Solar Facilities for the European Research Area

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Standardized tests for reflectors

Florian Wiesinger, DLR

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

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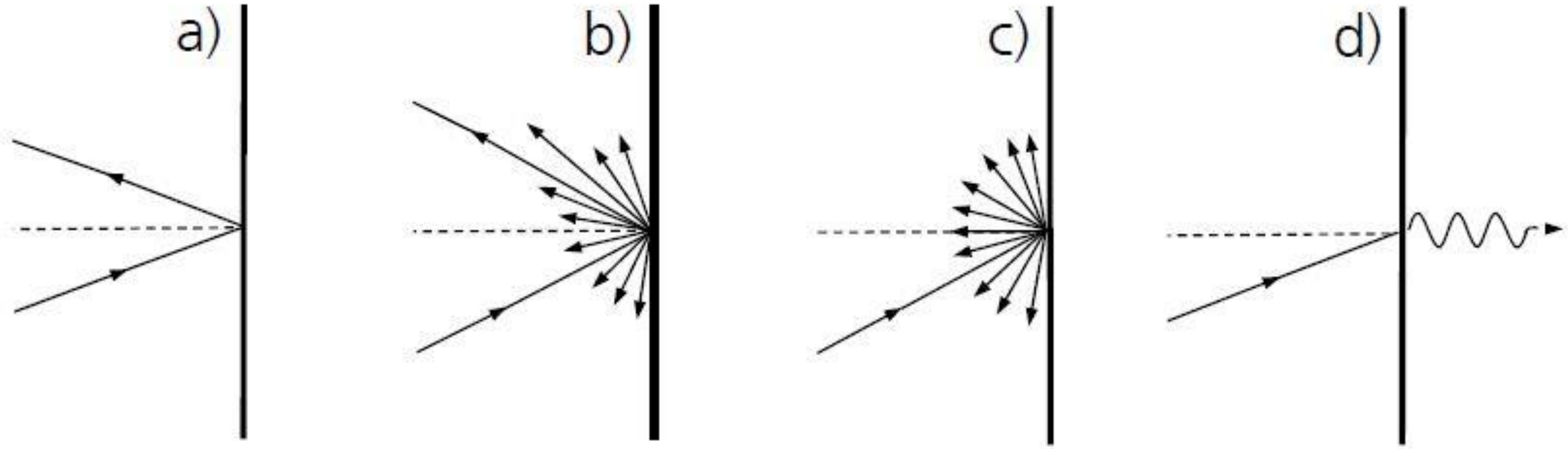
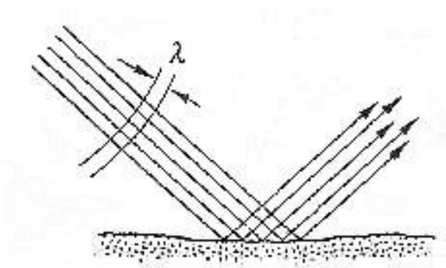


pure specular

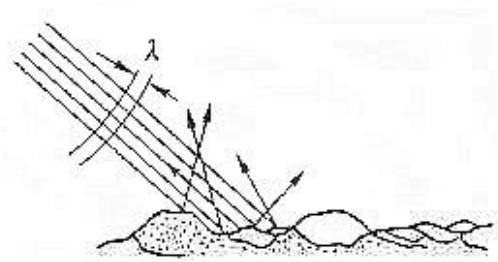
general reflectance, mixture from a) and c)

pure diffuse

absorptance/ transmittance



highly specular surface



diffuse surface

NB:
ρ = reflectance
τ = transmittance
α = absorptance

Reflectance – Crucial Parameter for CSP - Introduction

Examples for **diffuse** reflecting surfaces (room temperature)

High ρ [%]:

- Titaniumdioxid 99
- Magnesiumoxid 96
  (vapor deposited)
- Gypsum 80
- White Paper 70

Low ρ [%]:

- Black platinum 0.1
- Carbon black 0.8
- Black varnish 1-1.5
- Black paper 5

Examples for **specular** reflecting surfaces

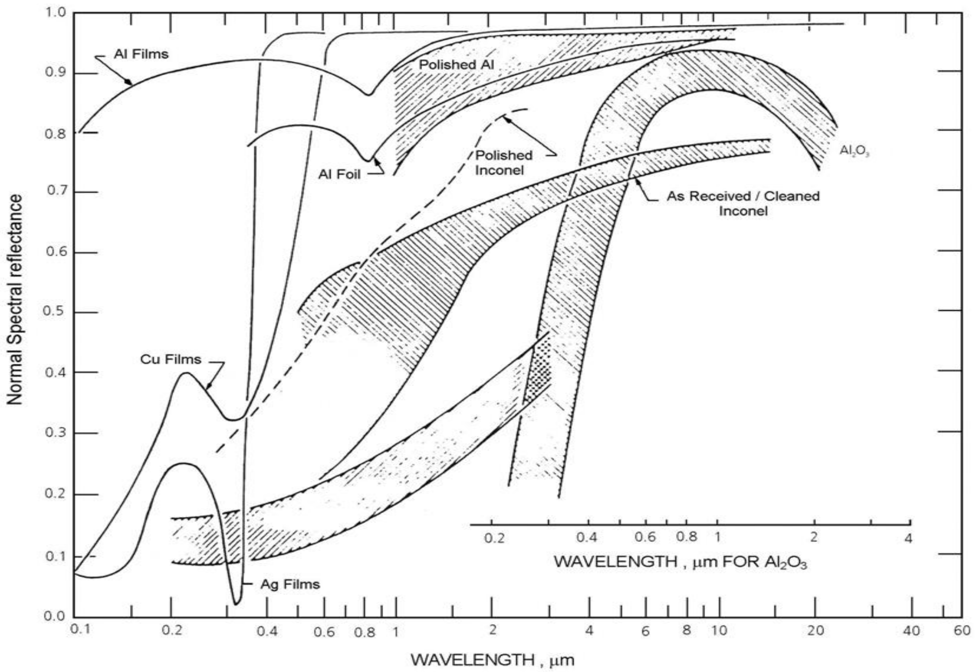
High ρ [%]:

