DOE Roundtable on OLED Lighting Industry Planning

October 1, 2013
Victor, New York

Report Prepared for Energy Efficiency and Renewable Energy
U.S. Department of Energy

October 2013

ACKNOWLEDGEMENTS

The U.S. Department of Energy (DOE) would like to acknowledge all participants for their valuable input and guidance provided during the discussion of OLED lighting. This report reflects the discussions that took place. DOE also thanks Tom Trovato of Trovato Manufacturing for hosting the OLED Planning Meeting.

Participants:

Michael Carmody	Intrinsiq Materials
Tom Trovato	Trovato Manufacturing, Inc.
Paul Tolley	CNSE
Tommie Royster	R-Display & Lighting
Raj Rajeswaran	Moser Baer Technologies, Inc.
Alan McReynolds	Trovato Manufacturing, Inc.
Peter Calandra	LC Technology Solutions, Inc.
John Hamer	OLEDWorks
Michael Hack	Universal Display Corporation
Barry Young	OLED Association
David Gottfried	CNSE
Sean Tham	WAC Lighting
David DeJoy	OLEDWorks
Norman Bardsley	Bardsley Consulting
Morgan Pattison	SSLS, Inc.
Keith Cook	Philips
Mark Taylor	Corning
Michael Boroson	OLEDWorks
Min-Hao Michael Lu	Acuity Brands
Kirit Shah	Alcoa Technology
Michele Ricks	EMD
Dennis O'Shaughnessy	PPG Industries
Nicholas Colaneri	ASU Flexible Displays and Electronics Center
Thomas Levendusky	Alcoa Technology
James Brodrick	U.S. DOE
Sean Armstrong	Kurt J. Lesker
David Collins	Kurt J. Lesker
J.W. McCamy	PPG Industries
Joel Chaddock	U.S. DOE

CONTENTS

1. INTRODUCTION

This OLED Planning Meeting was convened by the U.S. Department of Energy (DOE) solid-state lighting (SSL) program, in response to ongoing discussions within the U.S. OLED lighting community regarding the need for an OLED pilot production facility and/or collaborative research and development (R&D) framework to accelerate developments in OLED lighting technology and manufacturing. The scope of the meeting was expanded to also cover discussion of formation of a formal U.S. OLED lighting industry advocacy group, as well as the development of manufacturing and test standards that could help accelerate adoption through lower-cost manufacturing and improved customer acceptance of OLED lighting products. A final topic to cover at this meeting was DOE's role in facilitating discussion among OLED industry stakeholders.

The meeting was held on October 1, 2013, in Victor, NY, at the facilities of Trovato Manufacturing, Inc., which were graciously offered for use by CEO Tom Trovato. The meeting agenda was organized by the DOE SSL program to incorporate all the above-stated topics and to include volunteered inputs from the participants. DOE Lighting Program Manager Jim Brodrick kicked the meeting off by welcoming the attendees. The meeting was moderated by DOE SSL program technical consultants Morgan Pattison and Norman Bardsley, and the discussion and results are presented in this report. Ultimately, a single meeting cannot be expected to fully achieve all the described objectives; the intention here was to bring together the OLED community to initiate an ongoing discussion.

2. COLLABORATIVE R&D FRAMEWORKS

The creation of an OLED pilot production facility has been a common topic of discussion at recent DOE SSL workshops. Such a facility could enable materials suppliers, tool makers, panel manufacturers, and luminaire manufacturers to work together to develop manufacturing processes that would reduce the cost and improve the performance of OLED lighting products. These benefits could also arise from collaborative R&D performed at existing OLED production sites, if a working framework for collaboration could be developed. Some of the issues that need to be considered include work sites, necessary tools, intellectual property (IP), and funding requirements. The ultimate objective would be to develop a collaborative R&D system that is useful for a wide range of OLED lighting technology development; that effectively uses available resources; and that dramatically accelerates the pace of technology and manufacturing developments. A number of ideas were presented at the OLED Planning Meeting in Victor.

