DEVELOPING A HIGH VOLUME LARGE AREA MANUFACTURING PROCESS OF ORGANIC TFT FOR FLEXIBLE, SHATTERPROOF AND LIGHTWEIGHT DISPLAYS

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19th March 2012

IeMRC Printed Electronics
Loughborough University
OUTLINE

- Plastic Logic: Company update and technology

- Challenges on the way from Lab to Fab
  - Project milestones for the factory
  - Differentiations Lab – Factory
  - Equipments and processes
  - Process improvement
  - Material analysis
  - Failure analysis
  - Test methods: electrical and reliability
  - Reliability improvement

- First application
The Company Plastic Logic
Company History

Product Development

- 10+ transistors
- 100+ transistors
- 1.2M transistors
- First product
- PL 100

Research and Process Development, Manufacturing

- Cambridge Technology Center
- Dresden Display Factory: First plastic electronics factory in the world
- Mountain View Product Engineering
- Zelenograd Display Factory: Planning/construction

Our Locations

Mountain View, US
- Business Development
- Marketing & Sales
- Product Engineering

Cambridge, England
- Innovation Centre
- Research & Development
- Advanced Engineering
- Business Development

Dresden, Germany
- GEN3.5 Pilot Line and Production Facility
- Process Development
- Test Development
- Equipment Engineering
- Tech Transfer
- Large scale reliability work

Zelenograd, Russia
- Volume Manufacturing
- Manufacturing Engineering

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Plastic Logic Display Technology Leadership

- Plastic instead of traditional silicon semiconductors and glass
- Superior weight, durability, flexibility and thickness
- First and largest production of a plastic-based display
- Strong IP position
  - 88 patents and applications
  - 30 granted to date
- Wide portfolio of co-operations with suppliers, universities and institutes
Plastic Logic OTFT Backplanes + E-Ink Media

Flexible Display Structure
- e-paper Frontplane
- Plastic Logic Backplane

Active Matrix Backplane
- up to 150 ppi

Pixel Structure
- Transistor (TFT)
- Pixel Capacitor
- Via
- Gate Dielectric
- Gate Interconnect
- Data Line
- Drain
- Flexible substrate

Plan View - not to scale

Side View - not to scale
Establishing Volume Manufacturing
Dresden Display Factory

- First plastic electronics factory in the world
- Opened September 2008

- Fully automated
- Capacity of 100,000s of units per year
Groundbreaking            May 2007

Fab and Office Buildings Completed January 2008

Clean Room
   ➢ Validation/handover April 2008

Equipment Move-in, Installation and Start
   ➢ April 2008 to August 2008

Process Installation and Development
   ➢ September 2008 to December 2009
   ➢ Production ramp 2010
R&D and Production Set-Up Concept

R&D  14” | 355 x 355 mm
Proof of concepts
Highly flexible
Lab equipment
Manual handling
R&D Engineers
Several displays/week

Factory  Gen 3.5 | 780 x 650 mm
Developing a volume capable process
Production equipment
Automation
Engineers: Process, Equipment
Several thousand displays/week

Transfer of Concepts into Volume Technology
Dual Roadmap to Factory and Production Process

**Factory**
- Equipment Installation and Test
- Ramp Equipment
- Start of Risk Prod.
- Production Ramp

**Process**
- Testing of Materials
- Process and Design Verification
- Qualification
- Yield Improvement

**Areas of Focus:**
- Equipment
- Materials
- Process set-up
- In-line diagnostic
- Display testing

March 2012

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Organic Electronic Volume Production Set-Up: Challenges

- **Equipment different from the pilot-line set up in Cambridge**
  - Adaption to standard production equipment for flat panel Gen 3.5
  - New specified and developed equipment prototypes to industrialize

- **Process specification to be verified for stable volume production**
  - Size of the backplane differs by factor 5! → impact on processes

- **New materials to be tested in volume production**
  - Specifications to be developed
  - Selection and qualification of suppliers

- **Production control and test concept installation**
  - Test structures to be developed
  - Failure analysis to be developed

- **Yield, defects - key drivers to identify with consequences on process**

- **Training, know how for a new team**
  with experience of silicon and volume production for new equipment, materials and process flows
Process Differences have Consequences for Equipment

The key differentiators of our technology for organic electronics and flexible electronics are

- Solution processing
- Direct-write fabrication techniques to avoid mask-alignment
- Combination of wet coating and dry patterning
- Low process temperatures to permit use of cheap flexible substrates

Our key focus areas for equipment and process know how are

- Printing, spraying and other deposition of organic and inorganic materials
- Cleaning and conditioning of the layers
- Laser processing for printable electronics

We focus on the manufacturability of these processes such as:

- Reproducibility
- Homogeneity
Material Analysis and in-situ Measurements

- New organic materials are normally still analyzed separately in a laboratory.
- Production requires analysis of:
  - Complex samples with layer stacks
  - Thickness analysis of layers with similar composition or behaviour
- In-situ measurements in the production flow
- Local material analysis in μm areas

Layer stacks

State of the art Failure Analysis techniques for Si had to be developed again.
Display Testing

- Early testing of transistor and display parameters is required in the production flow
  - Transistor and other primitive device structures and test methods necessary
  - Electrical and optical tests of the display require very good alignment to select and improve material at an early stage

- Testing including handling of flexible displays in accordance with the test spec required

- Reliability studies give indications about the quality and lifetime behavior
  - Accelerated test and different environmental conditions must allow lifetime projections
  - Well proven models exist for Si-integrated circuits based on higher temperatures and acceleration factors
  - Organic materials show different behaviour, temperature sensitivities and reaction to cycling
# Reliability testing

Industrial state of the art reliability testing

<table>
<thead>
<tr>
<th>Name</th>
<th>Test</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermo cycling</td>
<td>TST</td>
<td>Mechanical robustness &amp; CTE mismatch</td>
</tr>
<tr>
<td>High Temperature Storage</td>
<td>HTS</td>
<td>Storage of transport conditions</td>
</tr>
<tr>
<td>Advance Humidity Storage</td>
<td>AHS</td>
<td>Stability against Moisture ingress</td>
</tr>
<tr>
<td>Low Temperature Storage</td>
<td>LTS</td>
<td>Storage of transport conditions</td>
</tr>
<tr>
<td>Real World Usage</td>
<td>RWU</td>
<td>display use in non accelerated mode</td>
</tr>
<tr>
<td>Advance Humidity Operation</td>
<td>AHO</td>
<td>Accelerated operation at high humidity</td>
</tr>
<tr>
<td>Low Temperature Operation</td>
<td>LTO</td>
<td>Accelerated operation at low temperature</td>
</tr>
<tr>
<td>Ambient Operation</td>
<td>AO</td>
<td>Accelerated operation at ambient conditions</td>
</tr>
<tr>
<td>Solar storage</td>
<td>SOR</td>
<td>Solar robustness</td>
</tr>
<tr>
<td>Altitude test</td>
<td>ALT</td>
<td>Pressure sensitivity</td>
</tr>
</tbody>
</table>
Our First Application
Plastic Logic 100 Features

Value
- Largest display available
- Touchscreen interface
- Amazingly light, thin, and unique ID

Simplicity
- Custom UI designed for efficiency & productivity
- Fast access to your information
- Looks and reads like paper, safe on your eyes
- Glare free, read in direct sunlight

Convenience
- One hand reading experience
- Easily transfer documents from PC to PL100
- Worry free: durable with shatterproof display
- Extra long battery life – recharge just once a week
• Performance increases allow more demanding devices such as RFID, OLED, LCD, etc

• Display and basic logic applications accessible using organic thin film transistors (OTFTs)