Manufacturing Process for OLED Integrated Substrate

2015 Building Technologies Office Peer Review

OLED device with no Extraction Layer

OLED device with PPG Extraction Layer

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

Cheng-Hung Hung, PPG Industries
hung@ppg.com

Project Summary

Timeline:

Start date: 8/1/2013

Planned end date: 7/31/2016

Key Milestones:

1. On-line IEL capability, 12/14
2. Low cost sputtered anode, 4/15
3. IEL, EEL, IEL/EEL evaluation, 7/15
4. Process optimization, 7/16

Budget:

Total DOE $ to date: $841,351

Total future DOE $: $1,504,287
(Includes Budget Periods 1 and 2)

Target Market/Audience:

OLED Lighting panel manufacturers for solid state lighting products in consumer and commercial applications

Key Partners:

Universal Display Corporation

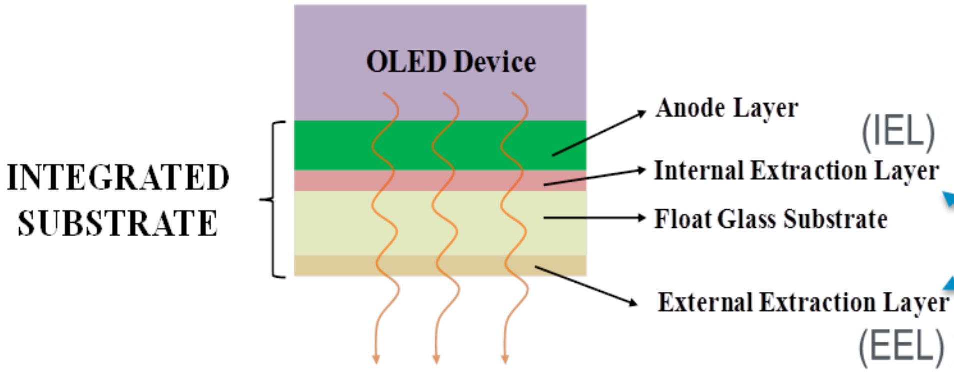
Project Goal:

Manufacturing process for a large area and low-cost “integrated” float glass based substrate product for OLED solid state lighting.

- ❑ Cost Target: $60/m^2 by 2015 and $28/m^2 by 2020
- ❑ Performance Targets: 50% extraction efficiency; sheet resistance 10 Ω/□ for anode layers

Purpose and Objectives

Problem Statement: Optical index differences in the OLED structure cause low light out-coupling efficiency. A cost-effective manufacturing process is needed to improve out-coupling efficiency with integrated IEL and EEL structures.



OLED DEVICE SCHEMATIC

Up to 80% light generated is trapped in the OLED

Use of extraction layers boosts the efficiency of the device by 50-100%

IEL Scale Up Challenges

> 300X

Lab Scale

Manufacturing Scale

Process Impact

- *Line speed*
- *Length of time for particle complete embedment*
- *Precursor feed rate*
- *Ribbon formation*

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

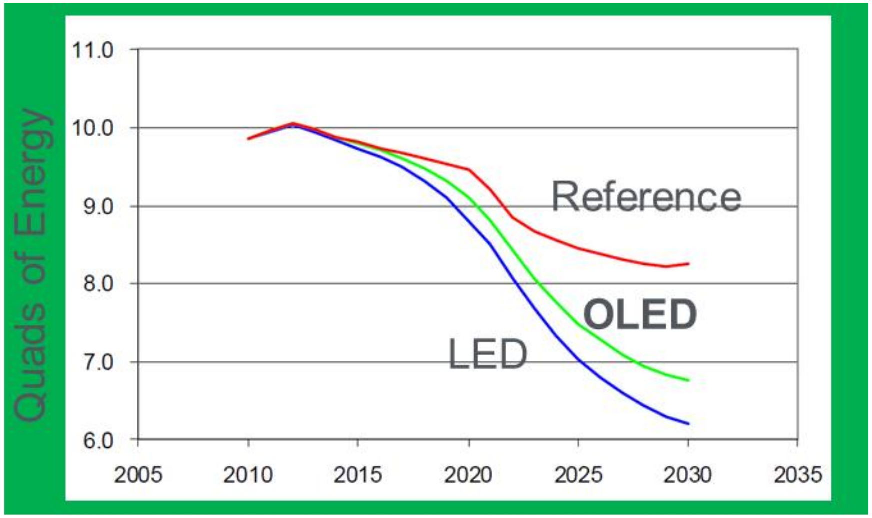
Purpose and Objectives (cont.)

