goal: *540 nm LED with 50% IQE*

DOE Sec. Bodman announced the National Center for SSL at the Nanoscale Science Research Centers

In 2006 Sandia was chosen as the lead lab for the National Center

Solid-State Lighting Science EFRC

- We are one of 46 Department of Energy Office of Science EFRCs
- Our Budget: $18M over 5 years beginning Aug 2009
- We are one of 6 EFRCs focused on efficiency, and the only one focused on SSL



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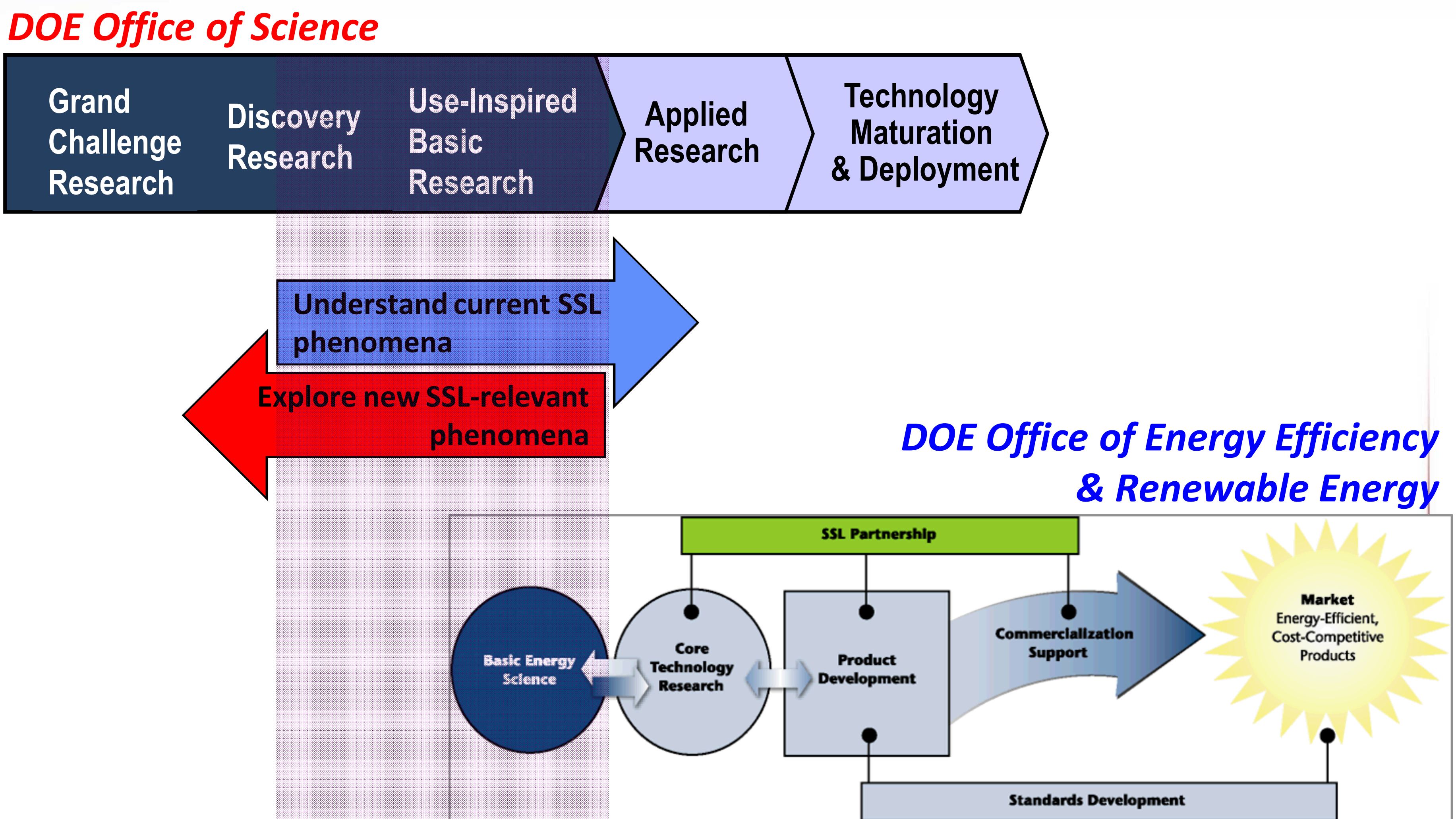
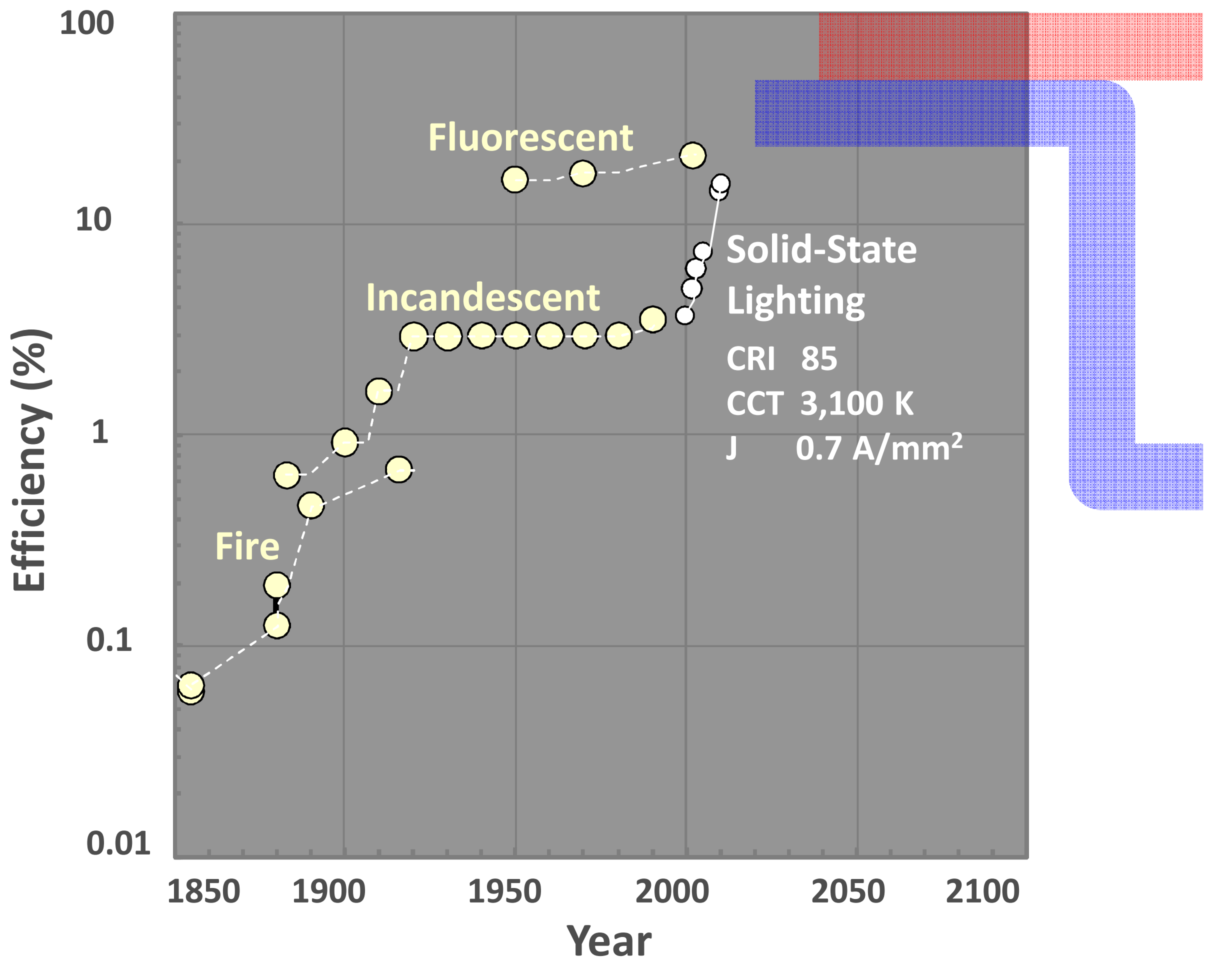
SSLS EFRC:
Use-Inspired *Basic* Research



