Innovations in Polyester Film Substrates for the Flexible Electronics Industry

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Outline

- Company Overview and Update
- Polyester Film Overview
  - Key PET Film Properties
  - Comparison of PET to other “Plastic Substrates”
- Developments for Flexible Electronics & Displays
  - Optically Clear, Low Shrinkage
  - UV Stable / UV Block & Hydrolysis Resistance
  - PCS – Peelable Clean Surface
  - Formable PET
- Summary
Mylar® and Melinex® Polyester Films
Global Reach ... Local Understanding

- Global Headquarters
  - Hopewell, VA
- Regional Headquarters
  - Europe- Luxembourg
  - China- Hong Kong
  - US- Hopewell
- Manufacturing
  - Europe- Luxembourg & Dumfries, Scotland
  - China- Foshan & Ningbo
  - US- Hopewell & Richmond
- Research & Development
  - Europe- Wilton
  - US- Hopewell
NEWS RELEASE – Oct 10, 2017

- New HVA segment for IVL with attractive growth platform
- World-class technology and innovation platform and a leading position in diverse industry segments
- Value creation and synergy potential
- Enables IVL to offer an even more compelling value proposition for customers
- Delivers immediate value accretion

Bangkok, Thailand – 10 October 2017 - Indorama Ventures Public Company Limited (IVL), a global chemical producer, has announced that it has entered into an agreement to acquire DuPont Teijin Films (DTF), a leading global producer of Biaxially-oriented Polyethylene Terephthalate (BOPET) and Polyethylene Naphthalate (PEN) films with total film/polymer capacity of 277,000 tonnes per annum. The DTF acquisition includes 8 production assets in the US, Europe and China, with a global innovation center in the UK. The transaction is expected to be completed during late 2017 or early 2018, subject to the usual regulatory approvals.
PET Polyester Film

• High stiffness
• Dimensional stability
• Optical transparency
• Solvent & moisture resistance
• Thickness = 0.6-500 µm

Melinex® & Mylar®
Polyethylene terephthalate (PET)

$T_m = 255^\circ C$
$T_g = 78^\circ C$

Run rates: 20 → 300 meters/minute (>1200 m²/minute)
Off-line heat stabilization for improved dimensional stability

**Typical Shrinkage (150C, 30min)**

<table>
<thead>
<tr>
<th>Film Type</th>
<th>MD</th>
<th>TD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard PET</td>
<td>1.0%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Partially Stabilized</td>
<td>~0.5%</td>
<td>~0.1%</td>
</tr>
<tr>
<td>Off-Line Stabilized</td>
<td>&lt;0.1%</td>
<td>&lt;0.02%</td>
</tr>
</tbody>
</table>

Heat Stabilized Polyester Films are frequently required for Flexible Electronics

- Displays (e.g. Cap Touch Sensors)
- FPC (Flexible Printed Circuits)
- Sensors
- Appliances
The Innovation tool box

**In-Line Coatings**
- Adhesion
- Antistatic
- COF control
- Release
- Sealant
- Hydrophilic
- RI Match
- etc.

**Polymer; Co-Ex Polymers**
- “Sacrificial”
- UV Resistant
- Hydrolysis Resistant
- Thermoform/IME
- Anti-Newton Rings?
- Flame Retardant (V-0)
- Gloss, Texture, Color
- Copolymers
- Voided
- Heat seal

Many of these Technologies and Capabilities are applied to Flexible / Printed Electronics
Tg does not define upper processing temperature for biaxially oriented films

- Processing temperature is defined by heat stabilization

### Graph

- **X-axis:** Temperature (°C)
- **Y-axis:** Polymer categories
- **Legend:**
  - Upper process Temp °C

**Polymers:**
- PET
- PEN
- Stabilized PET film
- Stabilized PEN
- PC
- COP
- PES
- Cigear PL
- PI

**Key points:**
- **Heat stabilized PET and PEN**
Easier handling with a stiffer film

- Tooling geared up for glass (stiffer is better)

Youngs Modulus is independent of thickness, rigidity defined as:

\[ D = \frac{E \cdot t^3}{12(1-\nu)} \]

where

- \( E \) is the tensile or Youngs Modulus.
- \( t \) is the thickness,
- \( \nu \) is Poissons ratio (0.3-0.4).