Target Market and Audience: Large volume manufacturing process required for producing integrated substrates for OLED Lighting panel manufacturers

Potential U.S. Energy Savings in Quads

Scenario	2015	2020	2025	2030	Cumulative
OLED	0.01	0.36	0.96	1.51	10.49
$ Saving* (Billion)	0.085	3.06	8.16	12.84	89

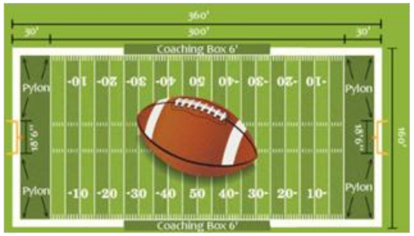
**Assumption: 1 Quad Production~ $8.5 Billion*



Source: DoE Report- Energy Savings Potential of SSL in General Illumination, 2010

- ~3,000MM ft^2 OLED panels# saves 1 Quad/yr

Enough to cover up 52,000 football fields



 # Calculations based on 0.17 ft^2/w, 120 lm/W, and 50% efficiency improvement

- A typical float glass line produces ~300MM ft^2 glass per year.

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

Purpose and Objectives (cont.)

Impact of Project:

1. Output: Large area OLED integrated glass substrates meeting DOE cost and performance targets

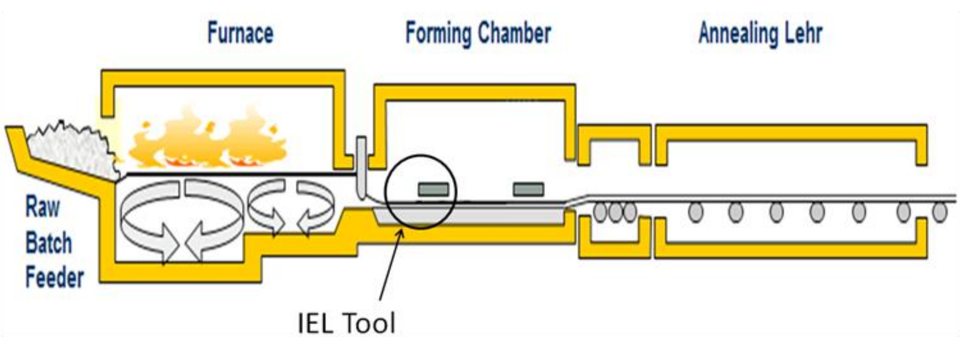
2. Impact path:
   a. Near term: Evaluation of integrated substrates by OLED device manufacturers
   b. Intermediate term: OLED device manufacturers use integrated substrates to produce reduced-cost OLED lighting panels
   c. Long term: Market acceptance of OLED drives further scale up in substrate size, performance improvement, and further cost reduction

Approach

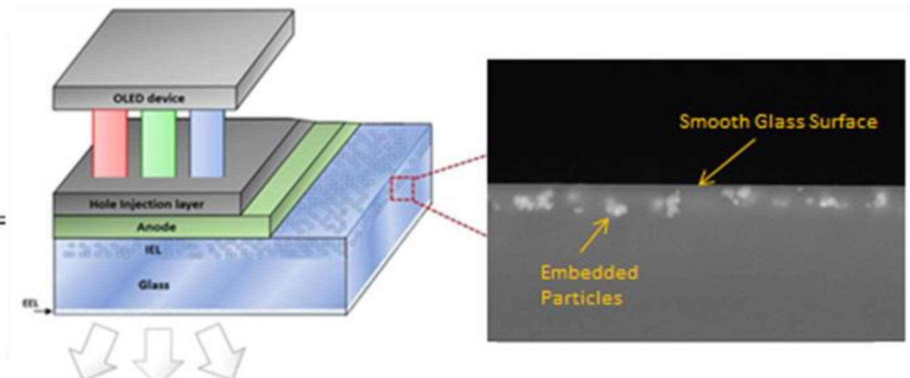
Approach:

Internal Extraction Layer (IEL): *In-situ* generation of nano-sized high optical index particles in a float glass manufacturing process without reheating the glass. Particles embedded in the glass with smooth surface for redirecting the light.

