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INTRODUCTION

Mr. Chairman, thank you for the opportunity to testify today on the promise of energy efficient solid-state lighting technology and the research in this area that is being conducted at Sandia National Laboratories. I am Alton D. Romig, Jr., Vice President for Science and Technology and Strategic Partnerships, and also Chief Technology Officer, at Sandia. Sandia National Laboratories is managed and operated for the U. S. Department of Energy (DOE) by Sandia Corporation, a subsidiary of the Lockheed Martin Corporation.

Sandia is a multiprogram laboratory of DOE and one of the three National Nuclear Security Administration (NNSA) laboratories with research and development responsibility for nuclear weapons. Sandia's job is the design, development, qualification, and certification of nearly all of the non-nuclear subsystems of nuclear weapons. We perform substantial work in programs closely related to nuclear weapons, including intelligence, nonproliferation, and treaty verification technologies. As a multiprogram national laboratory, Sandia also performs research and development for DOE's energy and science offices, as well as work in national security and homeland security for other agencies when our special capabilities can make significant contributions.

I will begin my testimony with some background on solid-state lighting technology, the current state of development, and where we think the research is headed. I will then discuss the enormous beneficial impact that solid-state lighting can have on our nation's energy security, with the potential to reduce electricity consumption by 10 percent or more by 2025. I will also briefly describe Sandia's ongoing research activities in solid-state lighting in partnership with industry. Finally, I will explain why we believe that a national initiative in energy efficient solid-state lighting research and development involving government, industry, and universities will provide the best avenue for rapid development and adoption of this promising technology.

THE DEVELOPMENT OF SOLID-STATE LIGHTING

This year, about 20 percent of the United States' electricity consumption will be devoted to lighting. The vast majority of that lighting will be provided by incandescent and fluorescent bulbs, technologies that have been around for decades (or longer than a century in the case of incandescents). Incandescents are quite inefficient, with only about five percent of their electricity consumption being converted to visible light. The remainder is converted to waste heat, which contributes significantly to the cooling loads in buildings. Fluorescent lighting is much better, but still converts only about 25 percent of the electrical energy into visible light. This wasted electricity represents an attractive target for reducing the nation's electricity bill.

Solid-state lighting, however, is a new technology that has the potential to far exceed the energy efficiencies of incandescent and fluorescent lighting. Solid-state lighting uses light-emitting diodes or "LEDs" for illumination, the same kind of practical and inexpensive devices that provide the letters on your clock radio. The term "solid-state" refers to the fact that the light in an LED is emitted from a solid object—a block of semiconductor—rather than from a vacuum tube, as in the case of incandescents and fluorescents. (Note: I will limit my remarks to LEDs made from inorganic semiconductor materials; but organic-based LEDs, or OLEDs, fabricated from plastic-like polymeric materials, are also expected to play a significant role in the evolution of energy efficient solid-state lighting.)

The first practical demonstration of an LED was in 1962. Since the late 1960s, the brightness of commercially available red LEDs has increased by a factor of 20 every ten years, while the cost has decreased by a factor of 10 every ten years. Early on, this rapid improvement in the technology resulted in LEDs replacing incandescent bulbs and other vacuum tubes that had previously been used for indicator lamps and numeric displays in electronics such as clock radios.

A few years ago, an innovative new semiconductor material was developed—gallium nitride (GaN)—which enabled the development of the first LEDs with bright emission in the blue and green spectral range. (Previously, bright LEDs were available only in red and orange.) This was a crucial development, since now white light could be realized by mixing different wavelength light from multiple LEDs, or alternatively by down-converting blue light to other colors of longer wavelength using phosphors. To their credit, the Department of Energy immediately recognized the significance of this discovery and in 1992 began the first analysis of applying it towards general illumination purposes, citing efficiency, cost, and complexity of manufacture as concerns.

In the past few years, the technology has progressed sufficiently that inexpensive and energy efficient LEDs are now the only logical choice for single color applications such as traffic signals. Conventional 12-inch-diameter red traffic signals use a long-life, white, 140-watt incandescent bulb. The red filter over it discards 90 percent of the light, allowing only 200 lumens of the red light to pass through. A commercially available LED replacement manufactured by LumiLeds of San Jose, California, for example, uses 18 red LEDs to provide the same amount of red light, but consumes only 14 watts—one tenth as much. While LED traffic lights cost more than incandescent traffic lights, the reduced electricity consumption allows them to pay for themselves in a year or less. They also last much longer, reducing maintenance costs. As a result, LED-based traffic signals are becoming widely adopted throughout the country. Similarly, 90 percent of exit signs, another single-color application, are now fabricated with LEDs.

