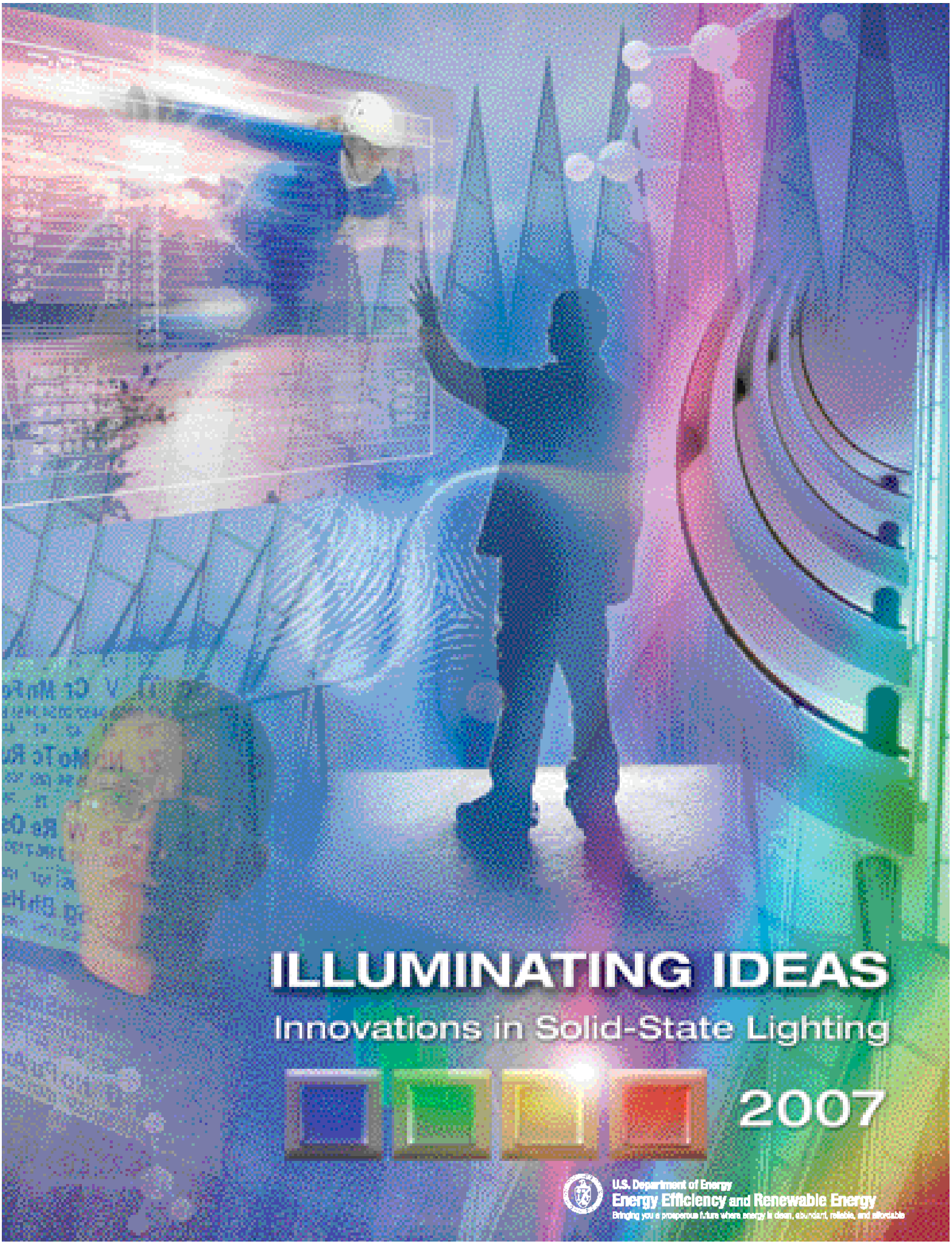
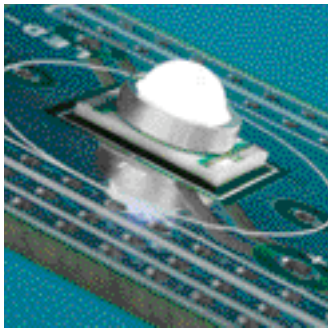
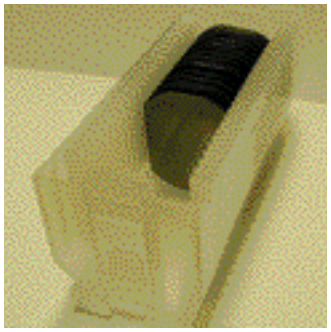

ILLUMINATING IDEAS
Innovations in Solid-State Lighting
2007
U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

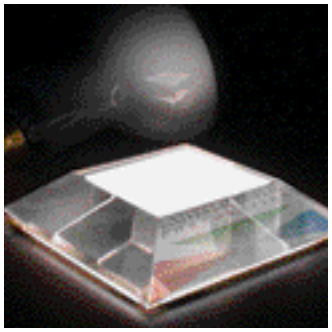
Lighting the Way to Energy Savings

Solid-state lighting is a pivotal emerging technology that promises to fundamentally alter and improve lighting systems – and buildings – of the future. No other lighting technology offers our nation so much potential to conserve electricity, at a time when our nation needs bold solutions to achieve greater energy independence.