Participant Presentations

The Flexible Displays and Electronics Center at Arizona State University (ASU)

Nick Colaneri of ASU's Flexible Displays and Electronics Center (FDEC) talked about the model partnership created between industry, government, and academia at the FDEC. The U.S. Army needed a lightweight, thin-form-factor, flexible display to allow communication between soldiers in combat situations, so it created the FDEC in 2004 with the goal of speeding the development and commercialization of flexible display and electronics technology. Among the initial challenges faced by the project was the fact that existing flat-panel displays all featured a thin-film transistor array on glass, which industry was initially uninterested in eliminating from the mix.

The Army has invested $100 million in the project, with a 15-percent co-investment from 41 industrial partners to date. An IP framework enabling open collaboration was set up to protect IP and commercial interests while incentivizing and rewarding investment, participation, and innovation. A very basic red-green-blue OLED device structure was used, with multilayer display architecture on a flexible plastic substrate. A generation-2 OLED deposition tool was accepted for use in February 2011, and development of a flexible, full-color OLED display prototype progressed from a 4.1" color OLED 6" substrate in the spring of 2011 to a prototype 14.7" color OLED generation-2 substrate in the fall of 2012. The infrastructure developed for display applications (property, plant, and equipment; technical staff; corporate partners; and network) are now being leveraged to pursue emerging opportunities in flexible electronics.

Collaborative R&D: A Manufacturing Technology Center for OLED Lighting

Tom Trovato of Trovato Manufacturing, Gopalan Rajeswaran of Moser Baer Technologies, and Paul Tolley of the State University of New York, College of Nanoscale Science and

Engineering (CNSE) in Canandaigua discussed a plan to set up an OLED center at CNSE, to foster the development of the U.S. OLED industry. Such a center would serve as an open-innovation platform for collaborative manufacturing R&D in OLED lighting and would involve all links in the OLED supply chain. Something similar for the semiconductor industry was tried at CNSE and was a big success, driving investments of more than $20 billion in New York State over the past decade and helping to make it a global center of the semiconductor industry.

CNSE's state-of-the-art facilities, which are located in the geographic center of the U.S. OLED industry, include a 10,000-square-foot class-100 cleanroom and a 30,000-square-foot MEMS foundry. OLEDs could save the country significant energy and create U.S. manufacturing jobs, but the OLED industry will need support to achieve sustainable growth. No single company can do it. OLED lighting requires capital-intensive process-integration activities, and the cost of participation is very high for individual players in the supply chain.

The proposed OLED manufacturing development facility (MDF) would be a place where device makers, equipment suppliers, and materials suppliers could cooperate in pre-commercial manufacturing R&D projects, protected by IP firewalls to foster collaboration in designing a manufacturing R&D platform for flexibility and capability rather than for capacity. A neutral partner managed by CNSE, the OLED MDF would enable collaborative research, development, and deployment and would be set up as a membership organization focused on OLED technology development, with fee-based access to technical infrastructure, a user-friendly IP policy, and DOE "kick-starter" support of facilities and leveraged R&D projects. The project could be implemented in less than nine months. The proposed timeline involves beginning the development of a strategic plan with academia and industry partners in the first quarter of 2014, creating partnerships in the second quarter of 2014, and launching the OLED MDF in the third quarter of 2014.

Collaborative R&D for Cost Reduction to Enable the OLED Lighting Market

Michael Boroson of OLEDWorks outlined a plan to accelerate worldwide market adoption of OLED lighting by having DOE facilitate and share the cost of collaborative manufacturing-scale experiments among U.S. companies. The idea would be to reduce time and cost barriers by funding collaborative experiments that could be completed within a matter of a few months, and that would be focused on lowering OLED panel costs. Such a model could enable fast learning cycles and, with DOE cost-sharing of at least 50 percent, could be a cost-effective way to spur OLED development.

Leveraging U.S. know-how, experience, skills, and assets, and featuring open communication between collaborative partners as well as frequent review and selection,

the proposed plan would focus on manufacturing-scale demonstration of materials, components, equipment, panels, and luminaires and would result in the fast adoption of the most-promising approaches. OLEDWorks, which plans to start selling OLED panels in the fourth quarter of 2013, has excess capacity and is offering its facilities for the proposed experiments, although these experiments could be done anywhere using existing infrastructure and equipment. A DOE board that met on a regular basis could be established to review and select proposals — which could be submitted using a short (2-3 pages), simplified form — and to process 2- to 3-page manufacturer reports summarizing completed experiments.