SSL: Two Future Scenarios



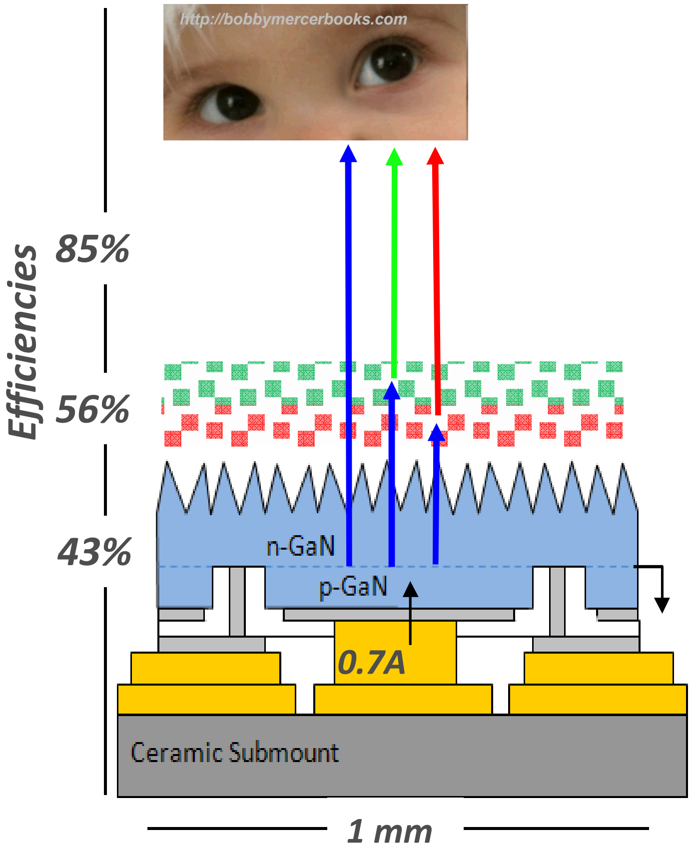
SSLS EFRC: 50-100%

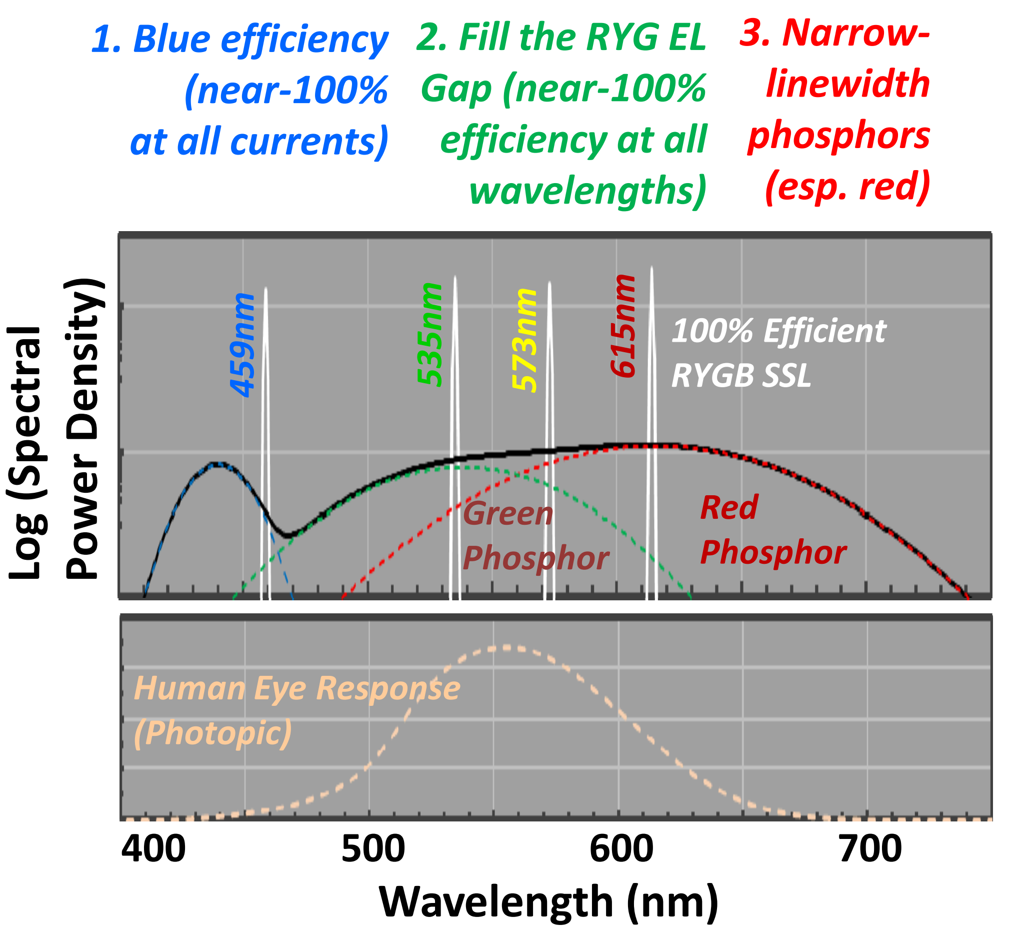
Enables the highest savings in energy consumption and gains in human productivity (but not obvious how to achieve)

EERE Programs: 25-50%

Enables penetration of traditional lighting (will almost certainly happen)