Of course, for general illumination, full spectrum, white light is required. LEDs must significantly improve to be economically competitive for general lighting. While today's best white LEDs are more efficient than incandescent bulbs (25 lumens per watt vs. 15), they also cost as much as 100 times more per lumen. Moreover, they are not yet as efficient as fluorescent lamps (80 lumens per watt).

Energy efficient solid-state lighting promises better quality and more versatile sources of lighting, including the ability to tune colors to virtually any shade or tint. Because the light can be controlled with extremely high precision, it is believed that by interfacing it with modern microelectronics, a "brave new world" of digitally controlled illumination will be achieved. Such "smart light" could even be used to interface computers into networks through the lighting fixtures themselves. In addition, solid-state lighting offers other desirable qualities, such as light weight, thinness, low heat output, flexibility in installation, lifetimes approaching ten years and longer, and extreme resistance to mechanical shock.

We believe that solid-state lighting can surpass conventional vacuum tube lighting technologies in both cost and performance within a relatively short time. With sufficient investment in research and development, it will be possible to produce a white LED with an energy efficiency of 150-220 lumens per watt, or 10-15 times the efficiency of incandescents and 2-3 times that of fluorescents. We expect that the cost of these highly efficient solid-state lights will become extremely competitive with all light sources, and that they will capture most of the lighting market by 2025.

THE PROMISE OF SOLID-STATE LIGHTING

What would be the impact of replacing most of the lighting in the United States with energy efficient solid-state lighting, or LEDs? The benefits to the nation's energy security and economic competitiveness would truly be enormous. A number of studies[1,2] find the following benefits to the United States alone (with global benefits that are proportionately larger):

- Reduction by 50 percent of electricity used for lighting
- Reduction by 10 percent of total electricity consumption
- Reduction by 17,000 megawatts of the demand for electrical generating capacity (roughly equivalent to 17 large generating plants or the residential demand from all the homes in California, Oregon, and Washington)
- Reduction in carbon emissions by the equivalent of 28 million tons per year

These large reductions in the nation's energy demands will help decrease our dependence on foreign energy sources, lessen the impact on the environment, and increase the reliability and responsiveness of the nation's electrical grid. Of course, the availability of energy is a major national security concern that has profound geo-political implications.

In addition, it should be noted that much of the fundamental technology being developed for solid-state lighting will provide ancillary benefits to a host of other national security interests. For instance, high-power electronics can use the semiconductor material gallium nitride (GaN), which may make it possible to manufacture much lighter high-power electronic devices. The new unmanned aerial vehicles now being used to great advantage by the military would benefit from lighter radars and other electronics, so that they can fly longer and farther. Even more closely related to solid-state lighting is an approach to the detection of chemical and biological warfare agents. GaN can be used to make ultraviolet LEDs and lasers. When illuminated with ultraviolet light, many biological agents will fluoresce (re-emit light at a slightly longer wavelength). We are exploring the feasibility of this technique for rapidly identifying pathogens, such as anthrax.

Finally, solid-state lighting will have an impact on our economic competitiveness, which is also a national security issue. Lighting—that is, the sale of light bulbs and tubes alone—is a $40 billion global industry, with the United States occupying roughly one-third of that market. With the higher performance and enhanced functionality that solid-state lighting offers, it is likely that the market will grow as new, unforeseen uses come into existence, eventually merging with other businesses within the lighting industry such as controls, fixtures, and distribution systems. I fully expect that New Mexico, with its rapidly expanding world-class optoelectronics research capabilities (including Sandia, Los Alamos, UNM, New Mexico State, and several industrial entities such as EMCORE, Zia Laser, Superior Micropowders, and others) will contribute to the growth of this new technology market.

Europe, Japan, Taiwan, and Korea have all established large government-sponsored industrial research consortia to further develop solid-state lighting technologies. Many of these have been engaged for several years and have already produced important discoveries. It is likely that without a substantial government/industry commitment in the United States, foreign competitors will come to dominate solid-state lighting. For all the reasons outlined above, this development would result in an unfavorable impact on our national security position.

SANDIA'S RESEARCH ACTIVITIES IN SOLID-STATE LIGHTING

Sandia has a long history of research in semiconductor optoelectronic devices. Indeed, we were pioneers in the technology of the vertical cavity surface emitting laser, or VCSEL, which is now a mainstay of the telecommunications industry.

