Challenges for OLED Deposition by Vacuum Thermal Evaporation

D. W. Gotthold, M. O’Steen, W. Luhman, S. Priddy, C. Counts, C. Roth
June 7, 2011
Outline

- Introduction to Veeco
- Methods of OLED Deposition
- Cost Challenges to OLED Technology
- Veeco’s Source Technology
- Summary & Discussion
Veeco Overview

- **Products and markets**
  - LED & Solar BU
    - MOCVD, MBE, CIGS systems
    - OLED, CIGS sources
  - Data Storage BU
    - IBE, IBD, DLC, PVD

- **Key facts:**
  - Founded in 1990
  - Over 300 patents
  - Over 1000 employees worldwide
  - Over 25 global locations
  - 2010 Revenue >$900M
Veeco St Paul: >20 Years of Thermal Deposition Source Innovation

- OLED
- Solar
- MBE

1986
- Material Specific Sources

1992
- MBE Systems
- Patented As/P VC

1994
- Patented SUMO®

1996
- UNI-Bulb® RF Plasma

1997
- MBE Systems
- Patented As/P VC

1999
- Corrosive Series VC
- R&D Cu Sources

2000
- 1500cc OLED
- 15L Valved Se
- 725cc Production Cu
- Mark V As VC
- Mark V Corrosive Series VC

2001
- Private MBE company acquired by Veeco
- 10,000g Ga Source
- 15L As VC

2005
- Monte Carlo Uniformity Modeling

2007
- Mark V Valved Hg
- PV-1500cc SUMO

2009
- Mark V Valved Hg
- PV-1500cc SUMO

2010
- Mark V Valved Hg
- PV-1500cc SUMO

Reloading OLED
Linear Metal Al
PV-15L Valved Se
PV-155cc SUMO-II
PV-Linear
Mark V P VC

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## OLED Deposition Technologies

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<th>Disadvantages</th>
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<td>Device Performance &amp; Lifetime</td>
<td>Materials Utilization</td>
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<td>Complex layer stacks</td>
<td>Material Degradation</td>
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<td>Substrate Heating</td>
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<td>Solution Processing</td>
<td>Processing Cost</td>
<td>Device Performance</td>
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<td>Solvent Management</td>
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<td>Vapor Phase Deposition</td>
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*There are a variety of variations and hybrids of these basic technologies*
Why VTE

Advantages

- Best demonstrated efficiencies
- Best demonstrated lifetimes
- Compatible with almost all materials
  - Not necessarily scalable
- Accurate film control for co-depositions and multilayered structure

Challenges

- Materials Utilization
  - Tradeoff with uniformity
- Material Degradation
  - Thermal budget
- Substrate Heating
- Rate control
  - Especially for long term operation
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### OLED Markets and Process Requirements

#### Market Requirements

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<thead>
<tr>
<th>Scale</th>
<th>Market Size ($)</th>
<th>Area (m²)</th>
<th>Cost ($/m²)</th>
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<tbody>
<tr>
<td>R&amp;D</td>
<td>Millions</td>
<td>0.04</td>
<td>10k</td>
</tr>
<tr>
<td>Mobile Display</td>
<td>100s Millions</td>
<td>0.7</td>
<td>5.3k</td>
</tr>
<tr>
<td>Large Display</td>
<td>Billions</td>
<td>2.0</td>
<td>700</td>
</tr>
<tr>
<td>SSL</td>
<td>Billions</td>
<td>0.7+</td>
<td>&lt;100</td>
</tr>
</tbody>
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#### Implication for OLED Process

<table>
<thead>
<tr>
<th>TACT (min)</th>
<th>Dynamic Rate (Åm/s)</th>
<th>Utilization (%)</th>
<th>Uptime</th>
</tr>
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<tbody>
<tr>
<td>10</td>
<td>0.33</td>
<td>&lt;5</td>
<td>1 day</td>
</tr>
<tr>
<td>3</td>
<td>5.2</td>
<td>20</td>
<td>3-5 days</td>
</tr>
<tr>
<td>2</td>
<td>12.5</td>
<td>50</td>
<td>5-7 days</td>
</tr>
<tr>
<td>0.5</td>
<td>40</td>
<td>&gt;70</td>
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Technology Cost Requirements

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<tr>
<td>R&amp;D</td>
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<tr>
<td>Mobile Display</td>
<td>6,000</td>
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<tr>
<td>Large Display</td>
<td>2,000</td>
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<tr>
<td>Solid State Lighting</td>
<td>1,000</td>
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Relative Cost and Area of Systems

Cost/m$^2$ vs. m$^2$/year

- R&D Display
- 2G Display
- 4.5G inline
- 5.5G Display

Cost range: $10 - $10,000
Area range: 10 - 10,000,000
### Bigger Not Necessarily Better

