The Route to Conformal, Low Power Wearable Displays

Mike Cowin, Strategic Marketing
Summary

• Background to SmartKem
• The big picture – what are the drivers for new display formats
• Why LCD and AMOLED on plastic are destined to succeed
• What makes organic semiconductors special
SmartKem Background

• Founded in 2009 to develop world leading semiconductor ‘inks’
• Series A funding Q4 2014 with investor syndicate
• SmartKem Facility based in Manchester, UK
• Core target market conformal & flexible LCD, OLED displays
• 4 JDA’s & 2 significant LOI’s for pre-production development
Highly experienced leadership team focused on commercialisation

- Rich heritage in OSC materials-science and electronics for industrial application
- Ex Avecia, ICI, Philips, Samsung, Merck, Kodak, Qualcomm, Liquavista, CDT
- 30 strong team rising to 35 by end 2015
Leaders in organic semiconductors

- Full synthetic molecule capability
- Full ink formulation capability
- TFT fabrication & test
- TFT circuit modelling Capability
- Application Prototype Capability
- Materials scale-up
- Turn-Key Technology Transfer Support

SmartKem Technology Centre
Manchester, UK

8,000 sq. ft. facility: turn-key development of TFT technology platform
The mainstream press see a new wave wearable & mobile technology

Sep 2014

March 2015
Market Drivers for Wearable Displays & Electronics

But how will people see, touch and sense the IoT?
Humans aren’t flat - technology needs to conform to us
Wearable technology – its all in the wrist

To drive mass adoption of wearable displays.
Technology needs to be unobtrusive, comfortable.
The Wearable Challenge

• How to make wearable displays lighter, conformal and a more natural (personal) fit?

• How to reduce power consumption but still maintain a great display?

• How to make them affordable and ubiquitous?
truFLEX™ Organic Semiconductors
A TFT backplane platform for LCD & AMOLED on plastic

- Processed on plastic at low temperatures
- Conformable & comfortable wearable displays
- Foldable displays for phones, tablets etc.
- Low power: Weekly charging NOT Daily
- Solution process: High throughput, low cost
- Lightweight and unbreakable

otFT’s are enabling a new generation of displays
trufLEX™ sits in the TFT processing sweetspot.

Allows high throughput, low cost sheet to sheet processing on plastic using standard slit coat equipment.
Drivers for Plastic AMOLED & LCD

Common Interest
New Market
New Applications
Low Cost

Material Company
New Markets

Panel Makers
Cost down: replace glass by plastic
Capacity Increase: replace CVD process by coating

Brand Designer
Thin and lightweight
Unbreakable
Conformal Displays

BOM structure:
Plastic film/alkali-free glass = 20%
Soda lime glass/alkali-free glass = 60%
Market still dominated by low mobility a-Si

Significant scope for uplift of a-Si performance by replacing with higher mobility oTFT, flexible form factor and reduced cost with LCD on plastic
A large stagnant LCD market is looking to benefit from low-risk, low cost, conformal product with performance uplift with truFLEX®

A modest AMOLED market is looking to breakthrough with foldable, differentiated product with truFLEX®
truFLEX™ Semiconductor Platform
Heritage of OTFT development over 20 years

Synergistic small molecule & binder combination is key that allows superb uniformity and mobility potential > 10 cm²/Vs

Originally developed by SmartKem team

Polymer x1000 improvement in semiconducting performance

APAC 2015
Functionalised polyacene material
- Reduce photo-oxidation compared to pentacene
- Higher pi-pi overlap than TIPS-pentacene
- High mobility potential

Hole transporting polymer
- Co-polymer containing triarylamine group
- Matched HOMO level to small molecule
- Surface energy modified to suit substrate
- Provide improvement to rheology for coating applications – ensures high coating & device uniformity

Formulated as ink
- Can be formulated for coating method
- Simplest is for spin coat application
What’s the Magic?

Intelligent semiconductor technology
truFLEX™ Semiconductors offer ultra-flexibility for any application.