A few years ago we began to realize the tremendous possibilities presented by harnessing semiconductor technology for lighting. Sandia, working with leading industrial scientists from Agilent, wrote some of the first papers on solid-state lighting.[3,4] In 2000, we helped the Department of Energy and the Optoelectronics Industrial Development Association (OIDA) organize a national Solid-State Lighting Technology Roadmapping Workshop in Albuquerque, which focused on the inorganic LED pathway to energy efficient lighting. That workshop identified the major scientific and technological challenges to be overcome and established technology milestones for future years. A follow-up LED workshop, also in Albuquerque and co-organized by Sandia, was held in May and updated the challenges and milestones. Copies of the Roadmap Reports from both of these workshops are available from OIDA.[5,6]

In the past couple of years, Sandia has also harnessed its optoelectronics expertise to perform internal research on solid-state lighting. Under the Laboratory-Directed Research and Development (LDRD) program, we are currently pursuing a Grand Challenge project devoted entirely to solid-state lighting. In fiscal year 2001, we invested $1.3 million in this project; in 2002 we invested $2.3 million; and in 2003 we will invest $3.3 million. At present, approximately 30 investigators are involved in the project, either full or part-time. Our research seeks to overcome the technical challenges identified in the OIDA technology roadmaps. It focuses on the physics of defects and impurities in gallium nitride-based semiconductors; the growth of high-quality, low-cost, gallium nitride semiconductor material; the design of high-efficiency LEDs; the development of phosphors for white light: and new encapsulants and packaging to give the LEDs long lifetimes and improved performance. We are collaborating in these research areas with several universities and industrial partners.

THE NEED FOR A GOVERNMENT/INDUSTRY PARTNERSHIP

While numerous university, industry, and national laboratories are already engaged in various aspects of energy efficient solid-state lighting research, there is a general consensus that a government-sponsored national initiative is needed to produce the breakthroughs required to make solid-state lighting a reality in the near future. Such an initiative would involve one or more consortia of U.S. industries in partnership with universities and national laboratories. There are four reasons why such a partnership is desirable:

1. Basic research in high-risk areas cannot easily be pursued by industry alone, particularly in today's tough business environment. This type of work provides understanding of the underlying physics. Industry can rarely afford to devote personnel and equipment for this high-risk, long-term activity. Industry agrees that this type of pre-competitive research will be essential for overcoming some of the challenges we face, and several industrial firms have expressed their willingness to substantially share the costs, both with in-kind and with cash, for this national research initiative.
2. A national initiative will provide a unifying focus for the entire effort, enabling research to be coordinated and tasks efficiently assigned. This will help ensure that the fundamental research performed at universities and national labs focuses on the most relevant and

promising areas, and that industry remains abreast of recent developments and is able to incorporate them rapidly into products.

3. A national government/industry partnership will help to develop an infrastructure of suppliers and equipment firms to support the commercialization of this new technology.
4. Finally, a national initiative in solid-state lighting research will provide a long-term funding structure and resources necessary to develop this new technology. While solid-state lighting might become a reality without federal investment, a government program would accelerate the process by one or two decades.

Studies[1,2] indicate that with an investment of approximately $50 million per year, solid-state lighting technology could be substantially achieved within ten years. The accelerated introduction of energy efficient solid-state lighting would pay for itself many times over in reduced electricity charges to rate-payers alone. I have already mentioned the economic benefits that could be lost if we yield leadership in this field to other countries, which have ongoing government programs.

The Next Generation Lighting Initiative Act introduced last year by Senator Bingaman and Senator Dewine represented an example of just such a government/industry partnership. One industrial consortium, coordinated by the Optoelectronics Industrial Development Association (OIDA) has already been formed in preparation for a national lighting initiative, in whatever form that might take. Other industry and academic groups are now forming to explore additional research opportunities and pathways to success. Members of these consortia include major firms such as Dupont, 3M, Kodak, Agilent, Philips, Osram, Corning, Siemens, and of course, General Electric. We envision that a national initiative will enable a second semiconductor revolution—this time in lighting.

SUMMARY AND CONCLUSION

The technology of energy efficient solid-state lighting is destined to change our lives. Early maturation of this technology will lead to enormous benefits for the nation and indeed the world. Economic, environmental, and national security advantages will be realized, not only by the general reduction in total electricity consumption, but also through spin-off technologies emerging from the underlying semiconductor sciences.

Although Sandia and other institutions in government, industry, and the academic sector are working hard on solid-state lighting, more needs to be done. A national initiative representing these groups will greatly accelerate the research and development process, bringing the benefits of energy efficient solid-state lighting to American taxpayers decades earlier than would otherwise occur. We are hopeful that the President's budget request for fiscal year 2004 will include funding for solid state lighting research and development sponsored by the DOE Office of Energy Efficiency and Renewable Energy, and we would urge your support of such an appropriation.

Mr. Chairman, I would like to thank you for your vision and leadership in introducing legislation to make energy efficient solid-state lighting a reality. Sandia supports such an initiative wholeheartedly, and we would like to offer our expertise in this national endeavor. We believe that a Next Generation Lighting Initiative will be a winner for all, benefiting both businesses *and* the consumer, both New Mexico *and* the nation, and indeed, humanity at large.

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