High Yield Equipment enables profitable OLED manufacturing

XueNa Zhang, PhD
Applied Materials, Display and Flexible Technology Business
Our Story

FOUNDED in 1967

Applied Materials began in a small industrial unit in Mountain View, California
OUR VISION
Our innovations make possible the technology shaping the future

OUR MISSION
To lead the world with materials engineering solutions that enable customers to transform possibilities into reality
Applied Materials Overview

Business Segments

- Semiconductor System
- Applied Global Service
- Display and Adjacent Markets

Key Statistics

- **$14.5B** $1.8B
  - FY 2017 Revenue
  - FY 2017 RD&E
- 1967
- CA, USA
- 90 in 17
- ~18,400
- >11,900

Data as of fiscal year end, October 29, 2017
Applied Display and Flexible Technology Group (DFT/AKT)

Applied Materials DFT Group
Applied is the world’s leading display equipment manufacturer, helping to make thinner, lighter, larger, flexible and higher resolution displays.

- Founded: 1991
- Headquarters: CA, USA
- Locations: 25 in 7 countries
- R&D: USA, Germany, Taiwan, India
- Manufacturing: Germany, Taiwan

FY17 Net Sales: $14.5B
FY17 Services: $1.9B

Display & Adjacent Markets: 100%
Inflection Waves Drive Display Industry

Future Displays
- OLED TV
- Foldable display
- Natural 3-D display
- uLED
- and more

Mobile OLED
- Curved form factors

LCD
- Scaling Resolution
- $7~$8B Capex

1998 2015 2020

$7~$8B Capex

2X Capex increase

Gen 10.5

$17B~$18B Capex

Capex increase

Display equipment spending based on Applied estimates
TV Size Growth Fueling Gen 10+ Fab Investment

**TV Panel Unit Demand**

- Units millions
- 2017: [Bar Graph]
- 2021: [Bar Graph]

**TV Panel Size Mix (by Area)**

- 2017: 88% (Green) for <60"; 12% (Yellow) for >60"
- 2021: 74% (Green) for <60"; 26% (Yellow) for >60"

**TV Panel Area Demand**

- M² millions
- 2017: [Bar Graph]
- 2021: [Bar Graph]

(Data Source: DSCC, AMAT Internal)

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**Gen 10+ fab investment**

13 Gen 10+ fabs* expected 2017-2021

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**Size Growth** is Most Important Driver for TV Area Demand

Large-size TV demand & area growth

*60K/m equivalent

Based on Applied estimates
Advanced TV Technologies Today - WOLED

- OLED TV growing due to superior performance vs. LCD
- But, adoption of current WOLED technology limited by cost structure

New OLED TV technology is needed to overcome WOLED cost challenge.
### Future wave: RGB OLED TV

#### OLED TV Technology Comparison

<table>
<thead>
<tr>
<th>Material/Quality /Lifetime</th>
<th>WOLED</th>
<th>RGB OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials/Quality/Lifetime</strong></td>
<td>VTE quality but some loss with color filter</td>
<td>Ink Jet (RGB) Good quality/lifetime</td>
</tr>
<tr>
<td><strong>Equipment/process maturity</strong></td>
<td>Production proven but yield &lt; LCD</td>
<td>Immature equipment</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Complex device w/20 layers</td>
<td>Path to parity with LCD</td>
</tr>
</tbody>
</table>

#### Cost Comparison in 2021 (normalized)

(Data Source: DSCC)

<table>
<thead>
<tr>
<th></th>
<th>LCD</th>
<th>WOLED</th>
<th>RGB OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>w/ Depreciation</strong></td>
<td>100%</td>
<td>175%</td>
<td>130%</td>
</tr>
<tr>
<td><strong>w/o Depreciation</strong></td>
<td>70%</td>
<td>115%</td>
<td>80%</td>
</tr>
</tbody>
</table>

**RGB OLED TV** can achieve LCD cost parity and mass adoption with **materials improvement** (ink jet) and/or **equipment innovation** (evaporation).
Why OLED for Mobile Phones?