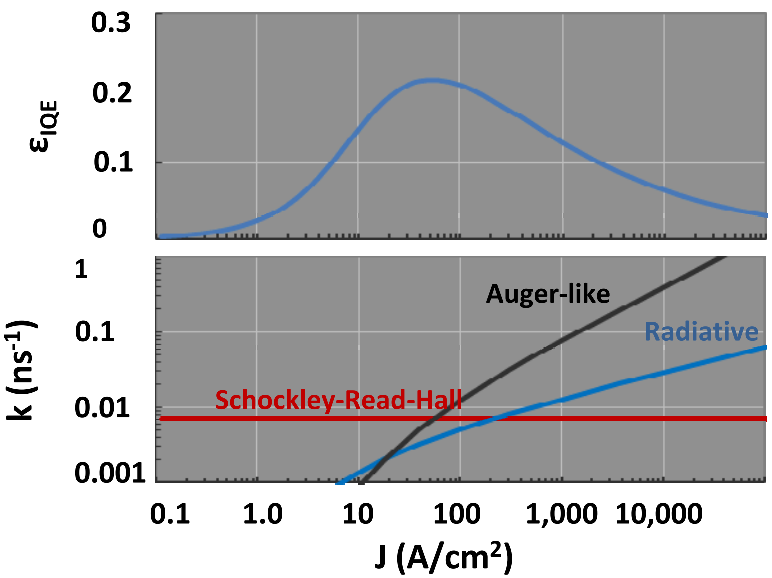
Opportunities for Science to Impact SSL





EFRC Thrust 1: Competing Energy Conversion Routes in Light-Emitting InGaN

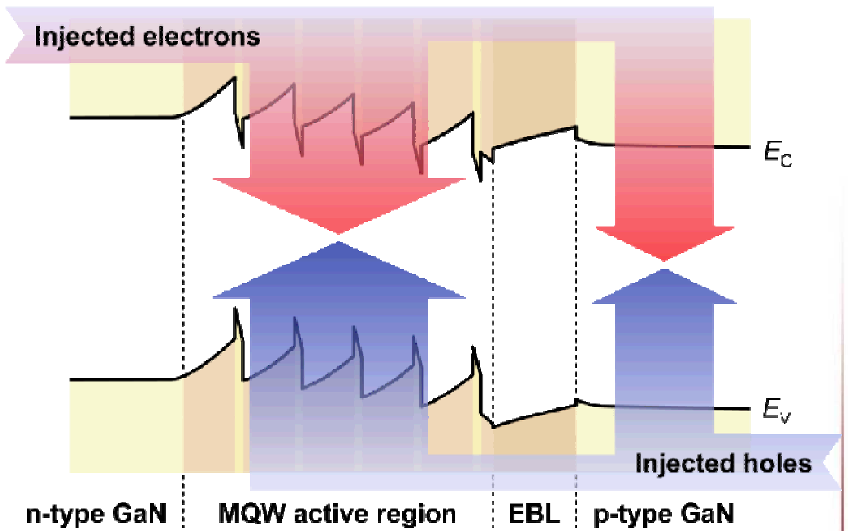
Recombination pathways



$$\varepsilon_{IQE} = \frac{Bn^2}{An + Bn^2 + Cn^3 + Dn^m + \ldots}$$

Shockley-Read-Hall (non-radiative at defects) — Radiative — Auger and higher-order processes

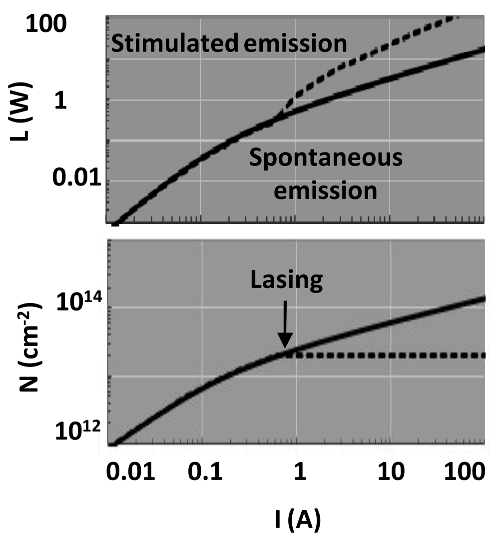
