Mask-Free OLED Fabrication Process for Non-Tunable and Tunable White OLEDs

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PROJECT TEAM

OLEDWorks LLC - Rochester, NY

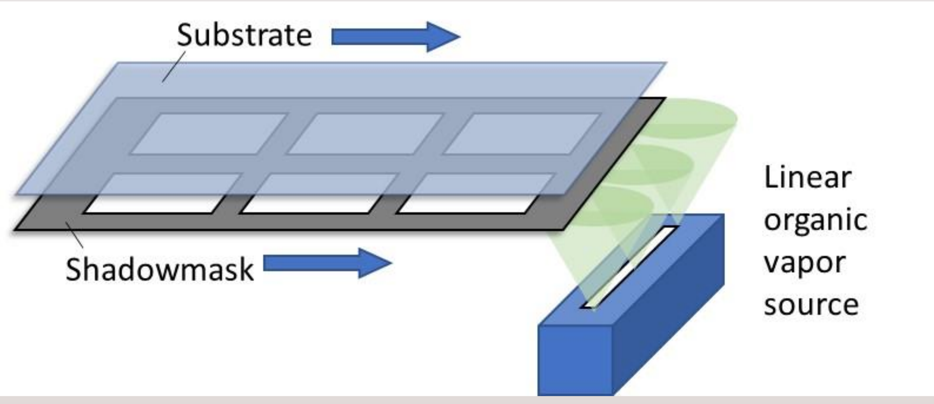
Role: Mask-free fabrication process development and prototype OLED panel demonstrations

Kurt J. Lesker - Vacuum equipment modifications

Keyence Corporation of America - Laser system provider

BACKGROUND

OLEDs are currently made using at least 2 shadowmasks to pattern the organics and cathode, with substrate and mask transported past a linear source. Masks are costly and are a source of yield loss due to particles.



SOLUTION: Eliminate use of shadowmasks by innovative substrate and encapsulation design, combined with an in-vacuum laser patterning process. A mask-free process could reduce the cost of OLED lighting in several ways:

1. Simplify deposition equipment and mask handling resulting in lower capital equipment cost
2. Eliminate cost of purchasing masks for every panel design, and cost of cleaning mask sets frequently
3. Increase yield by eliminating particles due to mask contact and handling
4. Eliminate a major barrier to R2R manufacturing

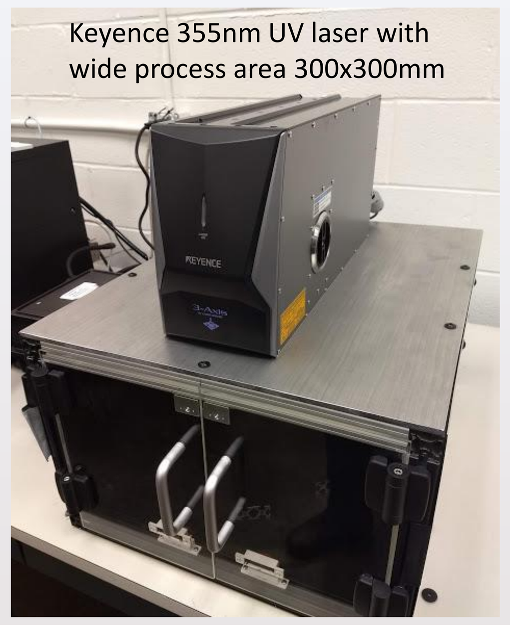
PROJECT OBJECTIVES

1. Develop a mask-free OLED fabrication process technology in R&D OLED coater
2. Demonstrate amber OLEDs and tunable amber OLEDs in R&D coater using the mask-free technology
3. Demonstrate scalability of the mask-free process technology in OLEDWorks' production coater
4. Using the mask-free process, demonstrate a white color tunable OLED panel with a CCT range of 2700K-5000K

SSL TECHNOLOGY IMPACT

The largest barrier to widespread adoption of OLED lighting is the high cost relative to LED and LFL. This project seeks to demonstrate lower cost manufacturing technology that is not only compatible with current manufacturing equipment, but also enables future roll-to-roll manufacturing of flexible OLEDs. Demonstration of cost-effective technology for producing white color tunable OLEDs could also open the door for OLEDs to enter this fast-growing market segment.

PROJECT ELEMENTS AND TECHNOLOGY



R&D Vacuum OLED Coater (BP1):

Modified R&D OLED coater to accommodate laser system. Laser installed outside vacuum chamber, coupled to AR-coated ZnSe optical window to allow laser processing inside chamber.

