SOLID-STATE LIGHTING RESEARCH & DEVELOPMENT AT SANDIA NATIONAL LABORATORIES

The bridge to a new way of lighting the world

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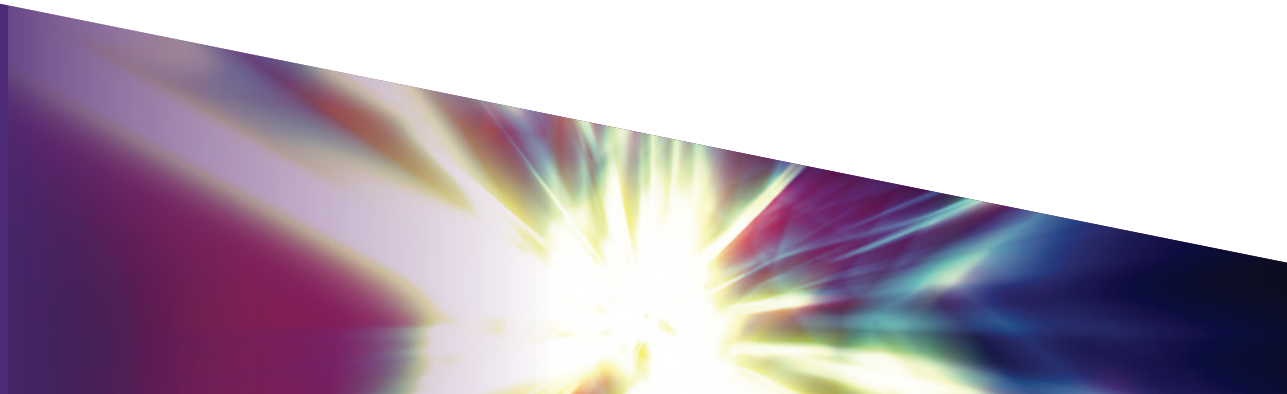
Sandia National Laboratories



SOLID-STATE LIGHTING: BETTER AND MORE EFFIC

THE ULTIMATE LIGHT BULB

Solid-state lighting is expected to be everywhere and in everything by 2030. In televisions, computers, and billboards. Providing safer roadway, signal, and v detect biological and chemical warfare agents. All this while promising to sav primary energy and 16% of the world's electricity. A doubling of lighting effici

THE BENEFITS

SMART LIGHTING SSL can tune colors to almost any shade or tint. It is compact, lightweight, and thin with low radiant heat output, flexible installation, and long lifetime (10 years or longer)—allowing people and machines to be more productive at the same cost, or as productive at less cost, than other technologies. It can offer inherent precision for digitally controlled illumination via interface with microelectronics.

MASSIVE ENERGY SAVINGS
Incandescent and fluorescent lamps convert less than 20% of electrical energy into visible light. But current monochrome LEDs are 70% efficient. Today's commercially available white LEDs are already five times as efficient as incandescent bulbs and on par with fluorescents. Semiconductor-based LEDs can potentially reach 70-100% efficiency—or 10-15 times that of incandescent bulbs and 2-3 times that of fluorescents.

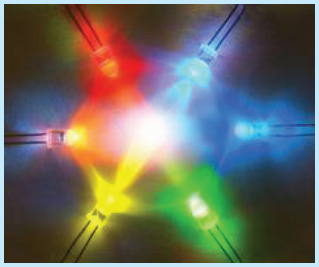
BIG BOTTOM-LINE PAYOFF
Because of these efficiencies, SSL can likely decrease electricity consumed by lighting by more than 50% and decrease total electricity consumption by 10% by 2025—helping the United States save $35 billion a year and the entire world $120 billion annually.

POSITIVE ECONOMIC IMPACT
From new applications created over time, SSL could significantly grow the lighting market—currently a $40 billion worldwide industry.

ENVIRONMENT FRIENDLY SSL is non toxic (does not contain mercury or lead) and can reduce emission of greenhouse gases, cut emission of acid rain, and lower mercury pollution.

