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23 June 2022

3:00 pm – 4:00 pm | CEST, Berlin
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pv magazine **webinars**

Chasing the sun – advanced analysis for innovative PV materials

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Welcome!

Do you have any questions? ❓ 🙋

Send them in via the Q&A tab. 👉 We aim to answer as many as we can today!

You can also let us know of any tech problems there.

We are recording this webinar today. 🎥

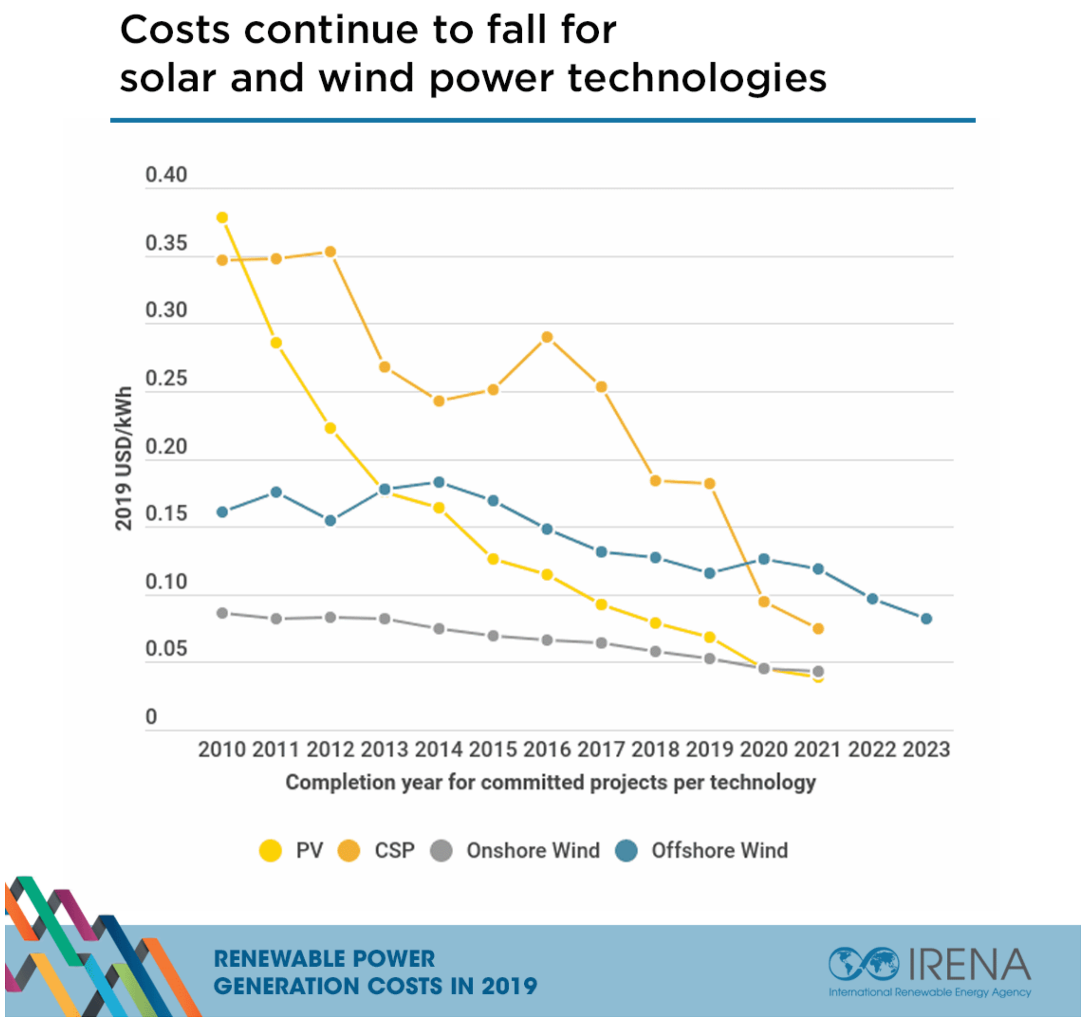
We'll let you know by email where to find it and the slide deck, so you can re-watch it at your convenience. 👀 💡

Chasing the Sun – Advanced Analysis for Innovative PV Materials

Advanced Analysis for Innovative PV Materials

Gerlinde Wita, Gernot Oreski, Serge Timmermans, Krystelle Mafina

Solar Economics & The Future



- Fastest growing of the renewables
- Huge diversity of manufacturers – facing similar challenges
- Cheapest since 2020 reporting

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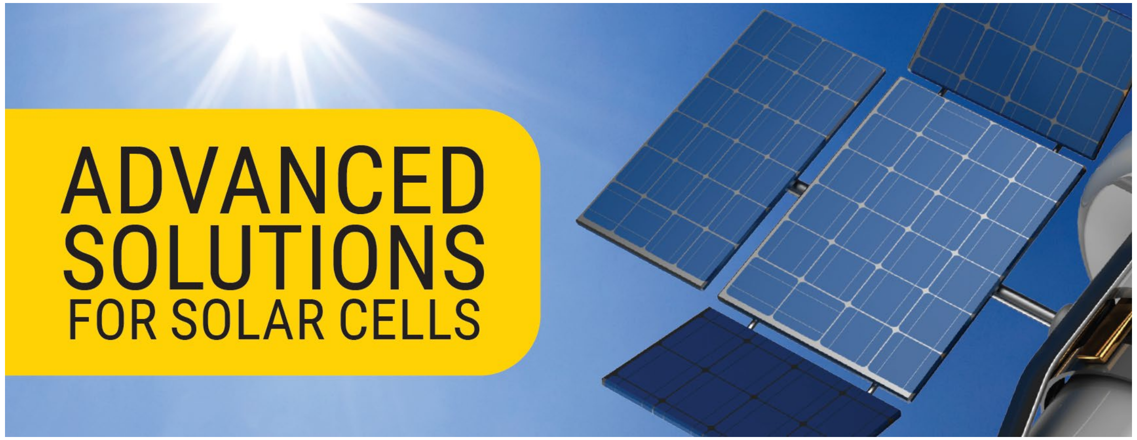
Innovation & Material Science Challenges



- Material Innovation – esp glass, silicon, polymers
- Properties of cells, wafers, interconnections is vital to understand
- High product quality and reduce costs are key in order to stay ahead of the competition

Polymers for photovoltaics

Ensuring module reliability via proper material testing

Dr. Gernot Oreski

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PV market

- Continuous strong market growth [1]
  - ✓ *Annual growth rates between 30 and 40 %*
- PV market is highly competitive with enormous cost pressure
  - ✓ *Average learning rate of about 80%*
- Market is driven by technological developments and market conditions [1]
  - ✓ *In recent years many new PV module materials and PV module designs were launched on the market*
- Motivation for new PV module materials and module designs [2]
  - ✓ *Decrease of LCOE: Cost reduction and performance improvement*
  - ✓ *New technological requirements*
  - ✓ *Sustainability and legal regulations*

- Higher efficiency
- Reduction of high impact materials
- Advanced production technology
- Economy of scale

Average price of PV modules fell by 20% for each doubling of production volume

[1] *European Comission, PV Status Report 2019,* https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/pv-status-report-2019
[2] G Oreski *et al* 2022 *Prog. Energy* **4** 032003, https://www.doi.org/10.1088/2516-1083/ac6f3f

PV Module technology

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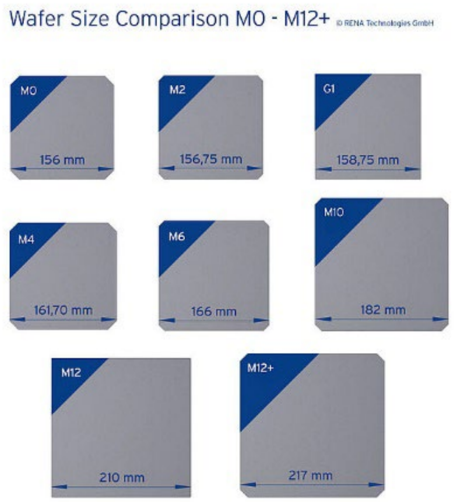
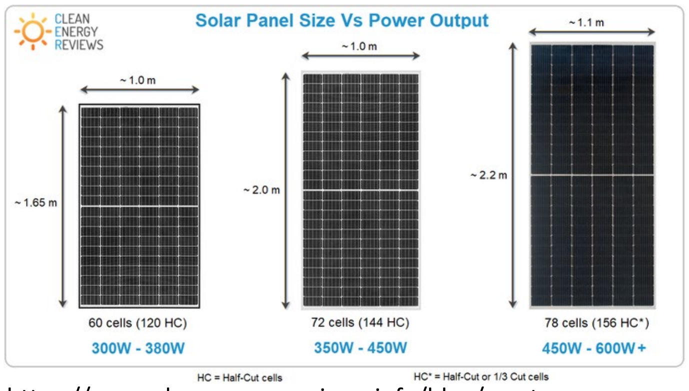
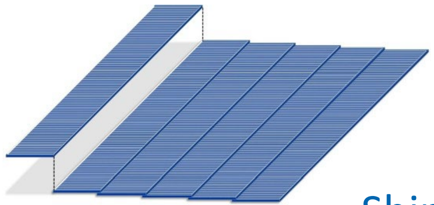


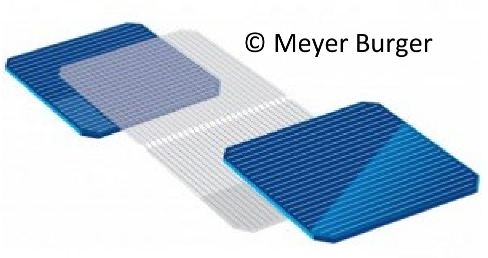
https://www.rena.com/en/products/large-wafer-wet-processing/

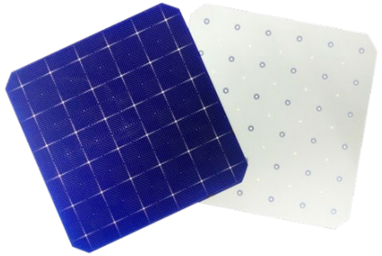


https://www.cleanenergyreviews.info/blog/most-efficient-solar-panels

New materials and technologies in PV modules [2]







Shingling Multiwires

https://doi.org/10.1016/j.apsusc.2020.145420

Structured foil

https://www.sunportpower.com/

- Wafer size increases
- PERC and HJT will become dominant cell technologies
- Bificial DG PV modules
- Polyolefin encapsulants
- New backsheet architectures (co-extruded, coated)
- New interconnection technologies
- Half cells will gain more market share
- Module sizes increase

New IEA Task 13 report on DESIGNING NEW MATERIALS FOR PHOTOVOLTAICS

- ✓ Report IEA-PVPS T13-13:2021, April 2021
- ✓ https://iea-pvps.org/key-topics/designing-new-materials-for-photovoltaics/

[2] G Oreski *et al* 2022 *Prog. Energy* **4** 032003, https://www.doi.org/10.1088/2516-1083/ac6f3f

PV systems designed for specific environmental conditions / Integrated PV

Desert PV

Vehicle integrated PV

© Sono Motors

Agri PV

© Fraunhofer ISE

BIPV

© Ertex Solar

PV in transport infrastructure

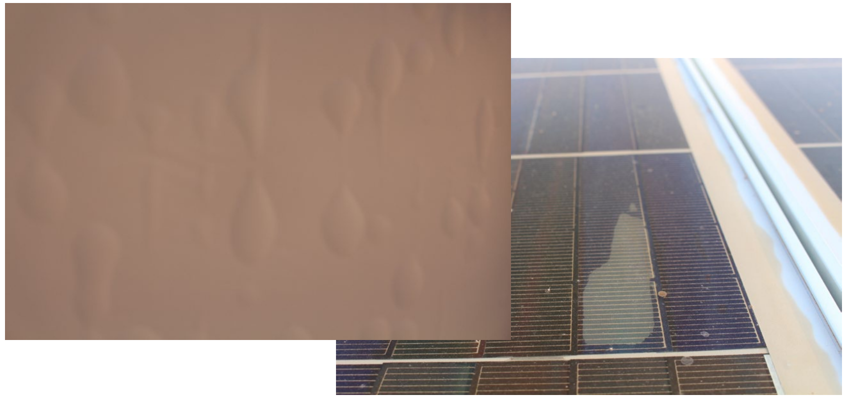
© AIT

Floating PV

© Baywa r.e.

Challenges for new materials and components: Compatibility issues

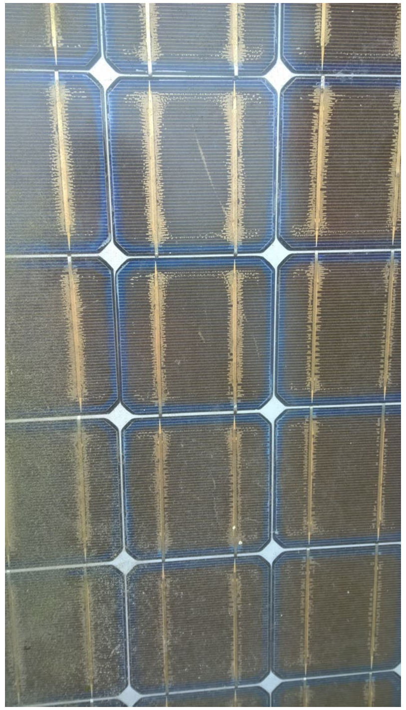
- Check of compatibility of PV module components will get more and more important in the future, as the variety on materials and components will grow
- **Emergence of new degradation modes** (e.g. LeTid, PID….)



Adhesion - delamination

✓ Adhesion to glass and solar cell strongly dependent of lamination parameters
✓ Surface treatment of backsheets usually optimized for adhesion to EVA but not alternative encapsulants

Backsheet yellowing: Migration of additives into backsheet-encapsulant interface are main cause for backsheet yellowing



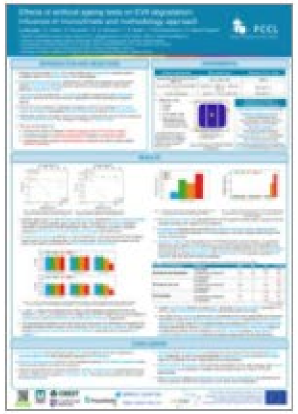
Corrosion: Broad variety of new ribbon materials, interconnection technologies and encapsulant films

Completely new degradation mechanisms?

Constant need for adaption of test methods and standards

Why is it important to know your materials?

