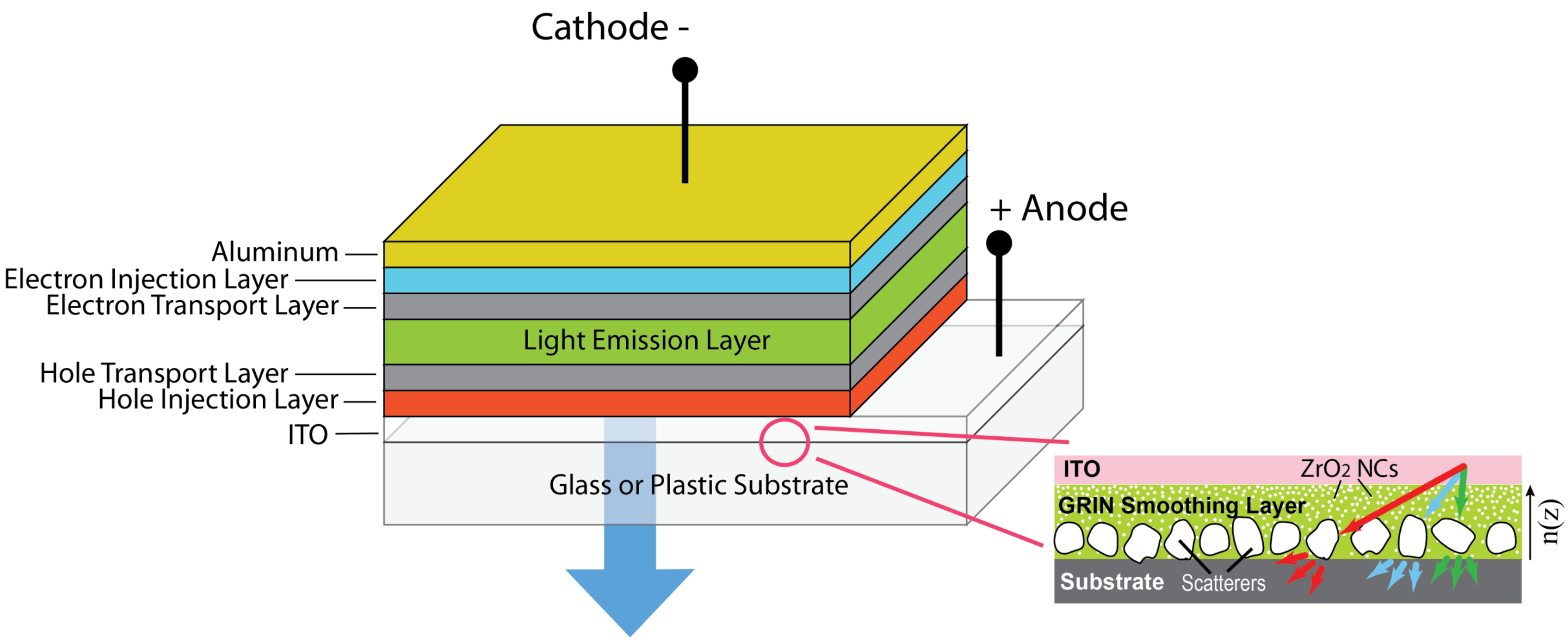
Advanced Light Extraction Material for OLED Lighting

2016 Building Technologies Office Peer Review



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Project Summary

Timeline:

Start date: Sept. 10th, 2014

Planned end date: Aug. 31st, 2016

Key Milestones

1. Identify Optimized Formulation: Dec. 2014
2. Build Gradient-Index Model: Dec. 2014
3. Film Formation Process Proof of Concept – Mar 2015
4. Build Scatterer Model, June 2015
5. Scatter Introduction Process Proof-of-Concept – Sept. 2015
6. Simulation to Identify Best Combination, Dec. 2015
7. First 2.5” Device Batch, June 2016

Budget:

Total Project $ to Date:

- DOE: $601,061
- Cost Share: $150,265

Total Project $:

- DOE: $1M
- Cost Share: $250K

Key Partners:

OLEDWorks, LLC
Petersen Advanced Lithography Inc.

Project Outcome:

- Build the gradient-index layer with scatterers and low surface roughness and compatible with OLED manufacturing; and
- Demonstrate a 4” by 4” white OLED test panel with an improvement to at least 2.9X light extraction efficiency at 3000 K CCT and < 0.004 angular spectral shift

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Purpose and Objectives

Problem Statement: This project addresses the priority C.6.3 listed in the DOE SSL 2014 MYPP. OLED lighting suffers from low efficacy due to low light extraction. External light extraction is not adequate to reach DOE efficacy target. A manufacturable and cost-competitive internal light extraction structure need to developed to achieve the MYPP efficiency goal.