TECHNOLOGY SNAPSHOT

SSL uses inorganic or organic light-emitting diodes (LEDs or OLEDs)—which are solid objects, thus the term "solid state." Monochrome LEDs (red, yellow, blue, green) have been around awhile. Because their 10-50% efficiencies are much higher than the 1% efficiencies of color-filtered incandescent bulbs, LEDs are now being used in almost all colored-light applications.



White light for general illumination requires a blend of colors. It is realized by mixing light from multiple LEDs, or alternatively by down converting blue light to other colors using phosphors. Today's commercially available white LEDs are rapidly reaching 20-30% efficiency and will begin to displace incandescent and fluorescent lamps in some applications. They can potentially approach full efficiency.

TECHNOLOGY CHALLENGES: TODAY AND TOMORROW

Sandia and other laboratories are researching ways to achieve 70-100% efficiencies in white LEDs with high color-rendering quality. Major challenges must be faced.

ELIMINATE "EFFICIENCY DROOP" OF THE BLUE LEDS that are at the heart of the current generation of white solid-state lighting. Blue LEDs tend to decrease their efficiency at high-drive currents.

IMPROVE THE PHOSPHORS, PARTICULARLY RED PHOSPHOR also used in the current generation of white solid-state lighting. Specifically, find a red phosphor with a relatively narrow emission linewidth to avoid "spill over" into the deep red where the human eye isn't very sensitive.

USE ELECTROLUMINESCENT SEMICONDUCTOR LIGHT EMITTERS rather than phosphors to fill in the red-yellow-green gap. This would enable the ultimate in efficiency—as well as enhance human productivity through real-time digital control of color.

MILESTONES: SANDIA'S LEADERSHIP IN R&D

1977 *Initiates decades-long investment into compound semiconductor science and technology, eventually establishing its Center for Compound Semiconductor Science and Technology*

1995 *Begins investing in gallium nitride (GaN) materials, physics, and device capabilities*

2001 *Launches its Grand Challenge Laboratory Directed Research and Development Project, "A Revolution in Lighting—Building the Science and Technology Base for Ultra-Efficient Solid-State Lighting"*

ICIENT ILLUMINATION USING SEMICONDUCTORS

30. Improving lighting of homes, offices, stores, and factories. Creating lush color displays for nd vehicle lighting. Enhancing lights for medical instruments. Bolstering light sources that help save huge amounts of energy. Lighting uses about 29.5 quadrillion BTUs, or 6.5% of the world's efficiency, easily possible with solid-state lighting, could cut these amounts in half.

SANDIA'S FOCUS: BRIDGING BASIC ENERGY SCIENCES AND APPLIED TECHNOLOGIES

Sandia leads the way in linking the two components. Scientific advances can be employed swiftly to improve technologies, while technological advances can be quickly used to uncover and explore new scientific questions.

TECHNOLOGY-ORIENTED RESEARCH Since Sandia spearheaded the first solid-state lighting "roadmaps" in 2000, the laboratory has benefited from investments from the DOE Office of Energy Efficiency and Renewable Energy. Today, DOE-EERE supports a $24.5-million program for R&D at national laboratories, universities, and companies nationwide. Sandia has participated in more than 14 projects, in particular those concerning InGaN and GaN as they relate to epitaxy yield, nanostructural engineering, and device efficiency.

SCIENCE-ORIENTED RESEARCH For decades, the DOE Office of Basic Energy Science has funded core research programs. BES backing paved the way for Sandia's increasing involvement and expertise in the science that underlies solid-state lighting. In 2009, Sandia was selected as one of 46 Energy Frontier Research Centers financed with $777 million from the BES from 2009 through 2014. These EFRCs collectively pursue basic and advanced discovery research to build a new U.S. energy economy. Sandia's EFRC focuses on Solid State Lighting Science and has been funded with $18 million over five years. Collaborators include university and industrial partners. For more information, go to **http://ssls.sandia.gov**.

