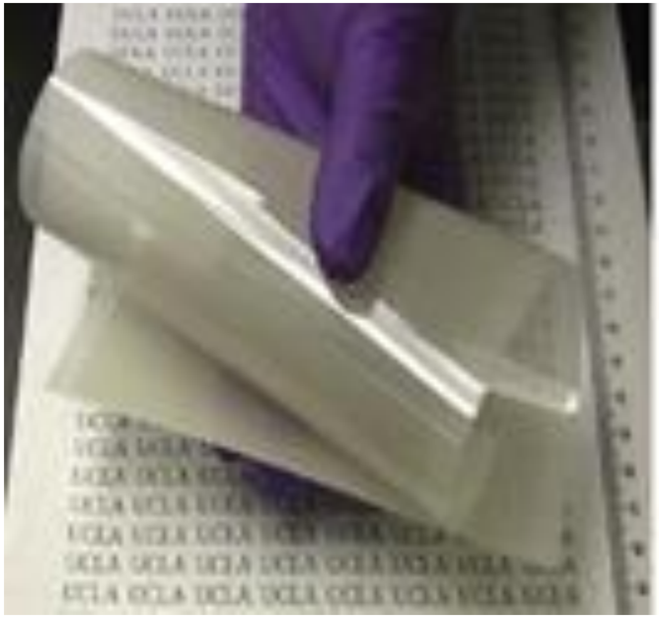
The Approach to Low-Cost High-Efficiency OLED Lighting

2016 Building Technologies Office Peer Review



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Project Summary

Timeline:

Start date: 9/4/2014

Planned end date: 8/31/2016

Key Milestones

1. White OLED on integrated substrate with high 150 lm/W efficacy at 1000 cd/m^2 (8/31/2015)
2. A flexible OLED based on a barrier substrate with 80 lm/W efficacy at 1000 cd/m^2 (2/29/2016)
3. White OLED based on a barrier substrate with 150 lm/W efficacy at 1000 cd/m^2 (8/31/2016)

Budget:

Total Project $ to Date:

- DOE: $377,111 (as of 12/31/2015)
- Cost Share: $95,225 (as of 12/31/2015)

Total Project $:

- DOE: $612,733
- Cost Share: $153,183

Key Partners:

Polyradiant Corp.
OLEDWorks

Project Outcome:

The project aims to develop an integrated plastic substrate to replace indium tin oxide transparent anode, glass substrate, internal and external light extraction structures for the fabrication of organic light emitting diodes with substantially improved energy efficiency and reduced manufacture cost. The integrated substrate matches the sheet resistance and surface smoothness of high-grade ITO/glass, but with major enhancement of light extraction.

Purpose and Objectives

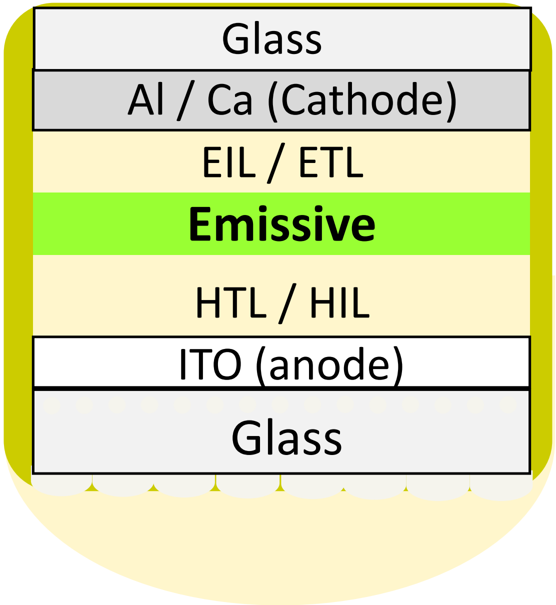
Problem Statement: DOE Solid State Lighting (SSL) program has set a tough target for lighting luminaires to reach 200 lm/W by 2020 for a projected annual energy savings of 395 TWh by 2030 or annual dollar savings of about $40 billlion. Organic light emitting diode (OLED) lighting panels can be made into large-area flexible form factors that can help market adoption, but face key technical challenges in low light extraction efficiency and high manufacturing cost.

Target Market and Audience: General indoor illumination for homes, office buildings, and public arenas.

