Protection of Organic Solar Cells for Long Lifetime


International Symposium towards Organic Photovoltaics
Linz, Johannes Kepler Universität
2008, February, 6-8
Outline

1. Overview
   - Historical background
   - Standard Isovolta products for the PV industry

2. Encapsulation Material for Flexible Solar Cells
   - Requirements
   - State of the art
   - Concepts
   - Today`s results

3. Automated encapsulation

4. Summary
Werndorf Plant
2005
Lebring Plant
- opened 2005
- expanded 2008
Locations

- Isovolta Werndorf, AT 1949
- Isovolta Wr.Neudorf, AT 1962
- Isovolta India, IND (40%) 1984
- Skyline, USA (100%) 1989
- Isovolta Hong Kong, CN (76%) 1990
- Teinser, E (60%) 1992
- Changzhou Isovolta, CN (70%) 1995
- Nippon Rika Isovolta, JP (34%) 1996
- Isovolta S.A., RO (99%) 1998
- Micafil Glimmer-Aktivitäten, CH (100%) 1999
- Isovolta di Mexico, MX (60%) 2000
- Gatex, DE (100%) 2001
- Isoma, BG (100%) 2002
- Skylife spol. s.r.o., SK (100%) 2003
- Isovolta Inc./US Samica, USA (100%) 2003
- Changzhou Olong, CN (40%) 2004
- Changzhou T C , CN (70%) 2005
- Lebring, AT (100%) 2005
- Deglarges, F (60%) 2006
Competence Center Werndorf

> 340 employees

- R & D
  - 15%
- empl.
  - 15%
- work.
  - 70%

Process Technology

R & D International
Encapsulation material for
- Standard crystalline cells
- Thin film cells
- Special encapsulation application solutions
Laminated Film

- Fluoropolymer (PVF, PVDF)
  - weather resistance
- Polyester
  - electrical insulation
  - mechanical stability
  - H₂O vapor barrier
- Adhesive
  - adhesion to EVA, TPU, PVB

- 23 years of experience
- 25 years guaranteed lifetime
- +30 years lifetime
Long Term Stability of Encapsulating Materials

Crystalline solar cells

Weatherability

- Damp-Heat Test @ 85 °C/ 85% r.h.: 2000 h – 3500 h
- UV-Stability: IEC 61730

Evaluation

- Adhesion between layers
- Discolouration
Application of Laminated Films

**stand-alone**
- PV-facility, New Mexico (USA) (Shell Solar Industries LP)

**integrated**
- ISOVOLTA AG, Wr. Neudorf (A) Headquarters PV-facade

**transparent**
- Floriade (Siemens Nederland N.V.)

**solar park**
- Solarpark Mühlhausen, D 33820 modules, ~ 5.3 MW

**thin film**
- Mercedes solar roof, D (Webasto Systemkomponenten GmbH & Co. KG)
- a-Si thin film modules (Kaneka Corporation)
Encapsulation Material for Flexible Solar Cells

© Konarka

© Fraunhofer ISE
Requirements on Encapsulation Materials for Flexible Solar Cells

- weatherability
- high transparency
- flexibility
- UV-stability - low yellowing
- no brittleness
- adhesion
- cost efficiency
- availability
- barrier properties (water vapour, oxygen)
### Barrier Requirements for Different Product Sectors

|                | WVTR  \[g.m^{-2}.d^{-1}\] | OTR  \[cm^3.m^{-2}.d^{-1}.atm^{-1}\] | Lifetime  
|----------------|-----------------------------|----------------------------------------|--------
| amorphous Si   | $< 10^0$                    | $< 10^0$                               | $> 20$ |
| CIS            | $< 10^{-3}$                 | $< 10^{-3}$                            | $> 10$ |
| Organic Solar Cells | $< 10^{-3}$                | $< 10^{-3}$                            | $> 5$  |
| OLEDs         | $< 10^{-6}$                 | $< 10^{-5}$                            | $> 2$  |

**Water Vapour Transmission (WVTR):**

Standard material today: 2 g.m^{-2}.d^{-1}

Goal: High Barrier Laminates $\rightarrow 10^{-5}$ g.m^{-2}.d^{-1} and lower
Barrier properties of technical polymers

Permeability, normalized to 100 µm thickness

Oxygen transmission (DIN 53 380): 23°C, 50% r.h.

