# DOE Supporting U.S. Manufacturing Growth

DOE's solid-state lighting (SSL) manufacturing R&D initiative is a collaboration between the federal government and the lighting industry to develop cost-cutting measures in manufacturing LEDs, OLEDs, and associated equipment, supplies, and components in an effort to maintain the U.S. market and the jobs it creates. In his opening presentation at the second annual DOE SSL Manufacturing R&D Workshop, held in Boston April 12–13, 2011, DOE Lighting Program Manager James Brodrick outlined what was at stake for U.S.-based companies:

- Keep and grow current U.S. SSL manufacturing base
- Retain and create U.S. jobs
- Increase sales of value-added exports
- Decrease imports
- Maintain U.S. technology leadership in product advances and future development

The panelists at the 2011 workshop provided solid evidence that the "gloom and doom" exhibited at the 2010 workshop over the potential loss of U.S. lighting manufacturing strength could be reversed with directed planning and the combined efforts of government and industry to stop manufacturers from moving their operations overseas. As requested by the panelists at the 2010 workshop, DOE and the industry have put their efforts into:

- Building cost-effective U.S. LED fabrication facilities
- Building U.S. capacity for supplying manufacturing equipment, non-chip lighting components, and source materials
- Focusing R&D resources on developments to reduce production costs.

Manufacturing R&D projects focus on achieving significant cost reductions and enhancing quality through improvements in manufacturing equipment, processes, or monitoring techniques. Selected projects address the technical challenges that must be overcome before prices fall to a level where SSL will be competitive with existing lighting on a first-cost basis.

Using funds from the American Recovery and Reinvestment Act of 2009 (ARRA), DOE has co-funded a number of industry R&D projects designed to improve manufacturing processes and improve cost engineering. At the 2011 workshop, attendees heard about eight projects that have exhibited significant progress in a number of manufacturing aspects. These presentations may be viewed at www.ssl.energy.gov/boston2011_materials.html. DOE funding is helping industry improve the tools and procedures used in producing LED and OLED devices, the automated procedures for analyzing and inspecting device production, and the methods of improving LED light quality to satisfy consumer demands.

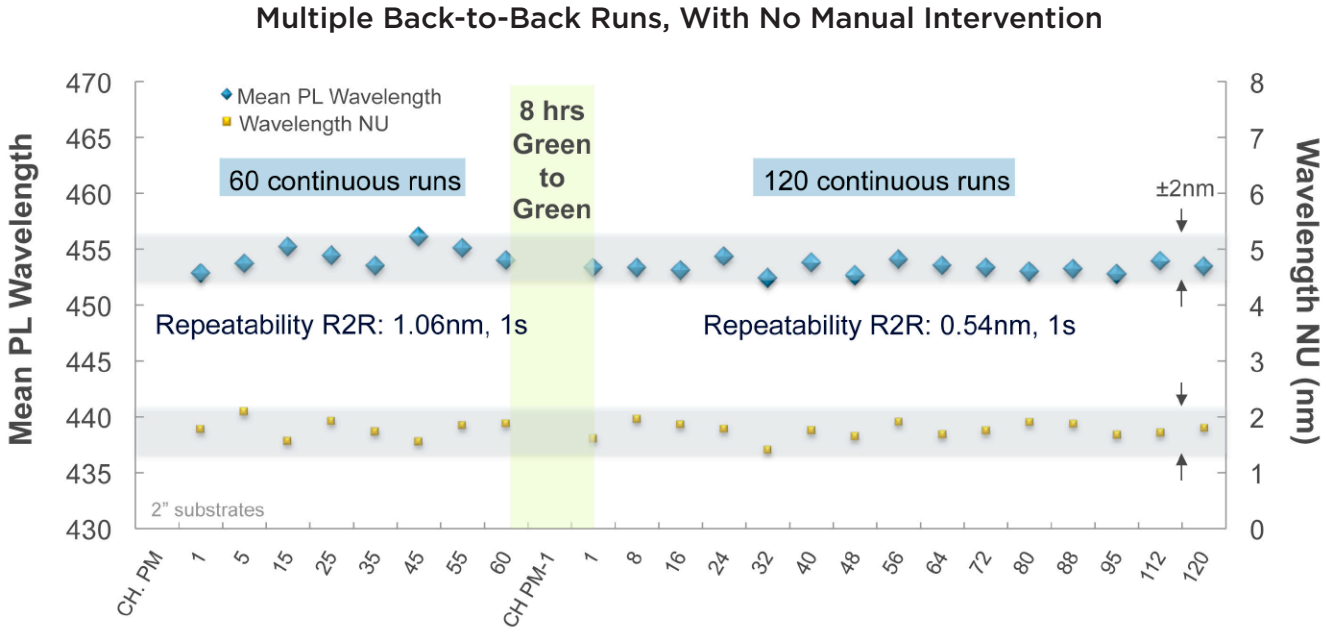
Following is a synopsis of the eight DOE co-funded research projects that were highlighted at the 2011 workshop, and why they're important:

## 1. Advanced Epi Tools for Gallium Nitride Light-Emitting Diodes

**Research Organization:** Applied Materials Inc., located in California's Silicon Valley, is a global leader in providing innovative equipment, services, and software to enable cost-effective manufacturing of advanced semiconductors such as LEDs, flat panel displays, and solar photovoltaic products.

**Project Goals:** A key component of making LED lighting a cost-effective alternative to conventional light sources is reducing the cost to manufacture the LEDs themselves. DOE has co-funded Applied Materials' efforts to increase lumen-per-watt output of LEDs and lower production costs by creating a multi-functional fabrication chamber that increases the speed and quality of production within a packaged system. The standard production method has been to use a single chamber to deposit each of the three principal layers of an LED structure, which slows down the production process and requires costly and time-consuming cleaning after each step. Applied Materials' method involves using a separate chamber for each layer, which facilitates optimization, with further efficiencies added by a self-cleaning process built into each chamber. In addition, a faster and cheaper new technology called hybrid vapor phase epitaxy is used instead of metal-organic chemical vapor deposition for one of the steps.

**Expected Results:** The new procedure is expected to bring down the cost of LEDs by increasing yield and lowering cost of ownership. Applied Materials has established a firm baseline for LED production quality in its current fabrication units as well as specific goals for reducing production cycle time from eight to four hours, while increasing LED efficiency by over 20 percent and tripling the production of top-tier LEDs during each cycle.




Applied Materials' advanced epitaxial growth system speeds up production by using a separate chamber to deposit each of the three principal layers of an LED structure. Source: Applied Materials

## 2. Roll-to-Roll Solution-Processable Small-Molecule OLEDs

**Research Organization:** GE Global Research is a wholly owned subsidiary of the General Electric Company and has its headquarters in Niskayuna, New York. Its lighting group is responsible for developing novel technologies as part of GE's "ecomagination" efforts, including an attempt to nurture OLED technology into marketable products.

**Project Goals:** GE is perfecting a method of machine-printing all four organic semiconductor layers of an OLED, in liquid form, onto a roll of polymer substrate, similar to the way a continuous sheet of newsprint is pulled through the printing process. The idea is to reduce OLED costs by speeding up mass-production time, while still getting high performance. GE has already developed the method and is perfecting the technique, with the goal of equalling the performance of OLEDs made by the standard method of batch-processing. The immediate goal is to improve OLED efficiency to 45 lumens per watt (lm/W) by 2012.

**Expected Results:** It is expected that GE's roll-to-roll manufacturing process will eventually lower OLED lighting product costs to affordable levels and provide the U.S. with "an opportunity to leapfrog the current Asia-dominated OLED manufacturing infrastructure." It will also reduce investment risk for low-cost manufacturing and shrink the timeline for OLED lighting to displace less-efficient conventional lighting.

## 3. Development of Advanced Manufacturing Methods for Warm-White LEDs for General Lighting

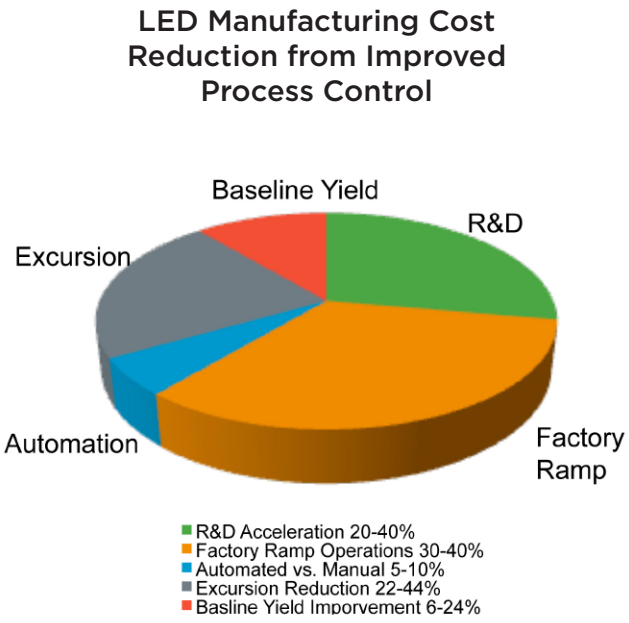
**Research Organization:** GE Lighting Solutions comprises GE Lighting's LED system operations based in Cleveland and its commercial and industrial lighting fixture group in Hendersonville, North Carolina. The units were combined in 2010 to support a strategy to serve as an industry-leading solutions provider for the rapidly growing indoor and outdoor fixture segments that use LED systems and other energy-efficient lighting technologies.