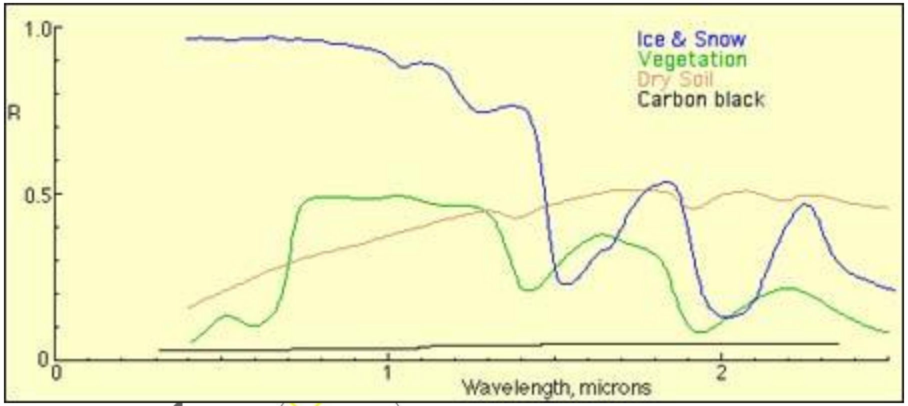
- Aluminum (polished) 87-92
- Silver (polished) 98-80
  (λ-range 0.37-1µm)
- Steel(polished) 93
- Stainless Steel 89

→ ρ is highly depending on λ

Handbook of Chemistry and Physics, 75th Edition
Manufacturer datasheet: Electro Optical Industries Inc.

Reflectance – Crucial Parameter for CSP - Introduction





<u>Characteristics for metals:</u>

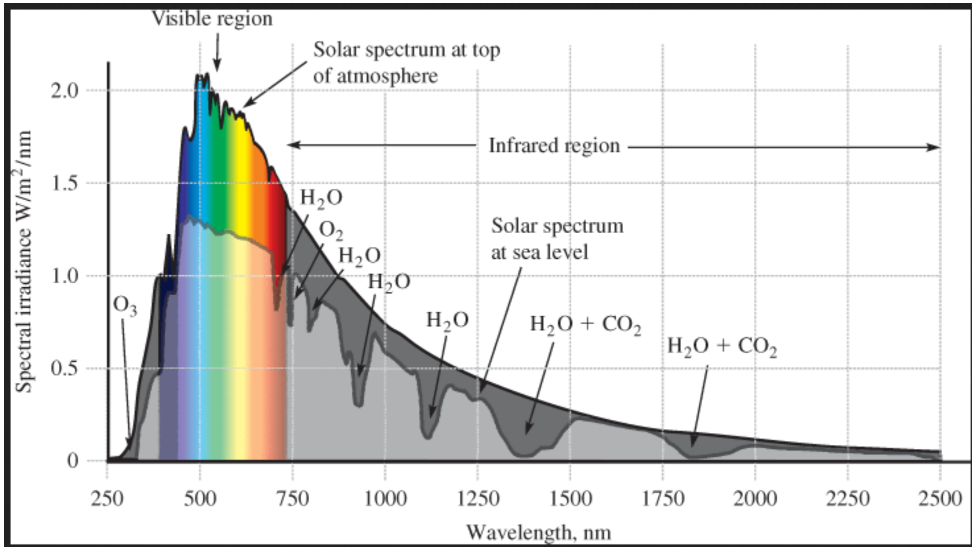
- High ρ in IR, drop at visible and UV
- Position of the edge depending on surface state and temperature.

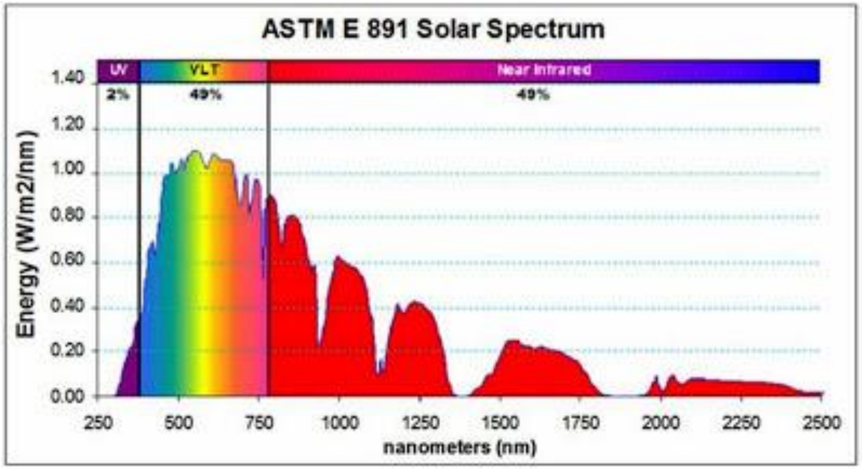
<u>Characteristics for non-metals:</u>

- Two absorption-edges, one in the visible and one in the IR, in between high ρ

→ How should ρ(λ) be modeled?

