Supporting the Next Generation of White Lighting Technology

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1 Introduction

The next generation of white lighting technology is upon us. It involves the use of solid-state diodes and conductive polymers to produce white light ten and two times more efficiently than traditional incandescent and fluorescent lights, respectively. It has the potential to displace our traditional lighting industries, which are based upon technologies that Thomas Edison invented more than 100 years ago. I believe that Congress has an obligation not only to maintain our leadership role in the industry our nation invented, but to promote new technologies for the more efficient consumption of the energy we produce.

Let me briefly outline this article. First, I will describe white light solid-state lighting technology and why it's important to support it from an industrial and energy policy perspective. Second, I will emphasize the importance of a focused, long-term R&D partnership led by industry with support from our universities and our national laboratories, and describe the elements necessary for its success. Third, I will conclude by describing the bill that my colleague Senator Mike DeWine and I have introduced to address this national shortfall.

2 Solid State White Light Illumination - the Next Generation in Lighting

Since Thomas Edison, the U.S. has been a world pioneer in the white lighting industry; it's a position we have held for 90 years. When we say traditional white lighting markets, we typically refer to white light produced by incandescent and fluorescent lamps. Combined, these lighting markets consist of a $40 Bn per year industry of which the U.S. currently occupies about one third.

The ability to produce white light from solid-state or semiconductor devices is described as "disruptive." These technologies are disruptive in the sense that they will permit nontraditional optoelectronics industries to enter and displace traditional lighting markets. There is a poignant analogy here: solid-state white lights are based upon semiconductors, the same as found in transistors, while our traditional incandescent lighting technologies are based upon vacuum tubes, which utilize glow discharge for illumination. We have seen this type of technology displacement before with the locomotive, the telegraph, containerized shipping and the Internet.

What are these new solid-state white light technologies and how did they arise? There are two solid-state technologies. The first technology is based upon Light Emitting Diodes or LEDs.[1] LEDs are point sources and are intended to replace an ordinary light bulb. Two Nobel prizes were recently awarded for the semiconductor physics underlying this technology.[2] The second technology involves conductive polymers, which are used today in flat panel displays in cell phones and some electronic instruments and computers. Light emitting conductive polymers are referred to as Organic LEDs or OLEDs. OLEDs are intended to replace fluorescent lights. Three Nobel prizes were recently awarded for conductive polymers[3]. Much has been written about the potential of these two technologies.[4,5,6]

Illumination from LEDs produces only a single color, but with high efficiencies. For instance, red LEDs have yielded efficiencies in the laboratory as high as 100 lumens per watt - or about 7 times that of a normal incandescent bulb.1 Since white light is a combination of a spectrum of colors, illumination from LEDs was not possible until six years ago, with the discovery of blue light from gallium nitride semiconductors, or GaN.[7] GaN now permits combinations of blue, green and red LEDs to produce white light. Industry experts think such LED combinations have the potential to achieve white light with efficiencies on the order of 160 lumens per watt, ten times more efficient than an ordinary light bulb.[8] Mixing even more colors could achieve efficiencies as high as 200 lumens per Watt. Organic LEDs may also have the potential to reach 200 lumens per watt, which is twice as efficient as fluorescent lamps.[6]

Market studies have been conducted for white light LEDs.[9,10,11] These studies show that once LEDs reach 160 lumens per watt, it will be possible to achieve a low-cost LED competitive with incandescent light bulbs. We think it will take a ten-year sustained R&D investment to reach 160 lumens per watt white light LEDs. A similar sustained investment will also produce OLEDs at 100 lumens per watt that are competitive with fluorescent lamps.4

LEDs and OLEDs depart from the traditional lighting technology in two ways. First, semiconductor lights are efficient in their consumption of power. How much combined energy savings are we talking about? For the white light LEDs, a 50 percent market penetration can yield 17,000 MW of power savings, the equivalent of about 17 large power plants.[10] That much savings is more than Con Edison delivers to the state of New York at peak periods.[12] This energy savings would also mean that carbon emissions from power plants would be significantly reduced. The elimination of the need for 17 large power plants, would avoid the generation of 32 million metric tons of carbon, thus reducing smog and acid rain as well as having a positive effect on global warming. Just recently, the National Academy of Sciences reported that the single best payoff in energy R&D was an investment in lighting technology: six million dollars invested in electronic ballast R&D yielded thirteen billion dollars in energy savings.[13] I foresee a similar winning payoff in R&D on solid-state white lighting, but on a far larger scale, as it will not only maintain our leadership role in the lighting markets, but it will help our country consume far less energy.