Sketch of float glass manufacturing process



Sketch of IEL in OLED device

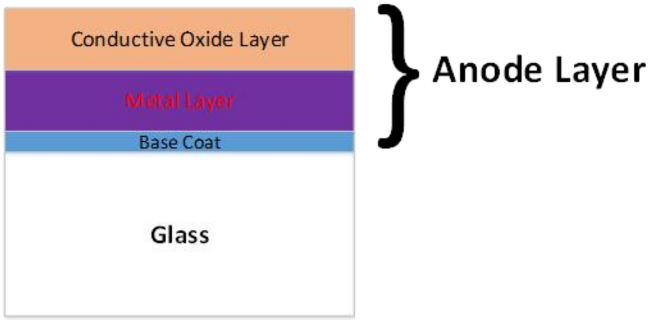


On-line IEL Layer Applied in a Low-cost Float Glass Manufacturing Process.

Approach (cont.)

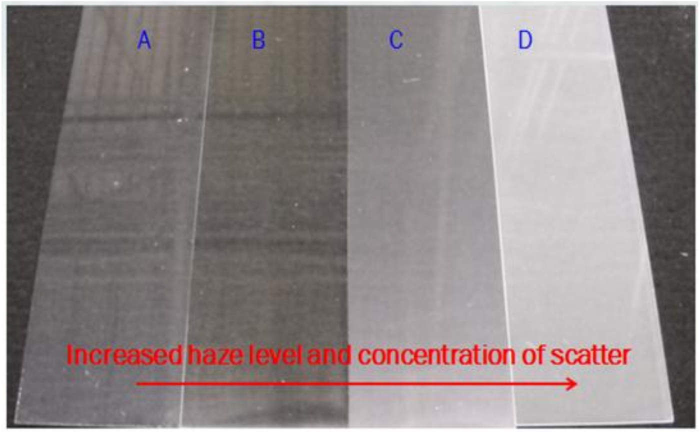
Approach:

Anode Layers: A sputtered process using metal/conductive oxide layers for providing low sheet resistance, high transmittance, and corrosion resistance.



A sketch of PPG anode design

External Extraction Layer (EEL): Use of off-line patterning to generate textured-type EEL with high durability.



Clear glass processed with EEL in different haze level.

Approach (cont.)

Key Issues:

- Complete particle embedment with high particle concentration and desired particle size and depth of penetration
- Reduced defects and low surface roughness on anode layer to prevent dark spots and short circuiting in OLED device
- Optimized light out-coupling performance with combined IEL and EEL

Distinctive Characteristics:

IEL

- Uniform distribution of particles in the glass
- An energy saving approach without reheating the glass
- Large area and low cost

Anode

- Low cost

EEL

- Low cost and durability

Progress and Accomplishments

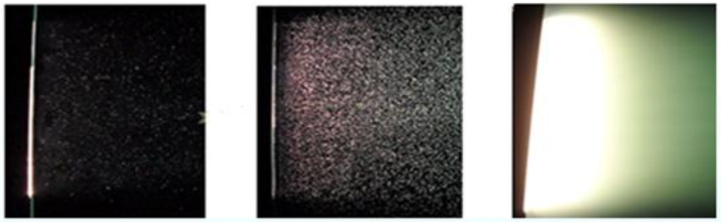
Lessons Learned:

- Scale up from laboratory to manufacturing was more challenging than expected.
  - Achieving high particle density in the glass required high starting material feed rate and high deposition efficiency into hot glass surface.
  - Stretching and compression in glass-forming chamber resulted in cracking line defects.

Key Accomplishments:

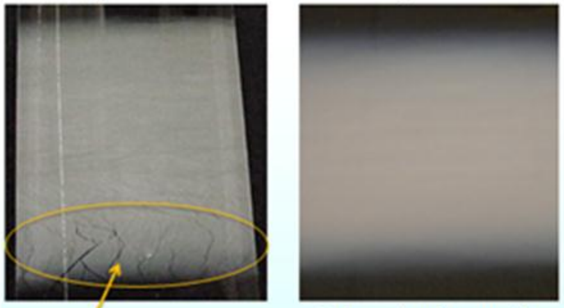
- IEL

Progress on Incorporating Particles in Glass



Photos of typical IEL samples illuminated with a 6" edge light from left side of the samples showing light scattering of particles. Higher particle density resulted in higher scattered light intensity.

Surface Quality Improvement



Surface quality was improved through process optimization

On-line IEL Process Demonstrated at High Line Speeds with Measured Haze >70%, Surface Roughness (Rq) <2nm.

Progress and Accomplishments (cont.)