Carrier injection and transport pathways



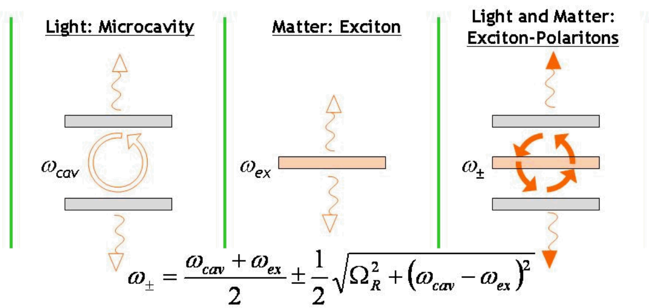
Courtesy of Fred Schubert, RPI

EFRC Thrust 3:
Beyond Spontaneous Emission

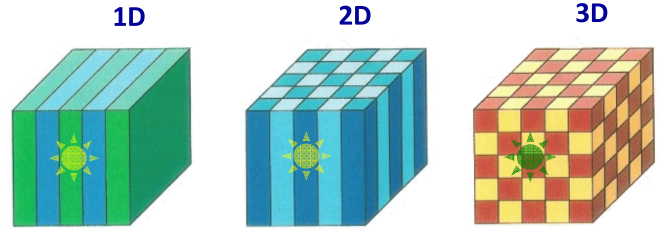
Lasers and stimulated emission



Polaritons in subwavelength photonic cavities

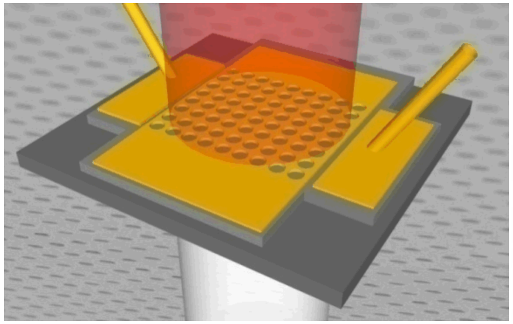


After A Nurmikko, "Basic Research Needs for SSL" Basic Energy Sciences workshop report (2006).

