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EASY-TO-CLEAN ABRASION RESISTANT ANTI-REFLECTIVE SOL-GEL COATINGS FOR CONCENTRATING PHOTOVOLTAICS-CPV

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Introduction

The aim of this work is the development of an anti-reflective (AR) coating for the cover-glass of a High Concentrating Photovoltaic (HCPV) system. This coating should improve the glass transmittance over a wavelength range as broad as possible, ideally between 300 and 2000 nm, where the photovoltaic (PV) multijunction cells are significantly active for PV generation.

Additionally, the coating should offer the following properties:

- Reliability and durability under ambient temperature and humidity conditions.
- Resistance to abrasion and erosion phenomena to which they will be exposed during in-field installation.
- Easy-to-clean properties to diminish cleaning operation costs.
- The coating process should be compatible with a tempered glass cover, commonly used in HCPV modules to comply with safety issues.

Experimental

Synthesis of sols

Pore generating agent + EtOH
→ TEOS
→ H_2O
→ Reflux at 60°C
→ H_2O
→ Reflux at 40°C
→ SiO_2 SOL

Deposition of porous SiO_2 films

- Substrate: low-iron float glass, 4 mm thickness ($T_{(300\text{-}2000nm)}$=90 %).
- EISA method: diblock copolymer as pore-generating agent at controlled relative humidity and temperature (1).
- Heat treatment : 350 - 550 °C.

Easy-to-clean properties HMDS treatment

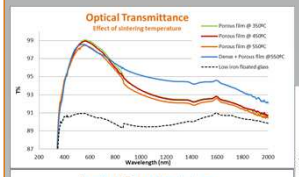
- Hexamethyldisilazane (HMDS) treatment of porous films to make the surface superhydrophobic with high contact angle.
- Coating treated at 350°C selected for HMDS treatment (one side coated glass).
- Immersion in HMDS propanol solution at various time intervals (10 min-4h) and temperatures (20-60 °C). Heat post-treatment at 100 °C.

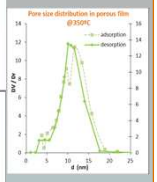
Characterization and accelerated aging

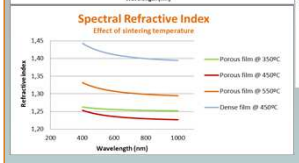
- Optical characterisation:
  - Thickness and refractive index: Ellipsometry
  - Transmittance and reflectance: UV-VIS-NIR Spectroscopy
  - Porosity: Environmental Ellipsometric porosimetry (EEP)
- Abrasion resistance:
  - Simulation of the cleaning process by reciprocating test, using liquid commercial detergent and soft sponge.
  - 25.000 cycles under 1kg load and 1Hz frequency.
- Accelerated aging: exposure in a climatic chamber for 1000h under 85 °C and 85% RH (CPV standard IEC-62108).
- Contact angle measurement by drop-test.

Results

Optical properties







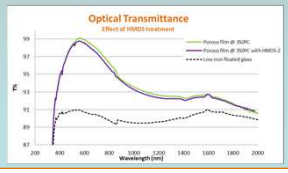
Coating (both sides)	Thickness (nm)	Refractive index (700 nm, 40 % RH)	Void fraction (%) (BEMA)	Integrated Transmittance (%) (300-2000nm)
Dense @450ºC	118,62	1,40	n.a.	92,3
Porous @350ºC	121,84	1,25	42,3	95,7
Porous @450ºC	118,36	1,23	n.a.	95,6
Porous @550ºC	95,82	1,30	n.a.	95,3
Dense+Porous film @550ºC	n.a.	n.a.	n.a.	96,2

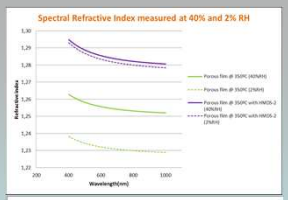
- The best transmittance in the 300-2000 nm range is obtained by coating both sides of the substrate with SiO_2 dense film and SiO_2 porous film. In accordance with CODE simulation results: 95 nm in thickness and refractive index of 1,42 for dense and 110 nm in thickness and refractive index of 1,25 for porous coating.
- Sintering temperature affects the refractive index and transmittance of the porous film: best results of 1,25 and 95,7 % with 350ºC treatment.
- Pore size in the untreated porous film sintered at 350ºC : 11,8 nm.