Example: Encapsulant degradation



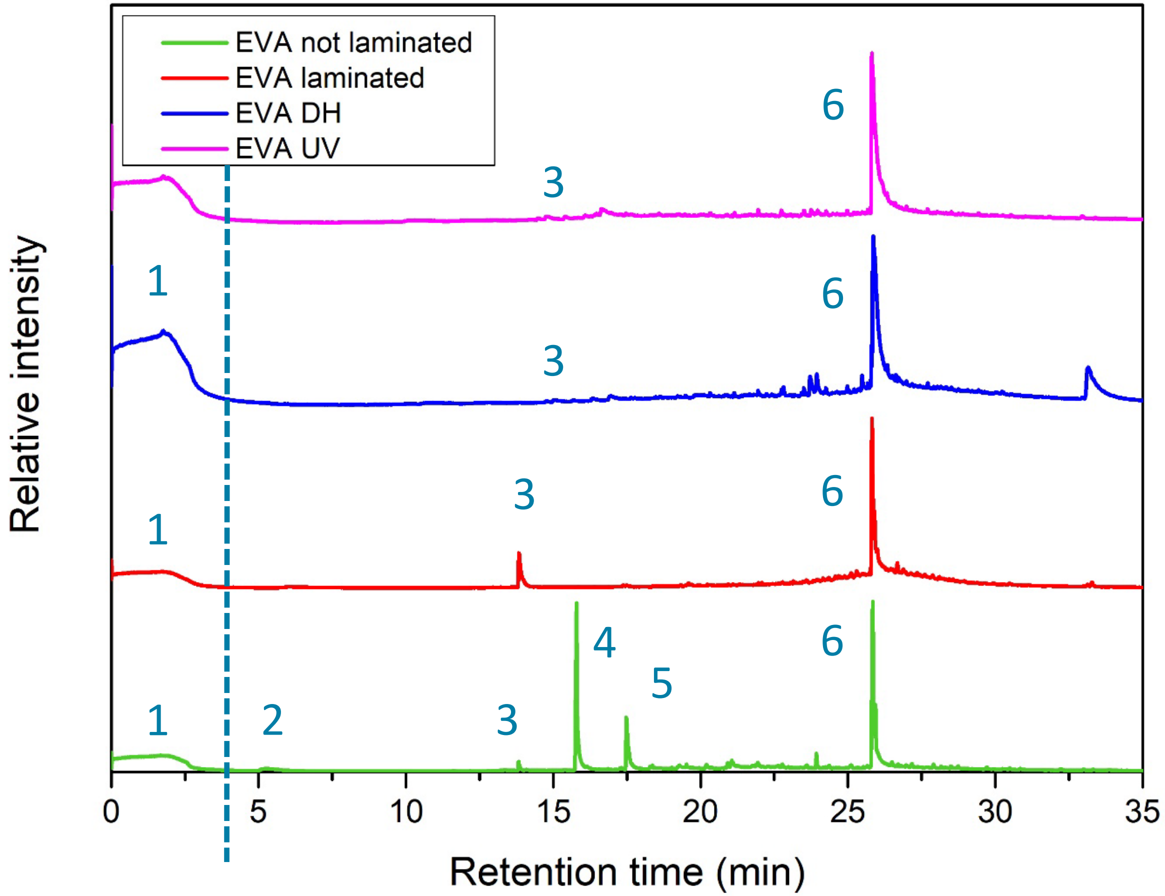
(6) EFFECTS OF ARTIFICIAL AGEING TESTS ON EVA DEGRADATION: INFLUENCE OF MICROCLIMATE AND METHODOLOGY APPROACH

Chiara Barretta[1], Gernot Oreski[1], Nikoleta Kyranaki[2,3], Djamel E. Mansour[4], Thomas R. Betts[2], Luciana Pitta Bauermann[4], Katharina Resch-Fauster[5].
[1]Polymer Competence Center Leoben GmbH (PCCL), Leoben, Austria [2]Centre for Renewable Energy Systems (CREST), Loughborough University, Loughborough, United Kingdom [3]Commissariat à l'Energie Atomique, CEA Grenoble, DRT/LITEN/DTS/SCPV/LCT, Le Bourget-du-Lac, France [4]Fraunhofer Institute for Solar Energy Systems (ISE), Freiburg im Breisgau, Germany [5]Department of Material Science and Testing of Plastics, University of Leoben, Leoben, Austria

AWARD WINNER

Encapsulant degradation

Additive analysis of EVA from PV modules

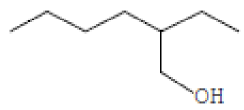


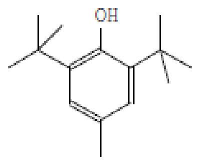
Thermal Desorption - Gas chromatography coupled with mass spectrometry

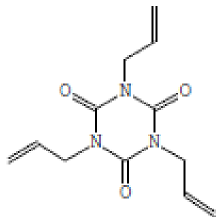
<u>Ageing tests:</u>

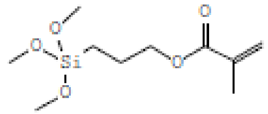
- DH (85°C/85% R.H.), 3000 hours
- UV exposure ~85 kWh/m^2 (ISO 4892-3 Cycle 1)
- Single layers of cured encapsulant

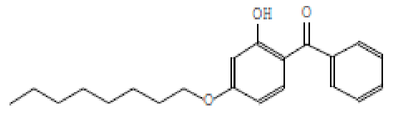
1) Acetic acid
2) Fragment of peroxide
3) Antioxidant
4) Crosslinking agent
5) Adhesion promotor
6) UV absorber





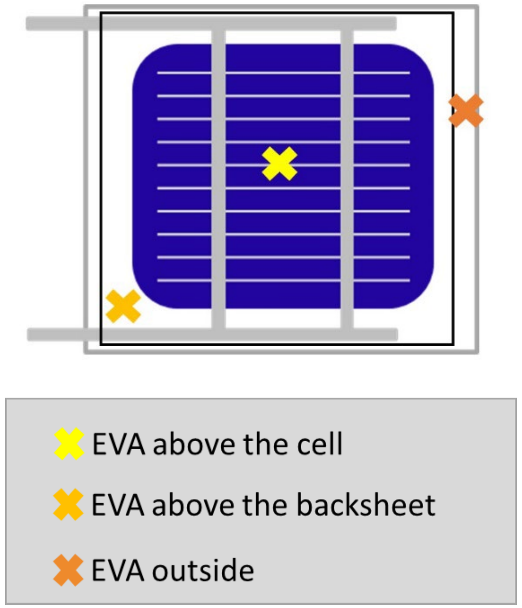






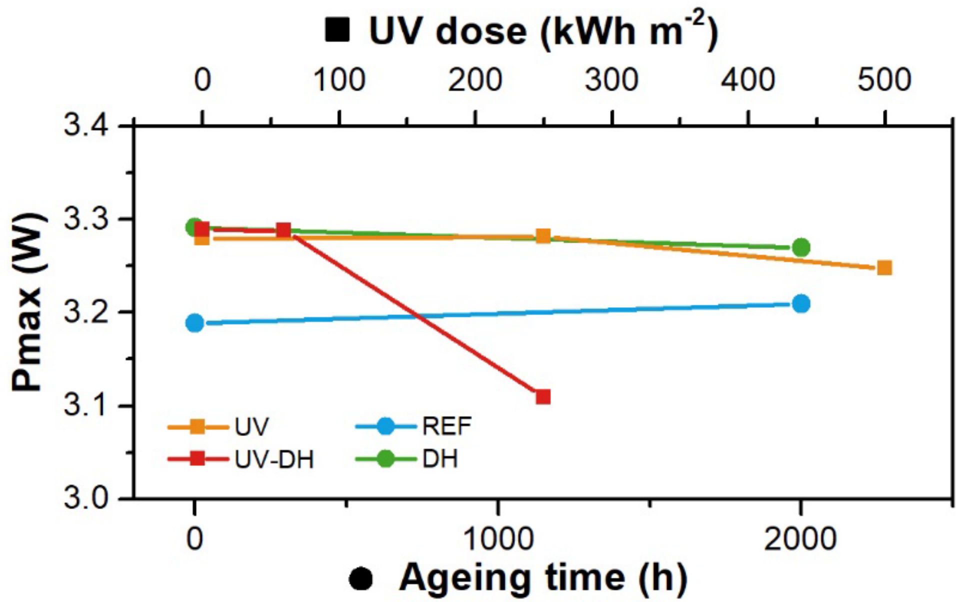
Encapsulant degradation

Artificial ageing test	Main parameters	Maximum Time / Dose
Damp Heat (IEC 61215- 2:2016 MQT 13)	85 °C, 85% Relative Humidity (RH)	2000 h
Dry UV IEC 61215-2:2016 MQT 11	250 W m^{-2} (280 nm – 400 nm), 60 °C	500 kWh m^{-2}
UV-DH combined	180 W m^{-2} , 60 °C, 85% RH	250 kWh m^{-2}



Different microclimate at each measurements position

- Decrease of P_{MAX} of about 5% for the sample exposed to UVDH combined test.
- **Decrease of power output associated to decrease in I_{SC}** with the same trend
- Decrease in I_{SC} might be associated to **discoloration** of encapsulant and/or **cell cracks**



Encapsulant degradation

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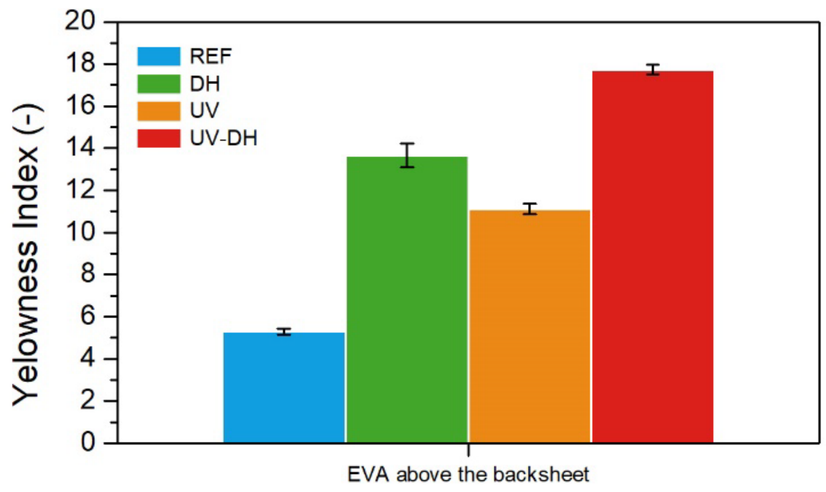
EVA *above the backsheet*	**REF**	**DH**	**UV**	**UV-DH**
Antioxidant - BHT	✓	✓	n.d.	n.d.
UV absorber - Benzophenone	✓	✓	✓	✓
EVA *above the cell*	**REF**	**DH**	**UV**	**UV-DH**
Antioxidant - BHT	✓	✓	✓	n.d.
UV absorber - Benzophenone	✓	✓	✓	✓
EVA *outside*	**REF**	**DH**	**UV**	**UV-DH**
Antioxidant - BHT	✓	✓	n.d.	n.d.
UV absorber - Benzophenone	✓	✓	n.d.	✓

- The antioxidant is no longer detectable in the samples exposed to UV and UV-DH combined test
- The UV absorber is detectable for all samples

✓= detected, n.d.= not detected

Thermal Desorption - Gas chromatography coupled with mass spectrometry

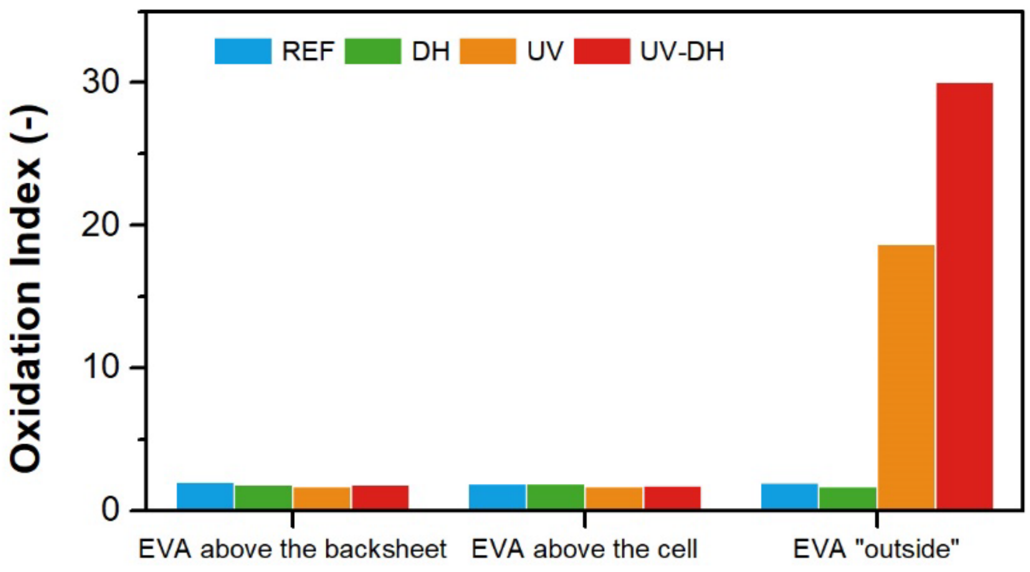


UV/VIS/NIR spectroscopy

- No relevant discoloration was observed for the EVA above the cell
- Discoloration was observed for the EVA above the backsheet, regardless the artificial ageing test applied
- Different mechanism behind discoloration
  - ✓ *DH: Interaction at backsheet / encapsulant interface*
  - ✓ *UV exposed samples: Discoloration correlated to degradation products of the antioxidant*

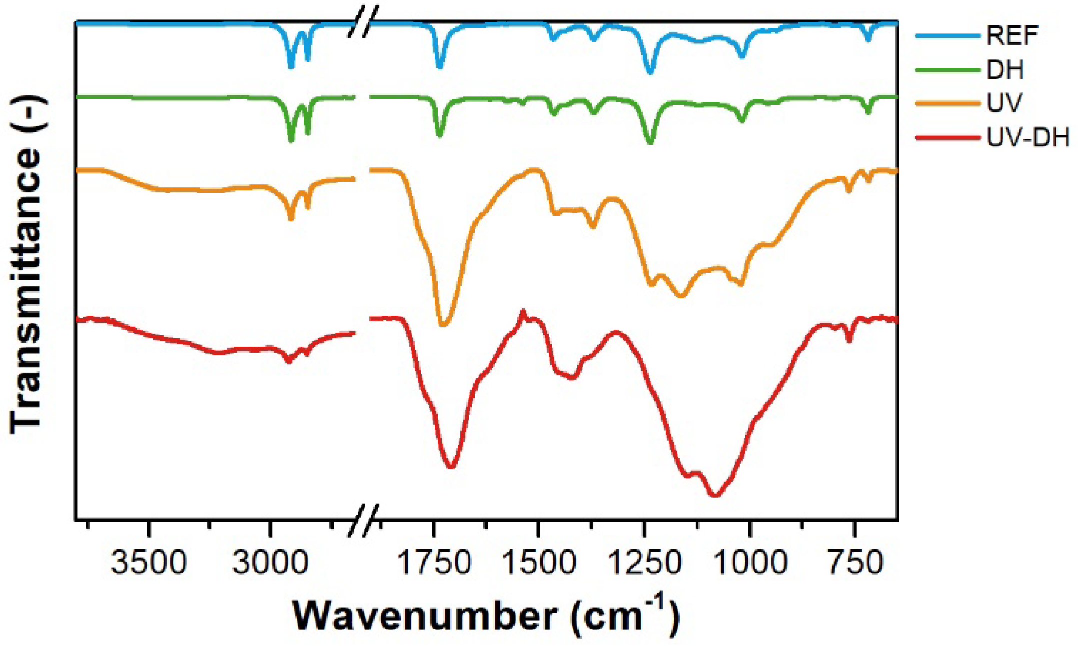
Encapsulant degradation

Oxidation index



FTIR-ATR spectroscopy

FTIR ATR spectroscopy of EVA outside



- No relevant changes detected in the encapsulant above the backsheet and above the cell, regardless the artificial test applied
- Strong oxidation signs for the encapsulant directly exposed to the environment in the UV and UV-DH combined test

- **Strong influence of micro-climate - no EVA degradation within the PV module**
- **Power loss can be attributed to yellowing**
- **Yellowing is not caused by degradation of the EVA molecules, but by additives**

How to predict and possibly prevent polymer related PV module failure modes?

Proper material selection and testing, testing, testing!