Second, beyond energy efficiency, there is a more dramatic revolution that solid-state lighting technologies can impact upon and that is in the way we use light. Since semiconductor LEDs and OLEDs are digital, they can be controlled through the Internet, which at the same time can be programmed to monitor market energy prices. This feedback loop between market energy prices and remotely adjusting a building's lighting, room by room, will give improvements in energy consumption that go far beyond the efficiencies of a single LED or OLED. Such feedback loops can collectively control the energy consumption of thousands of LEDs.

Another aspect of the impact solid-state lights will have on the way we interact with light involves OLEDs. OLEDs can display information at the same time they illuminate. That is, it will be possible to have large-area wall lights that illuminate and transmit information, controlled by the Internet. OLEDs will permit office panel lights that display pictures such as stock market information, while at the same time illuminating their surroundings. OLEDs represent a technological potential that merits a national investment to overcome its pre-competitive R&D hurdles in the shortest time possible. Other countries in Europe and Asia, which have not been traditional leaders in the white lighting industry, are also investing in government-led R&D consortia for both white light LEDs and OLEDs. [14,15]

3 The next generation of lighting - a government R&D partnership

I have just described two technologies that can significantly change not only the way we consume energy but also the way we interact with information and illumination. LEDs and OLEDs constitute a totally different paradigm for lighting; they will require an R&D knowledge base different from incandescent and fluorescent lamps. While the basic principles underlying white light LEDs have now been demonstrated, a number of fundamental science problems must be solved before their full promise can be realized and the above energy efficiency goals obtained. The organic and inorganic materials from which these devices are made still contain large numbers of imperfections or defects, which limit their efficiency. These occur, for instance, when an atom in a semiconductor goes into a different location than required by the perfect crystal structure. In order to reach the efficiencies believed to ultimately be possible, new approaches and techniques for growth of these materials must be developed. In turn, these methods will require a detailed scientific understanding of the physics of growth and materials properties, and how these change with, or control defect formation. These scientific challenges, and the equipment and expertise needed to tackle them, are sufficiently large and costly as to be beyond the capabilities of any single company, or for that matter, industry as a whole. Researchers estimate that at the current rate of investment, it will take 15-20 years to achieve a 160 lumen per watt white light LED.[9] They are simply not able to pursue, on their own, research with such a long-term payoff. Companies are generally not set up for fundamental research. Rather, this kind of high-risk, high-payoff pre-competitive research is the kind of fundamental science for which our universities and national laboratories are ideally suited.

Given the vast nature of these pre-competitive R&D hurdles, I propose a partnership led by the lighting industry and with the scientific support of our national laboratories, universities and other entities involved in white light solid-state lighting – it is called the Next Generation Lighting Initiative. Its purpose is to maintain our industry leadership role in lighting while bringing to market in the shortest time possible, significant energy savings.

Such partnerships are not new. In the 1980's, I introduced the legislation necessary to create SEMATECH.[16] Much has since been written about SEMATECH and the dramatic effect it has had on the resurgence of the U.S. semiconductor industry.[17,18] Some have questioned the need for such a partnership, claiming that the government should not meddle in a competitive industry. The need for government participation in SEMATECH, was driven by national security requirements. The Defense Department had a clear need for advanced semiconductor technology in its weapons systems. Just as with the computer, communications, and consumer electronics industries, the surest and most efficient way for the Defense Department to meet its semiconductor needs was through a world-class commercial semiconductor industry. Government thus joined with industry to provide funding for SEMATECH to seed the R&D infrastructure for chip fabrication so that we had a healthy U.S. chip manufacturing base upon which our weapons systems could rely upon.

At the time SEMATECH was conceived, the pre-competitive technical challenges to achieve major improvements in manufacturing technology were beyond the reach of a single company, or for that matter, a single industry. Moreover, the U.S. semiconductor industry was faced with foreign competitors who benefited from support from their governments. The U.S. industry also faced escalating costs of developing next-generation manufacturing technology. This dictated a consortium approach in which all users of semiconductor manufacturing technology, including the Defense Department, would share development costs and provide a forum to address common technical challenges. By setting clear technical benchmarks, such as producing equipment capable of producing 0.35 micron line widths, and fostering a culture of industry-wide cooperation on helping set common pre-commercial R&D goals, SEMATECH played an important supporting role in making the U.S. semiconductor competitive 14 years after the consortium's founding.[17] Ten years after SEMATECH was founded, it became reliant entirely on industry member funds - a testament to the commitment of industry to the partnership concept.