Major research challenges must be addressed before the full promise of solid-state lighting is realized. In partnership with industry, research and academic organizations, and national laboratories, the U.S. Department of Energy is working to accelerate technology advances 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 Inc.; Technologies and Devices International, Inc.; Universal Display Corporation

Catalyzing Developments in Solid-State Lighting

Solid-state lighting (SSL) technologies today are undergoing rapid change and improvements, and high performance products for general illumination are already emerging on the market. The U.S. Department of Energy (DOE) is leading research efforts to achieve the full energy-saving potential of SSL, investing in projects that target needed improvements to ramp up efficiency and performance while driving down technology costs.

DOE support acts as a catalyst for the creation of SSL partnerships, driving toward development of highly efficient, full-spectrum, white-light SSL sources that will ultimately replace incandescent and fluorescent lamps used for general illumination.

Through a series of interactive workshops, DOE and its SSL partners have developed an extensive research agenda targeting technology improvements in light emitting diodes (LEDs) and organic light emitting diodes (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.

DOE-funded researchers strive for technology advances and efficiency breakthroughs that will make SSL a cost-effective, energy-saving alternative for general lighting applications. The following project results from 2006 highlight major breakthroughs in both the lab and in products on the market, and represent important steps toward DOE's long-term research goals.

Cree Inc. released the new XLamp® 7090, setting new records for LED brightness and efficacy: 80 lumens at 350 mA, yielding 70 lm/W. Cree is also offering quantities of the XLamp LEDs that produce luminous flux of 95 lumens at 350 mA, or 85 lm/W.

Technologies and Devices International, Inc. released novel, low-defect GaN template substrates and InN epitaxial wafers for fundamental research, product development, and production of high efficiency, high-brightness LEDs.

Pacific Northwest National Laboratory researchers have created a blue OLED device with an external quantum efficiency of 11 percent at 800 cd/m^2. This achievement is particularly notable since it was achieved at very low operating voltage (6.2V), revealing the potential for much higher power efficiencies.

Universal Display Corporation successfully demonstrated a 2 mm^2 white organic light emitting diode (WOLED™) with a power efficacy of 40 lm/W at 1,000 cd/m^2, corresponding to an external quantum efficiency of 33 percent.

These research teams will continue to strive for further technology improvements, working to develop higher efficiency SSL technologies that compete in the general illumination market and deliver significant energy savings.

Sample Projects

The following projects initiated in 2006 provide a sampling of some key areas of focus. For more information on each project, see the DOE SSL Project Portfolio at *www.netl.doe.gov/ssl*.

Color Kinetics Incorporated: An Integrated Solid-State LED Luminaire for General Lighting

Color Kinetics is partnering with Cree Inc., to develop a novel hybrid-LED source with the goal of producing a warm, white solid-state lamp with a source efficacy of 80 lm/W and a CRI of 92+ by 2008. Their approach combines direct emission LEDs with down-conversion phosphors, which absorb incoming light and emit twice the amount absorbed (at lower energies) to produce high-efficacy white light devices. The researchers plan to manufacture a solid-state lamp that will replace existing 60W incandescent lamps and have a total flux of 800 lumens.

Fairfield Crystal Technology, LLC: A Novel Growth Technique for Large Diameter AlN Single Crystals (Phase II)

This project is investigating a novel physical vapor transport technique to grow large diameter AlN bulk single crystals as substrates for high-quality nitride epilayers needed for high-brightness LEDs. Single-crystal AlN is a superior substrate material for III-V nitride epitaxy, but currently it is not available in production-worthy sizes and qualities. Successful development of Fairfield's novel growth technique is expected to lead to larger diameter and higher quality single-crystal AlN substrates.

Lawrence Berkeley National Laboratory: High-Efficiency Long Lifetime OLEDs with Stable Cathode Nanostructures

LBNL scientists are investigating carbon nanotubes, nanoclusters, and lithographically defined nanostructures for use as cathodes in OLEDs. Replacing the current metal film cathodes with precisely designed nanostructural cathodes could improve the stability of OLEDs and possibly double their lifetime. Furthermore, using cathodes with controlled nanostructures and well characterized electrical transport properties could increase the quantum efficiency of OLED devices by as much as 40 percent.