Impact of Project: This project develops an integrated plastic substrate to replace 3 of the about 8 major costly components of OLED panels: indium tin oxide transparent anode, glass substrate, light extraction structures. The integrated substrate will eventually be manufactured at a projected cost of less than $2.5 per lighting panel (klm) to meet the SSL MYPP target of $10 per klm. The target panel efficacy is 80 lm/W in the near term (matching fluorescent tubes), 150 lm/W in the intermediate term, and 200 lm/W in the long term to meet the DOE MYPP target.

Approach

Approach: An integrated substrate is being developed comprising a layer of silver nanowires embedded in the surface of a polymer nanocomposite. The integrated substrate will replace the ITO anode, glass substrate, and light extraction structures in current OLED panels. The composition and processing conditions of the integrated substrate will be engineered to achieve flexible OLEDs with 2.5X enhancement of light extraction efficiency. A scalable, low temperature, solution-based large area coating process will be developed for the integrated substrate, such that at manufacturing scale, the integrated substrate can be produced at <$20/m^2.



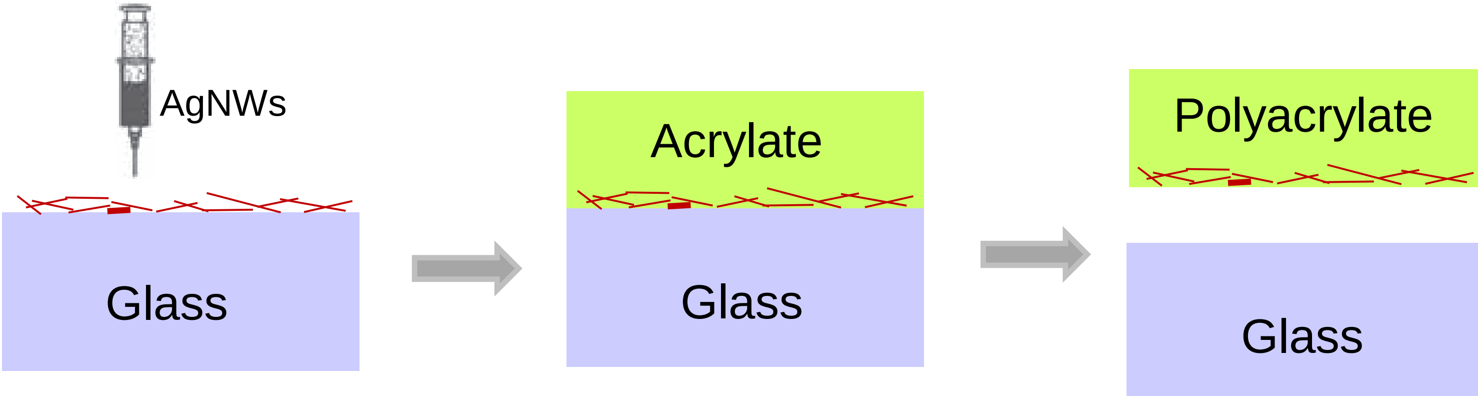
Key Issues: Ink formulation for the key ingredients, coating process to obtain high surface conductivity and low roughness, formulation of the substrate for high light extraction efficiency, and OLED fabrication process on the substrate.

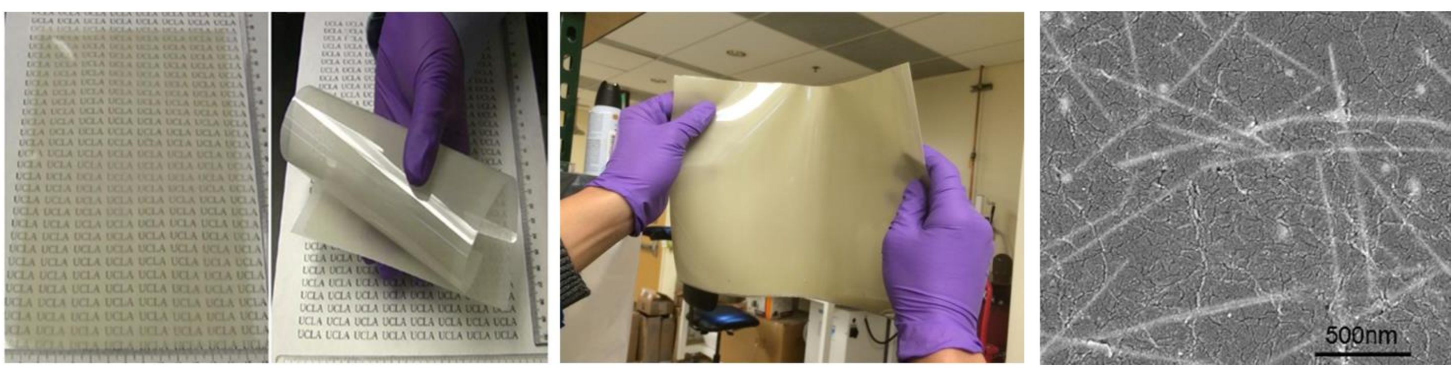
Distinctive Characteristics: A scalable, low-cost process to fabricate an OLED substrate that integrate high surface conductivity, low surface roughness, and high light extraction efficiency in a plastic sheet.

