

Present and future of OLED lighting

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Vision

- In 10 years there will be only Solid State Lighting; shared between LED and OLED
- Applications favoring OLED:
 - Close to the user
 - Low glare, low temperature, broad spectrum – e.g. office above
 - Unique form factors of OLED:
 - Thin and light weight for example transportation
 - Special design elements for example curved lights





Outline



- OLEDWorks
 - Our History and what we do
- OLED Product Performance
 - Today and Future Projections
- Looking ahead
 - Industrial activities
 - Flexible OLED Lighting
- Applications
- Summary



Visa Lighting's Petal and Limit luminaires





OLEDWorks – Our History

Founded 2010

- By OLED pioneers in Rochester, New York formerly of Eastman Kodak Company
- Initial focus on R&D and Consulting
- 2011 2014: Class A equity raise complete based on unique OLED lighting business plan
 - R&D lab completed and contract research underway
 - Novel Rochester production facility with emphasis on versatility, low cost expansion and low cost manufacturing is designed, built
 - OLEDWorks ships first prototypes from qualified manufacturing facility in Rochester
- 2015: Combination of two world-class teams, complete additional equity raise
 - OLEDWorks acquires Philips OLED key assets
 - Includes worldwide state-of-the-art, largest capacity OLED lighting production line and rich OLED experience in Aachen, Germany
 - 70 worldwide OLED experts
- **2016:** new products launched as OLEDWorks LLC and subsidiary OLEDWorks GmbH
 - Lumiblade Brite 2 60lm/W, 3000K and 4000K, > 90 CRI, 300 lm/panel, >50,000 hour LT70 @ 3000cd/m2
 - Keuka OLED module
 - See <u>www.oledworks.com</u> for complete current product offerings



Over 400 years of OLED expertise supporting your OLED experience







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OLEDWorks – What we do

- WE MAKE OLED LIGHT ENGINES
- OLED material, formulation, process and reliability experts
- OLED lighting manufacturing innovation
 - Aachen: Bold move to make world's brightest panels, high volume capacity
 - Rochester: Disruptive low cost structure, amber, low volume, scalable
 - Process integration competence

OLED collaboration and integration

Driver and electronics support, technical support, supplier collaboration



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OLED Panel Performance Today From 2016 DOE SSL R&D Plan

Today's panel performance:

- >20klm/m²
- Efficacy of >60 lm/W
- LT70 >50k hours
- CRI > 90
- R9 > 50
- These panels deliver the performance needed for most applications

OLEDWorks Brite 3 with >90 lm/W – for release in early 2018

Table 6.1 Components of OLED Panel Efficacy				New!
Source	LG	LG	OLEDWorks	OLEDWorks
Product	LL055RS1-62P1 ¹	LL055RS1-92P1 ¹	Brite 1 ²	Brite 2
Illuminance (Im/m ²)	7,700	7,700	20,700	20,700
LER (Im/W)	328	328	336	302
Electrical Efficiency (%)	80	80	73	70
Internal Quantum Efficiency (%)	65	65	62	62
Extraction Efficiency	35%	52%	31%	47%
Panel Efficiency (%)	18	27	14	21
Panel Efficacy (lm/W)	60	90	46	62
ССТ (К)	2700	2700	2900	2956
CRI (R _a)	>87	>87	80	93
CRI (R ₉)				76
Lifetime (L ₇₀) (hrs)	40,000	40,000	>50,000	>50,000

Note: All data provided in communications with represented company.

1. A hybrid triple stack with fluorescent blue emitters and phosphorescent red and green; 2700K

2. A hybrid 6-stage stack with fluorescent blue emitters and phosphorescent red and green; 2700K A double stack with all phosphorescent emitters [111]

DOE SSL R&D Plan, June 2016, pg 102

Illuminances corrected for total panel area Efficacy and Lifetime (L70) is quoted for 3000 cd/m2



Commercial product performance on steep curve

- For commercial products in the last 3 years we...
- ...tripled the efficacy
 ...tripled the luminance
 ...tripled the lifetime,
- ...and cut the price by 3
- ...and it does not stop here !





Prediction of Panel Prices and Volumes



OLED panel prices and market -IDTechEx predictions in 2013, unchanged in 2016

Panel prices – the industry is ahead of the curve as shown by red ellipse.

