Next Generation Tedlar® PVF Film for Photovoltaic Module Backsheets

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Global Market Segment Leader Photovoltaics
DuPont Teflon® and Tedlar® Films
Outline

• Tedlar® PVF film for Backsheets
  • Properties of FluoroPolymers
  • Tedlar® PVF in Backsheets
  • PV2100: A new generation of backsheet films
  • UL Recognition Testing
  • The laminators perspective

• Tedlar® film Capacity Expansion

• DuPont Photovoltaic Solutions (DPVS)
DuPont Pioneered Fluoropolymer Technology

Since the discovery of PTFE, DuPont has led the world in fluoropolymer technology.

Most fluoropolymers have been DuPont inventions.

DuPont is the world’s largest and most diversified supplier of fluoropolymer products.

Roy Plunkett discovers p-tetrafluoroethylene in 1938
Properties of Fluoropolymer Films

- UV Resistant
- Moisture Resistant
- Chemically Resistant
- Tough
- Wide Processing Temperature Range
- Good Electrical Properties
- Easily Cleaned
- Low Refractive Index
- Highly Transparent
- Flame Resistant
Tedlar® PVF Film

- Simplest Fluoropolymer
- Easy to pigment
- Adherable
- Available in thicknesses from 12.5 to 100 microns
- Available in a wide range of colors
### Typical Tedlar® Film Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>PV2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, cc/cm³</td>
<td>1.38 - 1.72</td>
</tr>
<tr>
<td>Tear strength, initial, kJ/m</td>
<td>129 - 196</td>
</tr>
<tr>
<td>Tensile modulus, MPa</td>
<td>44 - 110</td>
</tr>
<tr>
<td>Ultimate elongation, %</td>
<td>115 - 250</td>
</tr>
<tr>
<td>Continuous use temperature, °C</td>
<td>-70 – 107</td>
</tr>
<tr>
<td>Water vapor permeability, g/m²-day</td>
<td>24.5</td>
</tr>
<tr>
<td>Dielectric strength, short term dc, kV/µ</td>
<td>0.15 – 0.19</td>
</tr>
<tr>
<td>UL 94 Flame Class</td>
<td>HB</td>
</tr>
<tr>
<td>UL 746B RTI, Electrical, °C</td>
<td>140</td>
</tr>
<tr>
<td>UL 746B RTI, Mechanical (Impact Str), °C</td>
<td>120, 125</td>
</tr>
</tbody>
</table>

adapted from Ebnesajjad and Snow, Kirk-Othmer Encyclopedi of Chemical Technology, 4th Ed
Photovoltaic Module Backsheets

Function

- Physical protection: puncture and abrasion resistance
- Moisture protection: minimize moisture vapor ingress
- Electrical insulation: isolate the cells and connections from the environment
- Long term protection: UV stable and moisture stable over the life of the module, protects the P layer
- Color: provide the color that helps the modules blend into environment.
- More power: can improve efficiency through internal reflection

Tedlar® PVF film is the material of choice for TPT™ backsheets

- Readily available in a variety of film types, especially pigmented
- Durable, weatherable, and strong
DuPont Tedlar® Offerings for PV Backsheets

DuPont supplies PVF films to companies globally for conversion into PV backsheet laminates

PV2001
- 37.5 micron white PVF film… The most often used “T” in TPT™

TCC15BL3
- 37.5 micron black PVF film used where a dark color is desired for aesthetic purposes

TUT10BL3
- 25 micron clear UV absorbing film used when transparent backsheets are desired

Introducing the PV2100 series of Tedlar® Films for Backsheets…
PV2111: A New Tedlar® Film for Backsheets

PV2111, the first member of the PV2100 family, has all of the properties that have made Tedlar® films the standard in PV backsheets:

• Made from the same basic PVF polymer as PV2001
• Unaffected by extreme temperature and humidity
• Excellent adhesion to EVA encapsulants
• Good electrical, physical and barrier properties

In addition, PV2111 has

• Better dimensional stability than PV2001... Low shrinkage that is balanced at module laminating temperatures leading to virtually wrinkle free modules.
• Over 15% higher solar reflectivity for added power in modules that take advantage of backsheet reflectance
Dimensional Stability of Tedlar® Films

Graph showing the dimensional change of different films (MD PV2001, TD PV2001, MD PV2111, TD PV2111) as a function of temperature (°C).
Reflectance of Tedlar® Films and Backsheet

![Graph showing reflectance of different materials against wavelength](image-url)
Module Design and Backsheet Reflectivity

Backsheet Reflectivity has least effect here…
little exposed backsheets

Backsheet Reflectivity has more effect here…
more exposed backsheets

Backsheet Reflectivity has most effect here…
large areas of exposed backsheet

Photos from the DOE/NREL
Photographic Information Exchange
### Comparison of PV2001 and PV2111

