Advanced Display Manufacturing Technology

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Safe Harbor

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Applied Materials is the world’s leading display and flexible electronics equipment manufacturer with 25 years of materials engineering experience on large area rigid and flexible substrates.
Applied’s Display and Flexible Technology Products

CORE PRODUCT PORTFOLIO

CVD

PVD

NEW PRODUCTS
(launched in 2016)

Thin Film Encapsulation

E-Beam Tester

Roll-to-Roll E-Beam Evaporation PVD CVD

In-Line SEM Review
Displays are the Window to the Information Universe
New Display Era on the Horizon

**LCD Era**
CRT Replacement

**TODAY**

**OLED Era**

**Advanced 3-D Era**

**SCALING**

**RESOLUTION**

**FORM FACTOR / VISUAL PERFORMANCE**

2-D → “NATURAL” 3-D
# Display Technology Roadmap

## Resolution

<table>
<thead>
<tr>
<th></th>
<th>TV</th>
<th>PHONE</th>
<th>VR/AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>TODAY</td>
<td>HD</td>
<td>&gt;326ppi</td>
<td>400ppi</td>
</tr>
<tr>
<td>TRANSISTOR</td>
<td>Si</td>
<td>LCD</td>
<td>OLED</td>
</tr>
<tr>
<td>4K</td>
<td>&gt;600ppi</td>
<td>&gt;1000ppi</td>
<td></td>
</tr>
<tr>
<td>8K</td>
<td>&gt;700ppi</td>
<td>&gt;2500ppi</td>
<td></td>
</tr>
</tbody>
</table>

## Form Factor / Performance

<table>
<thead>
<tr>
<th></th>
<th>FPD</th>
<th>Curved</th>
<th>Rollable</th>
<th>Foldable</th>
</tr>
</thead>
<tbody>
<tr>
<td>TODAY</td>
<td>LCD</td>
<td>OR</td>
<td>MOx</td>
<td>Flexible</td>
</tr>
<tr>
<td>TRANSISTOR</td>
<td>a-Si</td>
<td>OR</td>
<td>MOx</td>
<td>Flexible</td>
</tr>
</tbody>
</table>

## Size

<table>
<thead>
<tr>
<th></th>
<th>TV</th>
<th>PHONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TODAY</td>
<td>40”</td>
<td>4.5”</td>
</tr>
<tr>
<td>TRANSISTOR</td>
<td>2-D</td>
<td>3-D</td>
</tr>
<tr>
<td>35”</td>
<td>5.5”</td>
<td>&gt;5.5”</td>
</tr>
</tbody>
</table>

- **FPD**: Flat Panel Display
- **LTPS**: Low Temperature Poly-Silicon
- **OLED**: Organic Light Emitting Diode
- **MOx**: Metal Oxide
## Display “Mega-Trend”: Components to Process

<table>
<thead>
<tr>
<th>Component</th>
<th>IN-CELL / ON-CELL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover glass</td>
<td>Thin film encapsulation / hard coat</td>
</tr>
<tr>
<td>Touch panel</td>
<td>In-cell / on-cell touch</td>
</tr>
<tr>
<td>Polarizer</td>
<td>Wire-grid polarizer</td>
</tr>
<tr>
<td>Color filter</td>
<td>RGB OLED emitter</td>
</tr>
<tr>
<td>Liquid crystal</td>
<td>OLED emitter</td>
</tr>
<tr>
<td>TFT backplane</td>
<td>Wire-grid polarizer</td>
</tr>
<tr>
<td>Polarizer</td>
<td></td>
</tr>
<tr>
<td>Backlight</td>
<td>OLED emitter</td>
</tr>
</tbody>
</table>

Needs Materials Engineering Innovation
Key Technology Challenges for Flexible Displays

**DISPLAY**
- TSP
- Panel
- FPCB, IC

**STRUCTURE**
- Cover Window
- Touch Screen
- Encapsulation
- Cathode
- Emitting Layer
- Anode
- Transistor (TFT)
- Substrate

**CHALLENGES**
- Flexible Window
- Flexible Touch Sensor
- Flexible Encapsulation
- Flexible OLED Emitter
- Flexible TFT
Increasing Complexity in Semi…and Display

Display can Leverage 30 Years of Semi Technology, Methodology and Knowhow
Backplane Yield Challenge Example: Particles

- OLED TFT active area larger than LCD increasing chance of “killer particle”
- Increasing resolution increases # transistors/area → requires smaller TFT → increases # of killer particles
You can’t FIX What you can’t SEE
Semiconductor Yield Management: Enabled by Inline SEM

Display TODAY

10µm 1µm 0.18µm 0.13µm 65nm 32nm 22nm


CD-SEM and SEM review introduction in 80s

SEMI TODAY 90% processes are SEMed!

