2006

ILLUMINATING IDEAS

Innovations in Solid-State Lighting

U.S. Department of Energy
Energy Efficiency and Renewable Energy
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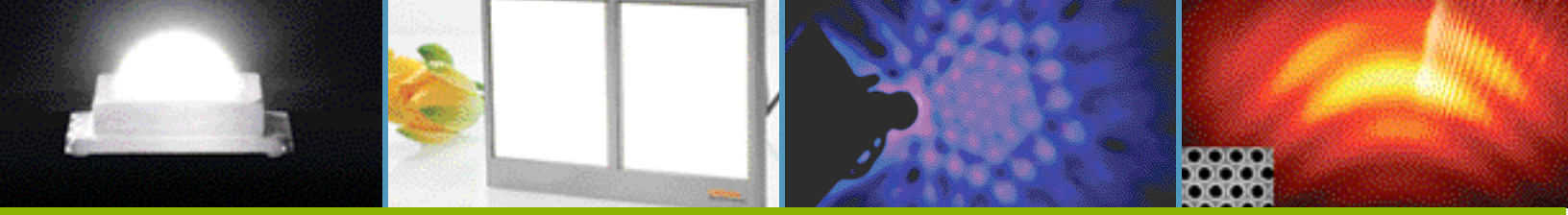


Lighting the Way to Energy Savings

In the next few decades, general illumination technology will undergo a remarkable transformation through improvements in solid-state lighting. No other single lighting technology offers as much potential to conserve electricity, and at the same time, enhance the quality of our building environments.

However, major research challenges must be addressed before the full promise of solid-state lighting is realized. In partnership with industry leaders, research organizations, academic institutions, and national laboratories, the U.S. Department of Energy is working to accelerate technology developments that will profoundly change the future of lighting. These collaborative, cost-shared efforts will ultimately deliver substantial energy savings for all lighting users and position U.S. companies for technology leadership in global markets for new products, systems, and services.

Photos provided by (left to right): Cree; OSRAM Opto Semiconductors, Sandia National Laboratories/University of New Mexico/Lumileds; and the University of California at Santa Barbara.

Developments in Solid-State Lighting

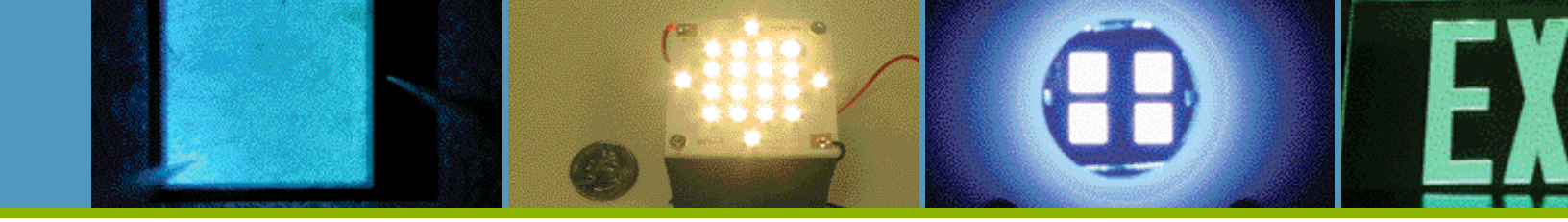
Breakthroughs in light-emitting diode (LED) and organic light-emitting diode (OLED) technology are catalyzing development of energy-efficient solid-state lighting (SSL). Once used only for indicator lights, SSL technology is now found in a variety of specialty applications, including automobile brake lights, traffic signals, exit signs, and flashlights. Research to achieve further technology advances is under way, driving toward development of efficient, full-spectrum, white-light SSL sources that will replace low-efficiency incandescent and fluorescent lamps used for general illumination.

The U.S. Department of Energy (DOE) has invested in SSL technology research since 2000. In this short time frame, DOE-funded researchers have made dramatic progress, achieving several world records.

