Recent Development of Flexible Display in Taiwan

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Outline

1) Opportunities and Recent Development in Flexible AMOLED
2) Technology Challenges with Flexible Displays
3) Foldable Display Development in ITRI
4) Conclusions
Anytime and Anywhere with Display
Opportunity for Mobile Applications

Foldable AMOLED

Rollable AMOLED

Tablet
Smart Phone
Opportunity for Wearable Applications

Casio G-Shock STB-1000 2014
Samsung SPH-WP10 1999
Seiko Pulsar 1978-1980

Curved AMOLED

Samsung Galaxy Gear fit (2014)

Galaxy Gear S (2014/9)
G Watch R (P-OLED) (2014/9)
Apple Watch (2015/3)

Wearable Display
Recent Development of Flexible AMOLED

**Curve**
- LG
- Samsung

**Foldable**
- LG
- Samsung

**Rollable**
- LG
## Displays on Flexible Substrate

<table>
<thead>
<tr>
<th>AMLCD</th>
<th>AMEPD</th>
<th>AMOLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Liquid Crystal Display)</td>
<td>(Electrophoretic Display)</td>
<td>(Organic Light Emitting Display)</td>
</tr>
<tr>
<td><img src="amlcd_image" alt="AMLCD Image" /></td>
<td><img src="amepd_image" alt="AMEPD Image" /></td>
<td><img src="amoled_image" alt="AMOLED Image" /></td>
</tr>
<tr>
<td>ITRI, 2007</td>
<td>ITRI, 2009</td>
<td>ITRI, 2009</td>
</tr>
</tbody>
</table>
Challenges for Flexible AMOLED

- Durability of touch panel
- Flexibility of touch panel
- On-cell touch panel

- Barrier for gas and water
- Flexibility of OLED
- Thinner Polarizer

- TFT process on plastic
- TFT’s performance on plastic
- Flexibility of TFT

- Substrate material
- Substrate handling
- Barrier for gas and water
## Substrate Handling Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>Ultra thin glass attached on carrier</th>
<th>Plastic substrate laminated on carrier</th>
<th>Plastic substrate coated on carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>UTG</td>
<td>Plastic</td>
<td>PI</td>
</tr>
<tr>
<td>Production</td>
<td>NA</td>
<td>NA</td>
<td>Yes</td>
</tr>
<tr>
<td>Temp. for TFT</td>
<td>~250°C</td>
<td>~250°C</td>
<td>~450°C</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
Development Topics
- Plastic Substrate Coated on Carrier

**Substrate Property for TFT Backplane**
- Temp. stability: > 500°C
- De-bonding force: < 3g/cm
- CTE: < 10 ppm/°C @ (250~450°C)
- Water absorption: < 0.1%

**Substrate Property for Front Plate**
- Temp. stability: ~300°C
- Transparency: > 90%
- b*: < 1

**Barrier for Gas and Water**
- Flexibility: > 100k times @ r < 3mm
- WVTR: < 5x10^{-6}g/cm²·day
- Transparency: > 95%
De-bonding of AMOLED on ITRI’s FlexUP™

Light on **during** de-bonding process

Light on **before** de-bonding

Light on **after** de-bonding
## Flexible TFT Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>a-IGZO</th>
<th>CAAC-IGZO</th>
<th>LTPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>Yes (for glass AMOLED TV &amp; S/M size AMLCD)</td>
<td>Yes (for glass S/M size AMLCD)</td>
<td>Yes (for glass &amp; plastic S/M size AMOLED)</td>
</tr>
<tr>
<td>Process Temp.(°C)</td>
<td>200 ~ 350</td>
<td>&lt;500</td>
<td>400 ~ 450</td>
</tr>
<tr>
<td>Mobility (cm²/Vs)</td>
<td>5 ~ 25</td>
<td>5 ~ 10</td>
<td>&gt; 50</td>
</tr>
<tr>
<td>Electrical Stability</td>
<td>Acceptable</td>
<td>Good</td>
<td>Excellent</td>
</tr>
</tbody>
</table>
Development Topics - Flexible LTPS TFT

**Flexibility**
- Maintain device property after inward and outward bending
- $V_{th}$ shift < 0.5V after bending
- Bending radius < 3mm