<table>
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<tr>
<th></th>
<th>G5.5</th>
<th>2’x4’</th>
</tr>
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<tr>
<td><strong>TACT Time</strong></td>
<td>1 min</td>
<td>1 min</td>
</tr>
<tr>
<td><strong>Uptime</strong></td>
<td>85%</td>
<td>80%</td>
</tr>
<tr>
<td><strong>Yield</strong></td>
<td>95%</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Yielded Panel Area Per Year</strong></td>
<td>925,000 m²</td>
<td>250,000 m²</td>
</tr>
<tr>
<td><strong>System ASP</strong></td>
<td>$150M</td>
<td>$20M</td>
</tr>
<tr>
<td><strong>5 Yr Depreciation Cost ($/m²)</strong></td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td><strong>OLED Chemical Cost ($/m²)</strong></td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td><strong>Glass, ITO, Cathode, Encap</strong></td>
<td>41</td>
<td>30</td>
</tr>
<tr>
<td><strong>Operating Cost + Labor ($/m²)</strong></td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total Cost ($/m²)</strong></td>
<td>90</td>
<td>76</td>
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Can achieve <$10/6” panel but each tool will produce 8M panels/year
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# Veeco Organic Source Product Line

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<tr>
<th>Source</th>
<th>Market</th>
<th>Features</th>
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<tbody>
<tr>
<td>Point Source</td>
<td>R&amp;D</td>
<td>- Low Cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Simple maintenance and material replacement</td>
</tr>
<tr>
<td>Bulk Valved Source</td>
<td>R&amp;D, Mobile Display</td>
<td>- Valve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Nozzle Distribution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Scanning &amp; Fixed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Flexible Geometry</td>
</tr>
<tr>
<td>Re-loading Source</td>
<td>Mobile Display, TV, TV</td>
<td>- Valve</td>
</tr>
<tr>
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<td></td>
<td>- Nozzle Distribution</td>
</tr>
<tr>
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<td>- Re-loading for high uptime and minimized degradation</td>
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OLED Bulk Valved Source

- Linear nozzle
- Flux monitor port
- Cooled nozzle cover
- Removable material crucible
- Valve actuator
- Cable connections
Organic Reloading Source

- Separate vaporization and distribution zones for easy scaling
  - Enables operation over a wide flux range (dopant to host)
- Bulkhead mounted for high speed in-line systems
- Closed loop valved flux control for rapid rate changes and precision control
- Low residence time of material in vaporizer to minimize degradation
- Source can be reloaded during normal operation
  - Enables extended operating times between system maintenance
Dosing Sequence

Storage Hopper

Doser

Vaporizer

Valve

To Nozzle
Key Technologies for OLED Source

- **Valve** – enables rapid flux control
  - Compensate for evaporation rate variation
  - Idle source between substrates

- **Flux gauge** – provides feedback for valve
  - Necessary for rapid flux control
  - Requires much longer lifetime than conventional gauge technology

- **Control algorithms** - integrated control of flux
  - Control software that can keep source in optimum operating range
  - Enables reloading process, which causes large changes in rate

- **Nozzle** – large area distribution
  - Achieve high utilization and uniformity on large substrates
Key Technologies: Valve

Valve Position Control of Rate

- Large Dynamic Range
- Highly Reproducible

Valve Opening (%)

Deposition Rate Vs. Time

- 100x rate control
- < 2s response rate

Valve reduces wasted source material.

- Allows rapid flux control to improve yield and CoO
Key Technologies: Flux Gauge

- Internally-developed *in situ* flux gauge integrates directly to sources
- Large linear range allows precise flux measurements
- Allows closed loop control of valve
- No lifetime error/drift issues as seen in QCMs
- Greatly improves flux stability
- Improves panel yield and CoO
Key Technologies: Flux Regulation

- Deposition Rate regulated to $\leq \pm 1\%$ for >30 hours
- Crucible temperature deliberately changed by 18ºC during test.
Key Technologies: Flux Regulation

12 hrs flux control with material reloading in 3 hr intervals.

- In Situ Gauge accurately controls over entire test.
- QCM readings develop errors and issues as material accumulates.
Key Technologies: Nozzle (Uniformity)

4G (0.73m) System
- Uniformity* = ±0.72 to ±1.87% depending on rate
- 1 Valved Source with linear nozzle
- 37% material utilization
- Source-to-substrate distance = 300mm
- Material; multiple

* Measured by ellipsometry

Gen III, 730 mm nozzle

±.72% @ 2.7 Åm/s

±1.80% @ 15 Åm/s

±1.87% @ 12 Åm/s
Key Technologies: Nozzle (Design)

- Strong tradeoff between material utilization and OLED/Glass heating
- Careful consideration must be given to impacts on nozzle conductance and uniformity.
Key Technologies: Nozzle (Heating)

![Diagram showing bonded thermocouples and static glass with source nozzle]

Average temperature increase is less than 10ºC even for static glass.
Requirements for Roadmap

- Reloading source has adequate dynamic rates for the MD and LD markets. Improvements are needed for SSL.
- Reloading source needs utilization improvements for LD and SSL markets.
Requirements for Roadmap – Current Results

- Reloading source has adequate dynamic rates for display markets. Improvements are needed for SSL.
- Utilization can be achieved, but requires system design optimization.
Conclusions

- Manufacturing process for current OLED technologies is feasible, however targeted equipment required
  - Need a target device structure
  - Market entry size challenging

- Need R&D that is factoring in manufacturing needs
  - Many aspects of device design still based on hero results
  - Materials only have to last hours for R&D testing
  - Lots of “if we simply add _____, this will be manufacturable”

- Veeco has developed thermal evaporation source technologies capable of large area displays and SSL
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