Target Market and Audience: The target market is the OLED lighting industry and more broadly is the solid-state lighting industry (SSL). As projected by DOE reports, SSL technology can potentially offer 217 terawatt-hours (2.5 Quad) energy savings in the US by 2015, corresponding to $21.7B annual savings.

Impact of Project:

1. The project's final products is a next-gen prototype of an internal light extraction structure that can deliver ~ 70% light extraction efficiency
2. Contribution towards the program's performance and interim market goals
    a. Near-term outcomes: develop a prototype of high performance OLED lighting panel
    b. Intermediate outcomes: Improve the performance and cost-competitiveness of the OLED lighting
    c. Long-term outcomes: Accelerate the market adoption of high performance OLED lighting

Approach

Approach: Develop an internal light extraction structure based on Pixelligent's high quality ZrO2 nanocrystals and nano-composites. The ZrO_2 nanocrystals provide high refractive index without reducing transparency. Also the extreme small size, it is possible to create film with gradient index with a simple coating process. Combined with scatterers, this approach is likely to produce highest extraction efficiency.

Key Issues:

- Gradient-Index Film formation: Demonstrate a simple manufacturable process to produce gradient index film
- Introduction of Scattering Centers: Develop a manufacturable formulation with scatterer
- Modeling and simulation: Identify the configuration that can produce maximum efficiency gain
- OELD Device Integration and Testing: Demonstrate a working prototype on a 4" by 4" substrate

Distinctive Characteristics: Potentially the most efficient light extraction strategy. Compatible with multiple OLED Lighting manufacturing approaches.

Progress and Accomplishments

Accomplishments:
- Developed stable scatterer/nanocomposite formulation
- Demonstrated uniform slot-die coated film across a 4” by 4” substrate
- Demonstrated up to 2.1X improvement in EQE and compatibility with OLED manufacturing process
- Developed analytical and simulation tools to characterize and design the extraction layer
- Developed double layer with ~ 0.2 RI gradient
- Developed a full wave finite element method (FEM) to simulate the internal extraction layer

Market Impact:
- Launched Gen 1 (high-n formulation) and Gen 2 (high n/scatterer) products specially for OLED markets (this program to develop Gen 3). Many leading OLED manufacturers are working on incorporating these materials into their products.
- Well on track to realize planned impact

Awards/Recognition:

Lessons Learned:
- Full wave IEL simulation is computationally intense and difficult to implement

Project Integration and Collaboration

Project Integration: Internally, the project team works closely Product Development and Engineering departments to transfer developed processes and specs for product launch; with Business Development and Product Management to get feedback from customers and work with them to meet customer requests.

Partners, Subcontractors, and Collaborators: Worked closely with OLEDWorks, the only US based OLED lighting manufacturer, to integrate the material into their manufacturing processes and produced test panels that demonstrated 2.1X efficiency gains. Also, worked with Petersen Advanced Lithography to develop a full wave FEM model to simulated the internal light extractions.

Communications: This works has been presented at DOE SSL Workshop in San Francisco in 2015, and in Raleigh in 2016, OLED Stakeholder Meeting in Pittsburgh in 2015, OLED World Summit in 2015, International Workshop for Printed Electronics in South Korea in 2015

Next Steps and Future Plans

Next Steps and Future Plans:

- Develop and improve process for gradient film manufacturing using slot-die coater
- Continue to optimize the scattering layer configuration and processing, and perform more device tests using 4” by 4” substrates at OLEDWorks

REFERENCE SLIDES

Project Budget

Project Budget: The total budget was \$1.25M with \$1M from DOE and \$250K cost share.
Variances: The project expenditure is largely on track with proposed, no modification to the work plan was made.
Cost to Date: As of 2/29/2016, \$601,061 DOE fund was spent with \$150,265, ~ 60% of total budget. Note a significant portion of the sub-contractor cost has not been invoiced to us.
Additional Funding: N/A.

Budget History					
Sept. 10th, 2014 – FY 2015 (past)		FY 2016 – Aug. 31st, 2106 (current)		FY 2017 – (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
\$454,609	\$116,490	\$545,391	\$133,510	N/A	N/A

Project Plan and Schedule