Reflectance – Crucial Parameter for CSP - Introduction





https://electricala2z.com/wp-content/uploads/2018/03/Solar-Spectrum-at-the-Top-of-the-Atmosphere-and-at-Sea-Level.png

Reflectance – Laboratory Measurements - Overview

Perkin Elmer Lambda 1050 spectrophotometer

Measures hemispherical reflectance, transmittance & absorptance

Multiple Wavelength Portable Specular Reflectometer, Model 15R-RGB

Measures specular reflectance

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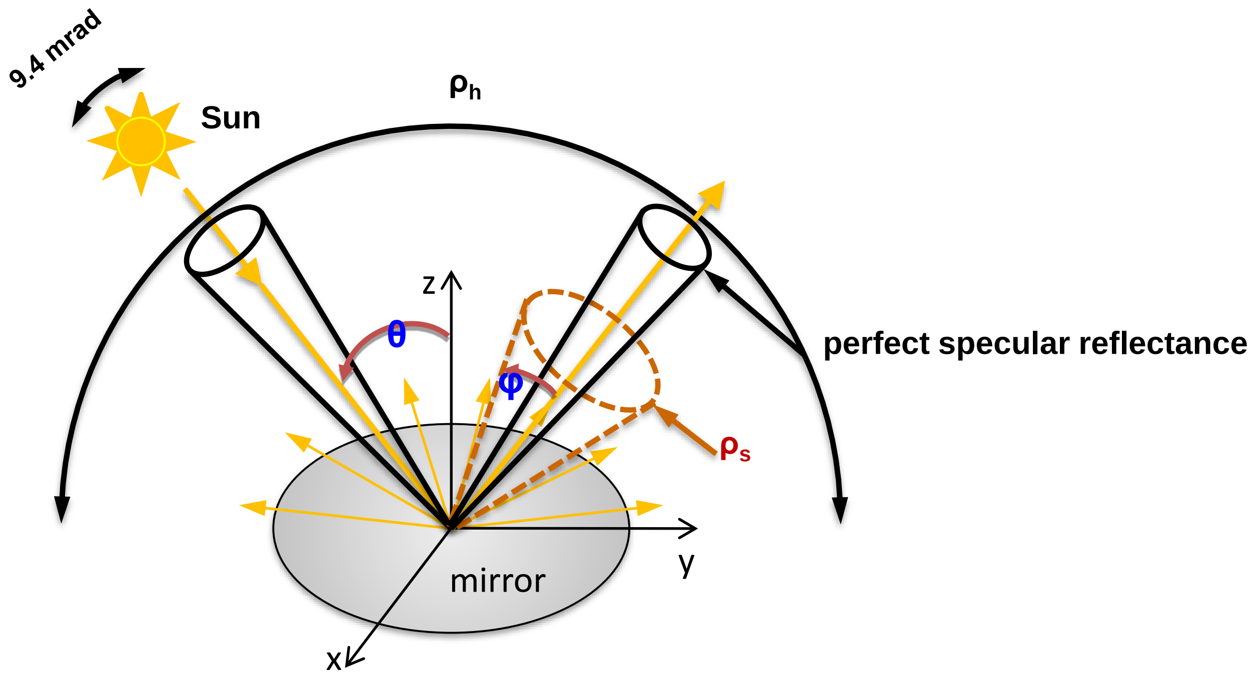
Reflectance – Fundamental Definitions

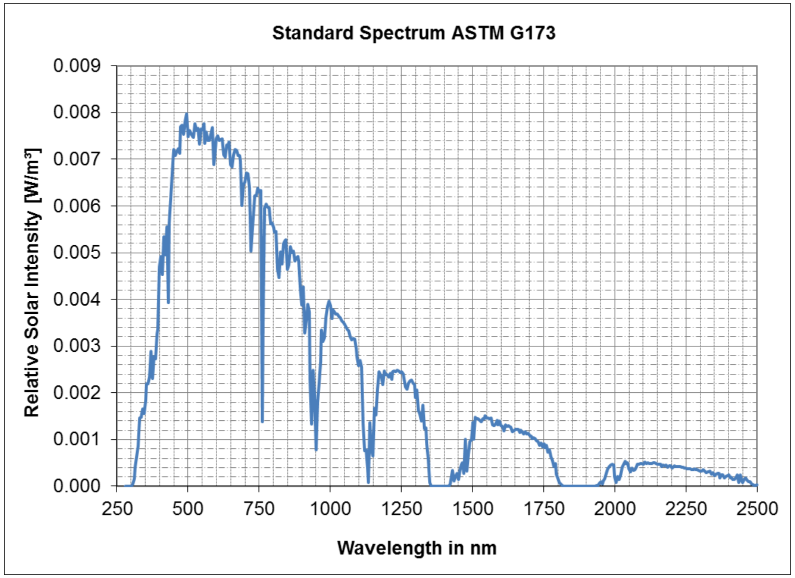


specular reflectance within acceptance angle φ

hemispherical reflectance (acceptance angle is complete hemisphere “φ=h”)

Reflectance – Fundamental Definitions

- Reflectance is wavelength dependent
- A suitable "mean value" of all relevant solar wavelengths is the solar weighted reflectance



$$\rho_{s,\varphi}([\lambda_a,\lambda_b],\theta_i,\varphi,T_s)$$

$$\rho_{s,\varphi}([\lambda_a,\lambda_b],\theta_i,\varphi,T_s)=\frac{\sum_{i=0}^{i_{\max}}\rho_{s,\varphi}(\lambda_i,\theta_i,\varphi,T_s)\cdot G_b(\lambda_i)}{\sum_{i=0}^{i_{\max}}G_b(\lambda_i)}$$

The spectral solar irradiance $G_b(\lambda_i)$ can be obtained in 5 nm steps from a reference spectrum, e.g. ASTM G173 with air mass 1.5 and 1000 W/m²

Reflectance – Fundamental Definitions

Every measured reflectance value needs to be declared in the format:

$$\rho_{\lambda,\varphi}(\lambda,\ \theta_i,\ \varphi,\ T_s)$$

λ	wavelength	[nm]
θ_i	incidence angle	[º]
φ	acceptance angle	[mrad]
T_s	surface temperature of the mirror	[ºC]

To indicate solar weighted values use “s“ as index and indicate the wavelength range of the weighting instead of λ