200µm Biax PET is \(~4\) times more rigid than 125µm

\(~12\) times more rigid than 125µm amorphous film
Printed/Flexible electronics in PET substrates

Membrane Touch Switch
- Automotive MTS, EL, e.g. seat sensors

Flexible Printed Circuits/Flat Flexible Cable
- Automotive wiring harness replacement with flat cables
- LED rear light clusters and daylight running lights

EL Lamps

Medical test strips
Key challenges for Engineered Substrates

Common CTQs

- Low coefficient of Thermal Expansion
- Low Shrinkage
- High Upper Temperature for Processing
- Optical Clarity
- Surface smoothness
- Solvent and Moisture resistance
- Rigidity – Formable, bendable, stretchable
- Commercial availability at low cost
- Other – Hydrolytic stability, Flame retardance
## Plastic Substrates for Flex Electronics

<table>
<thead>
<tr>
<th>Property</th>
<th>Biaxially oriented heat stabilised PET</th>
<th>Biaxially oriented heat stabilised PEN</th>
<th>Biaxially oriented PEEK</th>
<th>PC</th>
<th>COP</th>
<th>PES</th>
<th>Clear Polymide</th>
<th>Polyimide</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTE (±55 to 85 °C) ppm/°C</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td></td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>%Transmission (400-700 nm)</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√√</td>
<td>√√</td>
<td>√√</td>
<td>√√</td>
<td>√</td>
</tr>
<tr>
<td>Water absorption %</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td>√</td>
<td>X</td>
</tr>
<tr>
<td>Young's modulus (Gpa)</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td></td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Tensile strength (Mpa)</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td></td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Solvent resistance</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>√</td>
</tr>
<tr>
<td>Upper Operating Temp</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√√</td>
<td></td>
<td></td>
<td>√√</td>
<td>√</td>
</tr>
<tr>
<td>Birefringence</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>√√</td>
<td>√√</td>
<td></td>
<td>√√</td>
<td>√</td>
</tr>
<tr>
<td>Availability at commercial scale</td>
<td>√√√</td>
<td>√√√</td>
<td>X</td>
<td>√√</td>
<td>√√</td>
<td></td>
<td>√√</td>
<td>√</td>
</tr>
</tbody>
</table>
Polyester film offerings for the Flexible Electronics market
Optically Clear Films

Super Clear Melinex® TCH, STCH, and ST Films:

- Optically Clarity: ~0.3% Haze; > 90% TLT
- Near Zero Thermal Shrinkage (150°C, 30 minutes)
  - ≤ 0.1% MD; ≤ 0.02% TD
- Customized, in-line primer coatings:
  - Improve Adhesion
  - Eliminate Iridescence from Refractive Index mismatch
- What is Surface Haze (“Blooming”)?
  - Standard PET films will “haze-up” above 90°C
  - Improved “Low Oligomer Bloom” films are required

“Normal” PET aged 60 mins at 150°C

Low Bloom PET aged 60 mins at 150°C
Films with high weathering resistance

Perception:
- Polyester films hydrolyze rapidly
- Polyester films degrade rapidly under UV light exposure

Reality:
- Hydrolysis life time can be tailored to meet performance needs
- Polyester films have been modified to improve resistance to UV light
- PET films are reliable, cost effective alternatives to PVF films for PV applications

UV & Hydrolysis Stabilized PET

4+ years in Florida:
Mechanical integrity
Color $\Delta b^* < 1.5$

White UV stabilised Film weathered in Florida

Damp Heat Test Data of Various 125 um Films

Damp Heat Test = 85°C, 85% RH

White UV stabilised Film weathered in Florida
Clear PET Film: UV Stable & UV Block

- **UV performance can be Optimized to meet customer needs**
  - Life time
  - Color change
  - Mechanical properties
  - UV Blocking