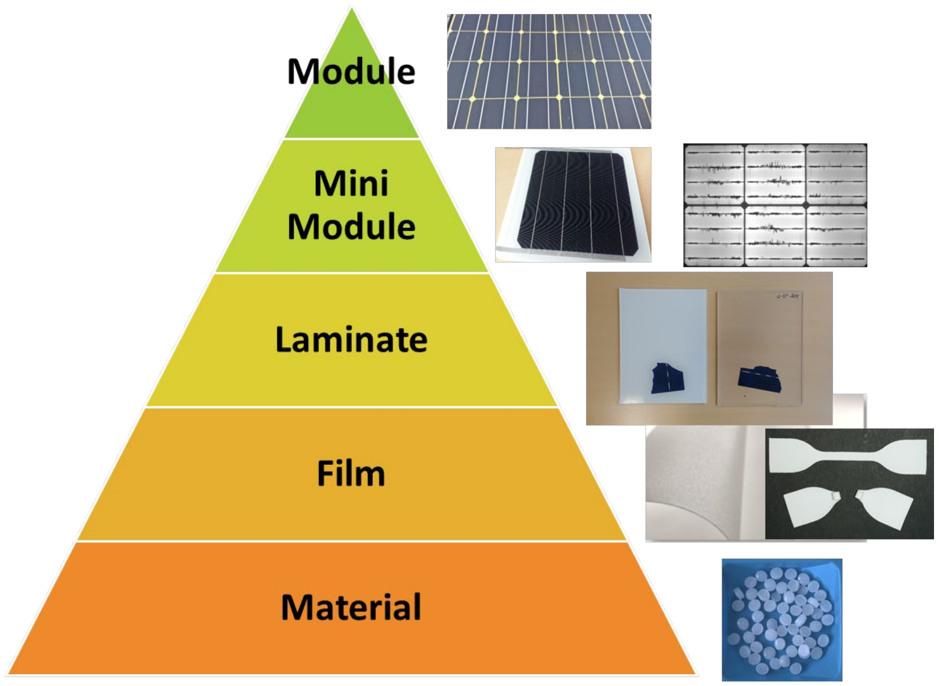
Testing of polymers for PV modules

Quality assurance to increase lifetime and reliability

DH + UV + TC / DML = Failure

Sequential / combined stress testing

- Currently the industry relies mostly on extended IEC testing for qualification of new module materials and module designs
- Material interactions and incompatibilities are getting in the focus of material and module developers
- Simultaneous combined or sequential stresses (UV, humidity, temperature and thermo-mechanical load) lead to more realistic degradation of PV modules in lab testing



Testing of encapsulants & backsheets in the lab

- Different levels with increasing effort in sample preparation and test procedures
- All levels of testing needed in order to guarantee high quality and reliability

Summary & Conclusions

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- **Role of the polymers in photovoltaic energy generation has generally been underestimated**
  - ✓ *No active role in power generation*
- **Choice of polymers has distinctive impact on PV modules attributes such as**
  1) ***Efficiency,*** *as the optical properties of encapsulant (transmittance) and backsheet (reflectance, back scattering) define the number of photons arriving at the solar cell*
  2) ***Quality,*** *as the main infant failures are caused by bad processing parameters, which are defined by the encapsulant properties, and material incompatibilities*
  3) ***Reliability,*** *as most PV module degradation modes are directly linked to polymer degradation and material interactions with polymer components*

→ Better understanding of material properties of polymers in PV modules and their influence degradation processes is a precondition for a successful development of new components and reliable PV module designs

Acknowledgements

Thank you for your attention!

Project funding

solartrain — This project has received funding from the European Union’s Horizon 2020 programme under GA. No. 721452.

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INFINITY — Energy Research Programm -, FFG No. **850414**, Klima- und Energiefonds

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PCCL Polymer Competence Center Leoben

Sustainable Polymer Solutions Group
March 2022

Optical Characterisation of PV Materials using the Lambda 1050

Peter van Nijnatten

High-End UV(Vis/NIR) applications for PV R&D

- **Variable Angle Spectroscopy**
  - Thin Film Analysis (layer thickness, Optical Constants)
  - Angular Resolved Scattering for PV Light Management
- **Measuring PV Cover Glass**
  - n
  - Glass Redox Measurements (Fe2+/Fe3+)
  - Total Transmittance and Reflectance measurements (diffuse and patterned cover glass)

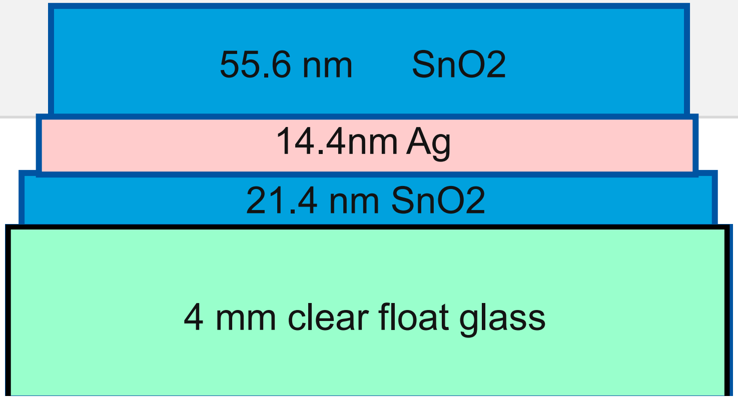
k

Tools for Variable Angle Spectroscopy

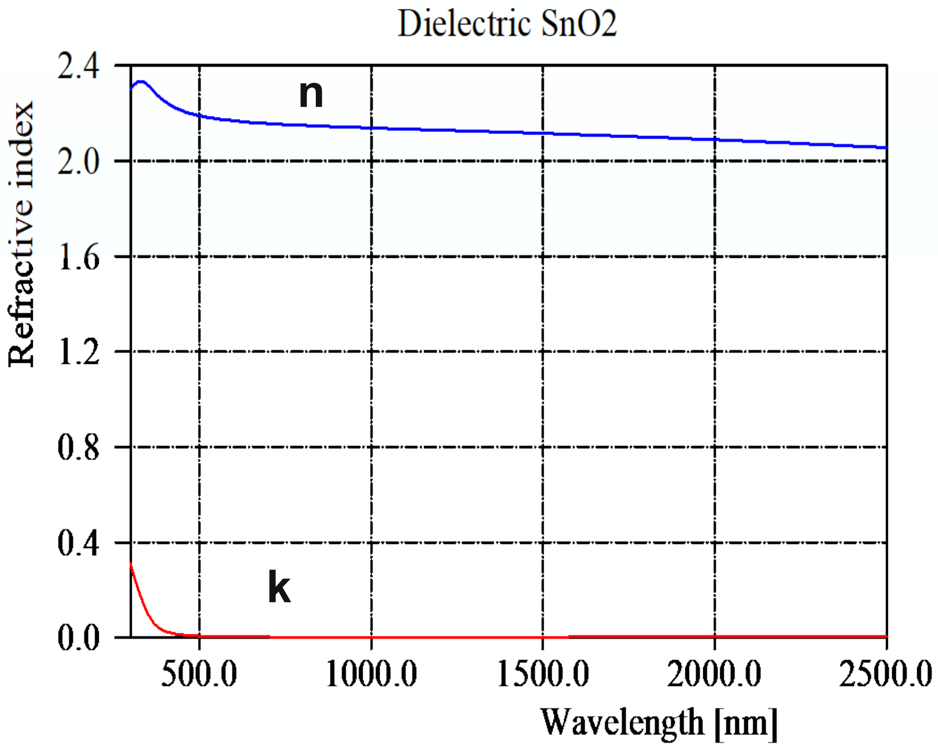
ARTA

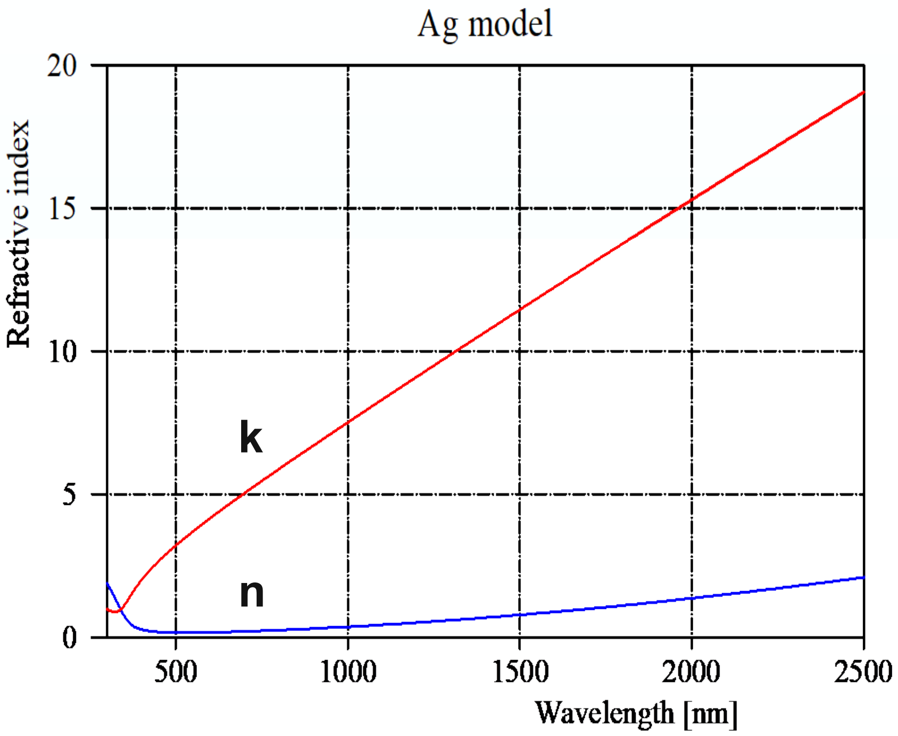
TAMS

Thin Film Analysis by VAS

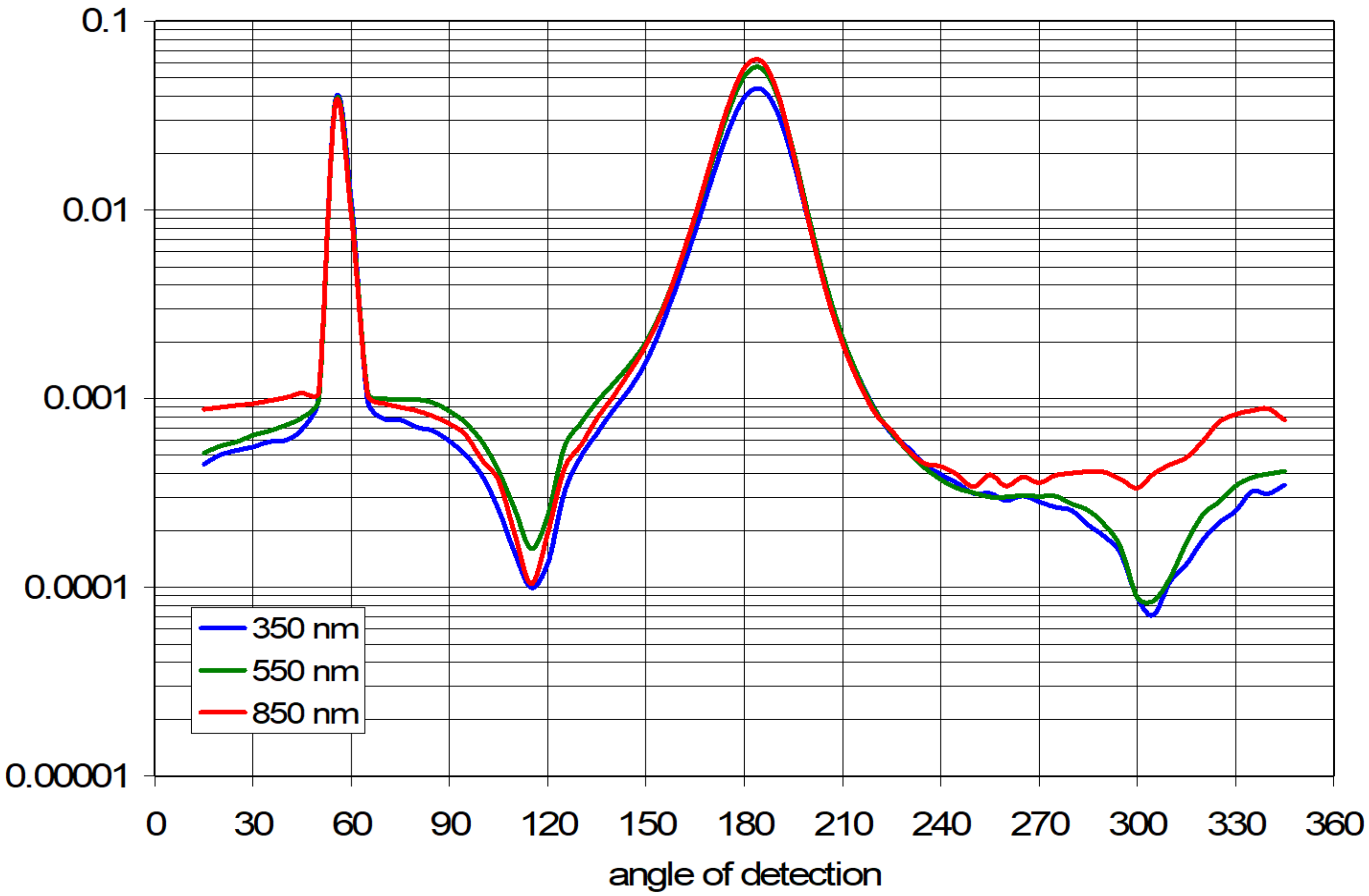


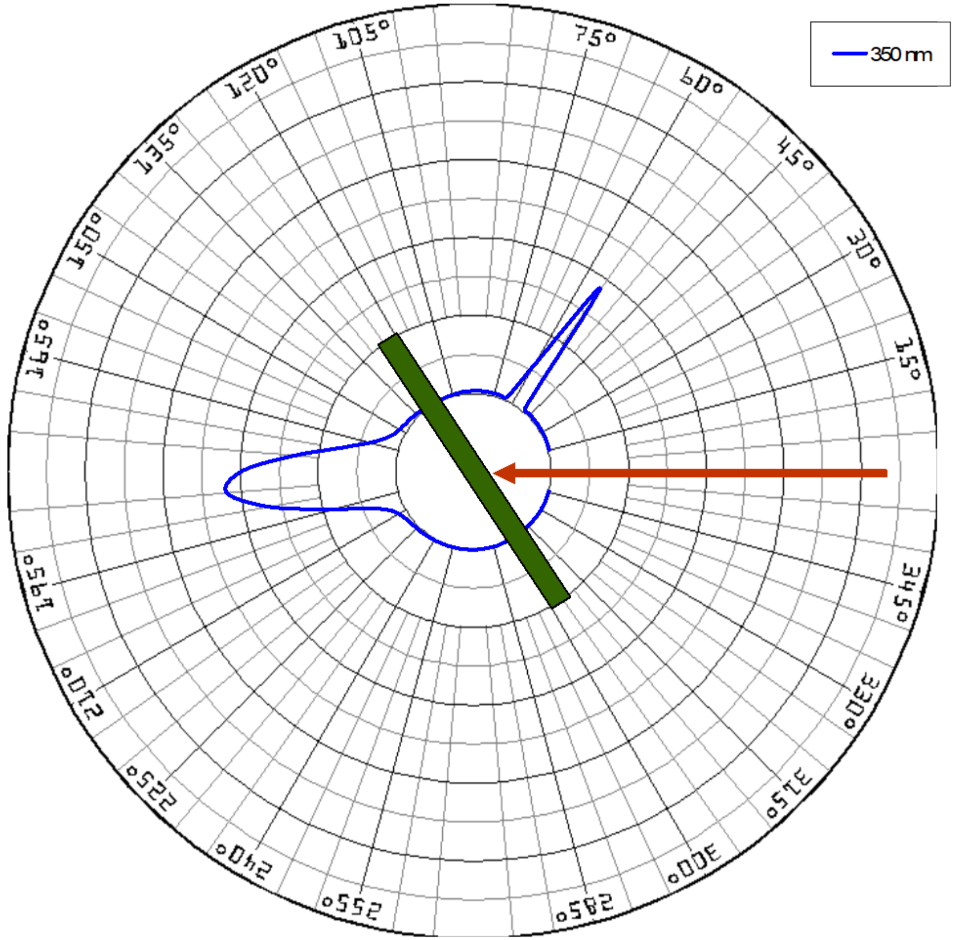
Non-linear regression is used to minimise the difference between measured and calculated spectra by varying the values for the thickness of the layers and the parameters of the dispersion models, resulting in their best estimates.