Progress and Accomplishments

Accomplishments:

Composite materials are deposited via a solution based, low temperature process. Conventional coaters may be used. Process can potentially be scaled up on a roll-to-roll production line.

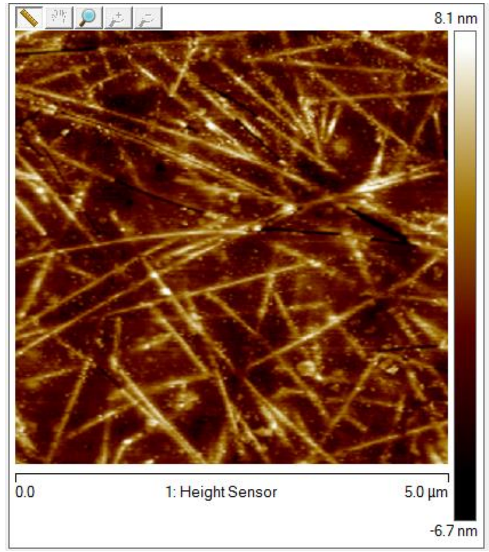




Progress and Accomplishments

Accomplishments:

Integrated substrate has been demonstrated in lab scale with sheet resistance and surface roughness match those of high grade ITO/glass, but exhibiting high mechanical flexibility, and 2.0X-2.5X light extraction efficiency.



Results	
Image Raw Mean	-547 nm
Image Mean	0.000003 nm
Image Z Range	127 nm
Image Surface Area	25.1 µm²
Image Projected Surface Area	25.0 µm²
Image Surface Area Difference	0.384 %
Image Rq	2.30 nm
Image Ra	1.78 nm
Image Rmax	127 nm
Raw Mean	0.00 nm
Mean	0.00 nm
Z Range	0.00 nm
Surface Area	0.00 µm²
Projected Surface Area	0.00 µm²
Surface Area Difference	0.00 %
Rq	0.00 nm
Ra	0.00 nm
Roughness Rmax	0.00 nm
Skewness	0.00
Kurtosis	0.00
Rz	0.00 nm
Rz Count	0.00

Property	ITO/Glass	Integrated Substrate
Ohm/sq	~10	5~10
Substrate bonding	Strong	Strong
Roughness	<2 nm	<2 nm
OLED EQE	15-20%	~40%
Mechanical flexibility	Thick and brittle	Thin and flexible