Water vapor transmission (DIN 53 122): 23°C, 85% r.h. to 0% r.h.
Barrier properties of laminates and composite materials

(PVD: physical vapor deposition)

OTR: (DIN 53 380: 23°C, 50% r.h.)
WVTR: (DIN 53 122: 23°C, 85% r.h.)
Flexible Encapsulation Materials: State of the Art (1)

**PML®-Process**
Polymer Multi Layer Process (by Vitex Systems, Inc.)
- alternating coating systems → acrylates & inorganic barrier layers

**BARIX™ encapsulation**

*Multilayer Barrier Deposition:*

- Monomer Liquid
- Cure
- Ceramic Deposition

*PET*

*High Speed, Large Area...*

*Burrows, P.E. et al.; MRS spring Meeting 2002, Boston, USA*
Flexible Encapsulation Materials: State of the Art (2)

Vitex, Inc.

PML® process

Barrier stack (alternating coating of acrylates and inorganic barrier layers)

Teonex® PEN substrate

Barrier properties
WVTR: 10-5 g/m²*d
OTR: 10-5 cm³/m²*d (Ca test)

- direct deposition on OLED, OSC substrate
- flexible
- formats: 7-9 in wide, up to 100 ft long
Flexible Encapsulation Materials: State of the Art (3)

SABIC (former GE Plastics)

Scheme of the graded inorganic / organic barrier layers:

The moisture rate of a PC substrate with the ultra high barrier (UHB) coating measured by the Ca corrosion test is less than $1 \times 10^{-5}$ g/m$^2$·d.

Application: 24 x 24 in OLED display (cooperation with Konika Minolta)

Flexible Encapsulation Materials: State of the Art (4)

**Nova Plasma, Canada**
- development of new encapsulation technology for OLEDs
- inorganic / organic PEVCD coating deposition on polymer substrates
- one-step multilayer
- flexible, transparent
- excellent T resistance
- OTR & WVTR rates: below the sensitivity limit of standard Mocon instrument (< 0.005 g/cm² *day)

**United Solar Ovonic, USA**
- world leader in thin-film amorphous PV technology & applications
- manufacture of a-Si cells & R2R vacuum deposition on substrate (substrate: rollable stainless steel)
- flexible Building-Integrated photovoltaic solar energy systems dimensions: 1.5 miles long, 14 in wide
Flexible Encapsulation Materials: State of the Art (5)

University and Related Institutes

- **IMRE, Singapore** (Institute of Materials Research and Engineering):
  - flexible barrier development
  - development of measurement system (> 10^{-6} g/ m2*d)

- **Fraunhofer Gesellschaft, D (FhG)**: development of flexible tailor made barrier layers (organic / inorganic hybrid materials)

Film Manufacturers – Barrier Films

- **DuPont Teijin, worldwide**
  - Teonex® Q65FA
  - Melinex® ST 506/504 (heat stabilized, optical clear, planarized)

- **Honeywell, USA**
  - Aclar® (PCTFE)
  - OxyShield® (PVdC coex. Nylon: moisture & O2 barrier)

- **Vacumet, USA** (metallized polymer films, e.g. BARRIER-MET®)
- **Pliant Engineered Films, USA** (Synergy™: hybrid moisture barrier)
Isovolta Concepts for High Barrier Materials

- Multilayer materials with inorganic coatings
- Multilayer structures with inorganic coatings and sealants
Substrates

PET 1  PET 2  PET 3  PEN 1

Influence of surface roughness before PEVCD!
MeO$_x$ – vacuum deposition, PEVD

Schematic set-up

© Applied Materials
Multilayer Materials with Inorganic Coatings (1)

Schematic drawing of a 4 layer PET/MeOx composite (thickness approximately 100 µm)
Multilayer Materials with Inorganic Coatings (2)