Funding, totaling $1–2 million annually, could be carried out through DOE's current funding opportunity announcement process and could be based on the assumption that the cost of a single-day experiment is $10,000–$20,000, with DOE's share being $5,000–$16,000. IP would be treated the same way as IP generated by a standard DOE SSL manufacturing project; that is, each company would maintain its IP rights, and in cases where collaborating companies generated joint IP, those companies would determine the IP rights.

There is an opportunity for OLED lighting to have a significant impact. A combination of LED and OLED lighting will enable the greatest energy and cost savings. With its skills, know-how, experience, and industrial base, the U.S. is in a strong position to participate in OLED lighting, with U.S. companies spanning the entire OLED supply chain, from materials suppliers to equipment manufacturers, panel manufacturers, and luminaire manufacturers. What is required is collaboration. OLED panel performance has been demonstrated, but the high cost of panels is slowing the market development of OLED lighting. Prices will stay high until volumes increase. But additional investment for large-scale equipment will not occur until volume increases. By thinking creatively and collaborating together, the industry can come up with lower-cost solutions. But the whole industry — from manufacturers, to materials suppliers, to equipment suppliers, to luminaire makers, to governments — must share the burden of getting started.

Joint Collaboration on a Pilot Line

Kirit Shah of Alcoa had asked to say a few words about the aluminum OLED substrates Alcoa is manufacturing, so he gave a short presentation on the topic. Alcoa would like to collaborate with U.S. OLED manufacturers. Most OLED substrates have been on glass, but aluminum has a number of advantages, including cost and flexibility.

Discussion

No real consensus emerged as to how to structure collaborative OLED lighting R&D, whether a change is really necessary, or whether collaboration would accelerate OLED developments. Lengthy discussion occurred on the merits of the R&D frameworks presented, which revolved around two distinct models. One model involved the proposed creation of a new pilot production facility based on similar existing facilities for MEMS and silicon processing at the CNSE. An alternative approach involved the development of a collaborative R&D framework that could be applied at any suitable site; would allow for short-duration, small-scale collaborative R&D efforts; and would provide a pre-existing IP arrangement and financing structure for OLED community members to work together, removing some of the typical barriers to collaborative R&D. Some participants questioned the underlying premise that a specific collaborative R&D framework or pilot line is necessary or effective for accelerating the U.S. OLED lighting industry. Several participants also expressed confusion as to what the ultimate objectives of the collaborative R&D frameworks would be. Because DOE's R&D efforts are constrained by limited funding levels, any proposed collaborative R&D framework would need to make very effective use of limited resources.

Discussion Details

- What the OLED industry needs from DOE is an IP framework and small bundles of R&D money.
- Many industries move forward without a central location.
- The demonstration of a low-cost process doesn't have practical value unless it's associated with a real product; money spent on a center is not money spent on core product development.
- Having a center and doing shorter-term testing are not mutually exclusive. Why not do both?
- The OLED industry has a lot of capacity but no market, which is a critical need. The industry could work on a lower-cost solution in parallel with developing a market.
- Volume makes a difference, just as it did with LED displays. Getting, say, 10,000 OLED products on the market would stimulate panel makers and others in the supply chain. Once they start producing, players will figure out how to drive the cost down.
- The "make or break" window of opportunity is two to three years. OLED lighting needs to be made affordable within that span of time.

Action Items

- DOE will consider a quicker-turnaround, smaller-dollar-value approach to funding OLED R&D; i.e., research projects that can be turned around in a matter of weeks and require a short, simplified proposal.
- Attendees will have follow-up discussions about collaborative R&D.
- Attendees will submit their top-three issues regarding the establishment of a pilot line and enhancing R&D collaboration.

3. A U.S. OLED LIGHTING INDUSTRY GROUP

The creation of a U.S. OLED lighting industry group could have multiple benefits that would be in line with objectives of the DOE SSL program. Such a group could pursue activities to spur adoption of energy-efficient OLED lighting products. These activities could include consumer education, test standards development, support of design competitions, demonstration of technology benefits, and general advocacy for the fledgling OLED lighting industry. Two related associations already exist that could provide a model for the OLED lighting group:

- Next Generation Lighting Industry Alliance (NGLIA), which promotes the understanding, implementation, and adoption of semiconductor light sources (OLEDs and LEDs) in specialty and general lighting systems
- OLED Association, which represents global OLED technology concerns, including display and lighting technologies.