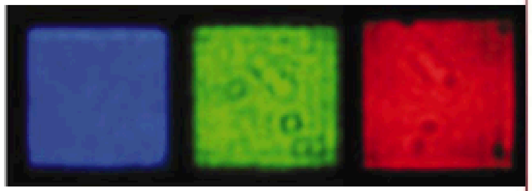


Photonic crystal nanostructure cavities, courtesy of Art Fischer, Sandia National Labs

Plasmonic intermediaries between excitons and free-space photons



Courtesy of Eric Shaner, Sandia National Labs



WL Barnes, et al, "Surface plasmon subwavelength optics," Nature 424, 824 (2003).

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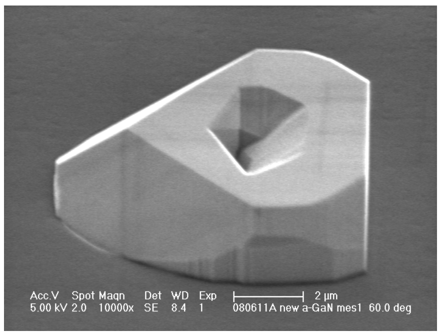
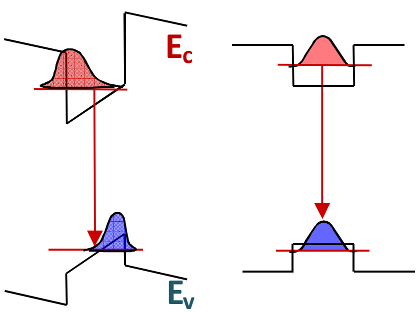
EFRC Thrust 2: Beyond 2-D

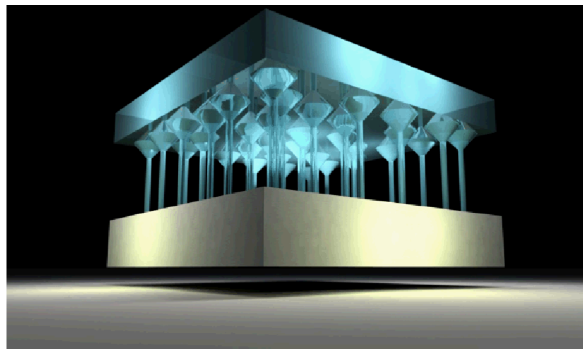
Non-planar growth: routes to non-polar orientations



Courtesy Jung Han, Yale University

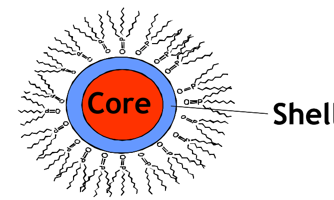


Nanowires: a test bed for materials / luminescence studies

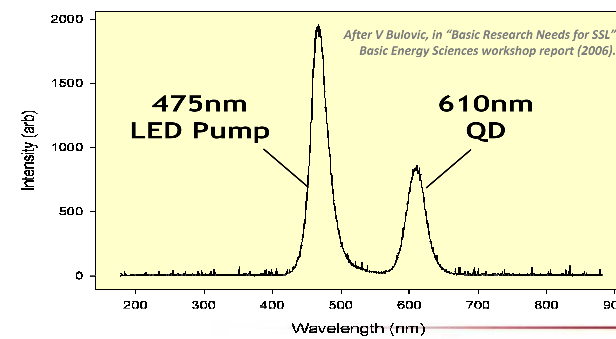


- Dislocation free
- Strain relaxation for compositional freedom
- Electron/hole confinement
- Facet engineering for control of polarization fields
- Waveguiding for lasers

