Anti-Reflective Coating on PV Cover Glass

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Overview

- Anti-reflective coating on PV cover glass
- KhepriCoat® --- outstanding efficiency and durability
- Brief introduction to DSM
Basic principles of ARC technology
PV-module, single sided coated

Simplified illustration disregarding e.g. absorption of glass
Penetration AR-coatings
In 2013 already >60% of all PV modules

Sources: DSM calculation
Sol-gel AR-coatings dominant technology for solar cover glass

Global shares AR-coating technologies solar cover glass

Sputtering: 2%
Etching: 2%
Sol-Gel: 96%

Source: DSM analysis
Sol-Gel AR Coatings: Traditional vs. Core-shell AR Coatings

"Traditional" AR coating

DSM’s patented approach
DSM’s anti-reflective coating technology

Mostly Other ARC
- Open surface
- Interconnecting pores
- Particle packing

DSM AR coating
- Closed surface
- Independent pores
- Strong binding with glass
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AR-coating benefit spectral transmittance
Transmission gain increasing with angle of incidence

Transmission gain PV (300-1200nm)
+2.9% (94.9%), 1-side coated

Transmission gain solar thermal (300-2500nm)
+5.1% (96.7%), 2-sides coated

At increasing angle of incidence up to:
+7% transmission gain for 1-side coated
+12% transmission gain for 2-sides coated

Courtesy of: Interfloat corporation
measurements done by SPF
AR-coating benefit at module level
Boost the flash test performance, lower the cost per Wp

- **2.8% flash test gain**
  perpendicular angle (90 degree)
- **4.5-5.2% flash test gain**
  over all angles

Source:

**Example KhepriCoat®**
+2.8% in flash test
+7 Wp for e.g. 250 Wp module
<€/Wp lower cost
KhepriCoat® benefit in installations
Angular effect ~ 4% energy output increase

- PV module installation, output measurements sunny day in 04/2013
- At noon, gain of ~3% in module efficiency
- U-shape shows extra gain due to angular effect
- Resulting in ~4% efficiency gain

Example KhepriCoat®
~4~5% efficiency plus
>1.2% on top of flash test
@ 0.00 € extra cost
Durability KhepriCoat®

Extended independent accelerated test and outdoor test shows outstanding durability

- Passed all test according to IEC 61215 & IEC 61730
- Industry leader laboratories and research institutes tested KhepriCoat®
- Module manufacturers in every continent have qualified KhepriCoat®
- Extensive DSM lab tests up to 4 times IEC norms
Durability KhepriCoat®
Damp-heat test, Interfloat/GMB single sided coated

Solar transmittance of 1-sided coated MM glass after extended damp-heat testing

- Interfloat 4000 hours damp-heat-test (85/85), loss of 0.2% in transmission
Humidity freeze 20 cycles

1-side roll-coated MM glass

Extremely good stability in extended humidity freeze test

<table>
<thead>
<tr>
<th>TÜV Rheinland®</th>
<th>Average transmittance (%) (400-1200 nm)</th>
<th>Transmittance loss/gain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>KhepriCoat S35</td>
<td>94,32</td>
<td>94,19</td>
</tr>
<tr>
<td>KhepriCoat S36</td>
<td>94,24</td>
<td>94,20</td>
</tr>
<tr>
<td>Reference uncoated glass</td>
<td>91,89</td>
<td>91,67</td>
</tr>
</tbody>
</table>
Ammonia corrosion test

1-side roll-coated MM glass

- KhepriCoat S31 before Ammonia test
- KhepriCoat S31 after Ammonia test
- KhepriCoat S32 before Ammonia test
- KhepriCoat S32 after Ammonia test
- Reference glass before Ammonia test
- Reference glass after Ammonia test

Extremely good stability of KhepriCoat® in Ammonia corrosion test

<table>
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<th>Average transmittance (%) (400-1200 nm)</th>
<th>Transmittance loss /gain(%)</th>
</tr>
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<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>KhepriCoat S31</td>
<td>94,27</td>
<td>94,09</td>
</tr>
<tr>
<td>KhepriCoat S32</td>
<td>94,31</td>
<td>94,18</td>
</tr>
<tr>
<td>Reference uncoated glass</td>
<td>91,70</td>
<td>93,05</td>
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</tbody>
</table>
Abrasion Test