**Process Integration**
- Yield of ELA & Ion Implantation
- Mobility > 100cm$^2$/Vs
- Device uniformity: $V_{th}$ 3σ < 0.1V

**Circuit Design**
- Robust circuit design for bending
- Compensation for degradation from mechanical stress
LTPS-TFT on FlexUP

Id-Vg before/after de-bonding and after folding
Folding Test: 100k times @ r=5mm

NBTS of LTPS-TFT after folding test
NBTS: Vg=-30V, Vd=0V, Temp.=70°C

Flexible LTPS-TFT
- Before de-bonding
- After de-bonding
- After folding

W/L=6/12 um

Initial
100s
500s
1000s
5000s

ΔVth ~ 0.47V
### Flexible OLED Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>WOLED + CF</th>
<th>FMM RGB OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure</strong></td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td><strong>Production</strong></td>
<td>Yes (for glass AMOLED TV)</td>
<td>Yes (for glass and plastic S/M size AMOLED)</td>
</tr>
</tbody>
</table>
| **Resolution** | 40 ppi (55” TV/LG)  
326 ppi (3.4” prototype/SEL) | 441 ppi (5”/Pentile/Samsung) |
| **NTSC (%) (Prototype)** | >100 (micro cavity by ITO) | >100 (micro cavity by HIL or HTL) |
Technology Challenges - Flexible OLED

**Thin Film Encapsulation**
- Low stress inorganic film
- Pin hole free

**Circular Polarizer**
- Thinner circular polarizer
- Coating type
- ~100µm circular polarizer
- ~20µm

**Flexible Adhesive**
- Increase elongation
- Low out-gassing

**Edge Sealing**
- Reduce edge delamination
- Moisture & gas blocking
- <1mm flexible substrate
ITRI’s Thin-film Encapsulation

OLED with thin-film encapsulation only, in the condition of 60°C/90%R.H.
ITRI’s Edge Sealing for Flexible OLED

Conventional Structure

ITRI’s Structure

Storage Condition: 60°C/90% R.H.

Conventional Structure

ITRI’s Structure
# Flexible Touch Sensor Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>Sensor on PET</th>
<th>Sensor on transparent PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate</td>
<td>PET roll</td>
<td>PI coated on glass carrier (carrier is re-usable)</td>
</tr>
<tr>
<td>Process</td>
<td>by R2R facility</td>
<td>by G/G &amp; OGS facility</td>
</tr>
<tr>
<td>Production</td>
<td>Yes</td>
<td>On-going</td>
</tr>
<tr>
<td>Thickness (μm)</td>
<td>40 ~ 125</td>
<td>3 ~ 15</td>
</tr>
<tr>
<td>Flexibility (with ITO)</td>
<td>Normal</td>
<td>Good</td>
</tr>
</tbody>
</table>
Technology Challenges - Flexible Touch Panel

Flexibility
- Foldable >100k times @ r< 3mm
- Reduce thickness

Optical Performance
- Transparency > 88%
- Yellow index b* < 0.5

Multi-function
- Ultra-thin flexible cover
- Integrate gas barrier
ITRI’s Curve Out-cell AMOLED

Demonstrated in Touch Taiwan Exhibition 2014
ITRI’s On-cell Touch Sensor on FlexUP™

~60μm

FlexUP™

Touch Sensor

Gas Barrier

TFT

Gas Barrier

FlexUP™

Loop resistance (ohm)

- W/O Folding
- Folding 7.5mm@10K Times
- △R(%)
ITRI’s Inward Foldable **On-cell Touch AMOLED**

(Folding @ 7.5mm)

*Demonstrated in Touch Taiwan Exhibition 2014*
ITRI’s Outward Foldable AMOLED
(Folding @ r=7.5mm)

Demonstrated in Touch Taiwan Exhibition 2014
ITRI’s Foldable AMOLED with on-cell touch panel
(Folding 100k times @ r= 5mm)

Demonstrated in Touch Taiwan Exhibition 2015
✓ Size : 7.1” (16:9)
✓ Resolution : FHD (310 ppi)
✓ Multi-Touch : 5 points
✓ Reliability Test : 85°C/85%RH for 500hrs
ITRI’s 7.1” 310ppi Z-Fold Foldable AMOLED