To indicate hemispherical reflectance use “h” instead of φ

Examples: $\rho_{\lambda,\varphi}(660\ nm,\ 15º,\ 12.5\ mrad,\ 25ºC) = 95.3\%$

$\rho_{s,h}([280,2500nm],\ 8º,\ h,\ 25ºC) = 94.1\%$

Optical components of CSP

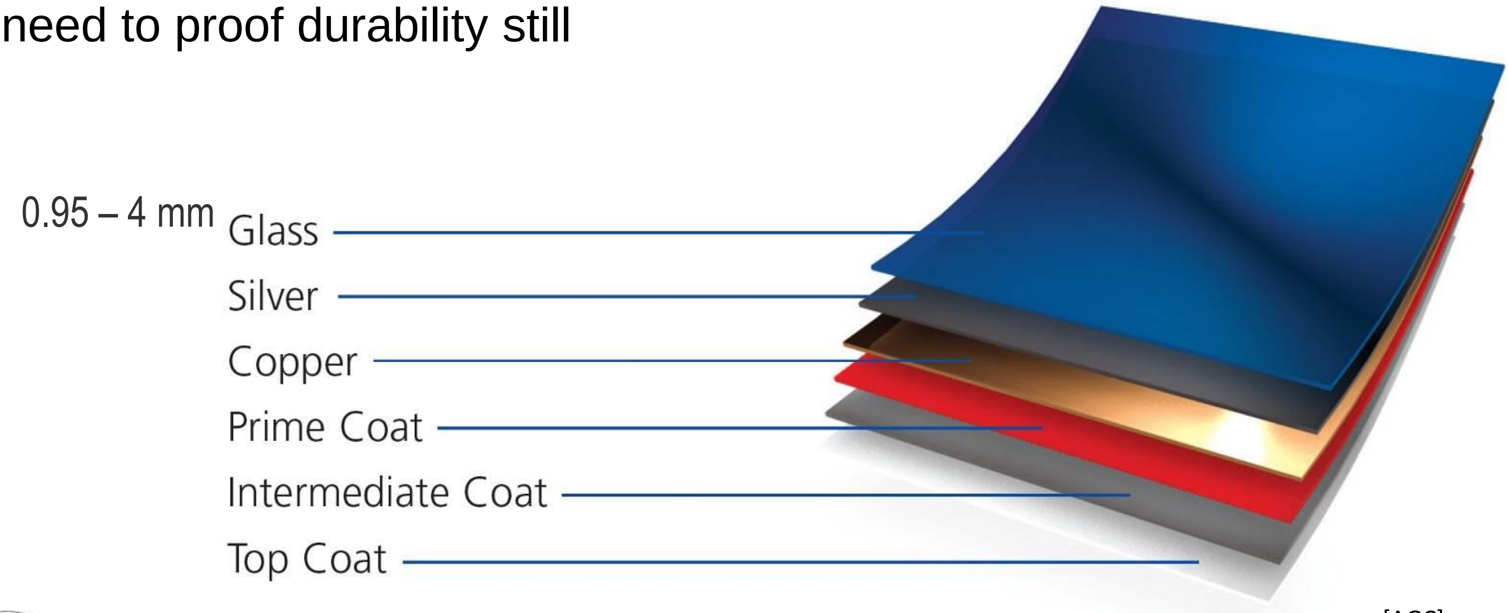
Mirror types – silvered-glass mirrors

Typical reflectance values:

$\rho_{s,h}$([280,2500nm], 8º, h, 25ºC) = 93.0 - 95.0%
$\rho_{\lambda,\varphi}$(660 nm, 15º, 12.5 mrad, 25ºC) = 95.0 - 96.0%

+ cost ~15€/m²
+ good durability: Pb containing paints proofed durability >30 years

Pb free paints need to proof durability still



[AGC]

Optical components of CSP

Mirror types – laminated glass mirrors

Typical reflectance values:

$\rho_{s,h}$([280,2500nm], 8º, h, 25ºC) = 94.5%

$\rho_{\lambda,\varphi}$(660 nm, 15º, 12.5 mrad, 25ºC) = 95.5%

+ Thin front glass increases reflectance

+ Excellent durability

- Cost

[Guardian]

Optical components of CSP

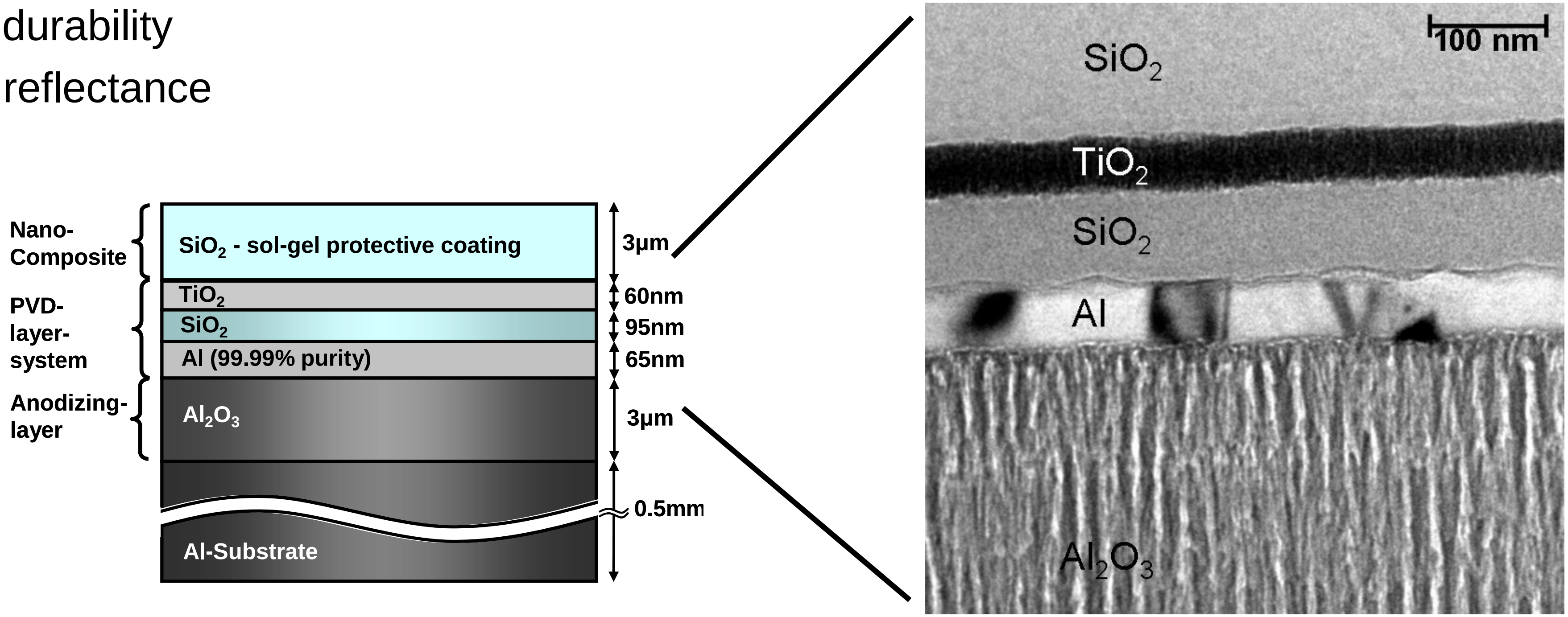
Mirror types – PVD coated aluminum reflectors