View from inside PC vacuum chamber

View from outside PC vacuum chamber

Production OLED Coater (BP2):

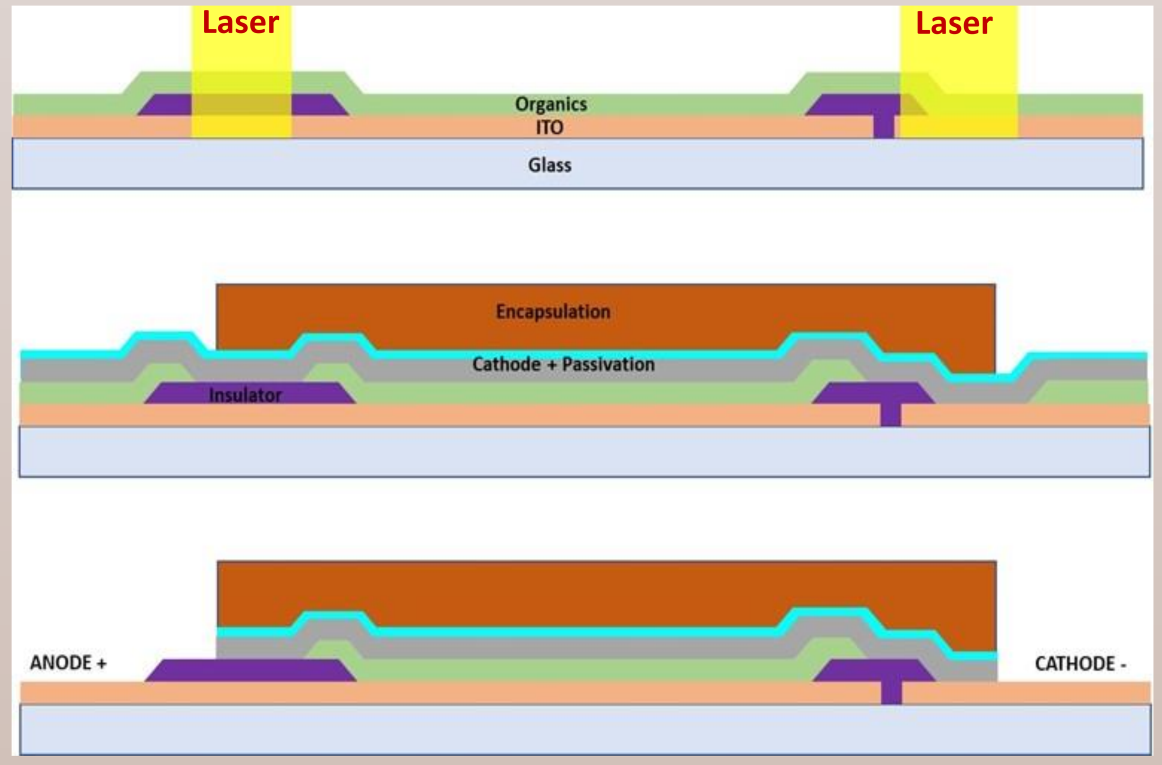
Modified production OLED coater to accommodate laser system. Extension into chamber. Laser head installed outside vacuum chamber, coupled to quartz optical window to allow laser processing inside chamber.

Laser System:

Tested and installed CO_2 and UV laser systems capable of high-speed organic material removal without damage to underlying substrate or inorganic insulator. Material removal through ablation or resublimation due to rapid heating in top surface of substrate.

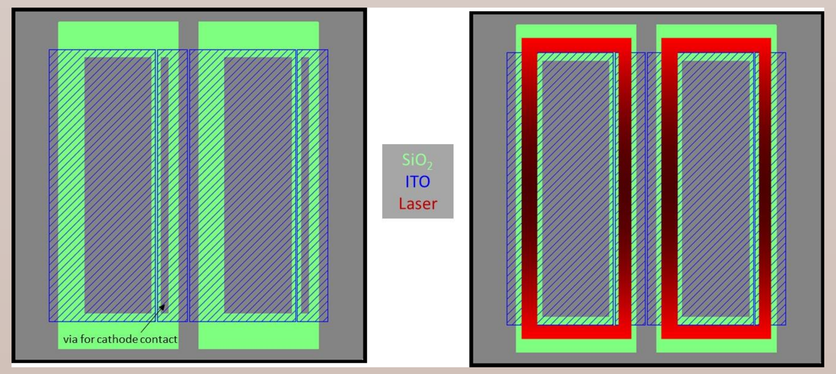
Mask-free OLED Fabrication Process:

- Blanket deposition of OLED organic material
- Remove organic material with laser in select areas to form moisture-impermeable seal area
- Blanket deposition of cathode and passivation layers
- Encapsulation using laminated film
- Contact pads cleared with post removal process