Size: 7.1”; Resolution: 310 ppi; Bending Radius: 5 mm

Demonstrated in Touch Taiwan Exhibition 2015
ITRI’s 7.1” 310ppi Rollable AMOLED

Demonstrated in Touch Taiwan Exhibition 2015
AMOLED & Touch Sensor Facility of DTC/ITRI

Gen. 2.5 Touch AMOLED Pilot Lab.
Substrate Size : 370×470 mm²
Cleaning Room : 3,124 m² (Class 100, 1000)

Facility :

- **FlexUP™** : slot die coater and oven
- **a-Si / MOx / LTPS-TFT** : thin-film deposition, photolithography and etcher
- **BE / TE / Transparent OLED** : evaporator, thin-film encapsulation and encapsulation
- **Touch Sensor** : spin coater, thin-film deposition and screen printer
DTC/ITRI’s FlexUP™ Facility

Slot Die Coater

Glass Carrier

PI

AMOLED

De-bonding Layer

Slot Die Coater of G2.5

Baking Oven of G2.5
DTC/ITRI’s TFT Facility of G2.5 Size

Processes for a-Si, MOx, LTPS-TFT and Touch Sensor
DTC/ITRI’s OLED Facility

**Thin Film Encapsulation**
- Polymer CVD
- Flip
- UL
- T/V
- Relay
- Core 3
- CVD

**Flexible Encapsulation**
- Film Laminator
- De-bubble
- L/UL Thermal cure
- UV Cure
- Dam & Fill
- VAS

**OLED Deposition**
- HTL
- Cathode
- Core 2
- ETL/CGL
- Mask stock
- IZO/ITO
- Relay
- Core 3
- Core 1
- Loading
- B Linear Source
- Linear Source
- HIL/CGL
- O₂ Plasma
- Mask stock
- G Linear Source
- R Linear Source
# DTC/ITRI’s OLED Capability of G2.5 Size

<table>
<thead>
<tr>
<th>Items</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate</td>
<td>✓ G2.5 (370mm x 470mm)</td>
</tr>
<tr>
<td>OLED Structure</td>
<td>✓ Top Emission</td>
</tr>
<tr>
<td></td>
<td>✓ Bottom Emission</td>
</tr>
<tr>
<td></td>
<td>✓ Transparent</td>
</tr>
<tr>
<td>Encapsulation reliability @ 60°C / 90% R.H.</td>
<td>✓ ~ 500 hrs</td>
</tr>
<tr>
<td>Resolution (ppi)</td>
<td>✓ WOLED+CF &gt; 400</td>
</tr>
<tr>
<td></td>
<td>✓ FMM RGB: 300~ 400</td>
</tr>
<tr>
<td>OLED Lifetime (hrs)</td>
<td>✓ 10,000</td>
</tr>
<tr>
<td>Capacity (pcs G2.5/day)</td>
<td>✓ ~ 20</td>
</tr>
</tbody>
</table>
Conclusions

1) **Opportunity for Display Market:**
Flexible AMOLED will create new form factors, and added value for smart handheld products. Wearable device, by integrating bendable AMOLED, will become the next main stream portable.

2) **R&D for Technology Issues:**
To realize bendable, foldable, rollable and large size flexible AMOLED, there are many technology challenges yet to be solved, including material, equipment, process integration, and structural simplification.

3) **ITRI’s Interest in Commercialization:**
ITRI’s role is to develop the fundamental technologies and, subsequently, transfer the capability to the industries. Collaboration with experts of various fields will be essential to accelerate the technology commercialization.
Touch Taiwan 2016

Organizers : TDUA (Taiwan Display Union Association), Chan Chao Int'l Co.
Show date : Aug. 24–26 (Wed.–Fri.), 2016
Venue : 1st Floor, Nangang Exhibition Hall, Taipei World Trade Center

CORETECH 2016

Organizers : TDUA (Taiwan Display Union Association), Chan Chao Int'l Co.
Show date : Aug. 24–26 (Wed.–Fri.), 2016
Venue : 4th Floor, Nangang Exhibition Hall, Taipei World Trade Center

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FPD International Taiwan 2016

Organizers : TDUA (Taiwan Display Union Association), Nikkei BP
Venue : 4th Floor, Nangang Exhibition Hall, Taipei World Trade Center
Welcome to Touch Taiwan 2016