Typical reflectance values:

$\rho_{s,h}$([280,2500nm], 8º, h, 25ºC) = 90.0%

$\rho_{\lambda,\varphi}$(660 nm, 15º, 12.5 mrad, 25ºC) = 85.5%

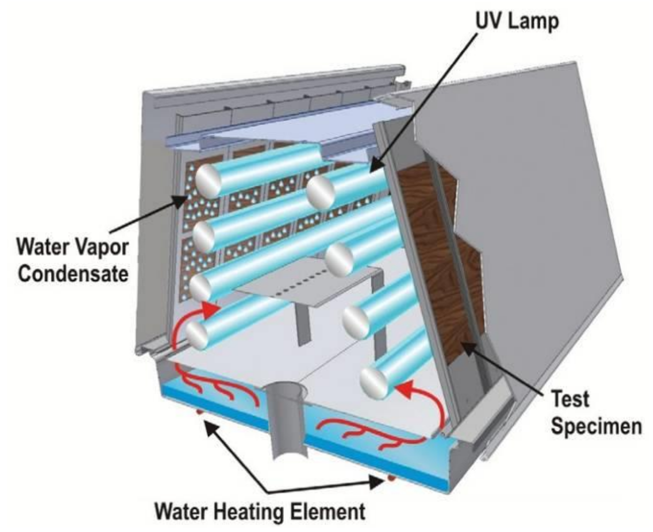
+ cost
+ flexible
- durability
- reflectance

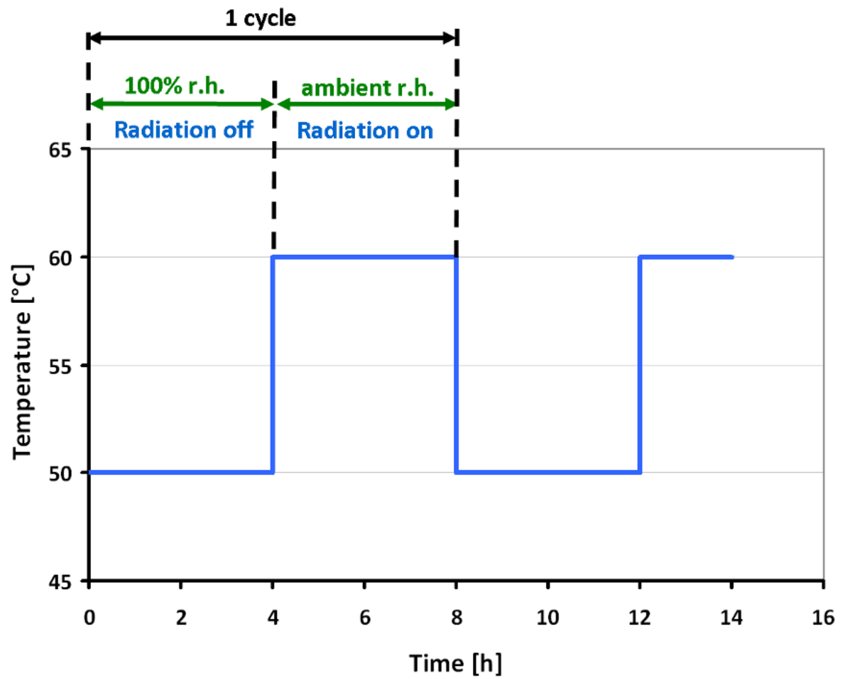


Accelerated aging tests

ISO 16474-3 (replaces ISO 11507): UV+humidity Test

Chamber temperature: 50 to 60° C
Humidity: ambient to 100% relative humidity
Radiation: lamp type II, UVA-340; 290-400 nm; peak emission at 340nm; lamp power matches 1 sun
Cycle time: 8 hours
Testing time: >1000 hours





Accelerated aging tests

IEC 62108 10.7a: Damp heat test 85/85

Chamber temperature: 85 ± 2° C
Humidity: 85 ± 5 % relative humidity
Testing time: 1000 hours

IEC 62108 10.7b: Damp heat test 65/85

Chamber temperature: 65 ± 2° C
Humidity: 85 ± 5 % relative humidity
Testing time: 2000 hours

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Accelerated aging tests

ISO 9227: Neutral salt spray test (NSS)

Chamber temperature:	35 ± 2 °C
Humidity:	constant 100% relative humidity
Sprayed solution:	demineralized water + 50 g/l NaCl (pH 6.5 – 7.2)
Condensation rate:	1.5 ± 0.5 ml/h on a surface of 80 cm^2
Sample position:	20 ± 5° respect to vertical
Testing time:	480 – 3500 hours

Accelerated aging tests

ISO 9227: Copper accelerated salt spray test (CASS)