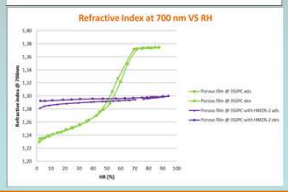
Easy-to-clean properties

Treatment name	Immersion time	Immersion T (°C)	Integrated Transmittance (%) (300-2000nm) (one side coating)	Contact angle (°)
HMDS-1	10 min	20	91.9	49
HMDS-2	4h	20	92.8	86
HMDS-3	4h	60	92.5	99
HMDS-4	2h	60	92.1	99

Coating (both sides)	Thickness (nm)	Refractive index (700 nm, 40% RH)	Void fraction (%) (BEMA)	Integrated Transmittance (%) (300-2000nm)
Porous @350ºC	121,84	1,25	42,3	95,7
Porous @350ºC with HMDS-2	119,43	1,28	29,8	95,4



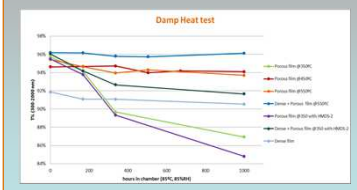




- Higher contact angles are obtained by increasing temperature.
- Treatment time in the studied range does not influence contact angle values.
- HMDS treatment reduces the void fraction in the film, and refractive index increases. No significant influence on transmittance values in comparison with untreated porous coating.
- Refractive index at different relative humidity values: whereas untreated coating absorbs water, HMDS-treated coating does not.
- Refractive index of HMDS-treated film is initially higher, but becomes stable when relative humidity increases. Untreated porous film absorbs water in the pores and refractive index is increased. Optical properties are expected to be more stable under environmental conditions for HMDS-treated coatings.

Durability

Damp-heat (DH) test



- Durability under damp-heat test is improved with coating sintering temperature. Film sintered at 350 ºC presents highest transmittance loss after testing.
- Film sintered at 350 ºC was selected to be treated with HMDS. Damp heat test results were similar to those of untreated film because of weakness of porous matrix.
- Durability of stack after 1000 h test is significantly improved by including dense coating under the porous one.

Abrasion resistance test

Coating description	Sintering T (°C)	Transmittance before abrasion testing	Transmittance after 25.000 abrasion cycles
Porous coating, one side coated	350	92.5	92.2

- The abrasion cycles do not affect the solar transmittance of the coated glass.

Conclusions

- ✓ The highest transmittance result in the range 300-2000 nm was 96,2 %, achieved by stack of dense and porous films sintered at 550 ºC. Besides, this system showed no significant decrease in transmittance after 1000h damp-heat test.
- ✓ The best anti-reflective porous coating in the range 300-2000 nm was obtained from SiO_2 film sintered at 350ºC. The coating shows 95,7 % T, refraction index (at 700 nm) of 1,25 and a porosity of 42,3%.
- ✓ For easy-to-clean properties, a superhydrophobic coating with a contact angle of nearly 100º was obtained by treating the porous AR coating with hexamethyldisilazane (HMDS). This treatment reduces void fraction of the original film and increases refractive index, with no significant change in the transmittance value. Refractive index values indicate that humidity absorption in HMDS treated coating is far less than in the untreated one.
- ✓ Coating transmittance is not decreased after 25.000 abrasion cycles.

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Acknowledgements

- Y. Castro and A. Durán (Instituto de Cerámica y Vidrio, CSIC) are acknowledged for the environmental ellipsometric porosimetry measurements.
- The research leading to these results has received funding from the EC Seventh Framework Programme (FP7-2007-2013) under the ENER/FP7/295985/"ECOSOLE" project.

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Sol-Gel 2013 XVII International Sol-Gel Conference Madrid
August 25-30, 2013, Madrid, Spain