Angular Resolved Scattering





Surface Topology of TCO's analysed by Angular Resolved Scattering

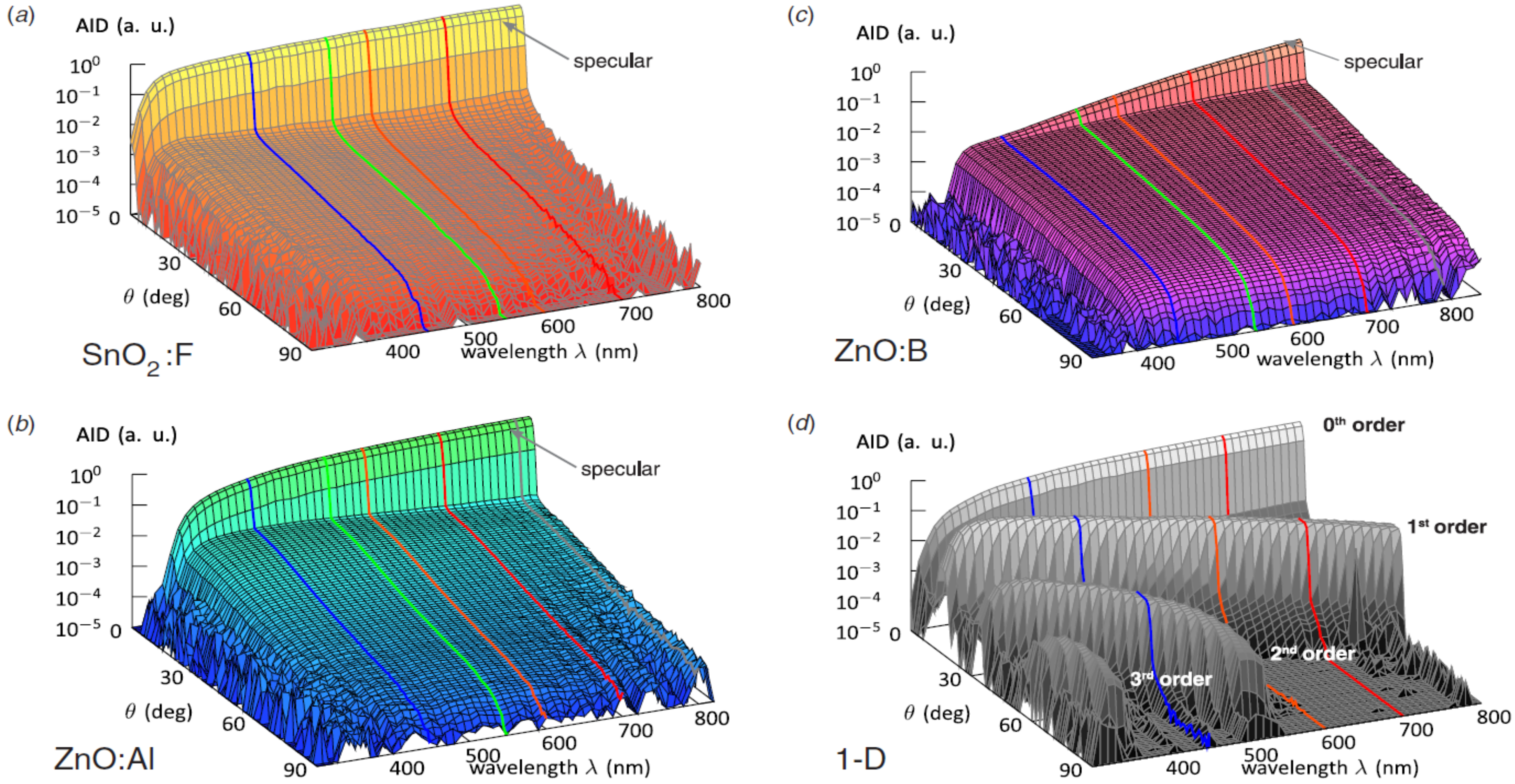
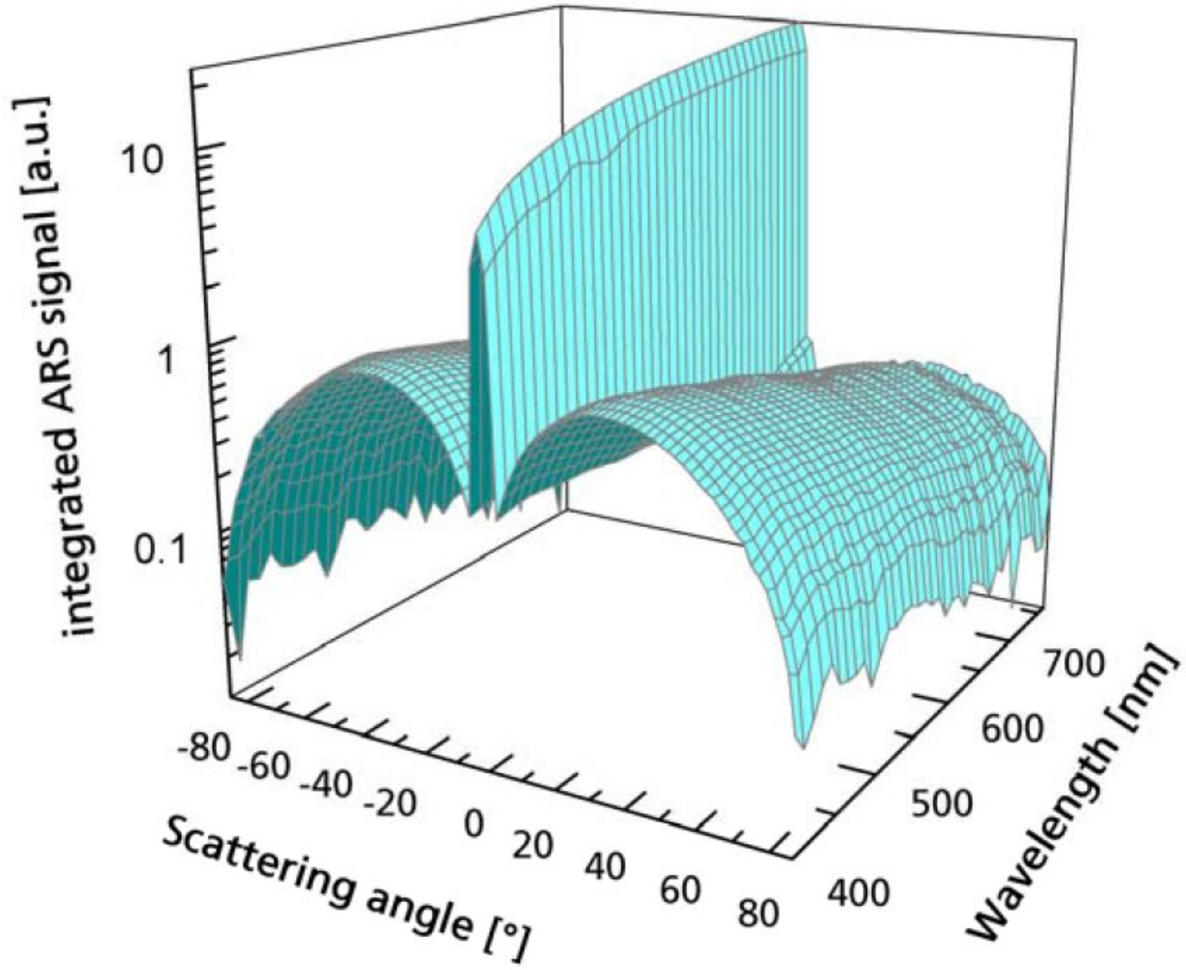


Figure 2. AID of light that is scattered when transmitting a surface-textured layer of SnO:F_2 (*a*), ZnO:Al (*b*), ZnO:B (*c*) and a 1D grating (*d*). The AID is shown as a function of the scattering angle θ

*) From: K Jaeger, O Isabella, R A C M M van Swaaij and M Zeman, Angular resolved scattering measurements of nano-textured substrates in a broad wavelength range, Meas. Sci. Technol. 22 (2011) 105601 (8pp)

Surface Topology of TCO’s analised by Angular Resolved Scattering



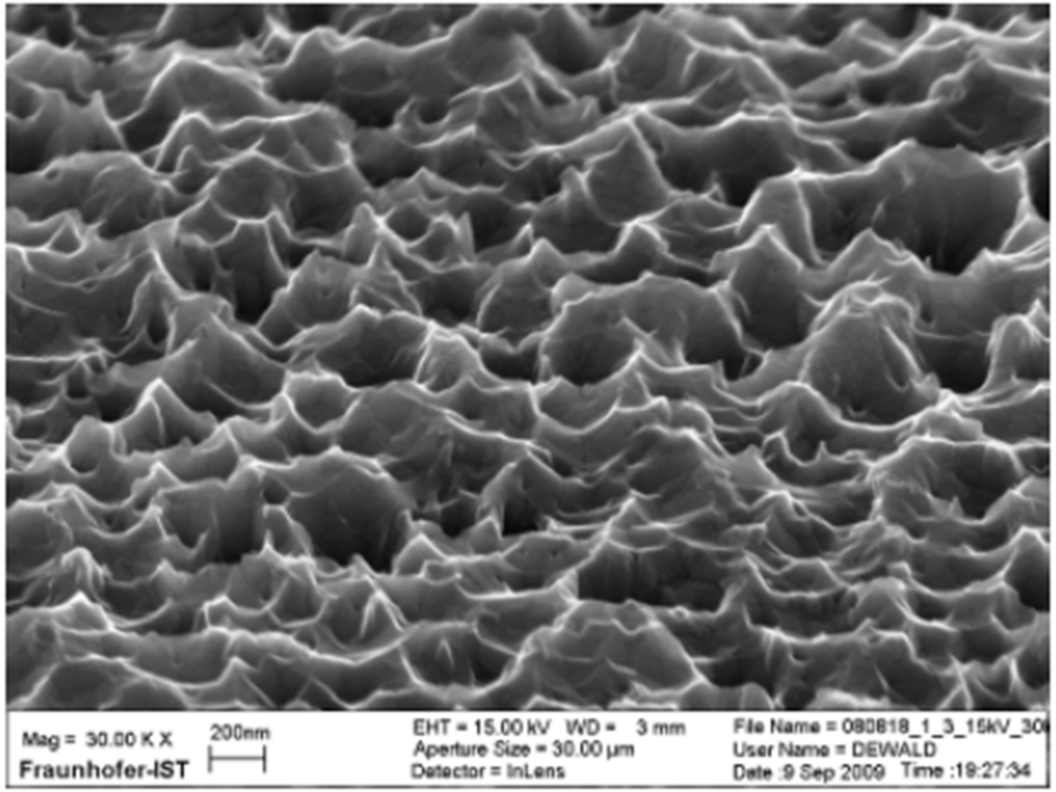
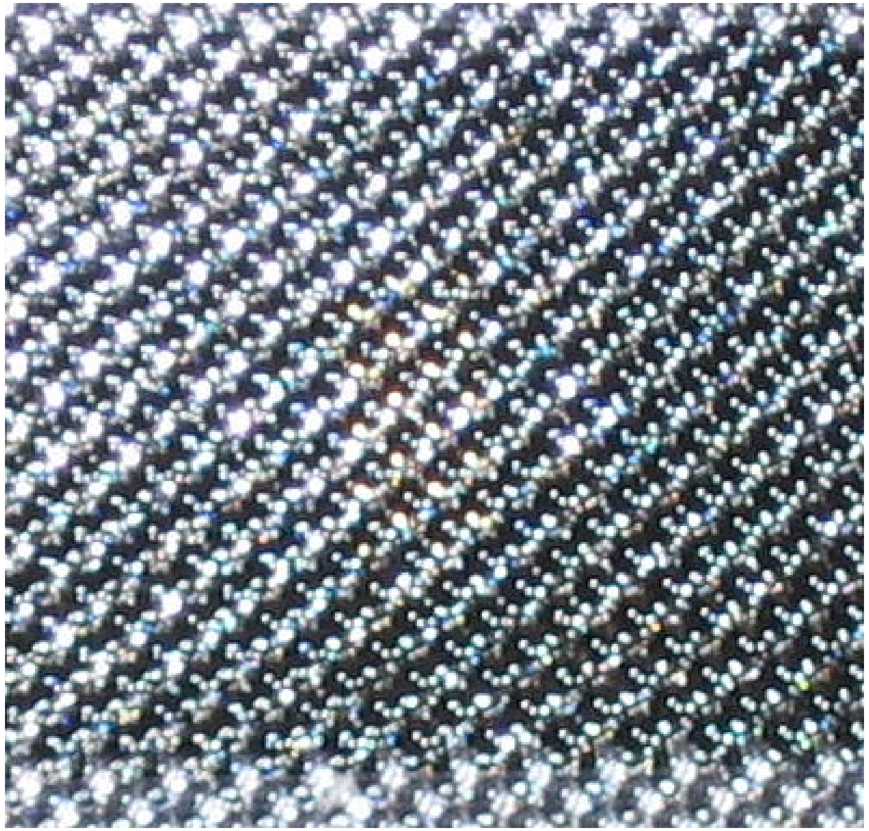
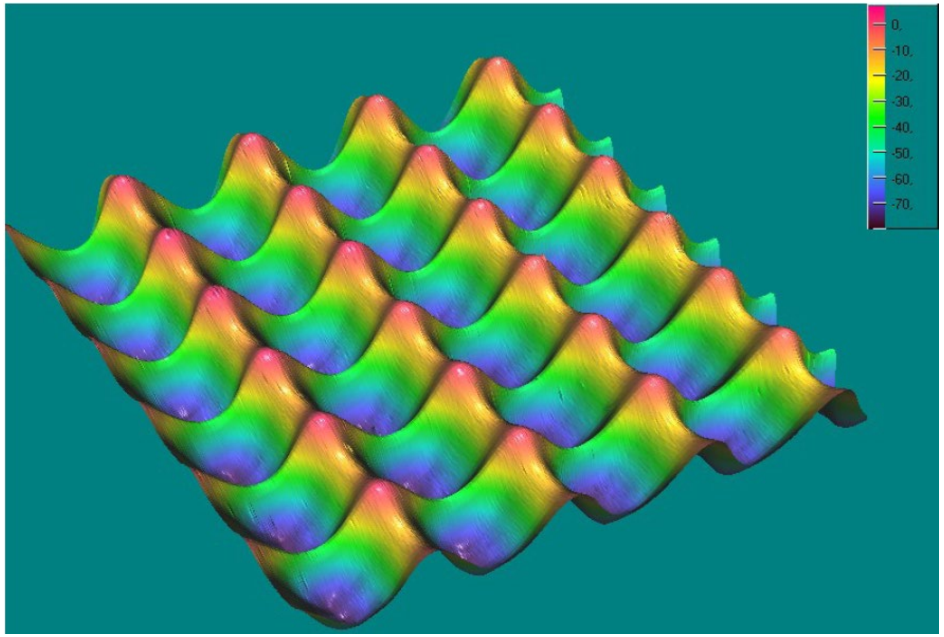


Figure 9: Integrated angular resolved light scattering (left) for a very rough and steep morphology (right).