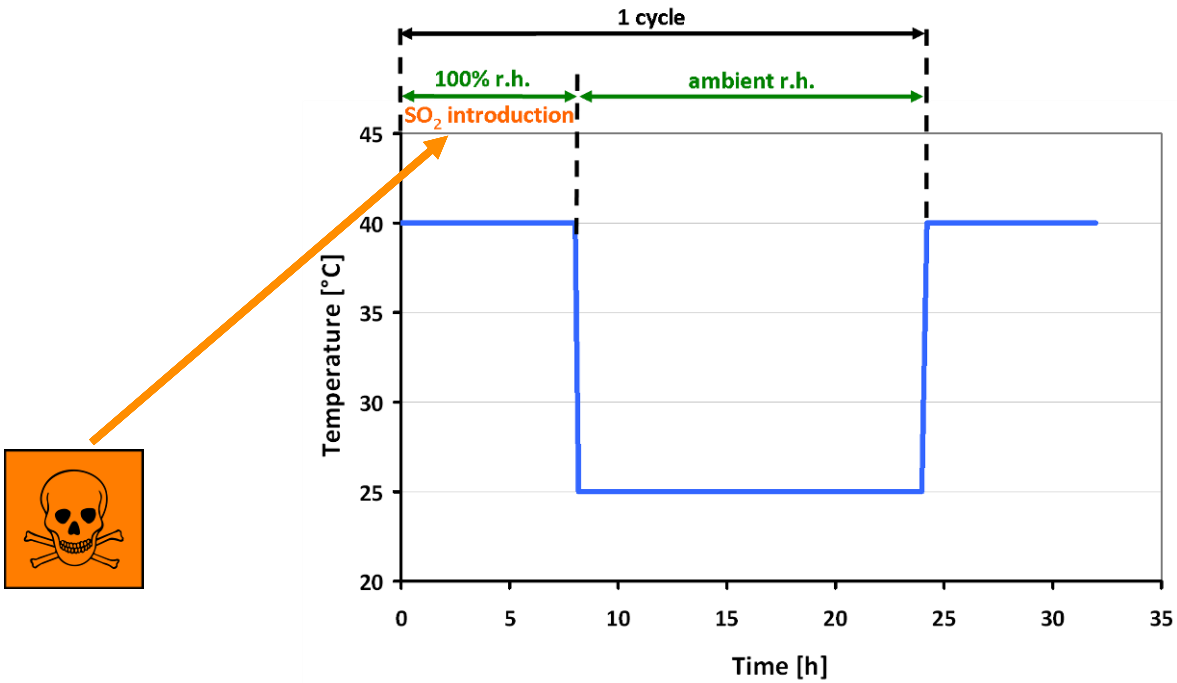
Chamber temperature: 50 ± 2 ° C
Humidity: constant 100% relative humidity
Sprayed solution: demineralized water + 50 g/l NaCl + 0.26 g/l $CuCl_2$ (pH 3.1 – 3.3)
Condensation rate: 1.5 ± 0.5 ml/h on a surface of 80 cm^2
Sample position: 20 ± 5° respect to vertical
Testing time: 120 – 480 hours

$CuCl_2$

Accelerated aging tests

DIN 50018 / ISO 6988: Kesternich Test

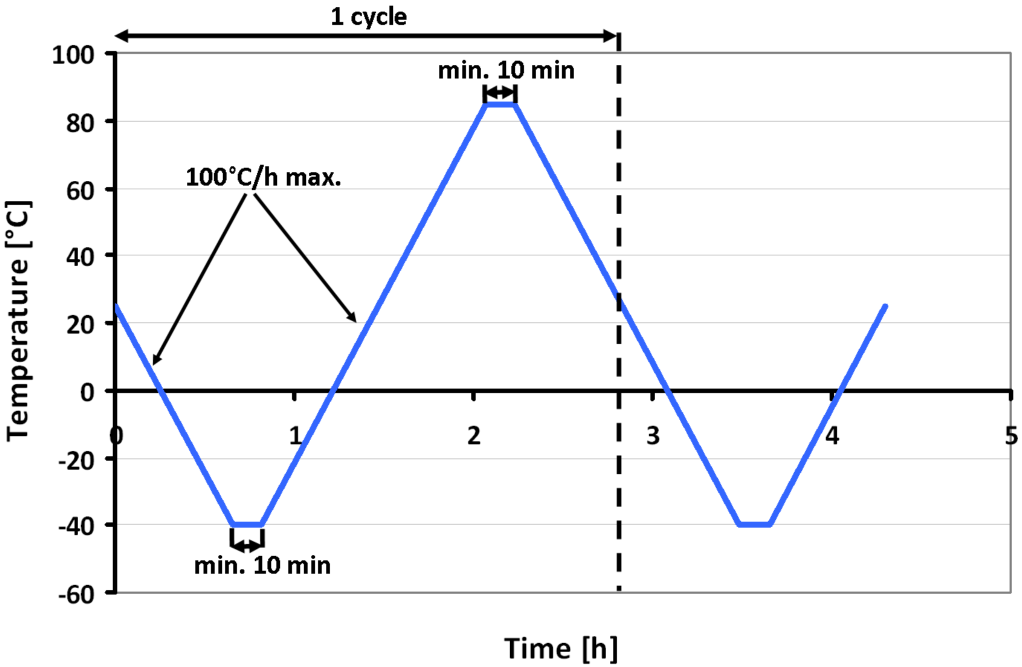
Chamber temperature:	ambient / 40 ± 3° C
Humidity:	ambient / 100% relative humidity
Initial SO_2 concentration:	0.33 or 0.67% of volume of testing chamber
Cycle time:	24 hours
Testing time:	>20 cycles



Accelerated aging tests

ISO 61215: Thermal Cycling

Chamber temperature: -40° C to +85° C
Humidity: dry
Cycle duration: min. 2h 50min, max. 6h
Recommended cycle number: >100



Accelerated aging tests

Thermal Cycling with humidity based on ISO 6270-2CH

Chamber temperature: -40° C to +85° C
Humidity: ambient to 100% relative humidity
Cycle duration: 24 h
Recommended cycle number: >20