- Cree Inc. has demonstrated a white LED device with a record-setting efficacy greater than 65 lumens per watt (LPW). The results are particularly significant because the improvement in brightness was achieved in a pre-production prototype using Cree's standard XLamp™ package, rather than a laboratory device.
- OSRAM Opto Semiconductors, Inc. has achieved a record efficiency of 25 LPW, the highest known efficiency achieved to date for a polymer-based white OLED. The white light emission was produced by applying a standard orange inorganic phosphor to OSRAM's record-setting blue light device.
- Lumileds Lighting, the University of New Mexico, and Sandia National Laboratories have demonstrated uniform light emission from the largest-area photonic crystal LED ever fabricated. This achievement is an important step toward low-cost, high-volume manufacturing of photonic crystal LEDs.
- Scientists at the University of California at Santa Barbara have pioneered several innovations in chip design for LEDs, altering the geometry of the chip in order to increase light output.

The Department supports research and development in six key areas: quantum efficiency, lifetime, sustainability and control, packaging, infrastructure, and cost reduction. Advances in these areas will result in SSL technologies that compete in the general illumination market and deliver significant energy savings.

Through a series of interactive workshops, DOE and its SSL partners have developed an extensive research agenda targeting technology improvements in LEDs and OLEDs. These ongoing workshops provide an interactive forum to ensure that DOE funds the appropriate research topics to accelerate development of efficient, full-spectrum, white-light SSL sources.



Sample Projects

The following sample projects highlight the progress of activities directed at decreasing the cost and improving the efficiency, longevity, and manufacturability of SSL technology. For more information on each project, see the DOE SSL Project Portfolio at *www.netl.doe.gov/ssl*.

Agiltron Inc.: Enhancing Charge Injection and Device Integrity in OLEDs

Agiltron is developing an innovative, low-cost anode surface modification technology for OLEDs, designed to increase device efficiency by a factor of 5-10, while improving device stability and lifetime. Researchers have developed stable, high-yield, high-mobility, hole-transporting molecules that can cross-link to form ultrathin coatings. These coatings will be used to modify the surface of the indium tin oxide (ITO) anode of the OLED to enhance the injection of holes into the active area and increase device stability.

Boston University: Low-Cost Blue/UV LEDs for White Lighting

Researchers at Boston University have teamed with Science Applications International Corporation (SAIC) to explore a unique approach to growing GaN-based LEDs. Their objective is to develop LED structures on inexpensive GaN substrates having high internal quantum efficiency and high light extraction efficiency. This is accomplished through the use of textured multiple quantum wells which lead to suppression of polarization effects and enhancement of light extraction. This project is a combination of experimental work done at Boston University and simulation modeling studies done at SAIC. The project goal is to produce a near-UV-blue LED device with a minimum efficiency of 50 LPW. The team has produced violet, blue, and green LEDs, as well as phosphorless white LEDs.

Cree Inc.: Small-Area Array-Based LED Luminaire Design

Cree is designing and developing a compact LED luminaire that is a drop-in replacement BR/PAR-style integrated reflector luminaire, suitable for low-cost insertion into existing commercial and residential lighting fixtures. To reach this objective, researchers are investigating arrays of small-area LED chips, combining modeling and iterative prototype design to overcome optical, electrical, and thermal challenges. Outputs of 54 LPW of cool white light have already been achieved; the ultimate goal is 100 LPW.

General Electric Global Research: High-Efficiency, Illumination-Quality White OLEDs

GE is developing a novel organic device design and corresponding materials set that will directly result in white OLEDs capable of producing >45 LPW by the end of the project. To achieve the project goal, GE will expand the existing library of materials and designs, and develop the necessary processing expertise to produce OLED devices in which all of the spin-state and charge-transport pathways are tightly controlled to convert 100% of the injected charge into a light suitable for use in a white light source.

Light Prescriptions Innovators, LLC: Solid-State Lighting Via Remote Phosphor

LPI and OSRAM Opto Semiconductors, Inc. are developing a multiple-chip LED package with a single remote phosphor, to attain high white-light output without the damaging heat increase that normally results from connecting LEDs. The key is to link top-emitting OSRAM ThinGaN blue LEDs optically, using LPI's patent-pending "combiner" optics. Optical links allow greater spacing among the LED chips and thus cooler operation. Remote positioning of the phosphor also reduces thermal stress to the phosphor itself, leading to increased lifetime. In addition, light reflected back to the LED from the phosphor is recycled by special optics, thereby increasing output efficiency.

