Unlocking the OLED display markets

March 2018
OLED technology reaches the volume market and is one of the fastest growing segments in the technology sector

$50 bn OLED display revenue by 2021 expected

- 23% CAGR in OLED panel shipments until 2021
- 25% revenue growth p.a. expected
- Adoption of OLED displays is now spreading from Samsung to Apple and Chinese smartphone makers
- Chinese government has announced strategic investment program

Novel form factors and display performance drive OLED adoption, also beyond 2021

- Foldable and flexible displays the next key driver in displays with potential 2-3x in market size post 2021
  - Better energy efficiency, brighter colors and higher resolution offered by OLED technology
  - TV and lighting following the mobile market later on

Source: APEVA, IHS, DSCC
Further spreading of OLED displays in the future expected – step changes in display performance and cost are required.

### Displays everywhere

- Ubiquity of information, IoT and smart home drive number of OLED displays and display size
- Significant improvement of OLED display production cost needed to reach tipping points for additional markets

### Novel form factors

- New applications and functionalities enabled by flexibility and transparency of OLED displays
- Enhanced display lifetime, energy efficiency and color brightness needed to satisfy application needs

**Next step in OLED display technology needed to address future’s cost/performance needs**

Source: APEVA
Today’s established VTE OLED technology faces challenges

Schematic of today’s VTE technology

- Evaporation of material from heated crucible (source)
- Spreading of material into all directions
- Larger distance between source and substrate

Challenges of today’s VTE technology

Limitations in display performance improvement
- Challenges in mixing materials
- High effort for controlling material flow
- Mainly simple OLED stacks

Limitations in substrate scaling
- High effort to produce desired uniformity
- Increasing complexity with substrate scaling

High production cost
- Lower efficiency in usage of expensive organic materials (up to several hundred USD per gram)
- Downtime from frequent cleaning

Source: APEVA
APEVA has developed a disruptive OLED display technology – Organic Vapor Phase Deposition (OVPD)

**Schematic of OVPD technology**

**Principle of OVPD technology**

Material flow is generated in patented sources:
- Material in powder form is brought into the gas phase
- No damage to organic components from low temperature processing
- High uniformity and precision in dosing possible

Mixing of materials and spreading across the entire substrate

Deposition occurs by condensation on the cooler substrate

**Key modules are IP protected**

Source: APEVA
OVPD technology value proposition: Enabler of improved OLED display performance

**VTE technology**

- Separate deposition chamber needed for each material
- Mixing of materials limited

**OVPD technology**

- Multiple materials can be mixed and well controlled in deposition system
- Improved display properties possible, e.g., better display lifetime, color and brightness

**OVPD technology opens the way to OLED display performance improvements**

Source: APEVA
OVPD technology value proposition:
Scalability to larger substrate sizes while maintaining process performance

VTE technology

- Uniformity for large substrates require increasing distance (d) from source to substrate
- Complexity of system increases with scale-up

OVPD technology

- APEVA’s sources can be scaled up to provide throughput needed for larger substrates
- Scaling in size with limited effort while maintaining uniformity across larger substrates

OVPD can be scaled to larger substrates while today’s VTE faces challenges

1 Gen 6H approx. 1,5 x 0,9 m ; Gen 6 approx. 1,5 x 1,8m ;
Source: APEVA
Rival alternative production technology OLED printing has several disadvantages compared to APEVA's OVPD technology.

### OVPD (APEVA)

- **Resolution and applications**
  - Highest resolution
  - Patterning with mask technology possible → Resolution driven applications, e.g., mobile

- **Materials**
  - Existing materials in powder form from VTE can be used w/o changes

- **Production size/energy cost**
  - Small footprint for reactor
  - No dedicated drying

### Organic OLED printing

- **Resolution and applications**
  - Limited resolution
  - Larger Displays eg TV, Outside panels → Lower resolution applications

- **Materials**
  - New materials in liquid form

- **Production size/energy cost**
  - Larger area in factory needed for drying equipment

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**OVPD and OLED Inkjet printing to date address different segments of the OLED market**

*Source: APEVA; Printing process courtesy of Kateeva*
APEVA’s disruptive OVPD display technology comes with a strong value proposition for the OLED displays of today and of tomorrow.

1. **Enabler of improved OLED display performance**
   - Deposition of multiple materials in a single process chamber
   - Precise flow rate control and high process stability
   - Supporting display lifetime improvement

2. **Scalability to larger substrate sizes**
   - Deposition uniformity is maintained upon scaling up substrates
   - Higher material flow rates needed for large substrates possible

3. **Significant Total Cost of Ownership (TCO) reduction in deposition of organic stack**
   - Reduced variable cost due to high efficiency in usage of expensive OLED materials
   - Smaller production footprint possible

4. **Compatibility to existing OLED materials and suppliers**
   - Usage of existing organic materials that are in mass production today

Source: APEVA
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