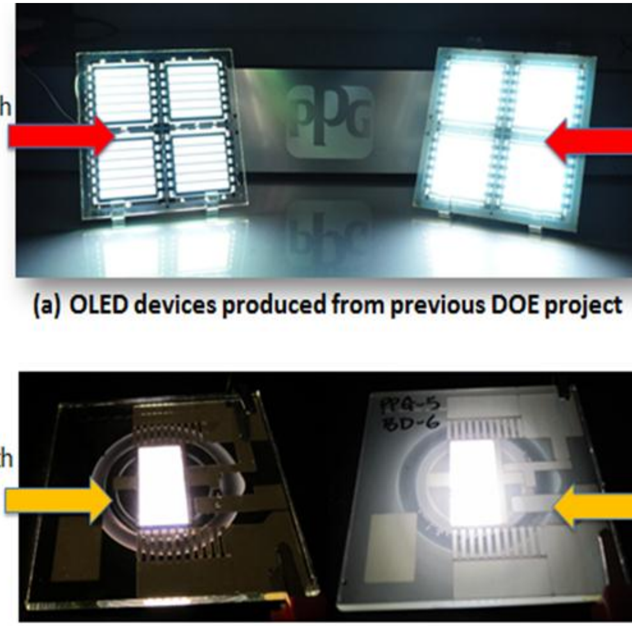
Key Accomplishments:

- Anode – achieved sheet resistance (<10 ohm/□), high transmission (>85% weighted in the visible), and surface roughness (Rpv) <12 nm.

- EEL - targeted haze 20% to 50% achieved with measured pattern depth (Rq) 180nm to 1µm.

Market Impact:

- PPG is working with OLED lighting manufacturers for evaluation of early stage products.



(a) OLED devices produced from previous DOE project

(b) OLED devices produced from current DOE project

OLED light extraction evaluation of *(a)* off-line produced IEL substrate (UDC device) and *(b)* PPG on-line produced IEL substrate (OLEDWorks device).

Preliminary Results Showed Comparable Light Extraction Enhancement for the On-line Produced IEL.

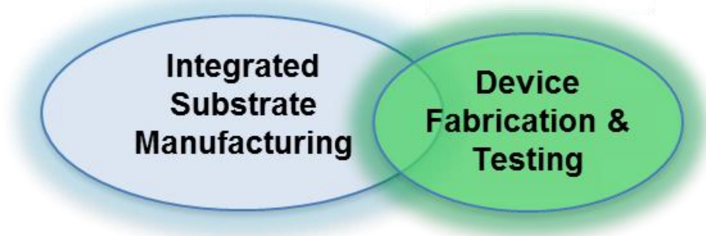
Project Integration and Collaboration

Project Integration:

- PPG Glass Business and Development Center (GBDC) leads project.
- GBDC collaborates with manufacturing plants to develop processes, optimize product properties, and generate prototype samples.

Partners, Subcontractors, and Collaborators:

- UDC as partner in OLED device fabrication and testing



Communications:

- Presentation made at project review/DOE visit
- Project results reported monthly and annually to DOE staff
- Presentation and posters made at DOE SSL workshops
- Presentation made at OLED project peer review
- Presentation and poster made at PPG cross group meeting

Next Steps and Future Plans

Next Steps and Future Plans:

- Continue on-line IEL manufacturing process development
- Complete sputtered anode manufacturing development
- Evaluate efficiency of textured glass EEL, IEL, and combined IEL/EEL
- Fabricate and characterize OLED panels with UDC
- Develop commercialization plan
- Optimize process and manufacture large area panels

REFERENCE SLIDES

Project Budget

Project Budget: The project spend is significantly under budget, due to delays in achieving initial technical results and subcontractor issues that combined to necessitate a major change to the project plan and schedule.

Variances: Budget Period 1 received an initial 9-month extension and an additional 3 months has also been granted. The planned spend from subcontractor Solvay is being redirected to alternate in-house anode manufacturing process development.

Cost to Date: Current spend is 61% of Budget Period 1 total.

Additional Funding: PPG is providing substantial unplanned funding to support this project through a major internal realignment.

Budget History					
8/1/2013 – 2/28/2015 (Budget Period 1 to date)		3/1/2015-7/31/2015 (Budget Period 1 Remaining)		8/1/2015 – 7/31/2016 (Planned Budget Period 2)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$841,351	$841,351	$531,745	$531,745	$972,541	$972,541

Project Plan and Schedule

Project Schedule		
Project Start: 8/1/13		Completed Work
Projected End: 7/31/16		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned)
		Milestone/Deliverable (Actual)

	FY2014				FY2015				FY2016			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Program management plan												
On-line IEL manufacturing				(Site 1)			(Site 2)					
FTO anode development												
Current/Future Work												
IEL evaluation												
Sputtered anode development												
Texture glass EEL												
OLED devices												
Commercialization plan												
Go/No go decision												
Process optimization												
Final OLED devices												