Participant Presentations

Next Generation Lighting Industry Alliance

Keith Cook of Philips talked about NGLIA, which he chairs. NGLIA is an alliance of for-profit corporations and was formed by Congressional directive to accelerate SSL development and commercialization through government-industry partnership. Its charter includes support for both inorganic- and organic-based solid-state lighting. Support includes public advocacy for SSL and the Next Generation Lighting Initiative, which means that NGLIA lobbies for SSL. Lobbying as a group has a larger impact than doing it on an individual-company basis. NGLIA also promotes and supports DOE's ongoing assessment of SSL potential, the state of SSL technology, and DOE's SSL R&D program. In addition, NGLIA is an avenue of communication between members and other parties that have a substantial interest in SSL and the Next Generation Lighting Initiative.

Some of NGLIA's major activities include participating in, and providing input to, DOE SSL workshops and roundtables and, at DOE's discretion, participating in technical evaluations for research projects in DOE's SSL Core Technology program. Another aspect of NGLIA involves the development of metrics, codes, and standards for measurement and utilization of SSL products for general illumination, and providing input for voluntary DOE deployment programs such as LED Lighting Facts®. NGLIA is also involved in planning and promoting outreach activities for SSL technologies used for general-illumination applications, such as the Solar Decathlon. In addition, NGLIA is in the process of putting together an economic survey of the U.S. SSL industry. NGLIA is separate from, but managed by, the National Electrical Manufacturers Association (NEMA). All NGLIA members have one vote on the NGLIA board of directors. The board annually elects the chair and vice

chair. Dues cover public advocacy expenses plus NEMA administrative and coordination expenses and are divided equally among member companies.

The OLED industry needs to come together and mount a common communications effort. NGLIA and the OLED Association are two examples of communication channels. OLEDs could become a subcommittee of NGLIA. There are many advantages to coordinating activities through an association or consortium. The OLED industry needs to figure out a way to accelerate market adoption and acceptance. It should build upon DOE's LED learning experience rather than reinvent the wheel. OLEDs should leverage DOE's existing SSL Market Introduction programs, which have been very helpful in spurring LED lighting and eliminating market concerns. These DOE programs include GATEWAY demonstrations, CALiPER testing, the MSSLC, LED Lighting Facts, and design competitions such as L Prize® and Next Generation Luminaires™ (NGL). NGL may be more appropriate for OLEDs than L Prize, and NGL is already open to OLEDs, but so far there have been no submissions. OLED products can be submitted to LED Lighting Facts.

OLED Association and Ad-Hoc OLED Advocacy Group

Barry Young of the OLED Association talked about the Ad-Hoc OLED Advocacy Group that went to Washington, DC, in July 2013 to ask for continued DOE funding of the OLED industry. The group was made up of representatives from Acuity Brands, EMD Chemicals (Merck), Moser Baer Technologies, OLEDWorks, NGLIA, PPG Industries, Trovato Manufacturing, Universal Display Corporation, and the OLED Association, which is a consortium of about 20 OLED companies. The group visited the House Energy and Commerce Committee, the House Energy and Water Appropriations Committee, the Senate Energy and Water Appropriations Committee, the Office of Management and Budget, and DOE Assistant Secretary for Energy Efficiency and Renewable Energy Dr. David Danielson.

The group discussed a two-phase plan that would involve support for a pilot line for the development of key OLED technologies. The pilot line would lower the cost of OLED lighting manufacturing, reduce panel cost even at low to moderate volumes, increase material utilization of OLED deposition equipment, lower substrate costs, reduce the process time for thin-film encapsulation, and test the use of printing technology.

The next step for the ad-hoc group is to arrange a follow-up meeting with Assistant Secretary Danielson, probably within six to eight weeks, to re-emphasize the importance of the OLED program, provide more details on the pilot and mass-production phases, and show an increased level of industry support. Meeting attendees are invited to participate in this visit, as well as to join the Ad-Hoc OLED Advocacy Group, provide their input on how they view the program, and indicate their interest in establishing a permanent DOE OLED

support group. OLED products aren't available in the marketplace, and it's incumbent on the industry to change this. The U.S. is capable of having a full-scale OLED industry.