With oTFT any electronic wearable platform can be thin, lightweight, unobtrusive and comfortable.
truFLEX™ Semiconductors offer *true* flexibility

Recent Flexible Display Demo’s - no robust flexibility without truFLEX™
### truFLEX™ TRUE Flexibility

#### Most Flexible on Market

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>LTPS</th>
<th>Oxide</th>
<th>OTFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum bend radius</td>
<td>10mm</td>
<td>30mm</td>
<td>0.1mm</td>
</tr>
<tr>
<td>Fold capability</td>
<td>No</td>
<td>No</td>
<td>Proven</td>
</tr>
<tr>
<td>Robust Roll Capability &lt;3mm</td>
<td>Limited</td>
<td>Unproven</td>
<td>Proven</td>
</tr>
<tr>
<td>Repeated Bend Capability &lt;3mm</td>
<td>Unproven</td>
<td>Unproven</td>
<td>Proven</td>
</tr>
<tr>
<td>Scalability</td>
<td>Poor</td>
<td>Poor</td>
<td>High</td>
</tr>
<tr>
<td>Route to Stretch-ability</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Physical characteristics and suitability to scalable, truly flexible display manufacture

**truFLEX™ eliminates** the 5mm bend radius roadblock

*Fully conformable wearable displays and foldable mobile displays now achievable for first time*
Ease of truFLEX™ adoption onto depreciated a-Si line

Source: Display Search/IHS
truFLEX™ offer a 50% cost down opportunity

TFT Array Device CapEx & Cost Comparisons
(Channel & Gate Dielectric Layers)

<table>
<thead>
<tr>
<th></th>
<th>G6 LTPS PMOS</th>
<th>G8 a-Si TFT</th>
<th>SmartKem OTFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CapEx ($/m²)</td>
<td>$35.80</td>
<td>$12.12</td>
<td>$3.63</td>
</tr>
<tr>
<td>Mfg. Cost ($/m²)</td>
<td>$45.93</td>
<td>$41.09</td>
<td>$23.96</td>
</tr>
</tbody>
</table>

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truFLEX™ Manufacturing Comparison
Most Cost Effective on the Market

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LTPS</th>
<th>Oxide</th>
<th>truFLEX®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility (over large area)</td>
<td>No Size dependence</td>
<td>Issue</td>
<td>No Size Dependence</td>
</tr>
<tr>
<td>Mobility (over small area)</td>
<td>Grain Size dependence</td>
<td>Uniform</td>
<td>Uniform</td>
</tr>
<tr>
<td>Vth Control</td>
<td>Channel doping</td>
<td>Not possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Environmental stability</td>
<td>Excellent</td>
<td>Issue</td>
<td>Excellent</td>
</tr>
<tr>
<td>Run to Run reproducibility</td>
<td>Excellent</td>
<td>Issue</td>
<td>Excellent</td>
</tr>
<tr>
<td>Yield</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Process complexity</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Process temperature</td>
<td>&lt;450°C</td>
<td>200-350°C</td>
<td>100°C</td>
</tr>
<tr>
<td>Cost</td>
<td>High</td>
<td>Fair</td>
<td>Lowest</td>
</tr>
<tr>
<td>Scalability</td>
<td>Poor</td>
<td>Poor</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

Comparison of manufacturing technologies of LTPS, Oxide and truFLEX TFTs [ref; Jin Jang 2014 ].

The cost down route to flexible OLED & LCD displays on plastic
Impact of improvements on technical roadmap

- **Series 1**
  - 2012: Hi-Res E Paper backplane
  - 2013: Display Integrated Row Drivers (for fully flex display)
  - 2014: Functional logic ≥100 kHz bit rates
  - 2015: ≥200 dpi AMOLED backplane

- **truFLEX Series 2**
  - 2016: High Aperture ratio conformal LCD on plastic

- **truFLEX Series 3**
  - 2017: Large Size AMOLED backplane
  - 2018: ≥600 dpi AMOLED backplane