SCIENTIFIC THRUSTS OF SANDIA'S SSLS EFRC

1 COMPETING RADIATIVE AND NON-RADIATIVE PROCESSES Seek a microscopic understanding of the competition between e-h-pair recombination via radiative pathways that produce light and via non-radiative pathways that produce only heat.

2 BEYOND SPONTANEOUS EMISSION Explore energy conversion routes that shortcut conventional spontaneous emission but still produce free-space photons.

3 BEYOND-2D Investigate the use of non-planar nanoscale structures to modify energy conversion routes so that they might be isolated and better understood as well as engineered and optimized.

REAL-LIFE APPLICATIONS

CURRENT

- **PERSONAL LIGHTING** Flashlights, rear combination lamps, lighting fixtures
- **CONSUMER ELECTRONICS** Camera phones, backlit LCD displays
- **SIGNAGE** Red traffic lights (70% in United States), exit signs (90%)
- **AUTOMOTIVE** Center high mount brake lights, tail lights, instrument panel back lights, interior cabin lighting, head lights
- **PUBLIC SPACES** Theaters, bridges, swim centers, restaurants

FUTURE

- **PERSONAL HEALTH** Lights that regulate circadian rhythms for improved sleep and general well-being; room lights that also broadcast information
- **CONSUMER ELECTRONICS** Brilliant colors at big energy savings for televisions, computer monitors, and outdoor displays
- **AUTOMOTIVE** Headlights with peripheral vision; blue dashboard lights to reduce driver fatigue; smart road signs that flash warnings to drivers approaching a dangerous curb too fast
- **AGRICULTURE** Efficient spectral composition enabling plant growth in northern countries during non-native seasons
- **MEDICINE** Real-time identification of biological cells; during surgical procedures, enhanced rendering of cells and organs
- **NATIONAL SECURITY** Use of gallium nitride (GaN) to build lighter radars on aerial vehicles allowing them to fly longer and further and to make ultraviolet LEDs and lasers to detect chemical and biological warfare agents

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2006 *Co-chairs a Department of Energy Office of Basic Energy Sciences workshop entitled "Basic Research Needs for SSL"*

2007 *Designated the lead laboratory for Department of Energy Office of Energy Efficiency and Renewable Energy's National Center for Solid-State Lighting*

2009 *DOE-BES invests in five-year $3.6 million per year Energy Frontier Research Center for Solid-State Lighting Science at Sandia*

The Brooklyn Bridge "necklace lights" were replaced with LEDs in 2008 (Top banner photo courtesy Martin St-Amant, Wikipedia, under the Creative Commons Attribution 3.0 Unported License)

BE PART OF THE BRIDGE

to a new way of lighting the world

You can find out more about this revolutionary lighting technology and Sandia National Laboratories—what we're doing, where we're going, and how we work as part of the Energy Frontier Research Center for Solid-State Lighting Science.

JUST GO TO OUR WEBSITE AT

ssls.sandia.gov

- To read more about SSL technology
- To keep abreast of SSL progress worldwide
- To learn more about our versatile SSL R&D group

YOUR BRIGHT IDEAS ARE WELCOME

Innovation takes team work and collective power—intellectual, creative, financial, and otherwise. We are always looking for partners to contribute to the advancement of solid-state lighting—scientists, researchers, entrepreneurs, government officials, corporate leaders, and industry leaders. We'd love to hear from you with your ideas.

GOOD SOLDIERS *The 30-plus members of Sandia's Energy Frontier Research Center for Solid-State Lighting Science are full-time, world-class scientists deeply knowledgeable in the underlying science of solid-state lighting, from solid-state to semiconductor physics to material science and chemistry to nanophotonics. Sound R&D, teamwork, and openness to new thinking are the cornerstones of their work.*

Sandia National Laboratories NNSA National Nuclear Security Administration LOCKHEED MARTIN

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