Discussion

There was general agreement and almost universal consensus on the desirability of forming a domestic OLED lighting consortium.

Discussion Details

- Almost all the attendees expressed interest in joining such a group.

Action Item

- Keith Cook and Barry Young will get together and come up with a detailed plan for the OLED lighting alliance.

4. MANUFACTURING AND TEST STANDARDS

The development of certain manufacturing and test standards for OLED lighting could encourage the adoption and improve the manufacturability of OLED products. As LEDs transitioned from light sources to lighting products, adoption was slowed down by the lack of test and performance standards. For example, a new standard for photometric testing, IES LM-79, had to be developed to describe the lighting performance of LED-based light sources. Also, IES LM-80 and IES TM-21 test standards had to be developed to help describe the reliability of LED light sources, although these tests still do not fully capture the usual life of LED lighting products. In some cases, the OLED community can utilize the same or similar test protocols to describe performance; but in other cases, such as those involving reliability, new test standards and protocols will have to be developed. Wherever possible, it behooves the OLED community to develop these standards in advance of the market introduction of OLED lighting products. This is an important lesson from the introduction of LED lighting products. OLED lighting test standards development activities are currently taking place, and this needs to be communicated to the OLED community. The OLED lighting community should also consider what additional development activities are necessary for rapid product adoption. For manufacturing standards, wherever possible, standard descriptions of components, tooling, and materials along the entire value chain can facilitate manufacturing, development, and integration. This common vocabulary helps ensure that suppliers and purchasers can fully describe their requirements and products.

Participant Presentation

Common Manufacturing Platforms and Testing

Mike Lu of Acuity Brands discussed common OLED manufacturing platforms, standards, and testing. UL 1598 governs all luminaires. UL 8752, "Standard for Safety – Organic Light-

Emitting Diode Panels," drafted by Michael S. Shulman, is concerned with issues of safety, such as the sharpness of edges and corners, the security of wiring connections, and the flammability of materials. A UL listing at the component level is necessary, and Acuity Brands refers vendors to Walter Das to obtain the listing.

In addition to being a member of the UL technical committee, Lu serves as an International Electrotechnical Commission subject matter expert on US TAG34 and as part of a working group that's working on two standards, one involving safety and the other involving performance. The safety standard is concerned with such things as proper marking and flammability, while the performance standard is concerned with measurement methods and terminology. Lu is also a member of an Illuminating Engineering Society (IES) technical committee formulating OLED lighting standards, chaired by Jeremy Yon of Lite Control; recent discussion centered on such matters as panel orientation during measurement, and camera vs. spot spectrophotometer.

There are several dozen commercial white OLED panels on the market today, all with different form factors and current-voltage characteristics. LED standardization came at a later stage of development and is only at the module level so far; it's too soon to talk about OLED panel standardization. Acuity has four custom OLED products for sale. The panels have emitting areas of 90 x 90 mm, 40 x 190 mm, and 46 x 46 mm and a minimum efficacy of 55 lm/W at a CRI of 85–90, with L70 > 15,000 hours. Color quality is a key differentiator for OLEDs, which intrinsically have a broad color spectrum. The question was raised as to whether there's room for less-stringent color requirements, just as LEDs were used for Christmas lights, where color consistency and stability are not critical. This depends on the application. There are opportunities for OLEDs, but it's up to industry to figure out what they are. OLEDs follow the same protocol for projecting lifetime as LEDs, which use LM-80 and TM-21.

Discussion

There was widespread agreement that manufacturing platforms, standards, and testing are important for OLED market acceptance and improved manufacturing. It's not clear which standards are most critical. Ongoing standards activities touch upon some of the issues.

Discussion Detail

- What's important is the stability of the final product. OLED lighting products shouldn't be standardized yet, because they have considerable leeway in form, size, flexibility, etc., so there are many new opportunities for design.

Action Item

- DOE will compile a list of relevant standards activities currently underway and will poll attendees as to any such activities that should be undertaken.