From "OLED Lighting Opportunities 2016-2026: Forecasts, Technologies, Players", April 2016 http://www.idtechex.com/research/reports/oled-lighting-opportunities-2016-2026-forecasts-technologies-players-000472.asp



LED vs OLED Cost Comparison

- OLED light panels can be at higher prices (\$/klm) and still have fixture cost-parity, due to simpler fixture designs for lower costs.
 - No optics, no heat management, simpler mechanical designs.
 - Higher brightness OLED panels are important
- LED fixtures cover wide quality range
 - OLED can compete now at the high end.
- Unique form factor of OLEDs can give a design advantage that is difficult for LED to match.



Visa Lighting's Petal and Limit luminaires





OLED Processing Costs

\rightarrow R2R Needed for Ultimate Low-Cost Production

- As volumes increase, OLED lighting industry will have cost reduction due to economies of scale over today's manufacturing machines
- Major cost-down advantages will occur when we get to G5 Sheet-to-sheet machines
 - LG machine will be in production in Asia in 2017-18
 - North America or Europe in 201x?
- For further cost down mass production using R2R processing required
 - This make more sense then going to G8 diverging from the display model.
 - Now is the time to start working on the developing and commercializing the technologies that will be required to make this happen.



Two Critical Areas Require Development for Successful R2R OLED Lighting Manufacturing

- 1. Substrate Web Handling and Transport
 - Substrate must roll up without particles and damage
 - Within the machine, all moving contact points generates particles
 - Worst problems are in areas where deposition occurs
- 2. Masking for Vacuum Thermal Evaporation Deposition is used to:
 - Prevent OLED organic from depositing the seal area and cathode contact area
 - Prevent the cathode from depositing across to the anode contact area.



Possible Path Forward:

 \rightarrow Customers who want something special

- Restaurants, hotels, retail stores, offices, ...
 - Look special or offer a special experience.
- Partner to design and build OLED fixtures to meet their needs.
- Motivation for Curved and Bendable OLED Lighting
 - OLED lighting is currently higher priced than LED, and needs to achieve higher sales volumes to significantly reduce costs.
 - Unique selling points OLED lighting can be bendable, flexible, thinner, lighter than LED allowing more creative designs.





Selection of Substrate: Glass vs Barrier-Coated Plastic

- Glass Advantages
 - Excellent barrier properties
 - Lower cost than barrier-coated plastic
 - Available now in wide rolls
 - High transparency
 - High temperature processing capability
- Glass Disadvantages
 - Defects on surfaces and edges limit maximum stress and radius of curvature
 - Bending/twisting in 2D results in breakage
 - In processing e.g. in deposition/encapsulation equipment.
 - In handling of finished product.
- OLEDWorks and Corning have a Joint Development project for OLED lighting on Willow glass.





Design Challenges of Flexible Glass OLED Structures



- Careful engineering and design required to make the OLED product robust to handling
 - Selection of materials and thicknesses is critical to control stress and strain in each layer
 - The design of the location of neutral axis during bending is important
 - Protection of glass surfaces and glass edges is required to prevent damage which weaken the glass
- Market request is to match rigid technology platforms in price performance while additionally offer USP's bendable OLED's





OLED light sculpture in Frankfurt

Hatec with Groß + Partner & Eicke Becker



OLED luminaires at "Theater an der Elbe"

500xFL300 as the center piece of the new musical theater



OLED luminaires at the Audi Forum

Worldwide first use of OLEDs for functional lighting







DKB Offices – DOE Gateway



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Aerelight A1 Aerelight Design









LIMIT[™] & PETAL[™] Visa Lighting





Summary

- Solid State Lighting is the future and OLED will be a significant part of it.
- Applications where OLED will initially grow will be:
 - Close to the user due to the high light quality, low glare, and low temperature.
 - Low volume and weight.
 - Products where design elements affect buying decisions
- The combination of thinness, lightness, and <u>flexibility</u> of OLED will be key differentiators from LED.
- OLEDWorks will continue to introduce products with higher performance, lower cost and unique form factors to grow the market.
- The commercialization of our first bendable products has started now!
- Key technologies are needed for low-cost R2R.
 - We need to work together to develop these now.