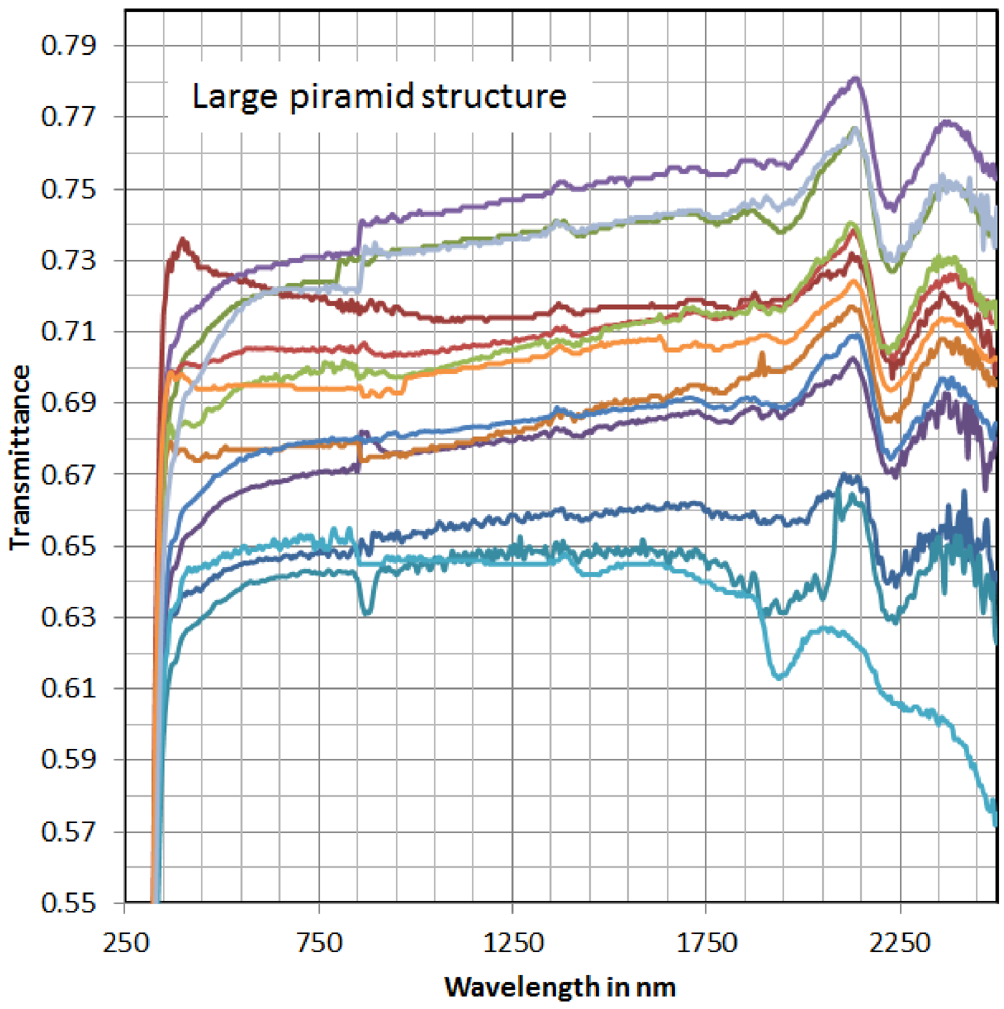
From Wilma Dewald, Volker Sittinger and Bernd Szyszka, Angular resolved light scattering measurements of textured TCOs, Fraunhofer Institute for Surface Engineering and Thin Films (IST)

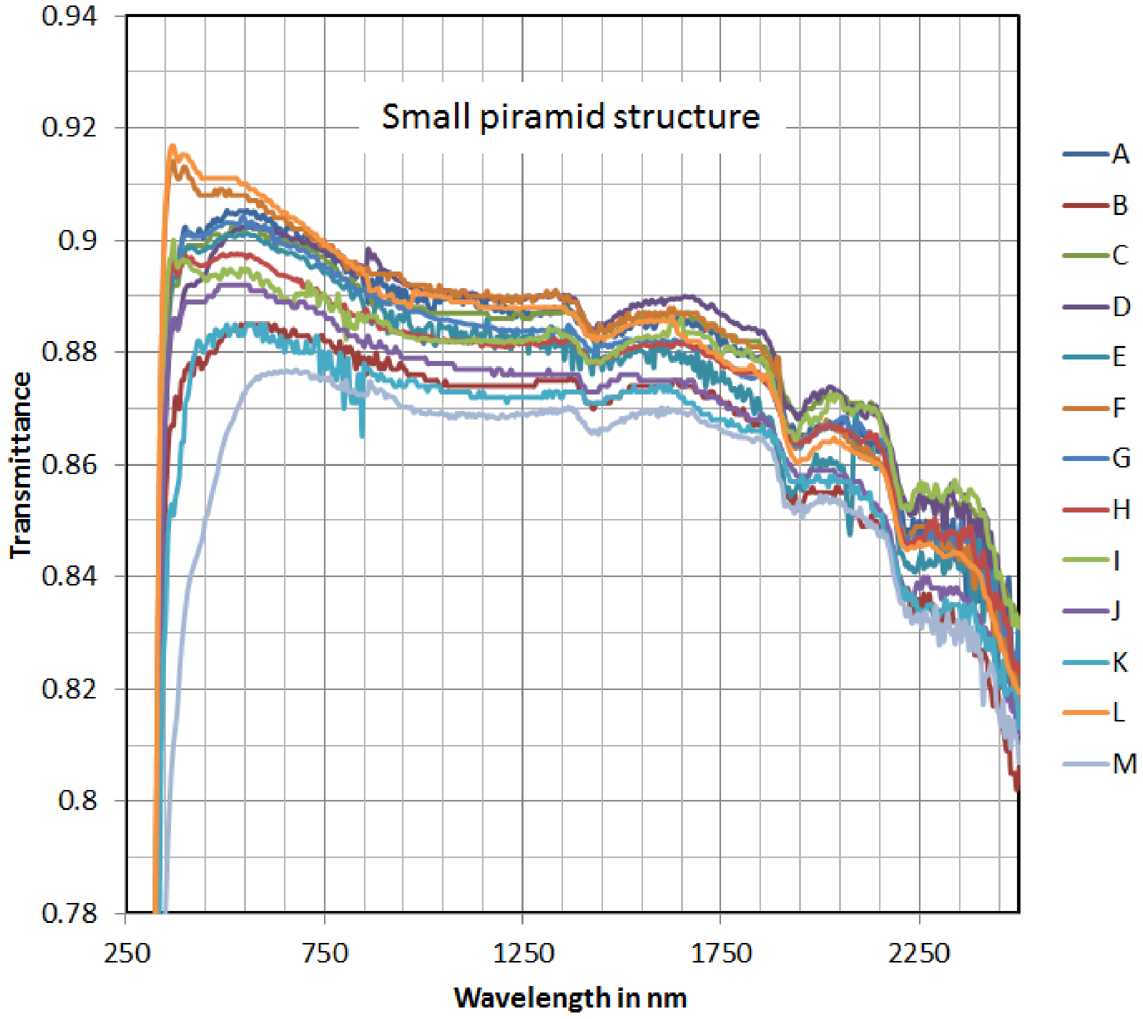
Characterising Solar Cel cover glass



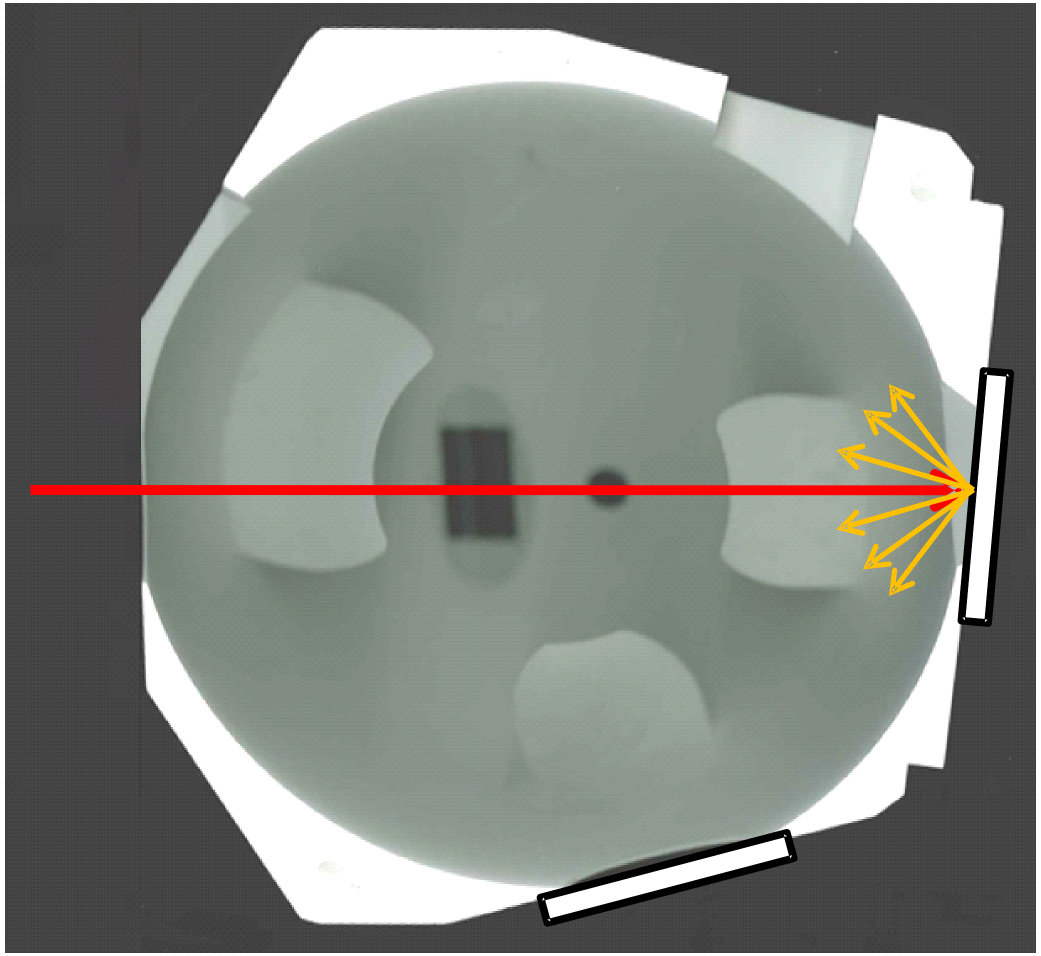


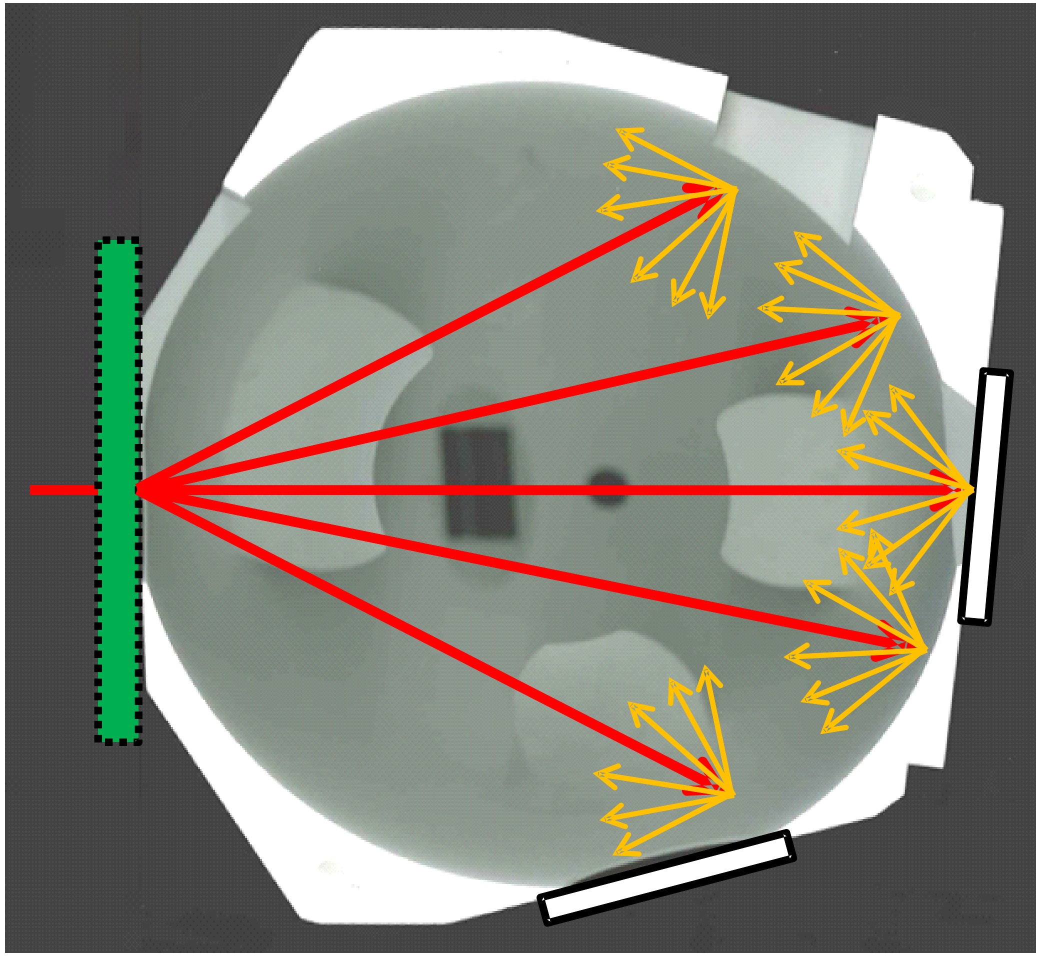
2007 Inter-Laboratory comparison of transmittance measurements



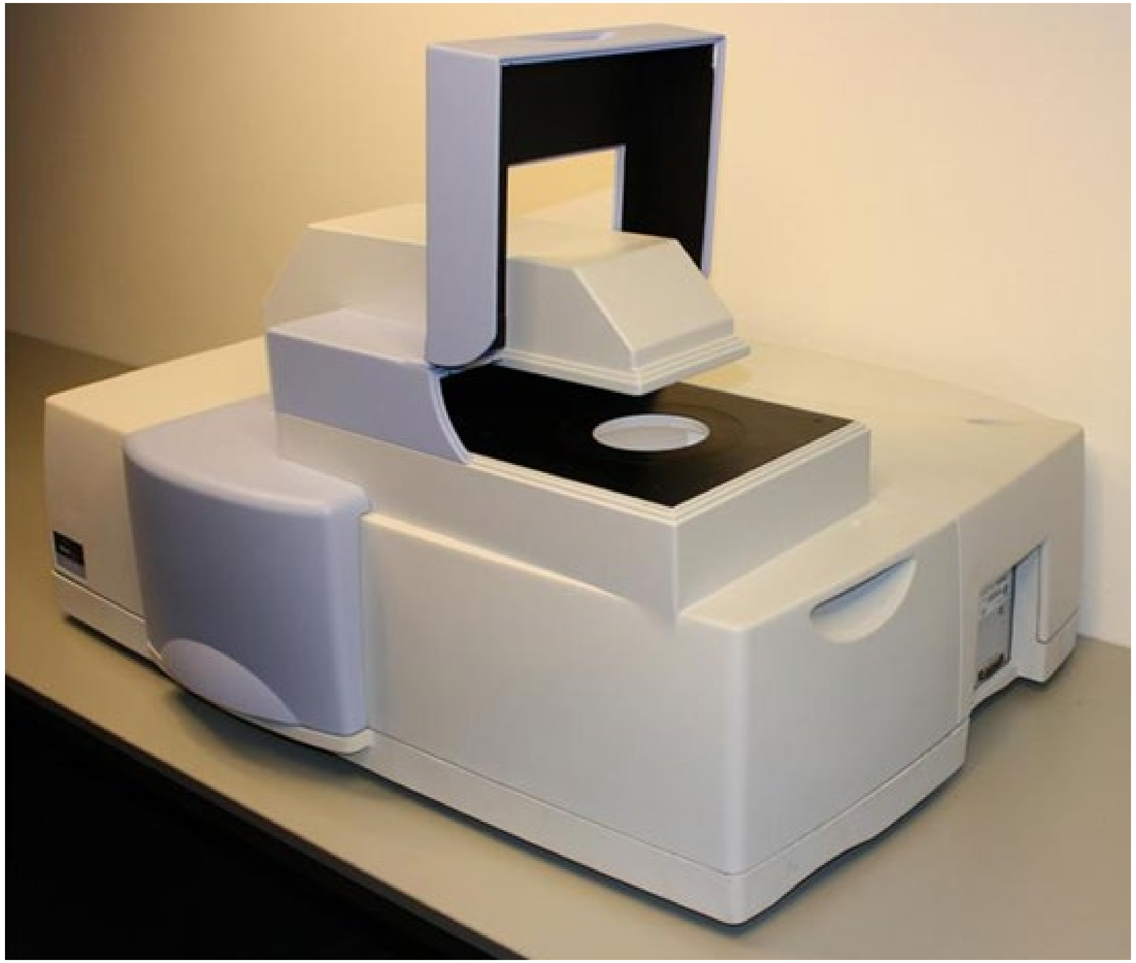


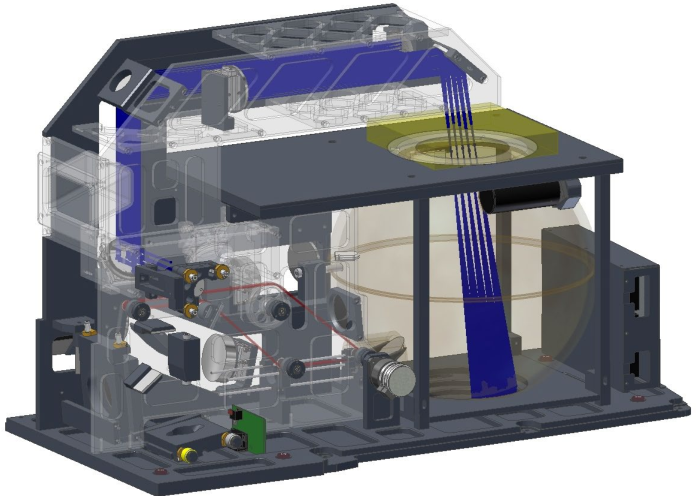
Measuring Solar Cel cover glass with the standard 150 mm sphere