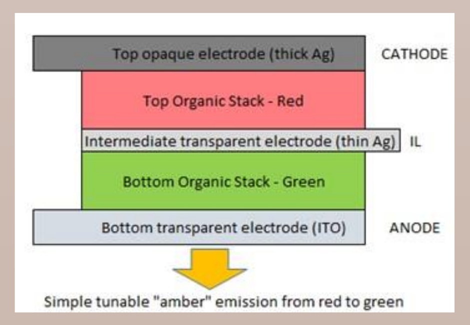
OLED Substrate Architecture:

- Glass substrate with pre-patterned ITO and insulator
- Change from organic insulator to an inorganic insulator material such as SiO_2 or SiN_x

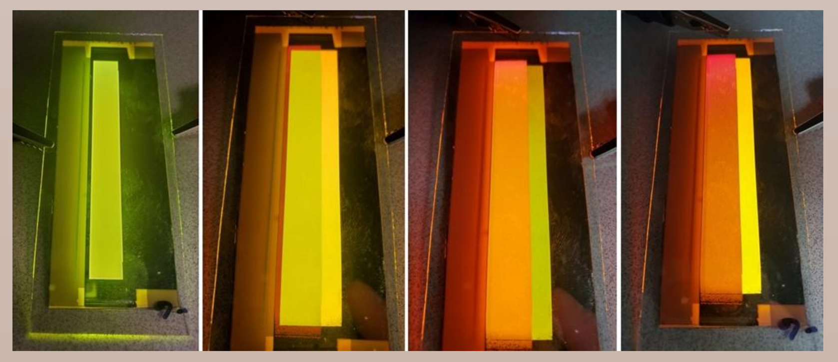


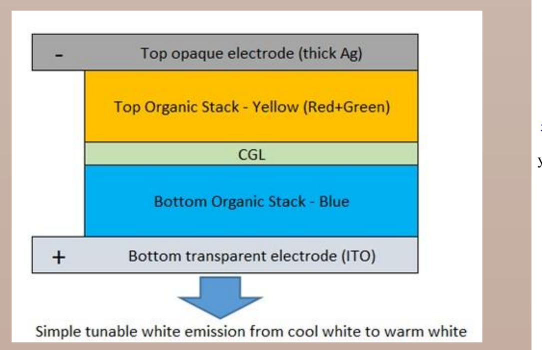
Color Tunable OLED Architecture:

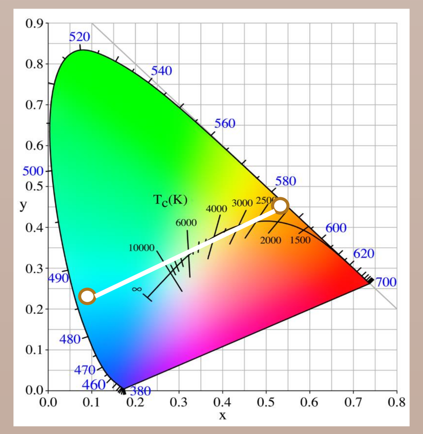
- Demonstrated 3-electrode approach to achieve tunable amber OLED with green and red stacks
- Developed novel 2-electrode white tunable OLED architecture where CCT is tunable as a function of current; simplifying the laser process so only 1 laser removal step is required.



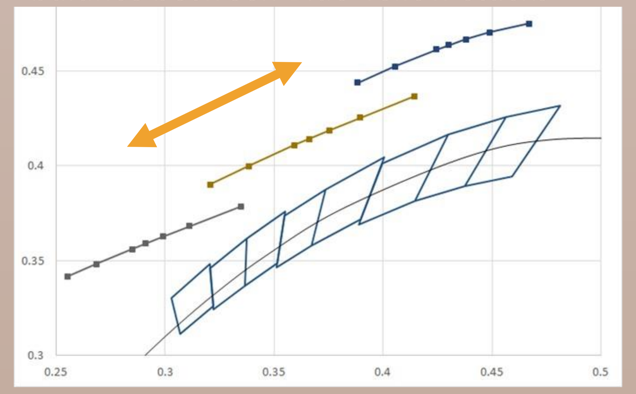
Tunable 3-electrode amber OLED demonstration