<table>
<thead>
<tr>
<th>Property</th>
<th>Method</th>
<th>PV2001</th>
<th>PV2111</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness, micron</td>
<td>Caliper</td>
<td>37</td>
<td>25</td>
</tr>
<tr>
<td>Elongation at Break (%)</td>
<td>ASTM D882</td>
<td>140</td>
<td>35</td>
</tr>
<tr>
<td>Tensile Strength (kpsi)</td>
<td>ASTM D882</td>
<td>10</td>
<td>5.2</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>ASTM D882</td>
<td>69</td>
<td>36</td>
</tr>
<tr>
<td>Tear Strength (kN/m)</td>
<td>Graves</td>
<td>129</td>
<td>213</td>
</tr>
<tr>
<td>60° Gloss</td>
<td>Gardner</td>
<td>6</td>
<td>74</td>
</tr>
<tr>
<td>Total Solar Reflectance (%)</td>
<td>ASTM E424</td>
<td>69</td>
<td>74&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dielectric strength (V/mil)</td>
<td>ASTM D150</td>
<td>3000</td>
<td>3000</td>
</tr>
</tbody>
</table>

<sup>a</sup> As TPT™, Reflectance increases to 80%
Underwriters Laboratories Recognition Testing of Tedlar® Photovoltaic Film Offerings

• Use of UL Recognized Components In PV Modules Is Critical to Global Product Acceptance

• DuPont Supports the UL Concept of Recognized Components in PV
  • Helps Ensure Long Term Module Performance and Reliability
  • Decreases Product Test Cost and Time to Market Release

• DuPont/UL Recognition Testing
  • Started in November of 2006 and Is Ongoing
  • Deals with Fire Resistance, Electrical, UV and Thermal Characterization
  • Complies with the Provisions of the IEC 61730 Safety Standard and the Next Generation of the UL Photovoltaic Safety Standard
  • Completes Characterization of the PV2001 Product and Provides Data on New PV2111 Offering
# Tedlar® Film Comparison in Underwriters Laboratories Recognition Tests

<table>
<thead>
<tr>
<th>TEST METHOD</th>
<th>PVF PV2000</th>
<th>PVF PV2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification</td>
<td>Complete Complete</td>
<td></td>
</tr>
<tr>
<td>Flame Classification</td>
<td>HB</td>
<td>HB</td>
</tr>
<tr>
<td>Flame Spread Index (Radiant Panel)</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>UV Exposure</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>Hot Wire Ignition (HWI) PLC</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>High Current Arc Ignition (HAI) PLC</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Comparative Tracking Index (CTI) PLC</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Inclined Plane Tracking Rating (IPT) PLC</td>
<td>IP</td>
<td>IP</td>
</tr>
<tr>
<td>Relative Temperature Index (RTI)</td>
<td>125 C</td>
<td>IP</td>
</tr>
</tbody>
</table>

**Performance Level Category (PLC)**
- 0 = Best
- IP = Testing In Progress
The laminators perspective
**New Gen-Tedlar® - PV 2111 → Akasol® PTL HR**

**History**

*we look back on almost 4 years of testing and approvals*

Start of internal tests: early 2004

First public announcement: 2nd workshop „Photovoltaic Module Technic“; TÜV Rheinland, Cologne; Germany

December 1st and 2nd, 2005

Session V: materials and components:

„Flexible Base materials and Special Laminates“ by K. Brust

First response on quality: “yellowing” after damp-heat test

Du Pont adjusted formulation to “cast” technology in 2006

2nd response since 2007: excellent bonding to EVA; good damp-heat behaviour: no yellowing

November 2007: more than 100 customers have received sample rolls and sheets

Forecast 2008: major share of PV 2111 compared with PV2001/TWH
Advantages – from the view as TPT™ backsheet manufacturer

+ thermal dimensional stability of PV 2111 is closer to the low shrink quality of PET-films; this results in less thermal stress between PVF and PET in TPT™
+ better homogeneity of pure PVF film due to no orientation process in film production;
+ excellent bonding to encapsulation polymer films (> 8 N/mm);
+ 2000h damp heat test (85% rh, 85°C) without failures

Disadvantages – are mainly given for the TPT™-production

- lower tensile strength, thinner film increases problem of film tearing during lamination of PET to PVF.
- low availability in 2nd half of 2007 and Q1/2008
PV 2111 and PV 2112 are approved by ISOVOLTA AG for Icosolar® 3469 as backsheet material
Tedlar® Films for Backsheets: Summary

Tedlar® Films have demonstrated over 20 year performance in PV backsheets.

Tedlar® Films are unaffected by harsh testing conditions and long term exposure conditions.

Tedlar® Films can be tailored to specific colors:

- Clear
- White
- Black
- Custom Colors

PV2100 Series represent a new generation of films designed for dimensional stability at lamination temperatures for wrinkle free backsheets

PV2111, the first member of the PV2100 family, is a white, highly reflective film.
New polymer plant started up
Tedlar ® Film Capacity expansions

Since 2002 through increased staffing, plant ream-outs, 6-sigma projects and new polymer and film lines coming on stream, we will have increased our capacity by 2009 with 300%.
The Solar cells are laminated between 2 sheets of encapsulant film, backed with DuPont™ Tedlar®, and topped with glass or DuPont™ Teflon®.
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