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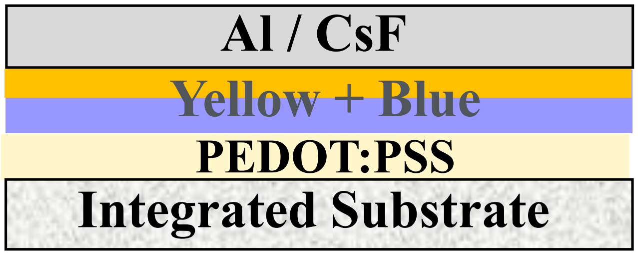
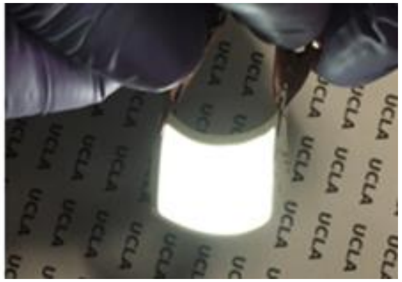
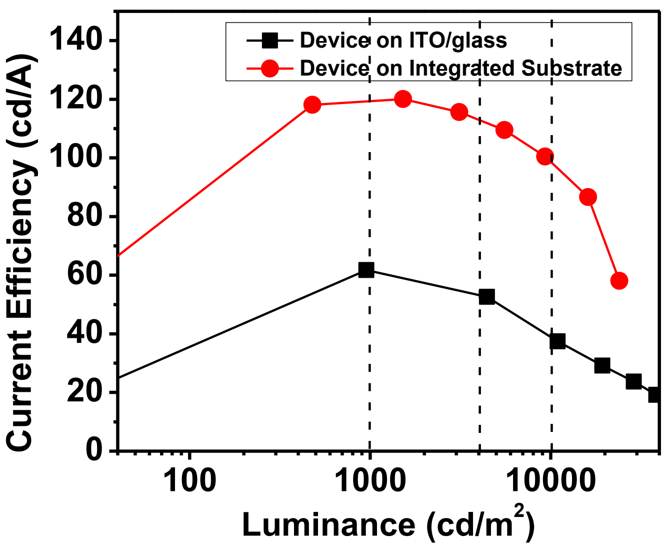
Progress and Accomplishments

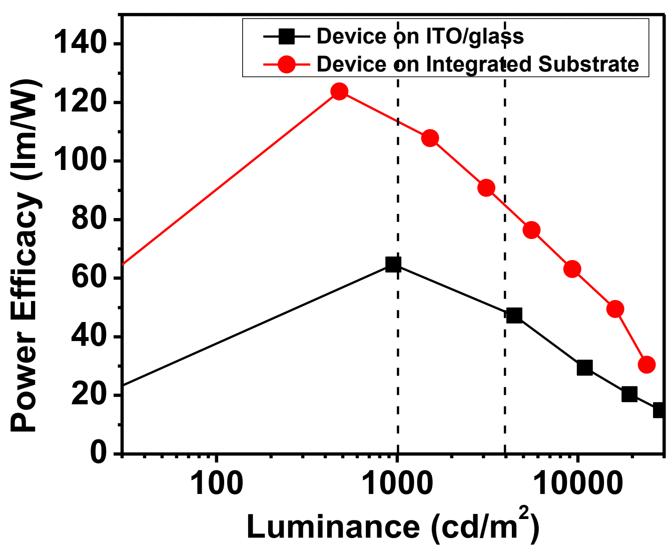
Accomplishments:

White OLEDs have been fabricated based on the integrated substrate with best efficiencies of 40% EQE and 110 lm/W at 1000 cd/m² luminance (CRI~55).