SEMI

Defect Inspection

AOI (Sub 1µm)

Defect Review

Inline SEM (with EDX)

Yield management (connect the dots → root cause)

DISPLAY

90% processes are SEMed!
New Inspection Methodology for Advanced Displays

Old way (Lab SEM)

- Destructive Inspection
- Long Cycle Time
- Low Sampling Rate

New way (Inline SEM)

- Non-destructive Inspection
- High Throughput
- High Sampling Rate
Inline SEM Brings Semi Methodologies to Display

<table>
<thead>
<tr>
<th>Inspection &amp; Review (defects)</th>
<th>Metrology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Process Inspection (API)</td>
<td>Auto-CD (ACD)</td>
</tr>
<tr>
<td>Auto Defect Review (ADR)</td>
<td></td>
</tr>
</tbody>
</table>

**Process & Defects**
- ITO residue

**Composition Analysis**
- EDX & BSE

**LTPS Grain Analysis**
- ELA in-line Monitoring
  - No Secco Etch

**CD Measurements**

Accelerates yield by “connecting the dots”
Inline SEM + yield management software → fast ramp & high yield
EBR Time Machine

[ w/o EBR ]
- Process time $\leq$ 60sec
- Inspection $\leq$ 60 sec
- Measurement $\leq$ several mins
- Analysis $\geq$ several hours or days

[ w/ EBR ]
- Process time $\leq$ 60sec
- Inspection $\leq$ 60 sec
- Measurement $\leq$ several mins
- Analysis $\sim$ several mins
## Thin Film Encapsulation (TFE) Requirements

### PROCESS

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depo temperature</td>
<td>&lt;100°C</td>
</tr>
<tr>
<td>Mask depo</td>
<td>Mask deposition</td>
</tr>
<tr>
<td>Water vapor transmission rate (WVTR)</td>
<td>&lt;1E-6g/m²-day</td>
</tr>
<tr>
<td>High deposition rate</td>
<td>&gt;2,500Å/min</td>
</tr>
<tr>
<td>Low stress</td>
<td>~ 0</td>
</tr>
<tr>
<td>High visible light transmittance</td>
<td>&gt;90% at wavelength ≥400nm</td>
</tr>
<tr>
<td>Good adhesion</td>
<td>No film peeling</td>
</tr>
<tr>
<td>High flexibility</td>
<td>Mechanical duration</td>
</tr>
<tr>
<td>Conformal particle coverage</td>
<td>No voids or diffusion channels</td>
</tr>
</tbody>
</table>

### Barrier Performance
- Stress Control
- Optical Transmittance

### Mask Depo

### Buffer Technology

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**Flexible OLED Device**

- **OLED & Thin Film Encapsulation**
  - Barrier Layer
  - Buffer Layer

- **PI Barrier**
  - PI (Poly-imide)

- **TFT**

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**External use**
**Enflexor Gen6H** TFE Solutions for High Resolution Flexible OLED

**SUBSTRATE SIZE**
925 x 1,500mm²

**SYSTEM ARCHITECTURE**
Single substrate operation system at cluster tool
- Max 5 TFE process chambers
- Mask chamber
- Pas chamber or DSSL (Dual Single Slot Load lock)
- Transfer chamber
- Dual arm vacuum robot

**KEY ADVANTAGES**
Superior WVTR & uniformity
Particle control
High system reliability
“One Cluster Solution”

Complete All TFE process in one cluster

- Vacuum Connection to EV tool
- Flexible sequence control by MCC software
- High reliability mainframe and vacuum robot
- Mask deposition with auto mask exchange and mask stocker

TFE Technology for OLED mass production new concept

All process under vacuum
Displays are the window to the “information universe” and better displays are constantly in demand.

Many display technology inflections need materials engineering innovation.

Display industry can leverage semiconductor methodologies to enable increasingly complex displays.