UL270 Sphere accessory with fixed 8° AOI for Transmittance and Reflectance





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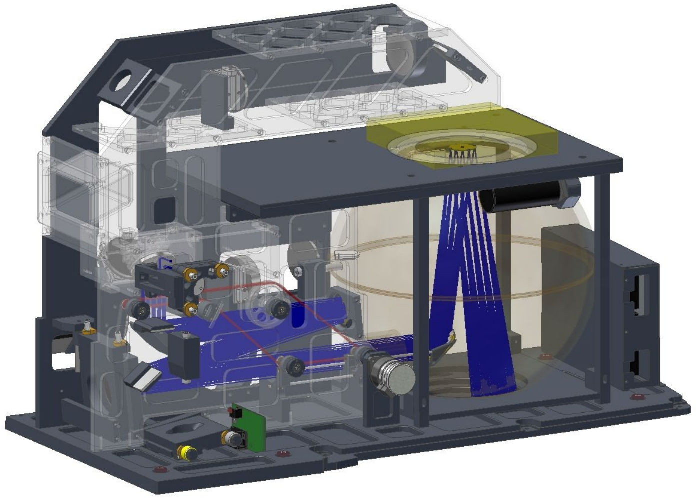

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2017 NFRC Intercomparison

National Fenestration Rating Council®

National Fenestration Rating Council Incorporated

NFRC 300-2017[E0A2]

Test Method for
Determining the Solar Optical Properties
of Glazing Materials and Systems

PREPARED BY:
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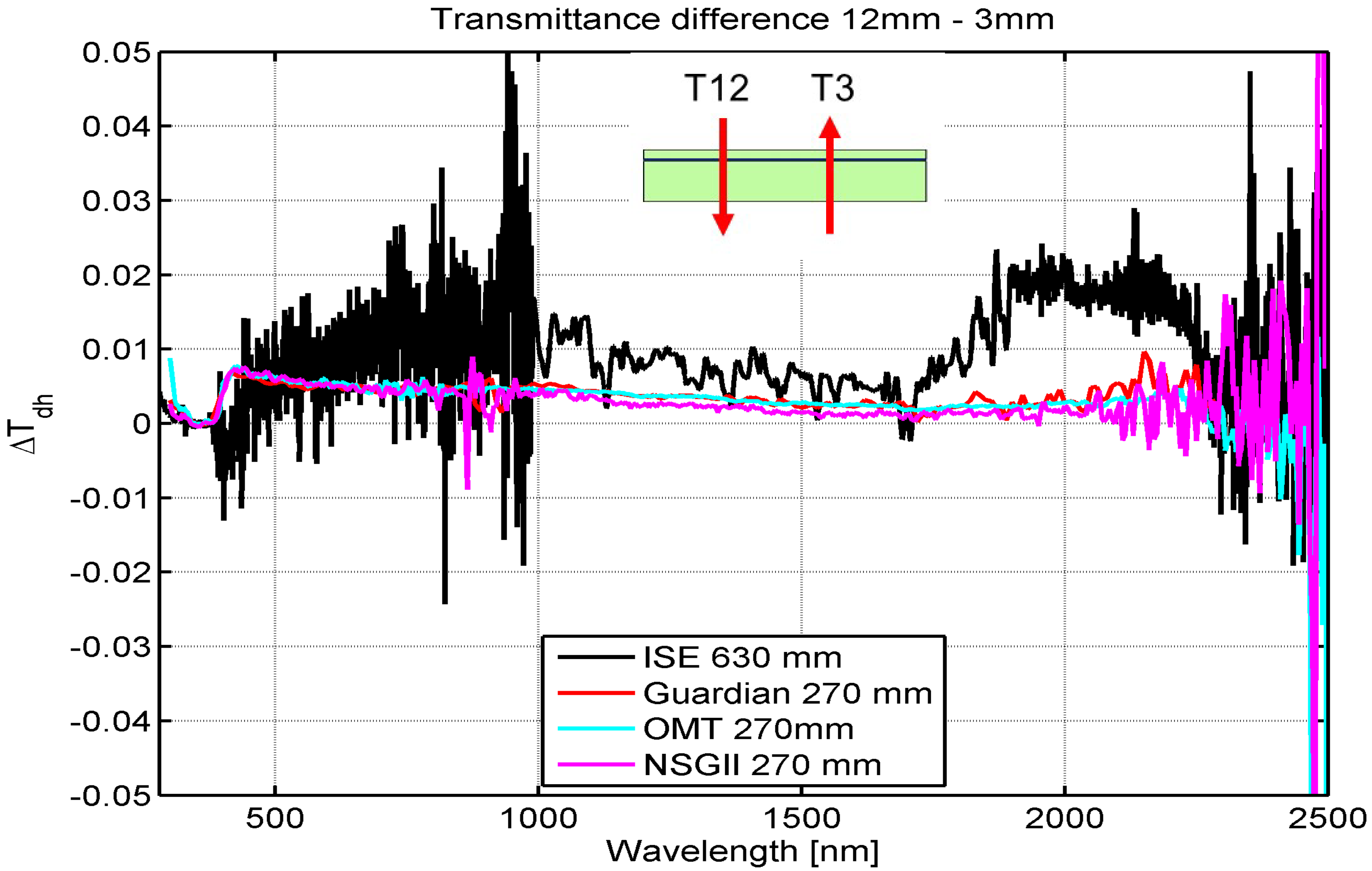

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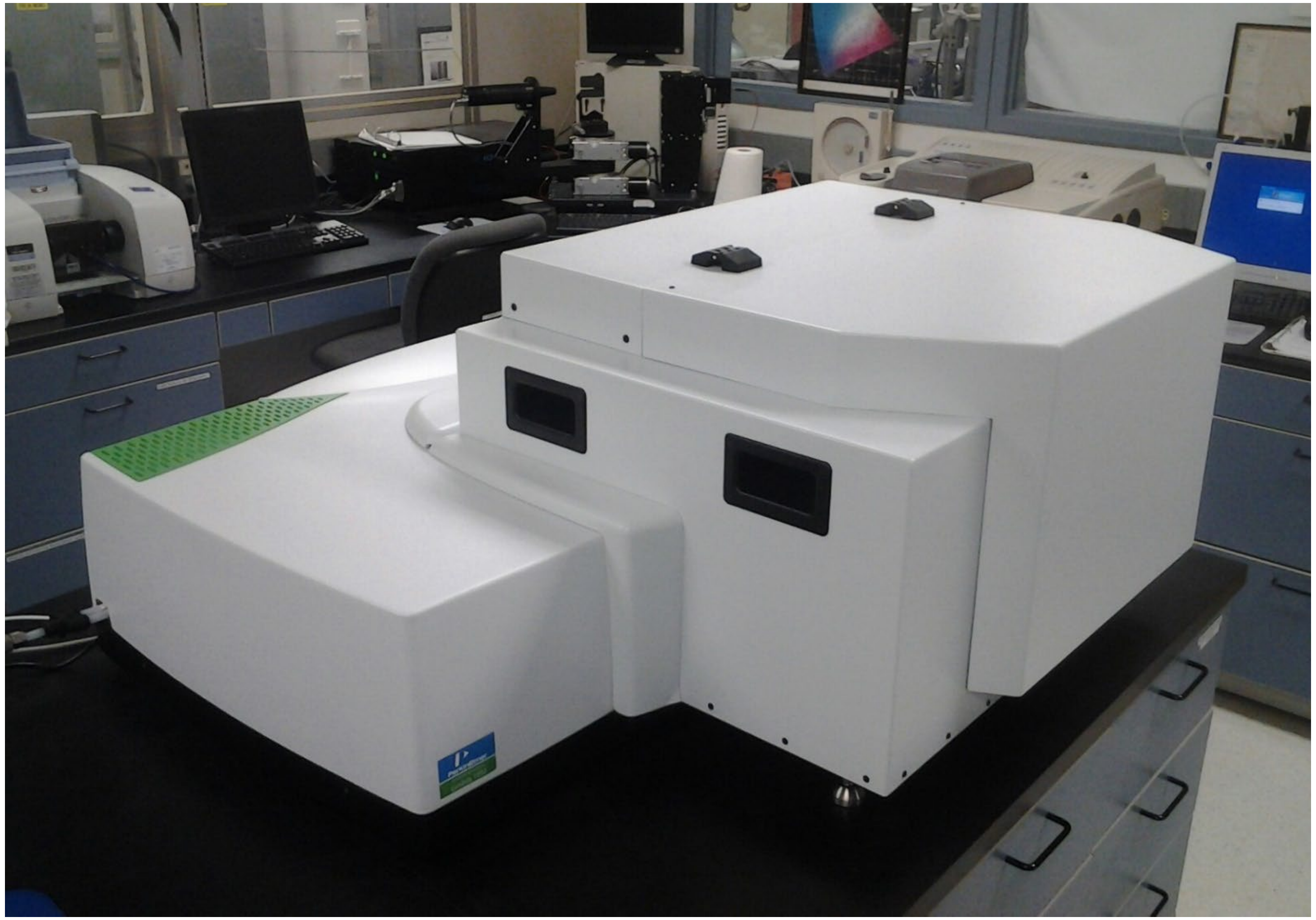
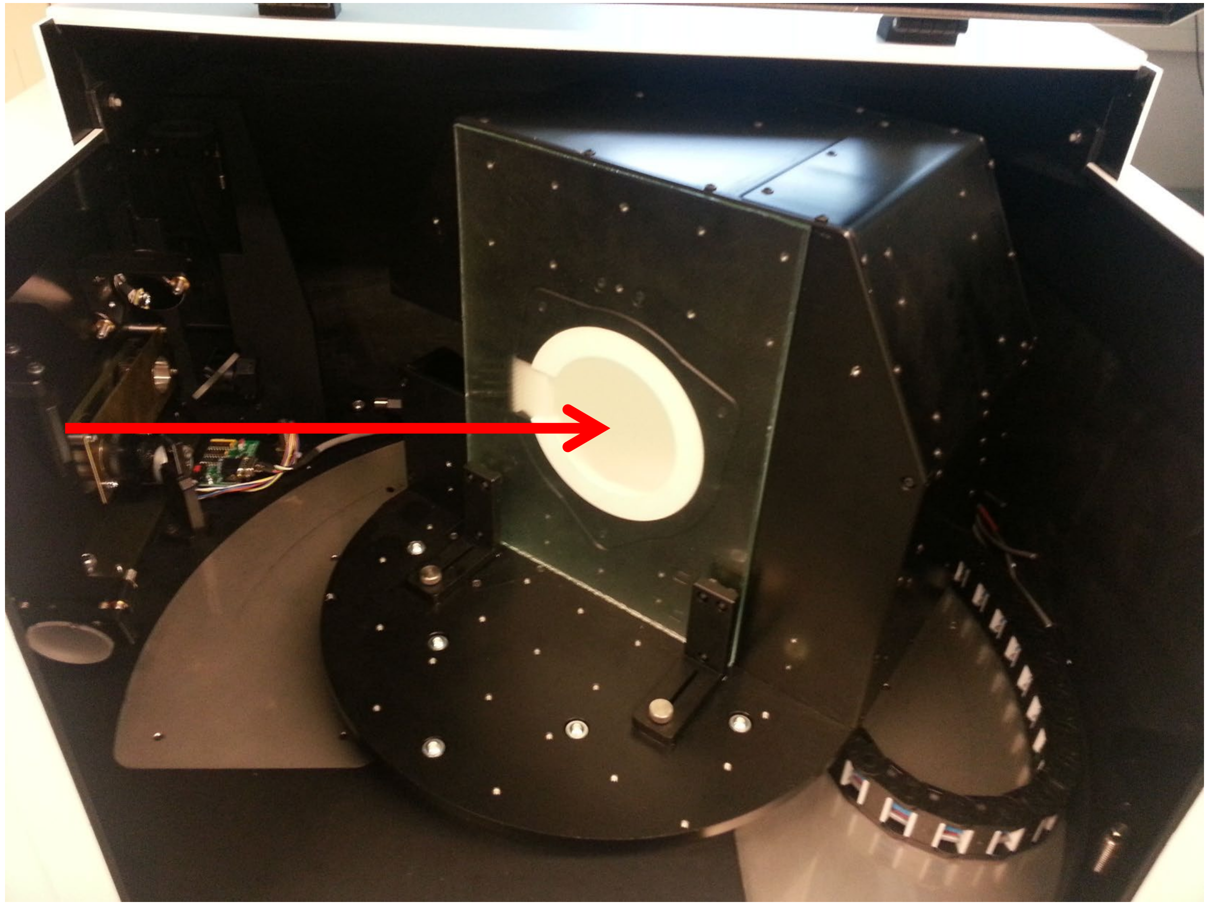
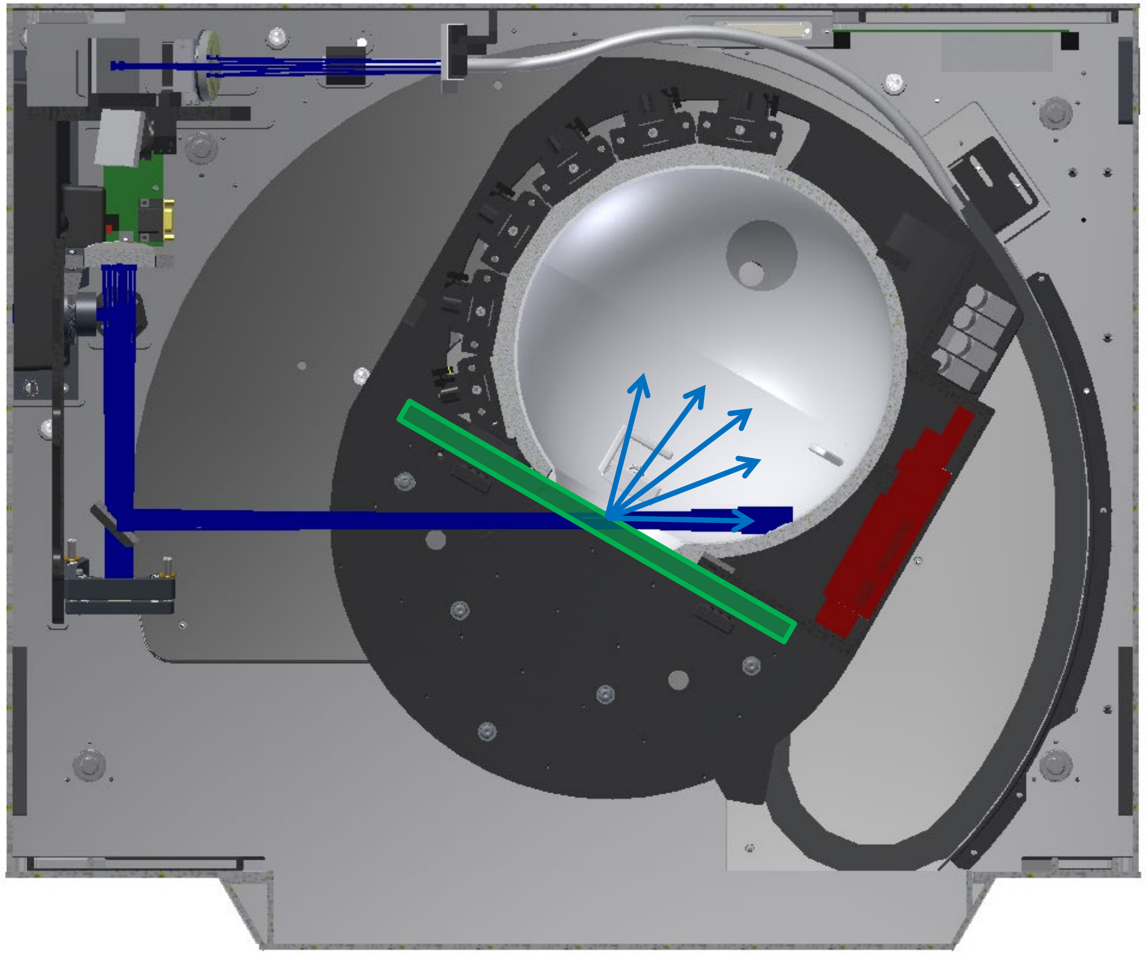
Measuring Directional R&T of diffuse and patterned cover glass