SEMATECH offers a number of lessons that are applicable to the Next Generation Lighting Initiative's partnership:[17]

1. SEMATECH demonstrated the effectiveness of a partnership based on complimentary needs by the government and industry. SEMATECH also demonstrated its cost effectiveness by bundling the internalized costs of pre-competitive R&D while eliminating duplicative R&D. A similar analogy is applicable to solid-state lighting R&D. For solid-state lighting, government has two needs, first and foremost to preserve our U.S. industrial base in lighting, something we've led the world in for 90 years, and second, to save energy, as solid-state lighting can save up to 17,000 MW of power. Complimentary to the government's needs, no one lighting industry can afford the required investment of pre-competitive R&D for solid state-lighting, an estimated $1 billion dollars over 10 years.[10] A consortium through the Next Generation Lighting Initiative can manage the pre-competitive R&D that merges the needs of government and industry while managing a cost shared research program over a period of ten years.

2. SEMATECH's purpose was not to subsidize inefficiently run companies. Rather, SEMATECH funded semiconductor manufacturing R&D. Member chip companies then utilized this pre-competitive R&D in their competitive products. In other words, SEMATECH "seeded" the pre-

competitive R&D infrastructure but not individual companies. Likewise, the Next Generation Lighting Initiative partnership can develop the pre-competitive R&D infrastructure which member lighting companies can use to compete with.

3. SEMATECH effectively committed industry to a long-term commitment through its partnership fee structure; in return, industry managed the consortium's goals. Traditional government R&D programs, at the time, funded individual companies with the government program manager at the lead of the entire effort - there was no collective commitment by industry as a whole. SEMATECH changed that. Likewise, today's lighting industry can benefit by committing to a long-term initiative through a partnership fee structure, and in return, the industry members can manage the pre-competitive R&D goals that they will later use in their product lines.

4. SEMATECH was focused on a single well-defined goal - a 0.35-micron line width semiconductor fabrication process. The Next Generation Lighting Initiative should be focused on two well-defined goals, white light LED packages that produce 160 lumens per watt4 and white light OLEDs that produce 100 lumens per watt.6 There must be no mission creep in the initiative's goals over time.

5. At its inception, SEMATECH was a vertically integrated consortium that funded pre-competitive chip manufacturing R&D for its member chip companies. SEMATECH's vertical integration between pre-competitive manufacturing R&D and competitive chip production helped to promote technology transfer with simple clear rules for sharing intellectual property. The Next Generation Lighting Initiative should also be vertically integrated by funding the pre-competitive research necessary to achieve solid-state white light illumination to enable the competitive manufacturing of lighting products by member companies. There must be clear rules for sharing the pre-competitive research developed from the lighting consortium on a non-exclusive basis to its members.

6. SEMATECH developed clear returns on investments in the range of 3.5 to 4.0, and, it stopped receiving government funding after a defined period.17 Any solid-state white lighting consortium must have clear metrics of success for its member's investment and, once the original goals are achieved, it should stop receiving funds from the U.S. Government.

A final lesson is evident today that perhaps was not relevant when SEMATECH was founded. Originally, SEMATECH was developed for national security reasons, to counter a loss of a technological capability to foreign competitors. Today, that situation has changed. In today's global environment, foreign collaboration with U.S. industry is the norm. In my opinion, joint R&D ventures with foreign industry should be allowed as long as the benefits obtained from the consortium are aimed at furthering manufacturing or research within the U.S. Such a criterion is termed a "national interests" test and is more flexible and accommodating than a dogmatic requirement of U.S.-only participation.[19] The national interest test has been successfully employed in the DOE's Extreme Ultraviolet Lithography Project with U.S. industry, Dutch partners and our national laboratories.[20]

Based on these observations, let me outline the bill Senator Mike DeWine and I have introduced.