- **Verified with accelerated weathering programs:**
  - Xenon
  - Florida weathering

![Graph showing transmission results of UV 125 micron with and without UV absorber, comparing UV and Visible wavelengths.](image)
Barrier Films need Clean Smooth Surfaces

**Traditional Approach** – Off-Line, Planarized Films

- Coating acts to cover surface defects on the polyester film
- Eliminate pinholes, reduce layers (cost), and increase yield
- Effective, but off-line = added cost

![Diagram of Clean Smooth Surfaces](image)
Peelable Clean Surface (Melinex® PCS)

Base PET for Barrier Films

- PCS
  - Peel layer for protection of the internal ultra clean surface,
  - High dimensional stability, low blooming
  - Scaled up manufacturing from pilot to production line
- DTF is a partner in the “LYTEUS” project – an EU funded program offering:
  - Prototyping OLED applications
  - Barrier substrate structures
  - Different structures available, meeting needs of application (packaging - OPV – OLED)
Mono layer Barrier Performance on PCS films

<table>
<thead>
<tr>
<th>Technology Proprietor</th>
<th>SiN PECVD</th>
<th>ZTO sputtering</th>
<th>SiOx Atmospheric PECVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrier performance g/m²/day</td>
<td>10E-6</td>
<td>Better than 1E-3 (hit test limit)</td>
<td>5E-4</td>
</tr>
<tr>
<td>Improvememnt over plain PET</td>
<td>100 (Melinex ST504)</td>
<td>&gt;500 (Melinex 401)</td>
<td>&gt;10 (best competitive alternative)</td>
</tr>
<tr>
<td>Test method/conditions</td>
<td>Ca test (Philips) 60C/90%</td>
<td>Bruger WDDG 38C/90%</td>
<td>Technolox Deltaperm 40C/90%</td>
</tr>
<tr>
<td>Pinholes /cm²</td>
<td>0.7</td>
<td>n/a</td>
<td>2.8</td>
</tr>
<tr>
<td>Thickness</td>
<td>200nm</td>
<td>100nm</td>
<td>90nm</td>
</tr>
<tr>
<td>Protection</td>
<td>Removable liner</td>
<td>Permanent or removable liner</td>
<td>Removable liner</td>
</tr>
</tbody>
</table>
Thermoformable PET for In-Mold Electronics

- In-Mold Electronics:
  - Brings “Touch” to other HMI Segments
  - Appliance, Automotive, Consumer & Medical Devices
  - Lower cost & weight, fewer assembly steps
- PC film is widely used in Film-Insert-Molding
  - Usually requires off-line hardcoat layer to overcome issue of poor chemical resistance
  - Flex resistance is poor compared to PET
  - Good corner formability
- New Formable PET combines PET’s chemical & flex resistance with PC’s formability
Flame Retardant: VTM-0 PET Film

**Melinex® FR films**

- Novel halogen-free, clear VTM-0 PET polyester film from DuPont Teijin Films.
- Provides improved safety by combining inherent PET polyester film properties with the VTM-0 flame rating certification available from UL’s UL 94 Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances.
Flexible Hybrid Electronics – Substrate Trends?

What type of device? How/Where is the film used?
- Touchscreen, Barrier Film, Display, Sensors, Surface Mount

Physical Requirements?
- Thermal Stability, Solvent Resistance, Moisture Pick-up
- Optical Clarity, Surface Quality, Birefringence
- Thickness, Film Stiffness, CTE, Thermal Conductivity

Performance vs. Cost Tolerance?

There are many Flexible Electronics applications, leading to a variety of substrate requirements. PET films provide a balance of performance, cost, and proven commercial availability.
What is the right combination for your Application?

- Conductive
- Planarization
- Hard Coat
- Bond/Debond

- Adhesion
- Index Match
- Release

- Heat Stabilized

- UV stable/block
- Flame retardant
- Optics – Clear, hazy, white
Thank you!

DTF plant – Hopewell, Virginia

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