Nanodots: routes to narrow-linewidth orange-red phosphor



Luminescence of CdS QDs



SSLS High-Level Facts

- Start date: August 1, 2009
- Lead institution: Sandia National Labs
- Budget: $3.6M/yr for 5 years ($415K/yr to external partners)
- Staffing (54)
  - Sandia staff / students (32)
  - External partners / students (18)
  - Sandia business + administrative (4)
- Leadership
  - Director: Mike Coltrin
  - Chief Scientist: Jeff Tsao
  - Senior Leadership Council: Jerry Simmons, Mary Crawford, George Wang, Igal Brener

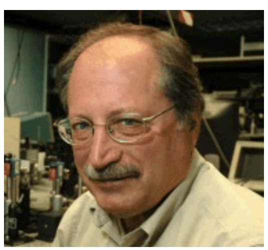
SSLS External Partners (funded)

Prof. Fred Schubert
Rensselaer Polytech

Prof. Lincoln Lauhon
Northwestern Univ.

Dr. Rohit Prasankmar
Los Alamos

Dr. Ken Lyo
Univ. Cal. Irvine



Prof. Steve Brueck
Univ. New Mexico

Dr. David Kelley
Univ. Cal. Merced

External partnerships (Unfunded)

Prof. Jim Speck
UCSB

Dr. Jy Bhardwaj
Philips Lumileds

Prof. Harry Atwater
Caltech

Prof. Jung Han
Yale Univ.

Sandia Facilities enable our EFRC SSL Research

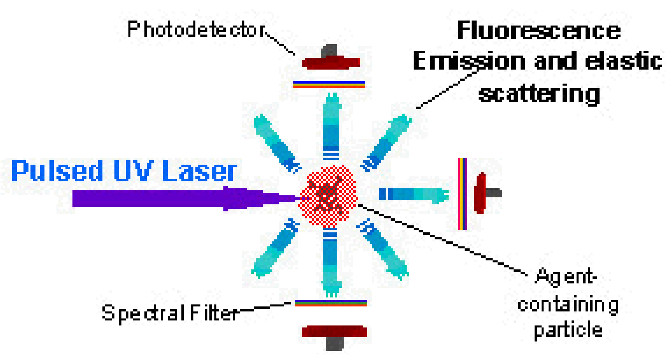
- Six buildings + equipment; largest ($600M) government investment in microtechnology in the world
- includes synthesis, processing, characterization, and modeling of compound semiconductor materials and heterostructures of interest to SSL science
- three commercial III-Nitride MOCVD reactors, full device fabrication and testing capabilities, and extensive optical and materials characterization tools

- one of five BES-supported Nanoscale Science Research Centers, housing state-of-the-art capabilities for the integration of nanoscience concepts and structures into the micro and macro worlds.

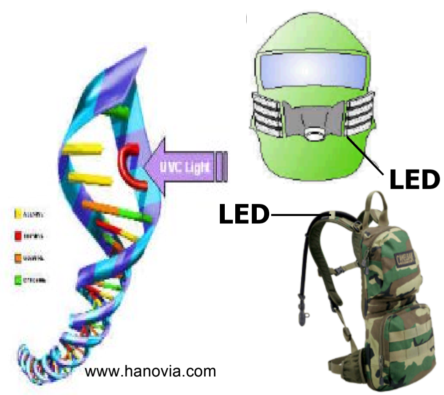
- individual labs operated by senior staff -- typically with capabilities focused on particular synthesis, characterization, or modeling techniques

Other Synergistic III-N Spin-Offs

- GaN power amplifiers for SAR and radar fuse applications
- High-power devices for the smart grid
- Biological agent detection (UV LIF)
- Non-line-of-sight communications
- Water and air purification
- Equipment / personnel decontamination