<table>
<thead>
<tr>
<th></th>
<th>Total transmittance 550 nm (%)</th>
<th>Total transmittance 900 nm (%)</th>
<th>Average transmittance (380 nm-850 nm) (%)</th>
<th>Average transmittance (380 nm-1200 nm) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>93,72</td>
<td>94,60</td>
<td>94,22</td>
<td>94,27</td>
</tr>
<tr>
<td>Abraded &amp; cleaned</td>
<td>93,64</td>
<td>94,66</td>
<td>94,27</td>
<td>94,28</td>
</tr>
<tr>
<td>Difference ΔT(%)</td>
<td>-0,08</td>
<td>0,06</td>
<td>0,05</td>
<td>0,01</td>
</tr>
</tbody>
</table>

60 Strokes per minute for a total of 500 strokes
No change in performance

KhepriCoat® on 3.2 mm Float glass (1-2014CAR025)
Excellent cleanability

- EVA
- EVA after cleaning with ethanol
- Fingerprint after cleaning with ethanol
- Fingerprint

- Tap imprint on some AR surface
- No tap imprint on DSM AR surface
- Rubber Imprints on some AR
- DSM AR: Relatively clean
Outdoor - Fraunhofer Speedcoll

Negev, Gran Canaria, Zugspitze, Kochi, Freiburg

Fraunhofer ISE

CONFIDENTIAL
Outdoor - Fraunhofer Speedcoll

- Glass samples aged outdoor for one year in:
  - Negev, Israel: hot desert climate, arid
  - Gran Canaria, Spain: hot desert climate, maritime
  - Freiburg, Germany: continental climate
- Comparison between cleaned and uncleaned sample with reference from lab
- In all cases no degradation of coating or glass visible

- Uncoated glass and DSM AR glass have similar performance
- In all cases, no degradation of coating or glass visible
Outdoor - Fraunhofer Speedcoll

- KhepriCoat® survived harshest environmental conditions
- Example Gran Canaria where serious corrosion was observed at metal coupons after one year already while coated glass performance did not show degradation at all
ATD & Manufacturing

ATD Lab in Shanghai (CN)
- Reverse roll coater
- Lab size dip- and spin-coaters
- Batch curing oven
- Climate chambers
- UV chamber
- Spectrometer

ATD Lab in Geleen (NL)
- Forward roll coater
- Large size spectrophotometer
- Slot die coater
- Lab size dip- and spin-coaters
- Batch curing oven
- “Tempering” simulation oven
PV installations of DSM colleagues!
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DSM at a glance*

- Sales ~€10 billion
- EBITDA ~€1.3 billion
- Global presence ~24,500 employees worldwide
- Listed at Euronext NYSE Share price quintupled in 25 years
- Sustainability leader
  - Top ranking Dow Jones Sustainability Index

• DSM is a global Life Sciences and Materials Sciences company active in health, nutrition and materials
• DSM delivers innovative solutions that nourish, protect and improve performance in global markets such as food and dietary supplements, personal care, feed, medical devices, automotive, paints, electrical and electronics, life protection, alternative energy and bio-based materials

* 2013 numbers total DSM
DSM - understands change

Evolution


- Classical
- Modern

Technological competences
- Mechanical engineering
- Chemical engineering
- Polymer technology
- Material science
- Fine chemicals
- Biotechnology

Profile and strategy
Strong & increasing global presence
World total ~24,500 employees*

North America
~5,000 employees

Latin America
~2,000 employees

Europe
~12,500 employees

China:
~3,500 employees

Rest of Asia:
~1,500 employees

2013 Sales by destination**

- North America: 20%
- Western Europe: 34%
- High Growth Economies: 41%
- Rest of the World: 5%

Increase in % of sales to High Growth Economies**

- 2005: 22%
- 2010 CSD: 32%
- 2013: 41%

** 2013 Sales from continuing operations

* 2013 numbers including employees Pharma cluster
Accelerating and supporting innovation @DSM

Supporting existing Business Groups globally in improving innovation and meeting innovation targets:
- Chief Technology Office
- Excellence in Innovation
- Licensing
- Venturing

Creating new businesses for DSM, outside the current scope of the existing Business Groups:
- Emerging Business Area Biomedical
- Emerging Business Area Bio-based Products & Services
- Emerging Business Area Advanced Surfaces
- Business Incubator
Development path of Advanced Surfaces

- **Nano-technology platform**
  - 2004

- **Pilot market**
  - 2008

- **Anti-reflective coating for Solar PV**
  - 2011

- **“Light trapping” film for Solar PV**
  - 2012

- **Innovative materials**
  - 2013

- Future
  - 2014
  - 2015
  - 2016
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