U.S. OLED Lighting Manufacturing Status and Trends

John W. Hamer
OLEDWorks LLC
OLEDWorks

Introduction

• We are the only US manufacturer of OLED lighting panels.
• Founded in Rochester NY in 2010
• Focused exclusively on OLED lighting and its benefits
  • Thin
  • Light weight
  • Low temperature
  • High efficiency, now and future potential
  • Solid state benefits including easy integration of drivers and controls
  • Specialty features - transparent, flexible, color changing, …
• Our first product is a maker light for health care applications.
• Larger panels will be shown at Lightfair.
OLEDWorks

Introduction

• 22 full-time OLED experts
  – Over 200 years of combined OLED experience
  – Experience across all areas of OLED technology

• Acquired equipment and set up of state of the art OLED R&D facility

• Design and startup of novel, flexible, scalable OLED production facility.

• Production of our first product has started.

• We work with many partners:
  – Suppliers to the OLED lighting industry
  – Downstream luminaire partners.
If I had $100M to build a large OLED lighting manufacturing plant, would I build it in the US?

Disadvantages
- OLED industry concentration is in Asia, focused on displays.
- Majority of industry suppliers are overseas
  - Equipment suppliers
  - Substrates suppliers
  - Encapsulation suppliers
  - OLED materials suppliers
- “Technology commons” for OLED in US is thinning
  - University, Gov’t research
  - Supporting industries (e.g. thin film)

Advantages
- OLED expertise critical mass is here. This is a huge factor.
- Luminaire customers want custom products and easy communications.
- Low-skill labor is only a minor part of Cost of Goods Sold.
- US is very competitive in R&D, and for industry success we rely on innovation for reduced costs and higher performance through:
  - Equipment
  - Processes
  - Materials
Current State of OLED Lighting Manufacturing in US

Our experience for early products, which uses conventional substrates, tandem OLED structures, and traditional encapsulation:

<table>
<thead>
<tr>
<th>Category</th>
<th>Attributes</th>
<th>Today</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>Custom</td>
<td>US - partnership</td>
<td>We needed innovations in manufacturing processes and equipment in order to succeed as a start-up with limited funding.</td>
</tr>
<tr>
<td>Substrates</td>
<td>Standard</td>
<td>US supply - probably Asia source</td>
<td>We need low cost, but we are small volume.</td>
</tr>
<tr>
<td>OLED Materials</td>
<td>Standard</td>
<td>Worldwide</td>
<td>We require competitive performance. We seek the latest improvements.</td>
</tr>
<tr>
<td></td>
<td>Custom</td>
<td>US - partnership</td>
<td>World class skill, great partnership.</td>
</tr>
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- **Summary** - For custom solutions, US partnerships offer tremendous advantages.
Importance of Partnerships - Models for Progress in OLED Lighting Mfg

• Solutions to OLED lighting challenges are multi-disciplinary:
  – For example - developing a new material/process/machine using advances from adjacent fields
    • Technology breadth of solutions often requires partnerships.
  – Development is faster and the results are better with partnerships.
    • Both parties benefit - Shared risks, shared rewards.

• Partnerships are facilitated locally
  – The “Technology Commons” – interaction on many levels
  – For smaller companies – collaboration can be easier
    • They need to pool resources – and often seek critical DOE funding
    • They are driven to succeed – willing to take risks, move faster
    • View that “a share of something bigger” is better than “all of something unknown”
Increasing OLED Lighting Manufacturing in the US - Proposal

1. Strategy – focus on growing the OLED lighting panel manufacturing industry here in the US – we need several companies manufacturing.
   – If the US loses this, the supporting component industries will diminish or leave the US to be near their customers.
     • Substrates, anodes, light extraction
     • Organic materials
     • Encapsulation materials and methods

2. The key in panel manufacturing is deposition operations – **both**:
   – Vacuum Thermal Evaporation, **and**
   – Solution Processing

3. The critical partnership is panel manufacturer and deposition equipment maker
   – Supporting and developing this technology partnerships here is required for success

4. The US can win at this – and have a strong OLED lighting manufacturing industry.
   – This will facilitate success of supporting component industries.
Future OLED Lighting - Will it be Vacuum Thermal Evaporation?

• The current vacuum thermal evaporation equipment is too expensive.
  – The Sunic G5 machine is predicted to have a depreciation of approx $100-200/m² (5 year depreciation at capacity).
  – The Cost of Goods Sold total target is $100/m² for OLED lighting to have high volumes (achieve $80/klm and compete in general lighting).
  – Alternative approaches with lower capital cost must be developed.

• Machines must be developed enabling businesses to make profits while the market grows.
  – Today’s VTE machines require business losses until machine is producing at capacity – and maybe beyond.

• Extra Challenge - It is difficult for US equipment companies to enter the foreign marketplace – even with a better product.
  – Strong partnerships already exit between foreign OLED makers and their equipment suppliers.
  – Decisions favor the local suppliers – often due to gov’t support – not a level playing field.
  – Applied Materials and Veeco appear to have stepped back.
Future OLED Lighting - Will it be Solution Deposition?

• Solution deposition has a good cost structure
  – Machine throughput can be very large
• The depreciation costs are still high.
  – Konica Minolta - $100M for 1M panels/month capacity (assume post yield and post substrate usage)
  – Product is 150x60mm (smaller size 50x30mm)
  – Deprecation is $185/m2 (5 year depreciation at capacity)
  – Alternative approaches with lower capital cost must be developed.
• Solution based formulations currently have lower performance
  – The number of layers and degree of control is less than with vacuum thermal evaporation
• The US has many companies with solution/solvent deposition capabilities
  – This technology will likely be the low-cost route.
  – GE appears to have stepped back, Kateeva is targeting displays.
Increasing OLED Lighting Manufacturing in the US – 
How to make progress in deposition

- Desirable attributes:
  - **Small and fast equipment**
  - Lower initial cost with low capacity
  - Ability to expand capacity with reuse of capital

- Focus on speeding up processing to get capacity
  - We must understand the speed barriers and how we can overcome these.

- Expandable with incremental investment:
  - Small initial size – multi function
  - Expansion by duplication and debottlenecking
  - Capacity increase by substrate speed increase

- Lighting does not need large-area substrates – unlike OLED displays
Why the US can Win at the Deposition Equipment Business

- There are interactions between:
  - Formulation and equipment
  - Process conditions and device performance
- The US can develop this equipment – we have this knowhow.
- We need partnerships between OLED makers and equipment makers and government.
  - Look at the German and Korean models
- The investment will be worth the risk.
- In 10 years, WW OLED lighting volumes may be 10M m²/year with 20% CAGR (~5% of lighting market)
  - This could be 30-50 fast machines.
  - With 8 new machines/year
- The US should aim to dominate this manufacturing industry.
  - Other countries have the same target.
Summary – Jobs of the Future in OLED Lighting

• Focus on improving deposition technology:
  – Small, fast, expandable, cost effective, flexible, profitable
  – There is a long way to go. Current equipment models for success don’t work.
  – Develop both VTE and solution deposition systems.

• Target partnerships to develop improved OLED deposition technology and use it in panel manufacturing
  – Primary Partnerships - OLED makers and equipment makers to expand panel manufacturing
  – Enable small profitable panel mfg operations through improved process and equipment by leveraging an understanding of the interactions between product and process

• Require all projects to achieve DOE milestones to enter general lighting

• We can grow the OLED lighting manufacturing industry here in the US.

• “OLED Lighting - If we aren’t nimble, the future is dim”
  – Dave Gotthold, Veeco, DOE Mfg Workshop, Boston, Mar 2011