**Project Goals:** One of the keys to the evolving LED general-lighting market is the ability to offer products that match the warm-white qualities of incandescent lighting. With financial assistance from DOE, GE is working to develop, design, and pilot advanced manufacturing methods for warm-white general-illumination LEDs, using remote-phosphor techniques. Phosphor is a critical element in LEDs because it converts blue light into warm-white light. With the remote-phosphor method, the phosphor forms a dome over the LED chip instead of being directly deposited on it. Phosphor is expensive, and GE is trying to reduce LED phosphor content by mixing it with a polymer carrier so that it can be injection-molded, and is also trying to scale the process up so that it can be used in the company's line manufacturing. The goal is to reduce the cost of the remote-phosphor LED by 53 percent, with an efficiency of more than 75 lumens per watt and a lifetime of over 50,000 hours.

**Expected Results:** The use of phosphors in warm-white products is currently expensive, and the manufacturing process is inefficient. GE Lighting Solutions is striving to reduce overall production costs by 53 percent by significantly lowering material, labor, and capital costs and creating a model automated large-scale manufacturing line.

## 4. Automated Yield Management Solution for LED Manufacturing

**Research Organization:** KLA-Tencor is headquartered in Milpitas, California, with sales and support facilities around the world. It is the world's leading supplier of process control and yield management solutions for the semiconductor and related microelectronics industries. The company's comprehensive portfolio of products, software, analysis, services, and expertise is designed to help integrated circuit manufacturers manage yield throughout the entire wafer fabrication process—from R&D to final yield analysis.




KLA-Tencor expects that its in-line inspection tool will be able to cut LED manufacturing costs in half by 2015. Source: KLA-Tencor

**Project Goals:** KLA-Tencor's expertise is in developing analytical techniques designed to significantly reduce fabrication costs. In this DOE project, the company is striving to cut LED manufacturing costs in half by improving the in-line inspection process. Since the use of LEDs for general lighting is relatively new, the DOE funding is being used to speed the process of adapting and developing analytical tools specifically for the lighting industry. The company has developed an automated visual inspection system that can identify defect sources early in the LED manufacturing process. Incorporating both hardware and software components, it can be used at various stages: during new process development, to find out where defects such as micropits and microcracks occur; to reduce the time it takes to ramp up production; and, in full production, to detect and reduce "excursions" (departures from the desired outcome).

**Expected Results:** In the first year of the project, KLA-Tencor has developed an automated visual inspection system that mechanizes what had been a partially manual function. It is expected that by the second year, all field tests will be completed and the system will be ready for general use. The improved process control will allow significant cost reduction through increased production yields, faster R&D, and quicker process ramp-up.

## 5. Low-Cost Illumination-Grade LEDs Enabled by Nitride Epitaxy on Silicon Substrates

**Research Organization:** Founded in 1999, Philips Lumileds Lighting Company is a leading manufacturer of high-power LEDs and a pioneer in the use of solid-state lighting solutions for everyday purposes, including automotive lighting, computer displays, LCD televisions, signage and signaling, and general lighting. It is headquartered in San Jose, California, with operations in the Netherlands, Japan, Malaysia, and Singapore and sales offices throughout the world.

**Project Goals:** Philips Lumileds has a history of improving the quality of computer monitors and televisions through its innovative LED production processes. However, the LEDs fabricated for these higher-margin industries are less suitable for the general lighting market, where the cost disparity between common products, such as incandescents and compact fluorescent lamps (CFLs) and LED lamps and luminaires, is still quite high. This two-year project is designed to lower the cost of illumination-grade LEDs by over 60 percent by replacing sapphire substrates with silicon, which is much cheaper and easier to obtain. Philips Lumileds is attempting to adapt the use of silicon to the manufacture of LEDs, drawing upon the knowledge base and depreciated equipment of the computer industry, which has been using silicon substrates for decades. The goal is to achieve the same light output with silicon as with sapphire.

**Expected Results:** By leveraging its thin-film technology and improving its current fabrication platform, Philips Lumileds expects to produce illumination-grade, 120 lm/W, warm-white LED chips by 2012, using a silicon substrate.