5. DOE ROLE

In recent years, participation by the OLED community in the DOE SSL R&D annual workshops has dwindled in comparison to participation by the LED community. So it's important to determine whether these DOE-sponsored meetings have the right format, frequency, timing, and duration for the OLED community, and how they — or other forums — can be set up to better address the OLED community's needs. It's also important to determine how else DOE can help nurture the OLED lighting industry — for example, by sponsoring design competitions.

Presentation

DOE SSL Program Role

Joel Chaddock of the National Energy Technology Laboratory gave an overview of DOE's role in supporting SSL R&D. Guided by a government-industry partnership, DOE's mission is to create a new, U.S.-led market for high-efficiency, general-illumination products through the advancement of semiconductor technologies, to save energy, reduce costs, and enhance the quality of the lighted environment. The goal is to develop, by 2025, advanced SSL technologies that — compared to conventional lighting technologies — are much more energy-efficient, longer-lasting, and cost-competitive, by targeting a product system efficiency of 50 percent with lighting that accurately reproduces sunlight spectrum.

But DOE is technology-neutral, in principle favoring neither LEDs nor OLEDs, and instead choosing to allow the technology to work itself out. DOE acts as a catalyst to drive R&D breakthroughs in efficiency and performance, and to equip buyers to successfully apply SSL lighting. Together with industry partners, DOE sponsors a comprehensive program to spur SSL research and development, and to facilitate successful market introduction of high-quality, energy-efficient SSL products for general illumination. A key goal is to support and accelerate the industry's move to higher levels of efficiency and quality.

With the exception of 2009, when extra ARRA funding was added to the mix, DOE's SSL budget has been stable, about $25 million annually. That $25 million goes to support all aspects of DOE's SSL program, including testing, product development, and market development. The funding is also used to support both LED and OLED technologies. What's more, there are many rules that govern how DOE uses the money. The bottom line is that DOE's resources are limited, and its main role is to act as a catalyst to accelerate the technology, but it's up to industry to do the "heavy lifting."

Historically, OLEDs have received a little bit more than one-third of DOE's R&D SSL funding, but there's no target defined for this distribution ratio. To date, 42 OLED R&D projects have received DOE funding, compared with 86 LED projects. The OLED projects

have totaled more than $100 million in funding, with an average cost-share contribution of 30 percent. In addition, DOE has funded more than 50 Small Business Innovation Research projects related to OLED technology. NGLIA is a key DOE partner for SSL.

Discussion

No clear consensus emerged on the optimal format for DOE-facilitated OLED meetings. While there was some feeling that DOE's three annual SSL workshops are weighted toward LEDs, there was also some acknowledgement that it's important for the OLED industry to know what's going on with LED lighting, and for the two technologies to work together to some degree rather than in totally separate silos. As a result, attendees were divided on whether to split those workshops into two (one for LEDs and a separate one for OLEDs). The idea of creating more separation between the two technologies within the existing SSL workshops was also raised. The idea of OLED design competitions came up, and the point was made that OLEDs are already welcome as entries in the NGL, although there have been no OLED applications to date.

Discussion Details

- The regular DOE SSL workshops don't seem to be working for OLEDs. How can that be changed to the benefit of the OLED industry?
- It feels as though OLEDs are second-class citizens compared to LEDs. Can DOE support begin to shift to OLEDs?
- It would be helpful if, at a DOE SSL workshop, there was a panel of OLED users — lighting designers, utilities, etc. — offering feedback from their own perspectives.
- Having only a single day of OLED-focused discussion at the annual DOE SSL R&D Workshop could enable better attendance.

Action Items

- DOE will consider including a panel of OLED users offering their feedback, at an upcoming DOE SSL workshop.
- DOE will consider launching the equivalent of the L Prize competition for OLED lighting, or including OLEDs as an L Prize category.
- DOE will investigate opportunities for future OLED forums, like the present meeting.

6. CLOSING

DOE would like to thank all attendees for their participation, and for their valuable insights into what needs to be done to help the OLED industry overcome the challenges it faces, as well as how DOE can facilitate that process. Ongoing discussions will be necessary to make concrete advancements in terms of collaborative R&D, the creation of an OLED advocacy group, and the development of timely manufacturing and test standards for the OLED industry. The DOE SSL program is pleased to act as a catalyst/facilitator for these ongoing discussions.