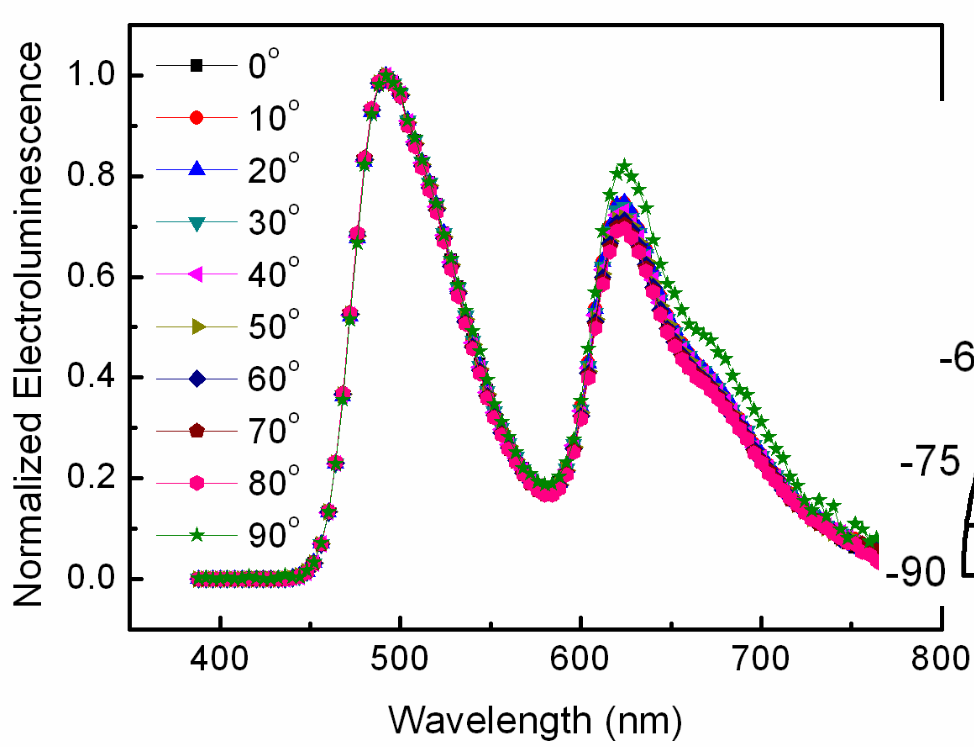


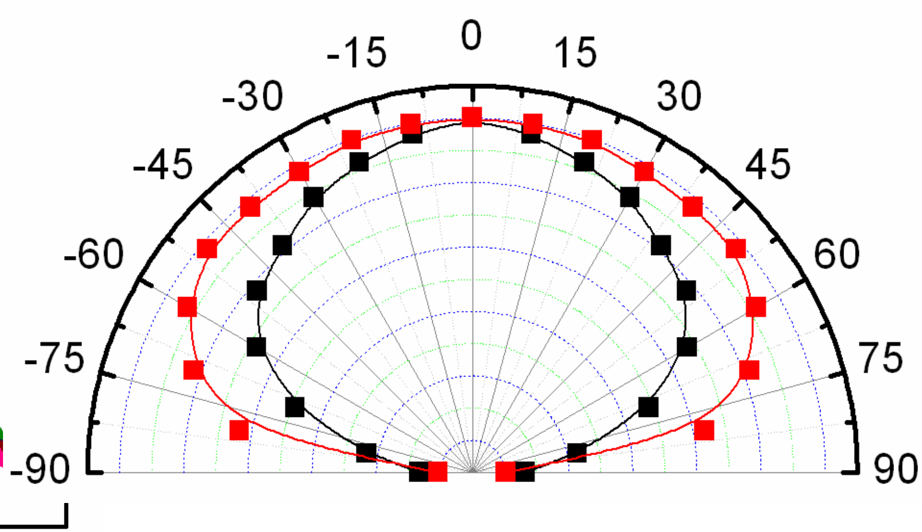


Progress and Accomplishments

Accomplishments:

The white OLEDs on the integrated substrate has wide viewing angle, ideal for general illumination.





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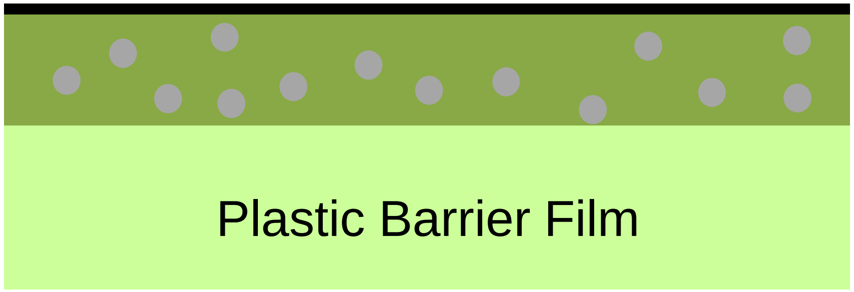
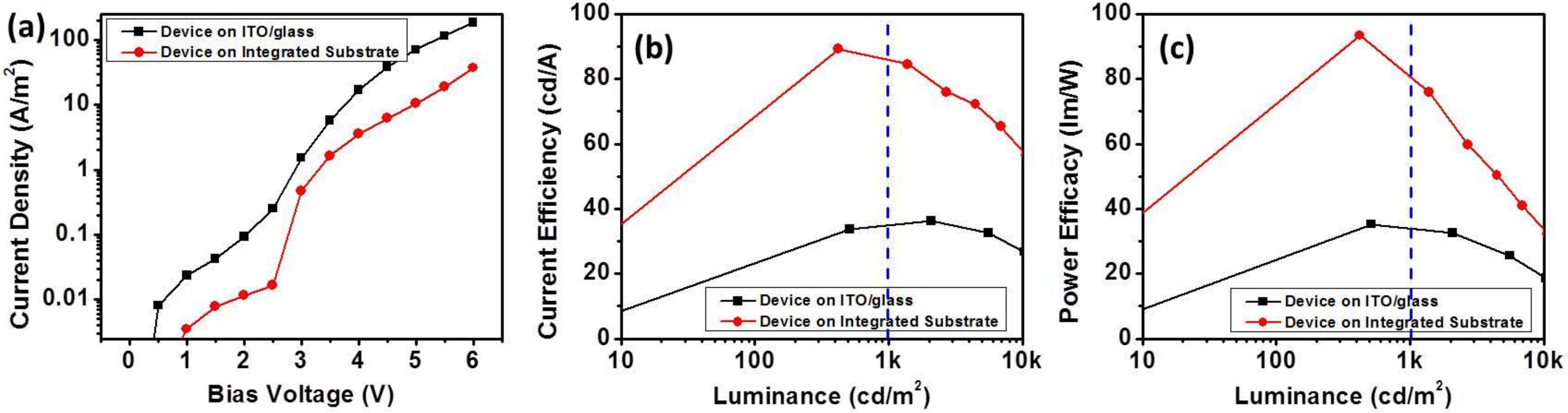
Progress and Accomplishments