**Mobility (cm²/Vs)**

**Year**

- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020
truFLEX® Ultra-Low Leakage Current

Material | tru-FLEX® | LTPS* | a-Si* | Oxide* |
---|---|---|---|---|
Leakage (A/μm) | $10^{-16} - 10^{-17}$ | $10^{-12}$ | $10^{-14}$ | $10^{-16}$ |
On/Off ratio | $10^{10}$ | $10^{7}$ | $10^{7}$ | $10^{9}$ |

truFLEX™ Leader in low leakage
### truFLEX® Ultra-Low Leakage Current

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumed Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppi</td>
<td>300</td>
</tr>
<tr>
<td>Outdoor luminance after polariser</td>
<td>200 cd/m²</td>
</tr>
<tr>
<td>Indoor luminance after polariser</td>
<td>60 cd/m²</td>
</tr>
<tr>
<td>RGB split</td>
<td>3:6:1</td>
</tr>
<tr>
<td>Power efficiency of the Red OLED*</td>
<td>30cd/A</td>
</tr>
<tr>
<td>Power efficiency of the Green OLED*</td>
<td>60 cd/A</td>
</tr>
<tr>
<td>Power efficiency of the Blue OLED*</td>
<td>10 cd/A</td>
</tr>
<tr>
<td>Reverse leakage of p-Si transistors</td>
<td>1pA/um</td>
</tr>
<tr>
<td>Reverse leakage of OTFTs 0.1fA/A</td>
<td>Reverse leakage of OTFTs 0.1fA/A</td>
</tr>
<tr>
<td>Display diagonal</td>
<td>42mm/1.665&quot;</td>
</tr>
</tbody>
</table>

**AMOLED panel driving assumptions for Smart Watch display power consumption calculations using truFLEX pause driving**

**AMOLED Smart Watch – what would be power saving with truFLEX™ ?**
Normalised (to LTPS) AMOLED Smart Watch Display Power Consumption using truFLEX\textsuperscript{®} at different frame frequency outdoor (LHS) and indoor (RHS)

truFLEX enables up to 90\% lower panel power consumption

*What’s does this mean in real terms?*

Weekly charging of Smartwatch with truFLEX\textsuperscript{™} NOT daily charging
# truFLEX® Performance Comparison

*The Lowest Power on the Market*

<table>
<thead>
<tr>
<th>Property</th>
<th>a-Si</th>
<th>LTPS</th>
<th>IGZO</th>
<th>truFLEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vt uniformity</td>
<td>good</td>
<td>fair</td>
<td>fair</td>
<td>Excellent</td>
</tr>
<tr>
<td>Vt stability</td>
<td>poor</td>
<td>good</td>
<td>poor</td>
<td>Excellent</td>
</tr>
<tr>
<td>Leakage Current</td>
<td>poor</td>
<td>poor</td>
<td>good</td>
<td>World Class</td>
</tr>
<tr>
<td>Mobility</td>
<td>1</td>
<td>50-100</td>
<td>10-30</td>
<td>5-10</td>
</tr>
<tr>
<td>Mobility Uniformity</td>
<td>good</td>
<td>fair</td>
<td>fair</td>
<td>Excellent</td>
</tr>
<tr>
<td>Device Type</td>
<td>NMOS</td>
<td>CMOS</td>
<td>NMOS</td>
<td>PMOS</td>
</tr>
<tr>
<td>PBS/NBS</td>
<td>Fair</td>
<td>Fair</td>
<td>poor</td>
<td>Good</td>
</tr>
</tbody>
</table>

The only *complete* technology solution for scalable, flexible, *lowest power consumption* TFT backplanes

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Private & Confidential
Summary

SmartKem’s truFLEX™ TFT platform is reshaping the display industry

✓ Most flexible TFT platform
✓ Lowest cost of production
✓ Lowest power consumption
✓ Low risk route to adoption
✓ Adoption underway

oTFTs have the potential to become the TFT platform of choice for conformal and flexible LCD and OLED wearables
Thank you

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