- Sample size up to 400 x 300 mm
- 270 mm integrating sphere with a large (100 mm) sample port
- PMT for UV/Vis, InGaAs detector for NIR
- Wavelength range 250 nm – 2,400 nm
- Measurement spot of approximately 10 x 25 mm at 0 degrees incidence
- Separate P and S polarization (automated polarizer drive)
- Directional Reflectance at 8° – 70° AOI (up to 80° with lower accuracy)
- Directional Transmittance at 0° – 70° AOI (up to 80° with lower accuracy)
- Haze measurement at -8° AOI in Transmittance

Measuring Directional R&T of diffuse and patterned cover glass





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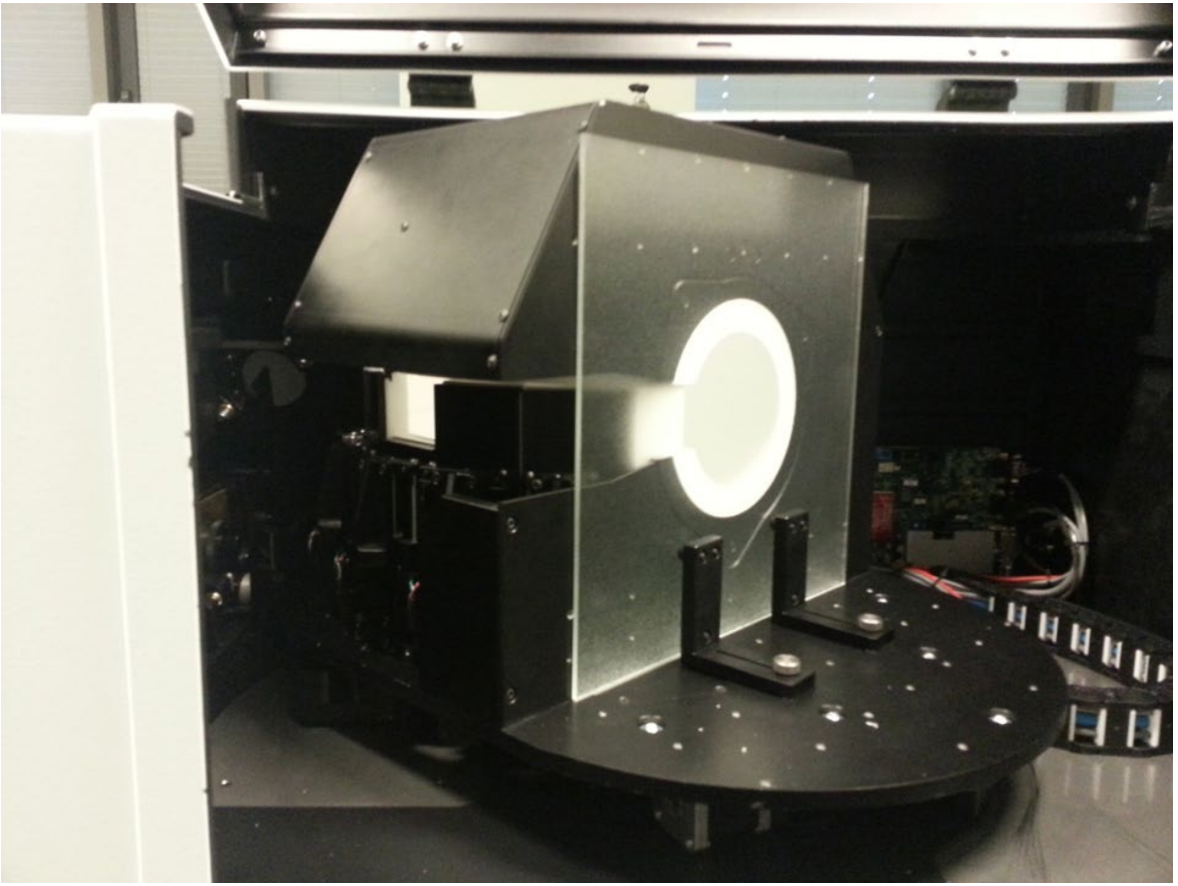
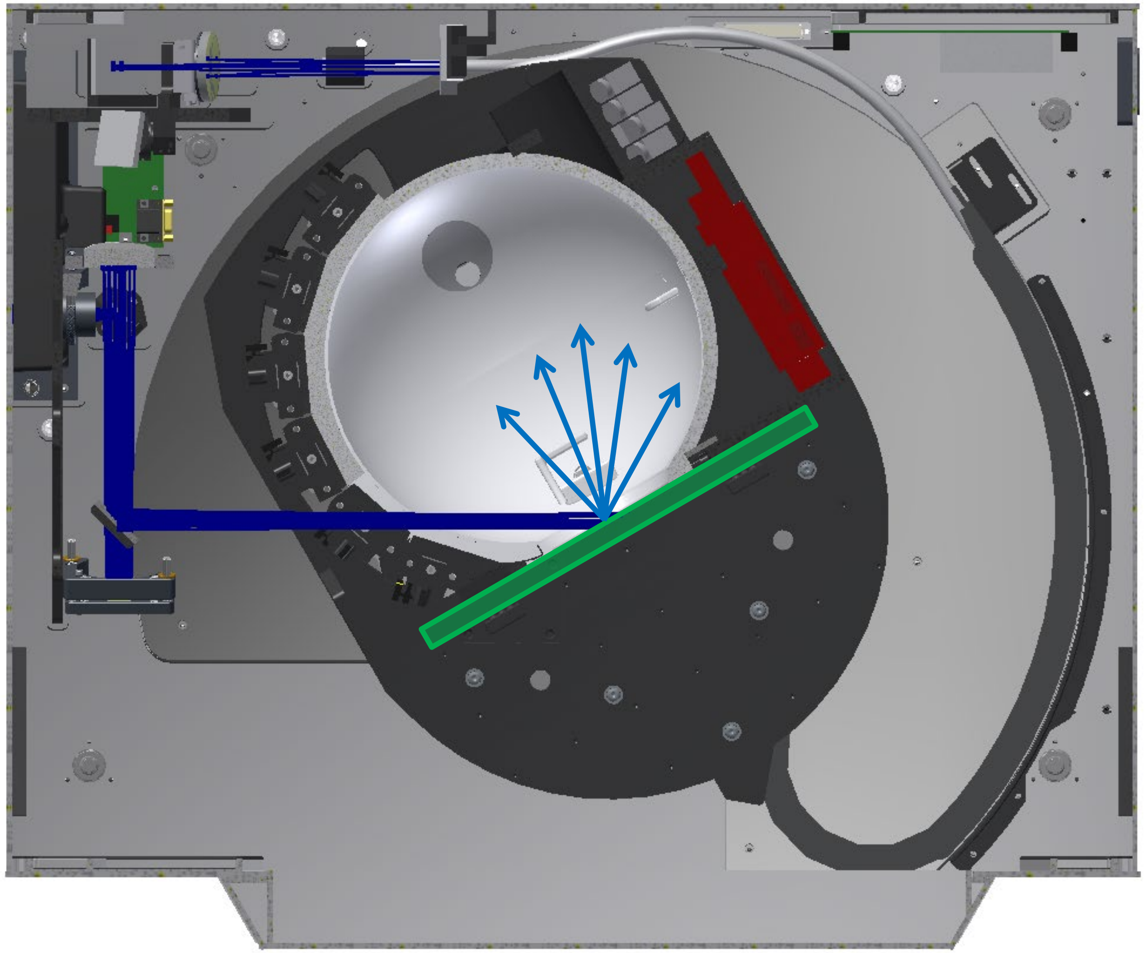
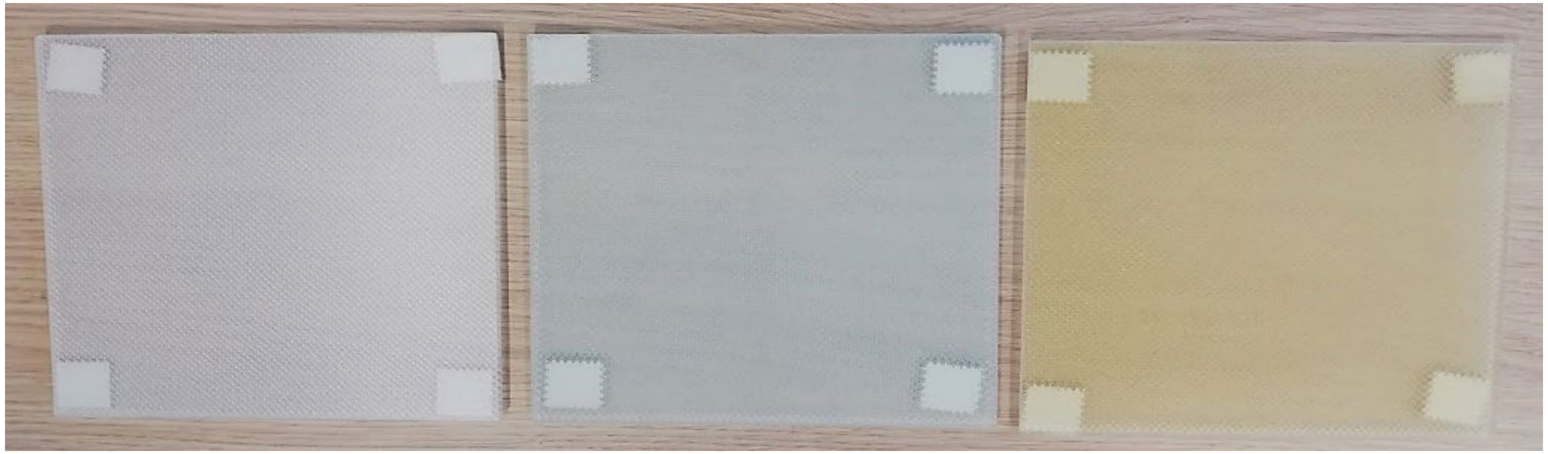
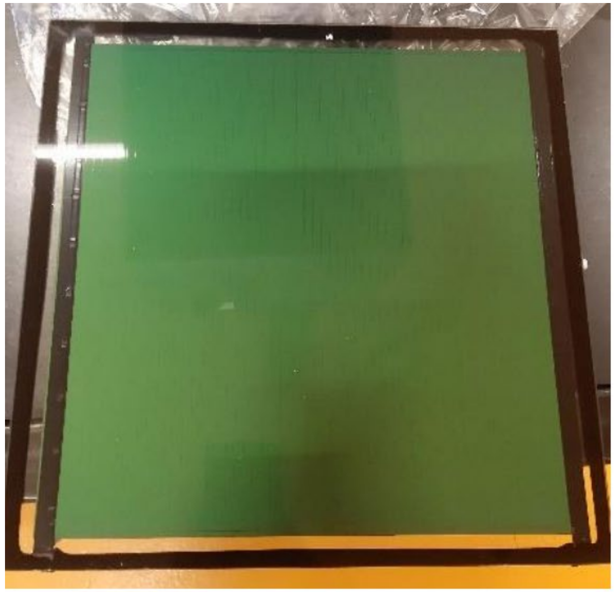
Measuring Directional R&T of diffuse and patterned cover glass

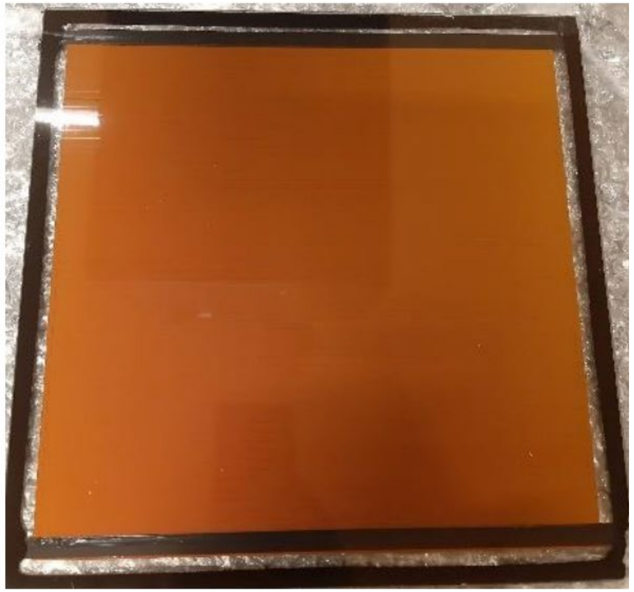




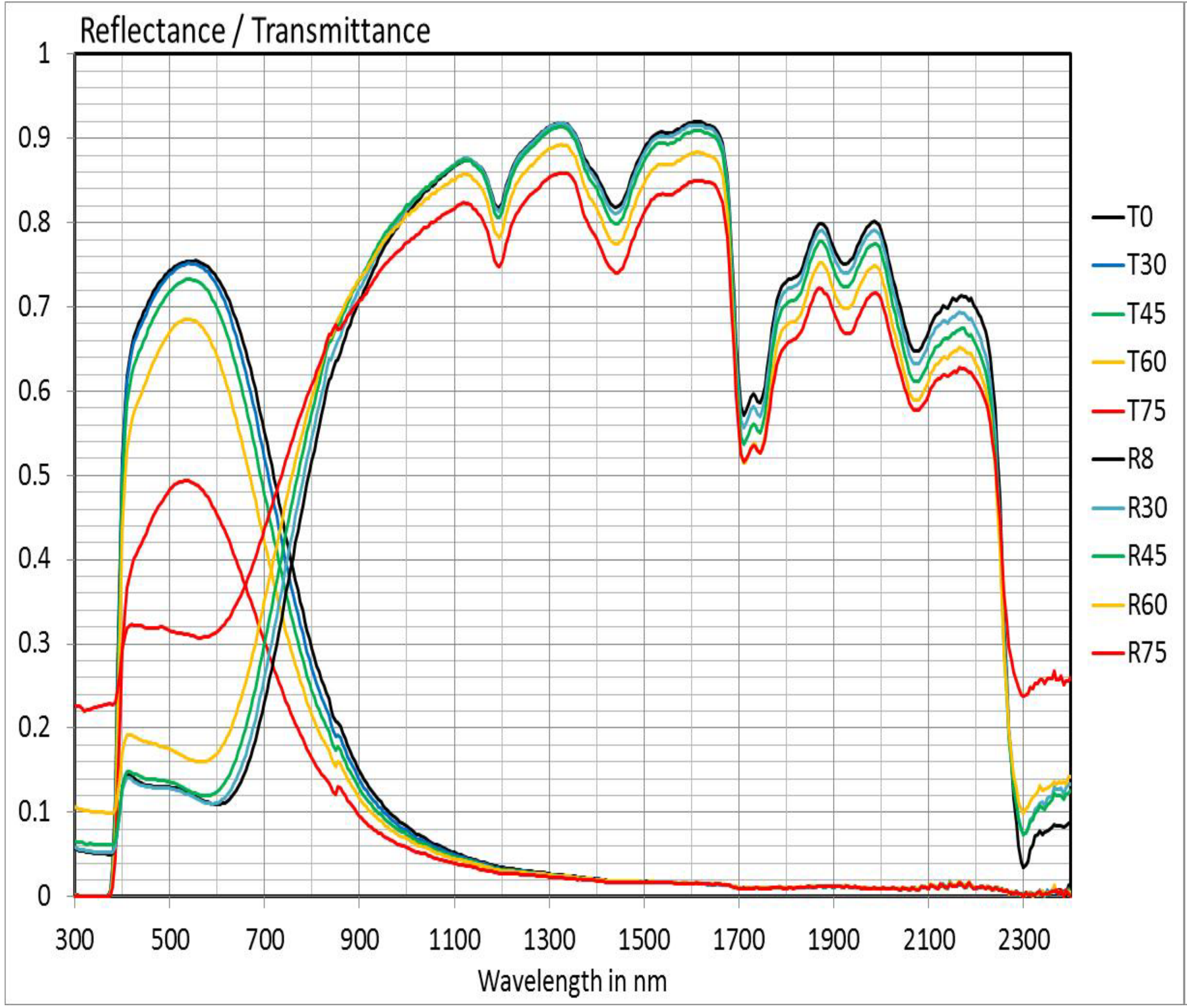
Colored Cover Glass for Building Integrated PV