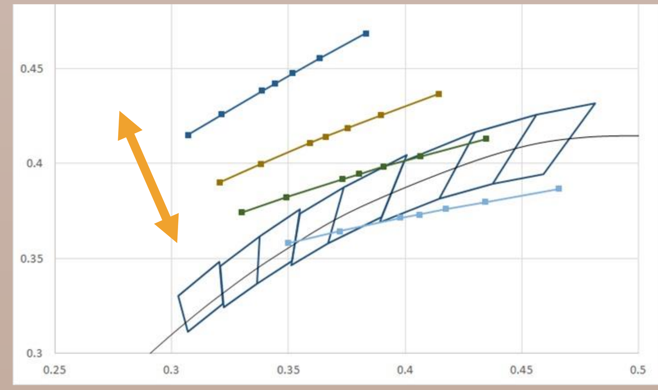




CCT range tunable by adjusting charge balance between Blue-Yellow stacks



Duv adjustable by varying red to green ratio



MILESTONES AND CURRENT STATUS

	Key Milestones & Deliverables
BP1	• Demonstrate R&D scale mask-free OLEDs with comparable performance to control OLEDs • Demonstrate concept for tunable amber OLEDs
BP2	• Demonstrate production scale mask-free OLEDs with comparable performance to control OLEDs • Demonstrate white color-tunable OLEDs (2700K-5000K CCT) made with mask-free process in production coater

BP1 completed successfully

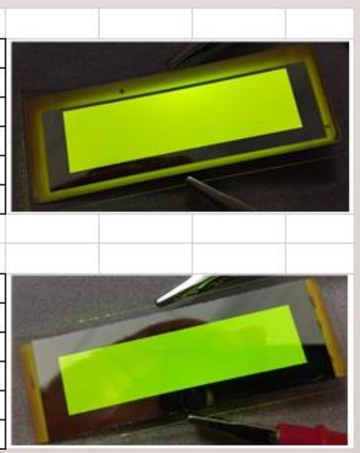
- Demonstrated mask-free OLEDs with performance similar to control OLEDs made with shadowmasks
- Demonstrated tunable 3-electrode amber OLED
- Determined CO_2 laser caused too much damage to underlying inorganic layers - 9.3um wavelength strongly absorbs in glass surface, very selective to other layers in stack.
- Decided path forward with UV laser in BP2

Controls made with masks

V	cd/m2	cd/A	CIEx	CIEy	lm/W	EQE
3.0	1550	51.6	0.453	0.536	53.5	15.9
3.1	1550	51.6	0.452	0.537	53.0	15.9
3.1	1550	51.7	0.454	0.535	53.0	15.9
3.1	1600	53.2	0.448	0.541	54.8	16.4
3.1	1590	53.1	0.450	0.539	54.1	16.3

Mask-Free OLEDs

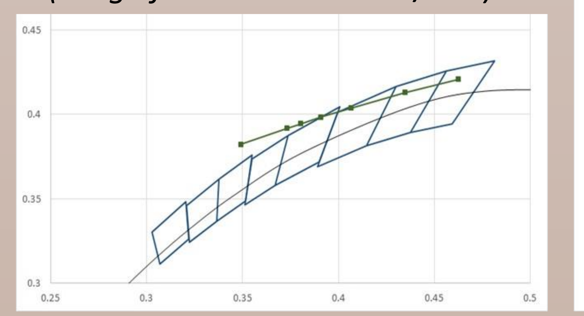
V	cd/m2	cd/A	CIEx	CIEy	lm/W	EQE
3.3	1630	54.4	0.458	0.531	51.5	16.7
3.1	1760	58.6	0.440	0.548	59.4	17.9
3.5	2080	69.4	0.433	0.554	62.8	20.9
3.5	1720	57.4	0.424	0.565	51.1	16.5
3.2	1610	53.6	0.426	0.562	52.5	15.8

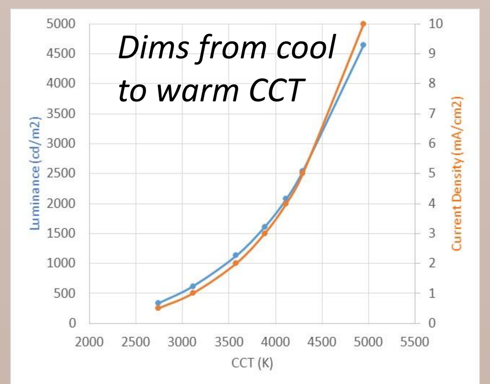


BP2 in progress, planned completion 6/30/2020

- UV laser system successfully installed and commissioned in production OLED coater
- Successful demonstration of mask-free green OLEDs
- Transferred tunable white OLED architecture to PC; Demonstrated ability to fine tune CCT range and Duv
- Laser process optimization in progress, now evaluating patterning uniformity over large area
- Final demonstrations planned for mask-free non-tunable amber and white OLEDs, and finally mask-free tunable white OLEDs

Tunable white OLED made on PC (range from 0.5 to 10 mA/cm²)





Tunable 2-electrode white OLED demonstration – see demo OLED device