Osram Sylvania Development Inc.: Phosphor White LED with High Package Extraction Efficiency

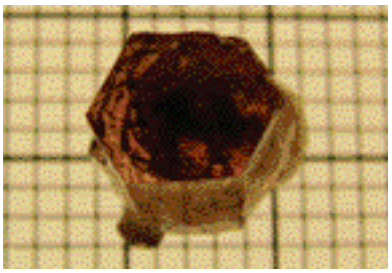
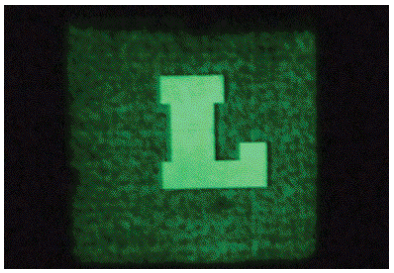
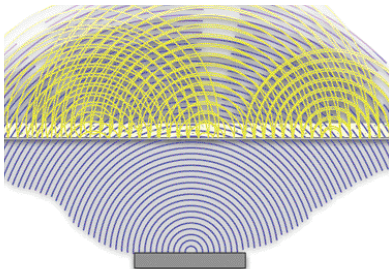
Osram Sylvania is attempting to increase the extraction efficiency of white LEDs by reflecting yellow photons scattered from phosphors. A multilayer thin film coating between the chip and phosphors reflects these photons, increasing their probability of forward escape. The researchers are testing three different coating configurations to improve the extraction efficiency of the phosphors-based LED, with a goal of 80 lm/W.

Pacific Northwest National Laboratory & National Renewable Energy Laboratory: Novel High Work Function Transparent Conductive Oxides for Organic SSL Using Combinatorial Techniques

A collaborative effort between PNNL and NREL aims at using combinatorial techniques to systematically discover and optimize new transparent conductive oxides (TCOs) for use in OLEDs. TCOs are transparent windows that allow light to pass through while doubling as an electrical contact in the device circuit. The combinatorial method will be used to develop novel TCOs with increased efficiency blue organic light emitters and indium-free compositions for improved stability.

Sandia National Laboratories: Innovative Strain Engineered InGaN Materials for High-Efficiency Green Light Emission

Researchers at Sandia are working to enhance the efficiency of green LEDs, which are crucial for the red-green-blue approach to SSL. The efficiency of green LEDs lags far behind the other colors. Strain in the InGaN material needed for green


emission is a critical problem, because it leads to internal electric fields that can cause inefficient recombination of electrons and holes (the light-producing process). Strain can also lead to increased defect densities and degraded performance. To overcome these problems, Sandia is investigating novel growth approaches to relieve the strain in controlled ways and improve material quality. The goal of the project is to achieve a 2X improvement in the internal quantum efficiency of current green LED technology.

Universal Display Corporation: High-Recombination Efficiency White Phosphorescent OLEDs (Phase II)

In Phase II of this project, researchers are using proprietary phosphorescent materials with a demonstrated 100 percent internal quantum efficiency in monochrome devices to optimize the recombination efficiency of electrons and holes in white OLEDs (WOLEDs™). This optimization of electron/hole recombination ensures the generation of a desired ratio of red, green, and blue excitons leading to white emission. UDC's goal is to produce a powerful, 6- by 6-inch WOLED with a CRI of >75, and an efficacy of 40 lm/W at a flux of >100 lm.

University of California, Santa Barbara: High-Efficiency Nitride-Based Photonic Crystal Light Sources

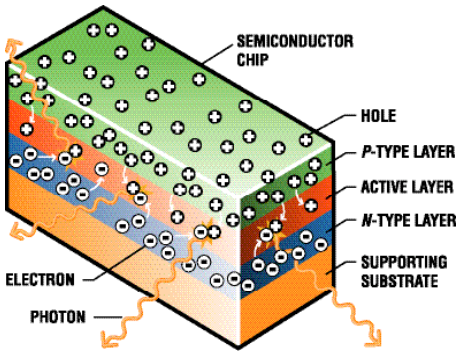
Researchers at the University of Southern California, Santa Barbara (UCSB) are attempting to extract light that would normally be confined in a conventional LED system to create brighter, more efficient LEDs. Strategic placement of photonic crystals in the structure is the key to enhancing light extraction. This technology could maximize the efficiency of a white LED by enhancing the external quantum efficiency.

University of Florida: High-Efficiency Microcavity OLED Devices With Down-Conversion Phosphors

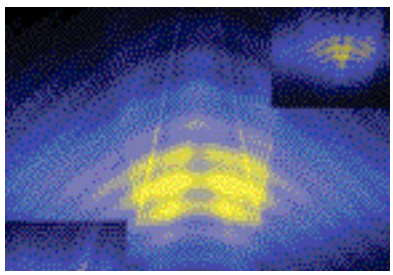
This project is focused on improvements in the overall performance of OLEDs in three key areas: improving the power efficiency of blue emitting devices by incorporating electrical dopants in the charge transporting layers; enhancing the light out-coupling efficiency with microcavity structures; and down-converting blue light to white light with phosphors. The objective is to demonstrate a white light source with efficacies exceeding 100 lm/W and a CRI of >90.

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.



Photos provided by (left to right): Fairfield Crystal Technology, LLC; Lawrence Berkeley National Laboratory; Osram Sylvania; Sandia National Laboratories; Universal Display Corporation; University of California, Santa Barbara

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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