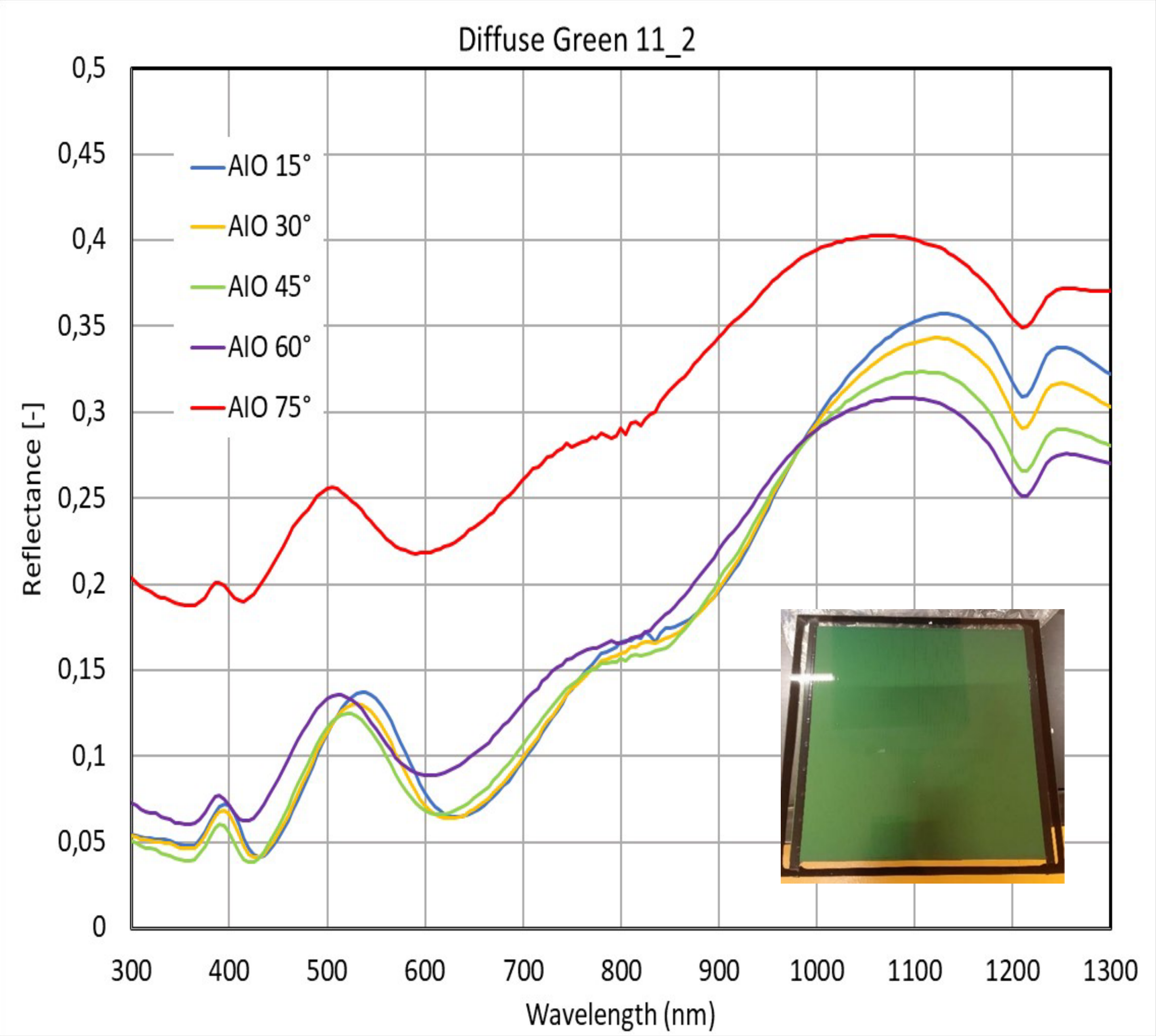






Examples of Directional R&T Results

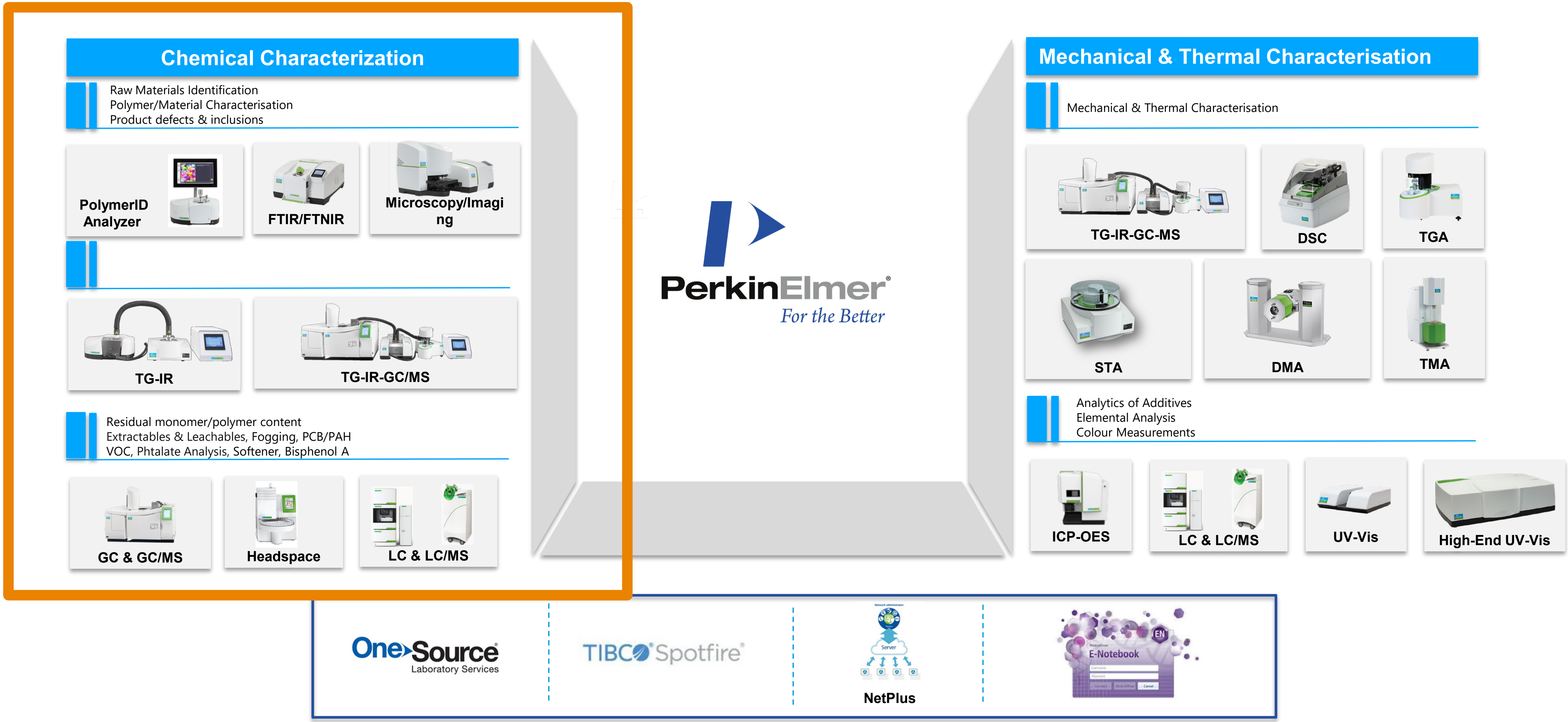




Analytical Technology Pros & Cons

Krystelle Mafina

Our Materials Charaterisation Product Portfolio



InfraRed for the Chemical Characterisation

Infrared spectroscopy (IR) measures vibrational and rotational transitions

Allows for both qualitative and quantitative information about functional groups

The range is split in 3 regions (FIR, MIR & NIR) each giving rise to a different set of information depending on need

Mostly used for chemical characterisation as it gives rise to accurate data when sampling is done appropriately

Pros & Cons of Infrared Spectroscopy

BENEFITS	LIMITATIONS
MIR/NIR/FIR in one instrument available	Tri-range in one system can cause some loss in sensitivity
Meeting a wide range of samples and method development flexibility	Limited use of all accessories for some of the regions especially FIR
Enhanced ATR accessory available	Only measures surface layer and a small area, a few microns depth at most
Faster scanning rate for maximum scan per seconds	
Higher accuracy of library searching using ATR	Spectra different from the ones obtained via transmission, must create an extensive one
One vendor Hyphenation with single instrument EGA solution	Amount of sample to use and destructive, always begin the run with thermal analysis

Hyphenation for the Chemical Characterisation

When at least 2 systems are combined to generate 2 sets of data from 1 sampling preparation

Usually based on the analysis of gaseous analytes for a better sampling transfer between the systems

Heat is involved thus care must be taken into maintaining heated sample transfer from one system to another

Carrier gas is required to enable a smooth sampling transfer

Event triggers are needed to start or stop the various system collecting data at the time/weight/temperature required for the analysis

Pros & Cons of Hyphenation

Instrument	TG-IR	TG-GCMS	TG-IR-GCMS
Consumables	Pans (crucibles) carrier gas (He/N2)	Pans (crucibles), columns, carrier gas(He)	Pans (crucibles), columns, carrier gas (He)
Software	Spectrum IR	Spectrum IR and TurboMass	Spectrum IR and Turbomass
BENEFITS	• Resulting data collected are time base resolved for a qualitative interpretation • Ready in seconds - no alignment required	•Unique injection valve system Allow the user to do TGA-GCMS or TGA-MS •Snap-shot or real-time measurement	•Highest controlled temperature transfer line to prevent condensation (Analysis of high boiling point samples)
LIMTATIONS	Quantification is available but not straight-forward	Cross-contamination within column, thus maintenance is important	Cross-contamination within column, thus maintenance is important

Our Materials Charaterisation Product Portfolio

Chemical Characterization

Raw Materials Identification
Polymer/Material Characterisation
Product defects & inclusions

- PolymerID Analyzer
- FTIR/FTNIR
- Microscopy/Imaging
- TG-IR
- TG-IR-GC/MS

Residual monomer/polymer content
Extractables & Leachables, Fogging, PCB/PAH
VOC, Phtalate Analysis, Softener, Bisphenol A

- GC & GC/MS
- Headspace
- LC & LC/MS

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For the Better

Mechanical & Thermal Characterisation

Mechanical & Thermal Characterisation

- TG-IR-GC-MS
- DSC
- TGA
- STA
- DMA
- TMA

Analytics of Additives
Elemental Analysis
Colour Measurements

- ICP-OES
- LC & LC/MS
- UV-Vis
- High-End UV-Vis

OneSource Laboratory Services | TIBCO Spotfire | NetPlus | E-Notebook

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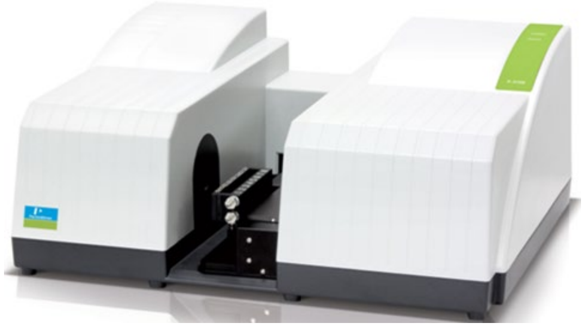
UV-Vis-NIR for Mechanical Characterisation

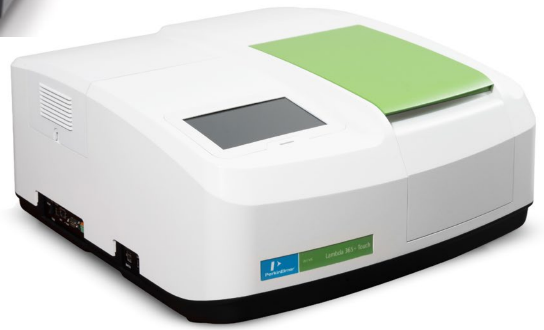
Exists in 2 principles
1. PDA design
2. Double Beam design

Photodiode array spectrophotometers work differently from conventional spectrophotometers as the sample is irradiated with white light and then the light passing through the sample is dispersed (using a polychromator) onto a photodiode detector.

Detection is simultaneous at all wavelengths and consequently the time taken to acquire a complete full range spectrum is less than two seconds.

Conventional instruments, by comparison, irradiate the sample one wavelength at a time (i.e. they are sequential).





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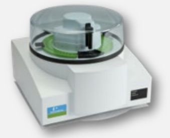
Pros & Cons of UV-Vis-IR

BENEFITS	LIMITATIONS
Double beam instruments collect data sequentially for better precision and accuracy	The data collection is slow as it does one wavelength at one time
Double beam instrument can handle higher absorbance	
Double instruments are complex system with moving parts	Require good maintenance
Covers a full UV-Vis-NIR range	PDA only covers UV-Vis
PDA instruments have fast scanning	Loss of sensitivity
PDA system have no moving parts and no need for sample lid	
Sample compartment on the double beam instrument is large for a variety of sample size	May require a specific accessory

Thermal Analysis Product Portfolio

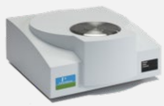
Thermal Characterization in QA/QC

Raw Materials Identification
Polymer/Material Characterisation



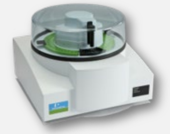
DSC4000/6000

Single furnace DSC (Heatflux)



TGA4000

TGA for routine applications



STA6000/8000

Simultaneous TG/DTA (DSC)

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For the Better

PYRIS

Software Pyris™

Mechanical & Thermal Characterisation for Research & problem solving

Thermal Characterisation

DSC8000/8500

TGA8000

Double furnace DSC (Power Compensation)

TGA for High Demand & Hyphenation

Thermal Mechanical Characterisation

TMA4000

DMA8000

TMA & DMA for various applications

HYPHENATION - Get better insights to understand when something happened, and also what happened

TG-IR

TG-IR-GCMS

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Thermal Analysis for Q&A

These systems are mostly used for routine analysis, especially useful for characterising the polymeric materials (layer) in the solar cells

They are used to identify and help discriminate between polymeric materials and their resulting effects

They are robust

Allow for high temperature analysis up to 1600 deg

They measure physical properties of a material against temperature or time.

- Glass transition
- Decomposition
- Degree of crystallisation
- Melting point etc ...

DSC6000/4000

TGA4000

STA8000/6000

Thermal Analysis for Problem Solving & Research

These instruments are more sensitive, allowing for more in-depth understanding

More accurate balance in the TGA8000

More parameters to be collated in the DMA8000

During these analyses, sample preparation is key for optimum results

They measure mechanical properties of a material against temperature or time.

- Mechanical behaviour
- Weight loss
- Long-term behaviour
- Cross-linking properties etc ...

TGA8000

DMA8000

Pros & Cons of Thermal Analysis

BENEFITS	LIMITATIONS
A variety of properties can be measures using thermal product line	Care must be taken when choosing the system for analysis
Up to 1.2 g of sample can be analysed	Only small density of sample can be used
Small density of material equates to improved precision and accuracy	May not be representative
Identify the material’s minimum process temperature	May not be able to differentiate if the material is too similar
Identify the amount of energy required to melt the material (heat of fusion)	
Different carrier gas can be used to mimic environmental conditions	Only up to 3 gases can be used .. but there is mixing pod accessory available
Identify, quantify and characterise material's components	Often struggles with multi-component dependent on sample preparation

Renewable Energy & Sustainability

Thank You.
Any Questions?

For More Information

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Chasing the sun – advanced analysis for innovative PV materials

Q&A

23 June 2022

3:00 pm – 4:00 pm | CEST, Berlin
5:00 pm – 6:00 pm | GST, Dubai
9:00 am – 10:00 am | EDT, New York City
6:00 am – 7:00 am | PDT, Los Angeles

Tim Sylvia
Editor
pv magazine USA

Lucy Jenner
Segment Manager of Industrial
PerkinElmer

Dr. Gernot Oreski
Division Manager for Sustainable Polymer Solutions
Polymer Competence Center Leoben

Peter van Nijnatten
R&D Director
OMT Solutions

Krystelle Mafina
UVS/TEA Product Manager
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Thursday, 30 June 2022
5:00 pm – 6:00 pm CEST, Berlin, Madrid
11:00 am – 12:00 pm EDT, New York City

Alleviating battery storage growing pains through quality assurance

Tuesday, 5 July 2022
11:00 am – 12:00 pm CEST, Berlin, Madrid
10:00 am – 11:00 am GMT, London

The pressing need for powerful storage: Technology trends, safety optimization, and challenges for deployment

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Thank you for joining today!

Tim Sylvia
Editor
pv magazine USA