Accomplishments:

Integrated plastic substrate has also been fabricated incorporating a commercial plastic barrier film specifically designed for flexible OLEDs. Flexible OLEDs fabricated on the integrated barrier substrate shows 81 lm/W at 1,000 cd/m^2.





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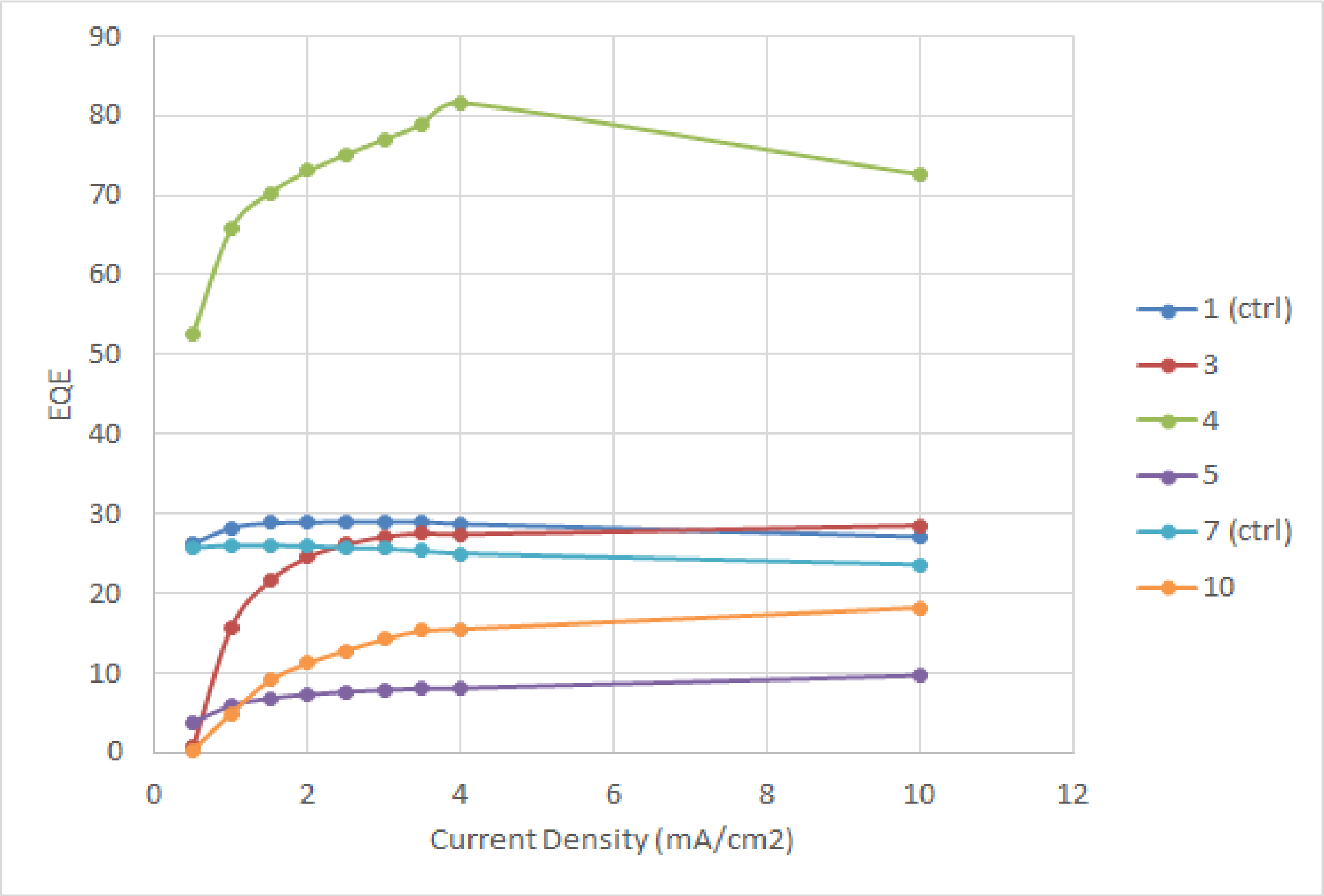
Progress and Accomplishments

