OVERVIEW OF PLASTIC SUBSTRATES FOR PRINTED ELECTRONICS

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Special thanks to:
  Karl Rakos
  Bill MacDonald
Overview

- Flexible Electronics Today
- Development Highlights
- Industry Challenges
- Conclusion
Printed Electronics Exist Today

- Membrane Touch Switch
  - Automotive MTS, eg seat sensors
  - PEN allows higher temperature specifications
- Flexible Printed Circuits / Flat Flexible Cable
  - Automotive wiring harness replacement with flat cables
  - LED rear light clusters and daylight running lights
- Optical Displays
  - Electroluminescent lamps and next generation displays
Printed Electronics Today

- Security, ID, health cards
- Passports
- Protective Labels
- Medical Test strips
FDC Technology on PEN

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Process Temperature</td>
<td>180 °C (flex)</td>
</tr>
<tr>
<td>Saturation Mobility (cm²/V-s)</td>
<td>0.7</td>
</tr>
<tr>
<td>ON/OFF Ratio</td>
<td>2 x 10⁹</td>
</tr>
<tr>
<td>Drive Current (μA)</td>
<td>30</td>
</tr>
<tr>
<td>Threshold Voltage (V)</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Typical output (a) and transfer (b) characteristics of a-Si TFTs fabricated on PEN

3.8-in QVGA E-Ink Display on PEN

TFT pixels at 4 corners of 3.8-in QVGA
Developments
Factors Influencing Substrate Choice-Property Set

- “Simple” circuitry
- Organic AM backplanes
- Inorganic AM backplanes
- OLED Lighting

More demanding property set

Increasing complexity of substrate structure
Key Challenges for Engineered Substrates into Flexible Electronics Applications

- Low Coefficient of Thermal Expansion
- Low Shrinkage
- Upper Temperature for Processing
- Surface smoothness
- Barrier
- Solvent Resistance
- Moisture Resistance
- Clarity
- Rigidity
- Conductive layers
- Commercial availability
  - Development started in late “90’s” primarily for OLED and LCD applications
- Substrates for the more demanding applications are likely to be multilayer structures containing both organic and inorganic layers
Factors Influencing Film Choice-Substrate Properties

Films grouped by thermal properties

<table>
<thead>
<tr>
<th>Substrates</th>
<th>Temp C</th>
<th>Tg C</th>
<th>Tm C</th>
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<tbody>
<tr>
<td>PET</td>
<td>0</td>
<td>50</td>
<td>100</td>
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<tr>
<td>PEN</td>
<td>50</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>100</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>Polyarylate</td>
<td>150</td>
<td>300</td>
<td>350</td>
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<tr>
<td>Polyethersulphone</td>
<td>200</td>
<td>350</td>
<td>400</td>
</tr>
<tr>
<td>Fluorene Polyester</td>
<td>250</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Polyimide</td>
<td>300</td>
<td>400</td>
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</tr>
</tbody>
</table>

- Semi-crystalline
- Amorphous
- Amorphous, solvent cast

DuPont Teijin Films®
Improved Process for Heat Treating

- Thermal finishing cycle virtually remove shrinkage: −0.01% at 180°C, 30’ (left graph)
- CLTE is reduced by 25%: 20 ppm/K † 15 ppm/K (right graph)

**Shrinkage % (180°C, 30min) vs. direction in plane of Teonex® PEN film (0°=MD)**

**CLTE (ppm/K) vs. direction in plane of Teonex® PEN film (0°=MD)**
Surface Roughness from Additive Packages

Standard Packaging Film

“Electronics” Grade Film

White Opaque Film

Laminating Film

DuPont Teijin Films®
Optimized Surface for Fine Features

AFM - 10 micron square
ST506 surface
Amplitudes +/- 30nm

AFM - 10 micron square
Planarised ST506 surface
Very smooth - within the noise floor
Does Roughness Impact Circuitry?

QVGA aSi TFT array built on PEN

Uncoated Heat stabilised PEN

Planariser

Planarised Heat stabilised PEN

Slide shown courtesy of Flexible Display Centre, ASU
Challenge from Scratches

Scratches and Surface Debris can easily cause trace breaks.
Industry Challenges

- For economics, machine scale is large, producing millions of square meters an hour.
  - Need large scale opportunities
  - Today, must leverage products for other markets to meet small scale demands

- Measurement
  - Size of defects and density becoming tighter
  - Measurement systems do not exist for volume QC, must rely on spot measurement

- Global Supply Chains
  - US producers must design for “best in class” global standards.
  - Aggressive investment in Asia for the LCD industry
Summary

- Development of Films for Printed Electronics have been ongoing for many years, leveraged from other industries.
- Choice of film type and thickness is crucial.
  - Important to pick the right film for the application.
- Control of surface quality is critical.
  - Critical to understand the type of surface defects which impact device manufacture and performance.
- Global supply chains are a given
  - “Best in class” assets need investment and on-going re-investment
How many times a day do you rely on PET and PEN polyester films from DuPont Teijin Films?