Method A

Step	Duration (h)	Temperature (ºC)	Relative Humidity (%)
1	4	85	Not controlled
2	4	-40	Not controlled
3	16	40	97 ± 3

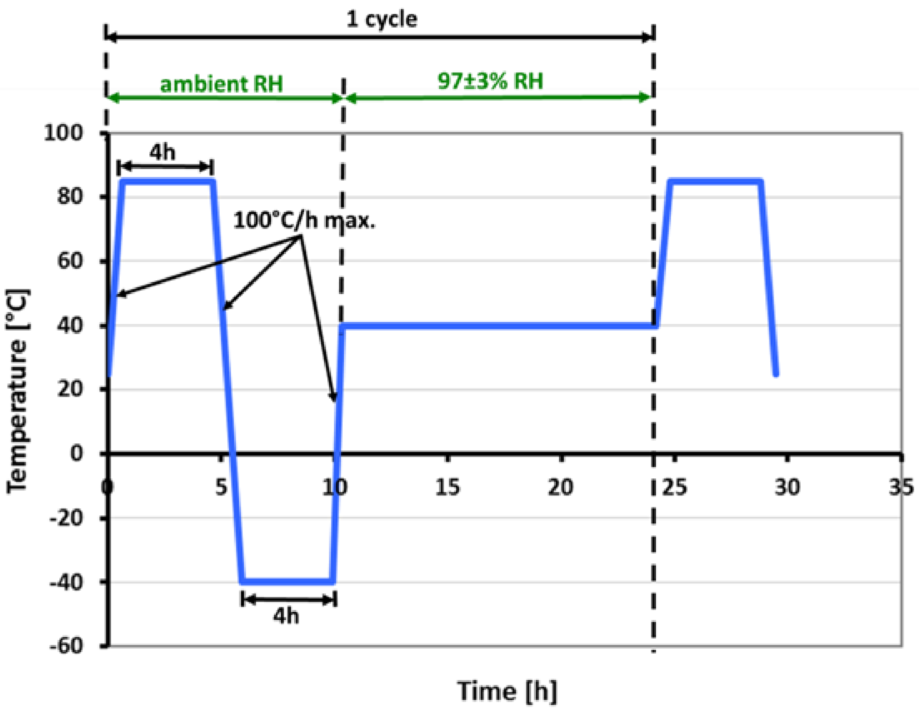
Method B1

Step	Duration (h)	Temperature (ºC)	Relative Humidity (%)
1	4	85	Not controlled
2	4	-40	Not controlled
3	16	85	85 ± 3

Method B2

Step	Duration (h)	Temperature (ºC)	Relative Humidity (%)
1	4	85	Not controlled
2	4	-40	Not controlled
3	40	65	85 ± 3

Method A

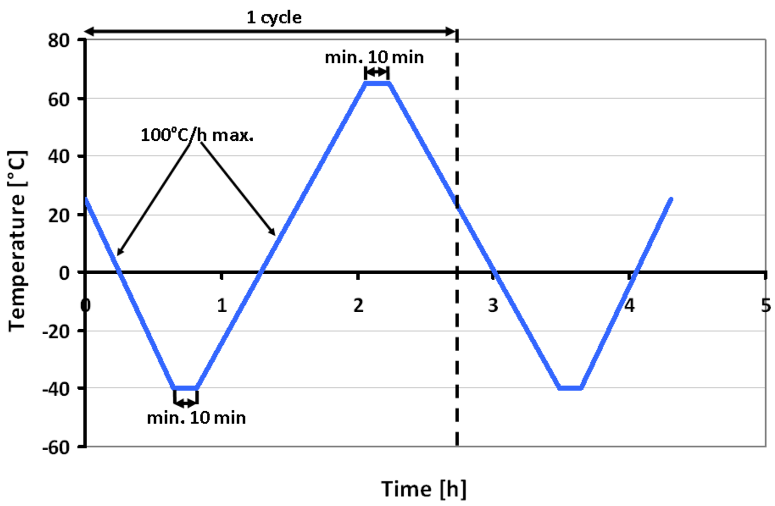


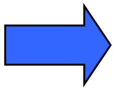
Accelerated aging tests

Humidity Freeze Test IEC 62108

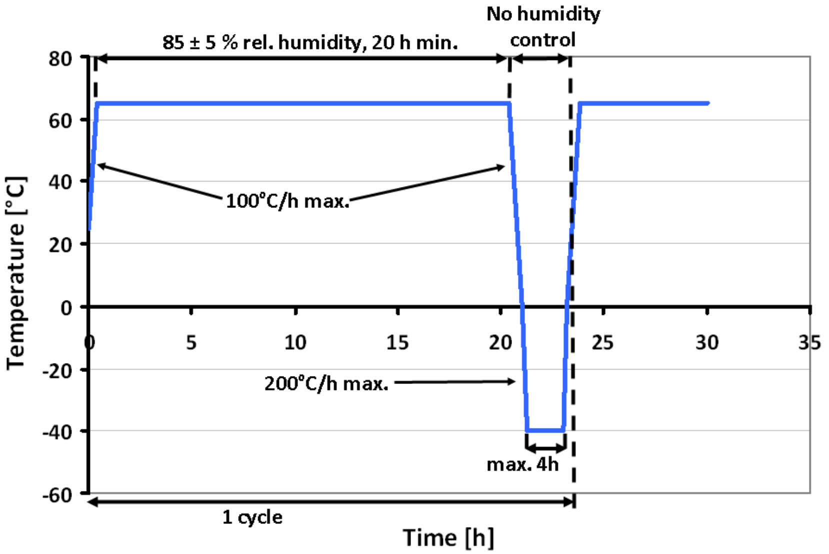
Chamber temperature:	-40° C to +65° C
Humidity:	ambient to 85% relative humidity
Precycling:	400 cycles
Cycle duration:	24 h
Freeze cycle number:	40
Total testing time:	~2000h