Market Impact: This is an ongoing core R&D project. The technology is under development, so there is no actual market impact yet.
Projected market impacts when the technology is fully developed and manufactured include:

1. The integrated plastic substrate could potentially be employed by OLED manufacturers to mass produce OLED lighting panels with high efficiency without using costly light extraction structures, high color stability, low production cost, and mechanical flexibility
2. The flexibility of the substrate will enable roll-to-roll manufacturing of OLEDs for significant reduction of panel cost.
3. The project team is working with OLEDWorks, an OLED panel manufacturer to evaluate the integrated plastic substrate in their prototype OLED fabrication line, with objective of rapid technology transition.
4. Project results have been disseminated by presentations in scientific/technical conferences and training of PhD graduate students (3), undergraduate students (2), and postdoctoral researchers (2).

Progress and Accomplishments

Lessons Learned: The OLED testing of the integrated plastic substrate by an OLED manufacturer uncovers potential barriers in technology transition, and allows the project team to address these barriers early on.



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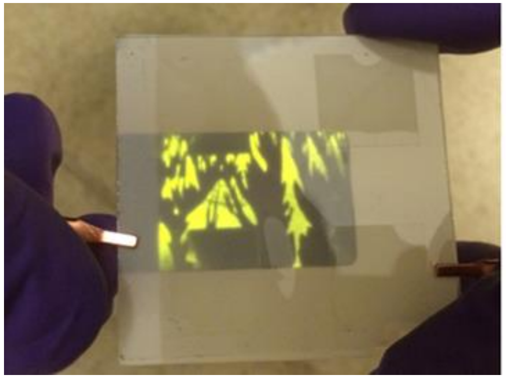
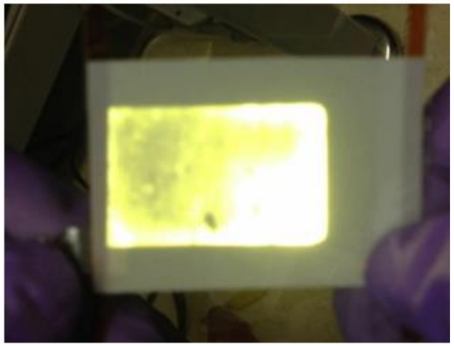
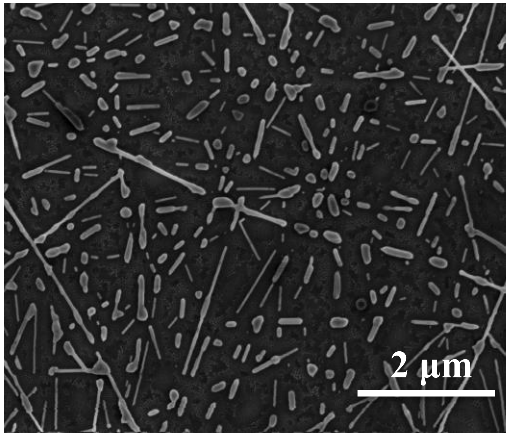
Progress and Accomplishments