TEM picture of a two layer composite, 26kx

Inorganic Coating defects → decrease in barrier coating properties

Sealants → close defects
<table>
<thead>
<tr>
<th>MeO$_x$ layers</th>
<th>WVTR [g.m$^{-2}$.d$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 layers</td>
<td>0.40</td>
</tr>
<tr>
<td>4 layers</td>
<td>0.10</td>
</tr>
<tr>
<td>8 layers</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Transmission of Transparent Barrier Laminates

> 85% light transmission!
**Multilayer Structures with Inorganic Coatings and Sealants**

**PET/MeO\textsubscript{x} with sealant, recoated with MeO\textsubscript{x}**

<table>
<thead>
<tr>
<th>MeO\textsubscript{x} layers</th>
<th>WVTR [g.m\textsuperscript{-2}.d\textsuperscript{-1}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 layers</td>
<td>0.06</td>
</tr>
</tbody>
</table>
## Barrier values of a 4 layer material

![Barrier structure image](image)

<table>
<thead>
<tr>
<th>Film material</th>
<th>Thickness [µm]</th>
<th>WVTR 1 [g/m²d]</th>
<th>WVTR 2 [g/m²d]</th>
<th>WVTR 3 [g/m²d]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>36</td>
<td>5.9</td>
<td>6.0</td>
<td>-</td>
</tr>
<tr>
<td>PET-SiOx</td>
<td>36.08</td>
<td>0.4</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Multilayer</td>
<td>102.32</td>
<td>0.063</td>
<td>0.057</td>
<td>-</td>
</tr>
</tbody>
</table>
Multilayer Structures with Inorganic Coatings and Improved Sealants

New sealants → further improved barrier properties
**Best Barrier Properties of Multilayer Material with Inorganic Coatings and Improved Sealants**

<table>
<thead>
<tr>
<th>MeO\textsubscript{x} layers</th>
<th>WVTR</th>
<th>OTR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[g.m\textsuperscript{-2}.d\textsuperscript{-1}]</td>
<td>[cm\textsuperscript{3}.m\textsuperscript{-2}.d\textsuperscript{-1}.atm\textsuperscript{-1}]</td>
</tr>
<tr>
<td>2 layers</td>
<td>&lt; 0.01</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

**Barriers of** $10^{-4}$ g.m\textsuperscript{-2}.d\textsuperscript{-1} **could be achieved on laboratory samples in cooperation with Fraunhofer Gesellschaft.**
## Results Up to Now

<table>
<thead>
<tr>
<th>MeO\textsubscript{x} layers</th>
<th>WVTR [g.m\textsuperscript{-2}.d\textsuperscript{-1}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>inorganic layers</td>
<td></td>
</tr>
<tr>
<td>2 layers</td>
<td>0.40</td>
</tr>
<tr>
<td>4 layers</td>
<td>0.10</td>
</tr>
<tr>
<td>8 layers</td>
<td>0.03</td>
</tr>
<tr>
<td>inorganic layers, improved sealants</td>
<td></td>
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<tr>
<td>4 layers</td>
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<tr>
<td>2 layers</td>
<td>&lt; 0.01</td>
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</table>

Both, hydrolysis and UV stability tests demonstrate good stability!
Further Developments in Progress

- Up-scaling of encapsulation material with $10^{-2}$ g.m$^{-2}$.d$^{-1}$ WVTR and $10^{-2}$ cm$^3$.m$^{-2}$.d$^{-1}$.atm$^{-1}$ OTR (cooperation with Fraunhofer Gesellschaft). Introduction into the market by end of 2008

- Improved sealants & MeO$_x$-substrates target values: $< 10^{-6}$ for WVTR & OTR

- R2R encapsulation process
R2R Encapsulation Process (1)
R2R encapsulation process (2)

Encapsulant

Thin film solar cells on flexible substrate

encapsulated solar cells
Applications for Flexible Solar Cells

©Brunton, SolarRolls™

©Konarka
Summary

- Organic solar cells require high barrier materials for encapsulation.
- Laboratory results of barriers in the range of $10^{-2}$ to $10^{-4}$ (Fraunhofer Gesellschaft) could be achieved.
- Encapsulation material, which fulfills all requirements has to be developed for industrial production processes.
- Automated encapsulation processes have to be developed.
Thank you for your attention!