## 6. Low-Cost Lithography Tools for High-Brightness LEDs

**Research Organization:** Founded in 1979 and located in California's Silicon Valley, Ultratech, Inc., manufactures advanced packaging lithography systems that deliver yield gains and increase product packaging performance with a low overall cost of ownership. The company's laser processing technology increases chip performance while reducing energy consumption.

**Project Goals:** Lithography is an important part of the manufacturing process for LED chip wafers. Ultratech is adapting an existing lithography tool for use in manufacturing high-brightness LEDs, in the process reducing capital expenditure and cost of ownership while increasing throughput and yield. Originally designed for the semiconductor industry, the tool uses a lithography method (projection lithography) that is more cost-effective for manufacturing commercial LEDs than the alternative method (proximity print lithography), which is suitable for R&D and low-volume manufacturing but not for high-volume production. Ultratech has improved the tool's alignment system and automation and has reduced the capital equipment costs by about half of the ultimate target.

**Expected Results:** Ultratech expects its tool to cut LED lithography costs—which currently run between $5 and $7 per chip wafer—by 50 percent and save chip manufacturers approximately $250,000 per year per each fabrication tool.

## 7. Creation of a U.S. Phosphorescent OLED Lighting Panel Manufacturing Facility

**Research Organization:** Universal Display Corporation (UDC) is a leader in the development of innovative OLED technology for use in flat-panel displays, lighting, and organic electronics. The company is headquartered in Ewing, New Jersey, but, with the support of DOE and the State of New York, has recently opened a state-of-the-art pilot fabrication facility in Canandaigua, New York.

**Project Goals:** In conjunction with Moser Baer Technology, Inc. (MBT), UDC is taking a big step in advancing the market availability of OLEDs by setting up a pilot OLED manufacturing line that will

provide prototype lighting panels to U.S. luminaire manufacturers and facilitate the growth of the embryonic OLED lighting industry. The new facility will utilize UDC's phosphorescent OLED technology and is being designed and built by MBT, which will also operate it. The prototype panels will enable U.S. luminaire manufacturers to test new design concepts and incorporate them into innovative lighting products. A major goal is to work with the luminaire manufacturers on the engineering and cost factors necessary to produce marketable products for commercial entities in the U.S.

**Expected Results:** While OLED technology lags behind LED technology in efficiency, UDC expects to begin production and ship samples to key customers in 2012, at which time the panels are projected to have achieved an efficacy of 80 lm/W with good color rendition, and a lifetime of 20,000 hours.


UDC's pilot OLED manufacturing line will be located in the Smart System Technology & Commercialization Center in Canandaigua, NY, and will be operated by Moser Baer Technologies. Source: Universal Display Corporation

## 8. Driving Down HB-LED Costs

**Research Organization:** Headquartered in Plainview, New York, with facilities around the world, Veeco is a global leader in LED fabrication technology. The company is a major supplier of fabrication reactors to all the major high-brightness LED chip manufacturers.

**Project Goals:** In conjunction with Sandia National Laboratories and Philips Lumileds, Veeco is attempting to drive down the cost of high-brightness LEDs by upgrading its process simulation tools and temperature control methods to get higher-yield chip growth. The goal is to facilitate a 75-percent cost reduction in the epitaxy phase of manufacturing, which will significantly reduce the cost of high-quality chips. Veeco is working with Sandia to reduce the cost of ownership of the deposition equipment by, for example, using a heated flow flange, which reduces the consumption of the expensive flow gases (ammonia, nitrogen, hydrogen, and the metal organics) by 40 percent. Two different types of pyrometers are also being tested to control the temperature, which helps determine LED color.

**Expected Results:** Working directly within the Philips Lumileds manufacturing structure, and with assistance from Sandia on chemical and thermal modeling, Veeco has already achieved a 10 percent

throughput increase by cutting process time from 361 minutes to 329 minutes. The next iteration of test units is expected to reduce process time by an additional 30 percent.

The funding provided by DOE for the eight projects described in this document should be viewed as seed money for the accelerated development of manufacturing processes that will keep a sizable portion of this growing industry in the U.S. The ARRA funding has afforded U.S. companies the opportunity to develop new techniques to lower the cost of LEDs and OLEDs through improved manufacturing methods, rather than looking to foreign sources for R&D funding assistance. This is extremely important, as the lighting industry must constantly compete with primarily Asian companies in lamp and luminaire manufacturing and in the tools that are used in such manufacturing. The DOE funding has provided a note of optimism to the question of whether the U.S. can maintain and grow its competitive advantage in LEDs and OLEDs. The continued DOE support of manufacturing efficiency and cost-cutting can play a significant role in further improving the chances of keeping solid-state lighting domestic.