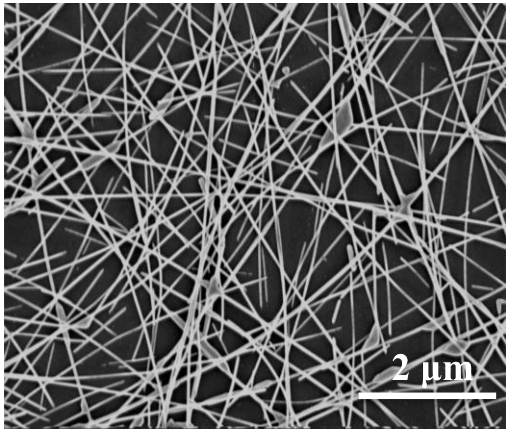
Lessons Learned: Two uncovered issues, employing a flexible substrate in a prototype line designed for rigid glass substrate and instability of silver nanowires, have been largely addressed.





Untreated AgNW Network: 155 mA/cm^2 for 1 hour





Protected AgNW Network: 155 mA/cm^2 for 1 hour

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Project Integration and Collaboration

Project Integration: This project is carried out by members from the UCLA Materials Science and Engineering Department and Polyradiant Corp. The UCLA team focuses on materials selection, formulation and structure design of the integrated plastic substrate for OLED performance. The polyradiant team focuses on ink formulation and process development for large-area fabrication and performance optimization. The close proximity allows the teams to interact on daily to weekly basis. The company management is additionally engaged in business development for the integrated plastic substrate.

Partners, Subcontractors, and Collaborators: Polyradiant is a substractor of the project. OLEDWorks is a service provider to evaluate the integrated plastic substrate in their prototype OLED fabrication line.

Communications: Invited talk at the SPIE Photonics, San Diego, August 2015; Invited talk at the European MRS, Warsaw, September 2015; Invited talk at OSA Conf. on Solid State Lighting, Suzhou, China, October 2015; Invited talk at the MRS Fall 2015, Boston; Panel presentation at the DOE SSL R&D Workshop, Raleigh, February 2016; Invited Keynote talk at the ACS Spring Conferences, San Diego, March 2016.

Next Steps and Future Plans

Next Steps and Future Plans:

From now till expiration on 08/31/2016, the project activities will include:

- Iterations of the integrated plastic substrate to further enhance the light extraction efficiency with a target efficacy of 150 lm/W at 1000 cd/m^2.
- Further improvement of the integrated flexible barrier substrate without any reduction in the light extraction enhancement. The barrier substrate is based on a commercial barrier film developed specifically for flexible OLED. The flexible OLED fabricated on the barrier substrate should not reveal any crack formation in the barrier layers that could lower the barrier property.

Beyond the project expiration:

- Continuation of the business development of the integrated plastic substrate for possible technology transition into commercialization.
- Seeking additional funding to further improve the integrated plastic substrate for OLEDs with up to 200 lm/W efficacy.
- Technology transition into manufacturing.

Project Budget

Project Budget: Total project cost is $765,916, including DOE fund of $612,733 and cost share of $153,183 by the primary and sub-contractors.
Variances: Project plan has not modified, and there is no budget change either.
Cost to Date: The project spending is on schedule.
Additional Funding: N/A.

	Budget Period 1 9/4/2014-8/31/2015			Budget Period 2 9/1/2015-8/31/2016			Total		
	Gov Funding	Cost Share	Total Value	Gov Funding	Cost Share	Total Value	Gov Funding	Cost Share	Total Value
UCLA	209,109	48,708	257,817	203,625	49,682	253,307	412,733	98,390	511,123
Polyradiant	100,000	24,740	124,740	100,000	30,053	130,053	200,000	54,793	254,793
Total	309,109	73,448	382,557	303,624	79,735	383,359	612,733	153,183	765,916
Cost Share		19.2%			20.8%			20.0%	

Project Plan and Schedule

- All milestones have been completed on schedule
- Go/no-go decision point (M2.1) was accomplished on time
- Current and future work are focused on delivering M2.2, M3.2, and M4.2. M2.2 is the final milestone to demonstrate a white OLED on integrated substrate with 150 lm/W power efficacy at 1000 cd/m^2 (8/31/2015)