Biological agent sensing



H_2O, Air Purification & Decontamination

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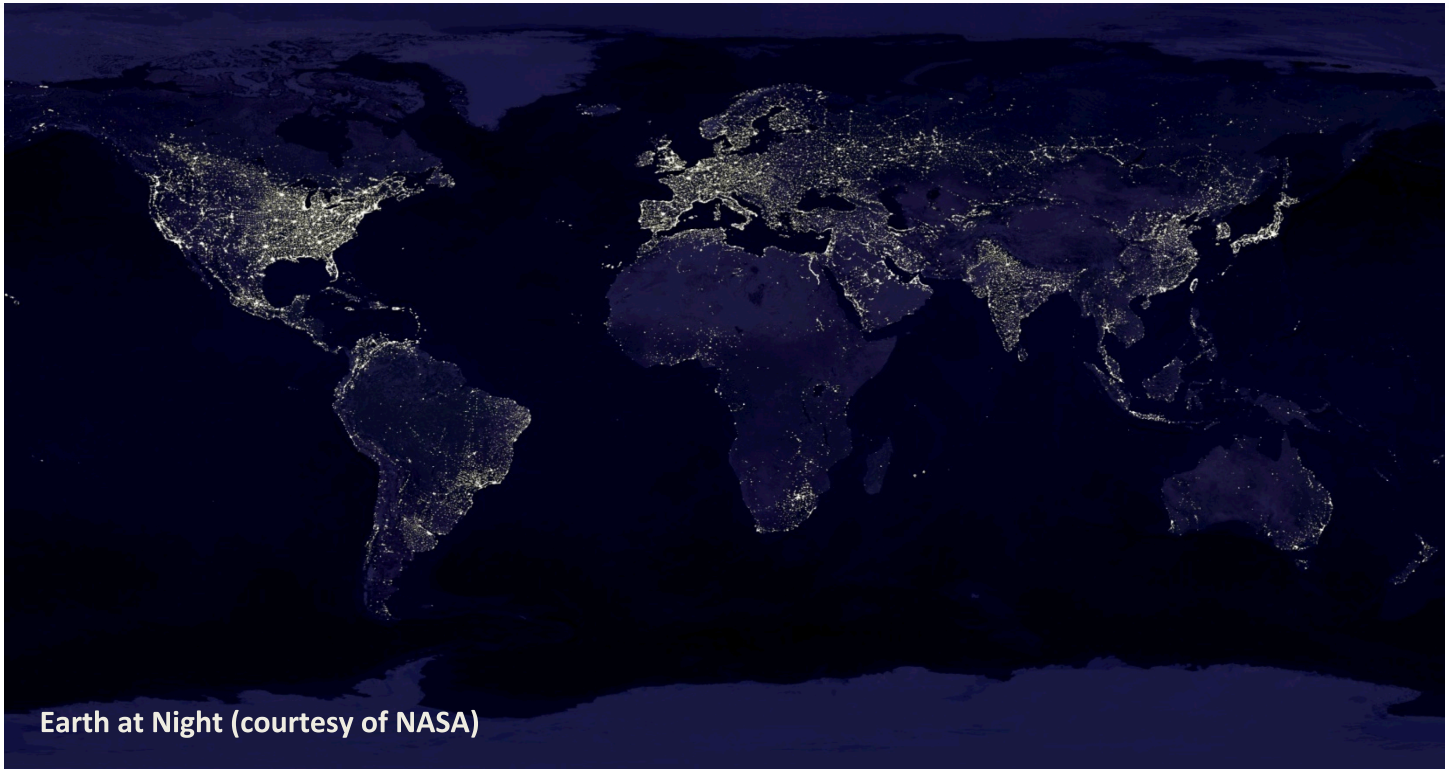
Lighting the Earth



- Energy Efficient Solid State Lighting could replace all conventional lighting in the next 25 years or so.
- This would result in a 10% reduction in global electricity use.
- Much of this revolution will be enabled by **SSL *research*.**