400 precycles -40 to 65° C, dry





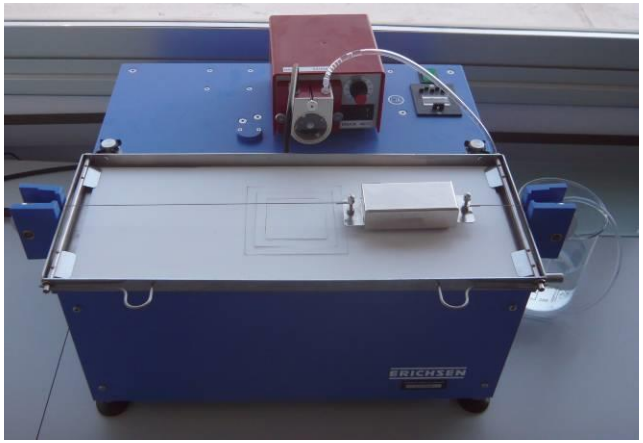
40 humidity-freeze cycles



Accelerated aging tests

Abrasion testing

Available standards: ISO 11998, DIN ISO 9211-4



Simulation of cleaning cycles

Scratching of coatings with controlled normal force

Accelerated erosion testing

Sand trickling test DIN 52348

sand container

meshes

rotating sample under impact angle α

Closed loop sand storm chamber (based on MIL-STD 810G)

Testing programs

Basic program

Test	Standard	Testing conditions	Duration
Neutral Salt Spray (NSS)	ISO 9227	T: 35ºC pH: 6.5 to 7.2 at 25ºC	480 h
Copper-accelerated acetic acid salt spray (CASS)	ISO 9227	T: 50° C pH: 3.1 to 3.3 at 25° C	120 h
Condensation	ISO 6270-2	T: 40° C RH: 100%	480 h
UV and humidity test	ISO 16474-3	4h UV exposure at 60° C; 4h 100% RH at 50° C	1000h on both sides
Combined thermal cycling and condensation test	AENOR draft Method A	4 h 85° C, 4 h -40° C, Method A: 16 h T° : 40° C and 97±3% RH	10 cycles (240 hours)

Advanced program

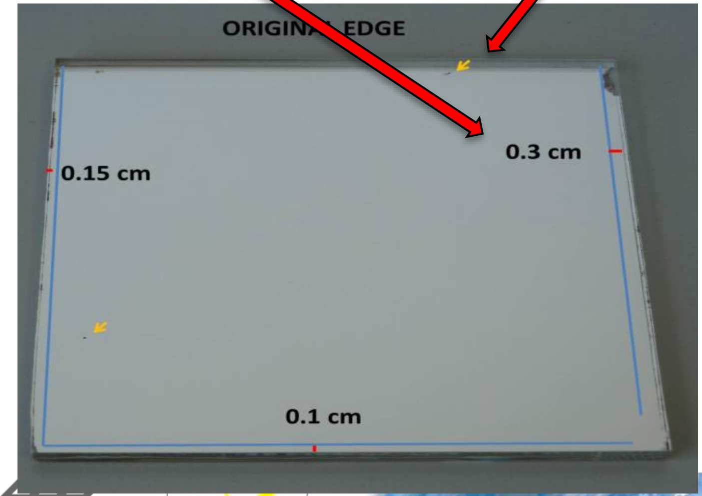
Test	Standard	Testing conditions	Duration
Neutral Salt Spray (NSS)	ISO 9227	T: 35ºC pH: 6.5 to 7.2 at 25ºC	3000 h
Copper-accelerated acetic acid salt spray (CASS)	ISO 9227	T: 50° C pH: 3.1 to 3.3 at 25° C	480 h
Condensation	ISO 6270-2	T: 40° C RH: 100%	1000 h
UV and humidity test	ISO 16474-3	4h UV exposure at 60° C; 4h 100% RH at 50° C	1000h on both sides
Combined thermal cycling and condensation test	AENOR draft	4 h 85° C, 4 h -40° C, Method A: 16 h T: 40° C and 97±3% RH	20 cycles (480 hours)
Thermal cycling	IEC 62108 (Test 10.6 TCA3)	T: 65ºC - -40ºC	150 cycles (~280 h)
Damp Heat	IEC 62108 (Test 10.7b)	T: 65ºC; RH=85%	2000 h
Combined thermal cycling and Damp Heat	IEC 62108 (Test 10.6 TCA3 + Test 10.7b)	1st step: thermal cycling as above, 2nd step: Damp Heat test	150 cycles + 2000 h
Combined thermal cycling and NSS	IEC 62108 (Test 10.6 TCA3) + ISO 9227	1st step: thermal cycling as above, 2nd step: NSS	150 cycles + 3000 h
Sand erosion test	Test dust ISO 12103-1 A4 coarse	v = 12.5 m/s, c = 100 mg/m³	10, 20, 40 and 60 min

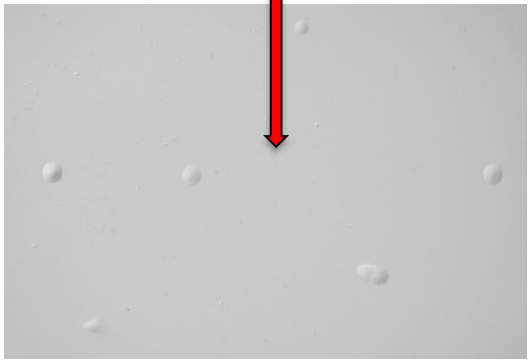
Accelerated aging testing

Analyzed parameters

Reflectance losses $\Delta\rho_s([280,2500],8^\circ,h)$ $\Delta\rho_\lambda(660nm,8^\circ,h)$ $\Delta\rho_\lambda(660nm,15^\circ,12.5mrad)$

Degradation results		
Maximum edge corrosion penetration (cm)	Number of corrosion spots >200µm per 300 cm² in the silver layer	Number of bubbles per 300 cm² in the paint layer
0.3	4	56





Thank you for your attention