4 Senate Bill S. 1166 - The Next Generation Lighting Initiative

Senate Bill S. 1166 was introduced July 11th, 2001. Its purpose is to lay the groundwork for debate on the need for a national initiative to develop white light solid-state lighting devices through an industry led consortium in partnership with the our government, national laboratories, universities and other similar organizations. The bill was subsequently referred to the Senate Energy Committee, where in abbreviated form, it became part of the Chairman's energy R&D mark by full committee vote on August 1. The House included elements of S. 1166 in its energy bill, as found in Division B for energy R&D in H.R. 4 as introduced July 26, 2001. At the time of this writing the Senate Energy Committee must still develop other portions of the comprehensive energy bill. This bill must be passed by committee and by the Senate before differences between the Senate and House bills can be resolved in conference and signed into law by the President.

What are the key provisions of S. 1166? First, the Energy Department is to work in a collaborative manner with an industry led consortium that is putting its own resources into the initiative. S. 1166 gives the Secretary of Energy the contracting authority to fund collaborative entities such as a Next Generation Lighting Initiative consortium to manage pre-competitive solid-state lighting R&D. This authority is called "other transactions authority," which agencies such as DARPA have by statue.[21] Such authority, while not widely used, gives DARPA a flexibility to contract outside the federal acquisition regulations, and in particular, the ability to contract directly with joint ventures that generate intellectual property. The Secretary of Energy does not generally have such authority – this bill gives him that power for the lighting initiative.

Second, S. 1166 is focused on two key pre-competitive R&D objectives. The first objective concerns overcoming the hurdles associated with white light solid-state diodes so they can produce 160 lumens per watt. The second objective concerns OLEDs, which are to produce 100 lumens per watt and have a 5-year lifetime. These OLEDs, which I feel hold some of the greatest potential for paradigm shift, must illuminate over a full color spectrum and cover large areas. Both these objectives were established through industry roadmaps developed in conjunction with the Department of Energy.[6] These goals are cross-checked against market studies by lighting industry experts to determine the financial viability of such an R&D investment.[9,10,11] This partnership is authorized for $480 million dollars over 10 years. If this program meets its objectives before the ten-year authorization, the Secretary should terminate it.

Third, S. 1166 makes grants for R&D in two distinct paths corresponding to basic and applied research. The first path is through funding by the Department of Energy to the Next Generation Lighting Initiative consortium. The consortium will manage the basic pre-competitive R&D. The government contribution is cost matched through the consortium participation fees at 20 percent.[22] The consortium then funds R&D at universities, national laboratories and other research organizations. Consortium participating members, including the Department of

Energy, develop its R&D goals. Because government funds the consortium, the Secretary will appoint an independent advisory committee to conduct periodic performance assessments to insure the consortium is meeting these goals. The consortium members have a non-exclusive royalty free license to the intellectual property developed through the consortium's R&D. By giving consortium members, which are primarily industry, the ability to define the pre-competitive R&D, a long-term commitment is made by industry to the initiative.

The second funding path is for competitive R&D funded directly by the Department of Energy using the pre-competitive R&D developed through the consortium. This applied R&D will bridge a gap that is often called the "valley of death" and which must be overcome in taking basic R&D to a stage at which industry will begin to invest[23]. Industry will then fund, on its own, the final development of a commercial lighting product. For this second funding path, which is competitive in nature, the intellectual property is directly negotiated between the teams and the Department of Energy. Thus, the consortium pools the funds to overcome the basic R&D hurdles far beyond the capability of any one industry – and commits the industry to the life of the project. Once these hurdles are met, industry can take the R&D and commercialise it directly with the Department of Energy or by itself without any additional funding.

5 Summary

Let me review what I have described in this article. First, I have recognized that a paradigm shift is occurring in the way we illuminate our surroundings due to innovations in solid-state technology. I have emphasized not only the merger of information and illumination, but described a potential for tremendous energy savings. I have also described the challenges that must be overcome to meet these objectives. I feel that these challenges warrant a national initiative establishing a partnership between our government, industry, universities and national laboratories. A consortium is needed to pool resources and preserve our leadership role in commercial lighting – one we have maintained since Thomas Edison. I have reviewed SEMATECH's key lessons and applied them to the Next Generation Lighting Initiative. Finally, I have outlined the elements of legislation that is now a part of the energy bills in both the House and Senate.

I hope that a national debate can ensue on the role that Congress and the Executive Branch should play in well-defined industrial partnerships that are of national consequence. I also hope that our colleagues in both the House and Senate consider the importance of this bill, and the objectives it sets forth for energy savings and the long-term viability of our lighting industry, and support it in a bipartisan fashion as Senator Mike DeWine and I do.

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