Image quality
- contrast ratio
- color gamut
- refresh rate
- viewing angle

Form factor
- thin
- light
- unbreakable
- curved

Roadmap
- necessary step toward foldable

Cost & Differentiation
- Rigid, cost parity with LCD
- Flexible massive differentiation
Mobile OLED Challenges - Backplane

**Device performance & Yield requirements**

- **PARTICLES**
  >10x density reduction

- **UNIFORMITY**
  3x improvement

**Advanced Materials and Device Design**
LTPS, LTPO, High-K

<table>
<thead>
<tr>
<th>LCD</th>
<th>OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 TFTs</td>
<td>12 TFTs</td>
</tr>
<tr>
<td>150ppi</td>
<td>300ppi</td>
</tr>
<tr>
<td>48 TFTs</td>
<td>600ppi</td>
</tr>
</tbody>
</table>

Repairable defect
Killer defect

High Resolution
Mobile OLED Current Challenges - Frontplane

“Factory within a Factory”
One mega-system with evaporation and encapsulation chambers

- >100m Length
- >30 Process chambers
- >10 Layers (combination of deposited and patterned)

Innovations in
- Glass handling
- Mask technology & cleaning
- Temperature and process flow control
- Scalability
- Encapsulation
- Yield management

Required for
Yield and cost improvement
Future Wave: Foldable OLED Display

**LCD**
- Cover glass
- Touch panel
- Polarizer
- Color filter
- Liquid crystal
- Glass TFT backplane

**Flexible OLED**
- Cover glass
- Polarizer
- In cell / on cell touch
- TFE *
- OLED emitter
- Plastic TFT

**Foldable OLED**
- Hard coat
- Wide grid polarizer
- In cell / on cell touch
- TFE *
- OLED emitter
- Plastic TFT

Enabling “Components-to-Process megatrend”
Solving foldable Display technical challenges
Requires Materials Engineering Innovation
Creates new opportunities for process/equipment providers
Capex Trend

- LCD: $7~$8B Capex
- Mobile OLED: 2X Capex increase
- Future Displays: $17B~$18B Capex

Display equipment spending based on Applied estimates
Complexity Drives Increased Capital Intensity

**TV Trend**

- G8.x → G10.5
- a-Si → Oxide → OLED

**Expected Capex/fab**

- OLED: ~2X
- 8K: 1X
- 2K/4K: 1X

**MOBILE Trend**

- Complex Process with OLED

**Expected Capex/fab**

- RGB OLED: ~5X
- >300ppi: 1X
- <300ppi: 1X

Based on Applied estimates

*Generation 8.5 60k/month capacity  **Generation 6 30k/month capacity
Complexity Drives Increased Equipment Capex Intensity

Display Equipment Capex/year

**Old normal**

~$7B~8B

2013-2015

**“New normal”**

~$18B

2017-2020

**Future**

Beyond 2021

Display Capex*

“New Normal” >2x “Old Normal”

**Future inflections** with increasing process complexity provide further growth potential in Capex and SAM**

* Display Equipment spending
** Served Available Market

Display equipment spending based on Applied estimates
Applied’s Display and Flexible Technology Products

CORE PRODUCT PORTFOLIO

CVD

PVD

NEW PRODUCTS
(launched in 2016)

Thin Film Encapsulation

In-Line SEM Review

E-Beam Tester

Roll-to-Roll E-Beam Evaporation PVD CVD
E-Beam Review (EBR): Combined Semi & Display

- **Mature Platform**: 10 years EBT array test production
- **G2.5~G11**
- **5-10nm SEM resolution**
- **EDX integrated**
- **200eV ~ 15KeV Beam Energy**

**EBR inline-SEM uses Zero Damage LE Technology**

- **2015**: 1st Evaluation inline SEM
- **2018**: Full Automation, Products in Korea, Japan, China, Taiwan, USA
Enflexor Gen6H: TFE Solutions for High Resolution Flexible OLED

**Barrier Performance**
- Excellent barrier performance
- Superior particle control
- Matching with inkjet buffer

**Mask Depo**
- Mask Technology and auto Mask exchange
- Eliminate etching process for contact

**Buffer Technology**
- HMDSO film property control
- Particle coverage technology
- Path to foldable and rollable
- Enable rigid / TV OLED panel

100% Market Share at OLED Panel Leading Company
R2R Vacuum Processing Equipment

- **Front Surface Contact Free**
  - Web support from back eliminates contact-based defects

- **Winding Versatility**
  - Low-friction roller bearings and optimized load cell positions for precise web tension
  - Dual-bearing roller architecture to ensure roller-to-roller parallelism
  - Supports a broad variety of substrate types and thicknesses
  - **Usable coating width 1.5 m**
Adoption of new display technologies, such as flexible OLED mobile and RGB OLED TV creates many opportunities and challenges.

We continue to develop equipment which addresses these challenges.