Materials Modification, Inc.: Zinc Oxide Light-Emitting Diodes

In order to improve the cost and efficiency of OLEDs for solid-state lighting, Materials Modification, Inc. is seeking to replace expensive

Photos provided by (left to right): Boston University, Cree Inc., General Electric, Materials Modification, Inc., Philips Electronics North America Corporation, University of Southern California

indium tin oxide (ITO) transparent conducting oxide anodes with doped zinc oxide (ZnO). In this project, MMI is incorporating dopants in ZnO in an effort to produce low-cost transparent conducting oxides for green OLEDs with transmission properties equal to or better than ITO. One near-term potential application for high-efficiency, low-cost green OLEDs is in exit signs. Green exit signs provide enhanced visual recognition to the human eye during a fire.

Philips Electronics North America Corporation: Efficient LED System-in-Module

Philips is developing a self-contained LED lamp for general lighting applications. The lamp contains multiple colored LEDs that will allow the user to select the color and intensity of the generated light using intuitive local or remote controls. Color mixing, optical feedback, thermal control, and drive electronics will all be integrated in this LED System-in-Module (LED-SIM) approach. Researchers expect this approach to provide a direct path to lamp systems useful in most commercial lighting and residential lighting applications.

University of California, San Diego: Nitride-Based Heterostructures for Phosphorless SSL

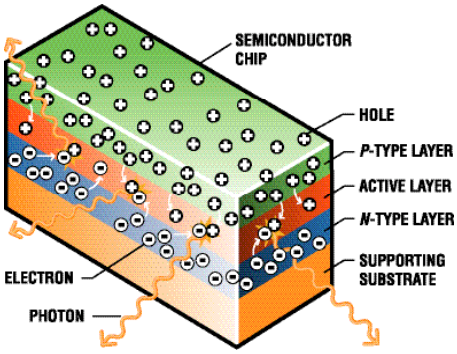
Researchers at UCSD and OSRAM SYLVANIA are taking a dramatically different approach to producing white-light LEDs. They are working to produce new LED powder materials by combining nitride semiconductor alloys (GaN, AlN, InN) with carefully chosen activator ions by solution chemical routes. Thin films of these well-characterized materials will then be made by metal organic vapor phase epitaxy, and placed into a new LED architecture. This work could have a significant impact on traditional nitride devices by substantially improving internal quantum efficiencies by as much as 30 percent, with virtually no added manufacturing complexity or cost.

University of Southern California: Novel Materials for High-Efficiency White Phosphorescent OLEDs

USC, together with Princeton University and Universal Display Corporation, is performing a large-scale synthesis of novel materials for use in white phosphorescent OLEDs. Materials to be examined include carrier transporting/injecting materials, host materials for the doped emissive layer, and phosphorescent dopants, in a range of colors as well as broadband emitters. Many of the materials prepared for this project will be useful in a range of OLED structures, and could be adopted by others to enhance the efficiency and stability of their devices. In addition to new materials, the team is developing optimized structures for white emission, utilizing both fluorescent and phosphorescent emitters.

Efficient Production of Light

When efficiency goals are met, SSL will produce light with less heat than any other source. At the heart of an SSL device is a sandwich of semi-conductor layers built on a substrate. Electrons released from the negative n-type layer combine with holes from the positive p-type layer. These electron-hole pairs recombine in the active layer to produce photons.



An LED is a very small (dot-sized) electrical device that produces light through the semi-conducting properties of its metal alloys. An OLED is a surface-shaped device, similar to an LED, composed of small molecules or polymers that emit light.

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

To Participate in DOE Solid-State Lighting R&D

Does your company, research organization, or university have a promising solid-state lighting technology that will save energy? If so, your research and development efforts may be eligible for funding of up to 80%. To learn more, visit **www.netl.doe.gov/ssl**

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