Key reliability aspects for the integration of PV in passenger cars

Loic Tous, Sophia PV Reliability workshop 2024

AGC 2024

Your Dreams, Our Challenge

Agenda

Introduction AGC Glass Europe

30 years of progress with solar roofs

User benefits with AGC's SolaRoof

Safety qualification standards for PV and automotive

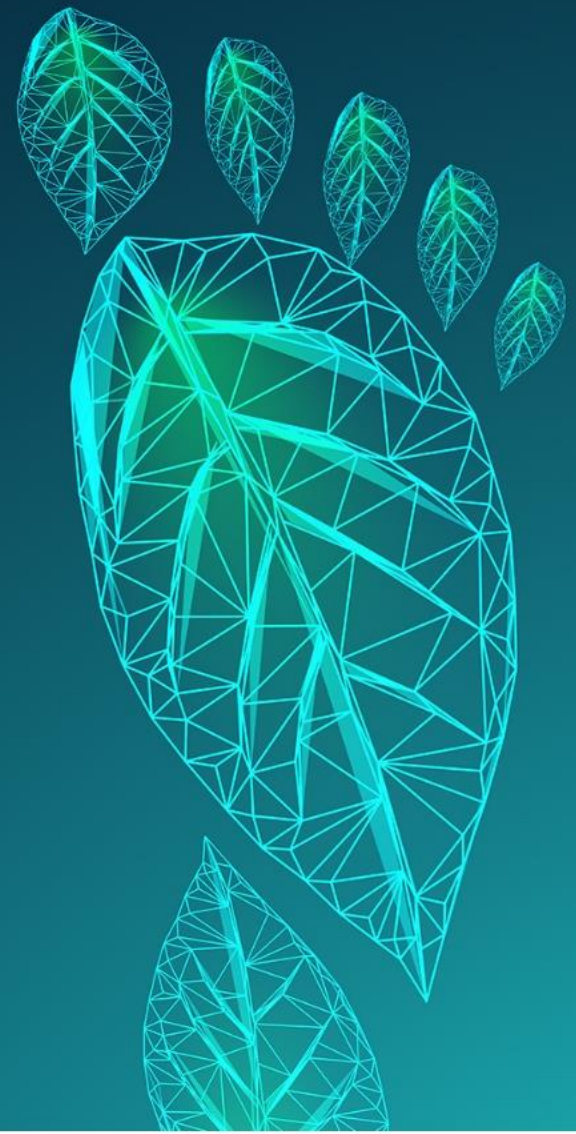
Experience from a Tier-1 supplier like AGC

Key reliability aspects to consider

Summary and conclusions

AGC Glass Europe
Contributing to a sustainable future

In the journey to net zero carbon by 2050, we are working on **eco-friendly** products that contribute to reducing CO_2 emissions, and upgrading our manufacturing processes towards carbon neutrality **to enable the realization** of a sustainable society.



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while saving energy

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AGC Sustainability Report 2023

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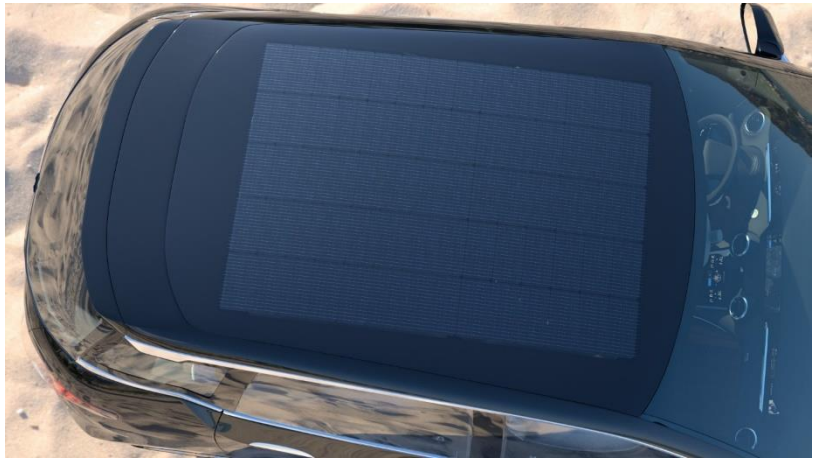
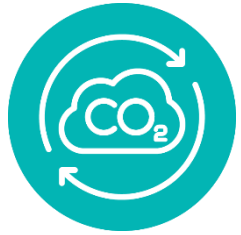
AGC’s next generation SolaRoof

Panoramic sunroof with PV cells inside glass-glass sandwich

Panoramic roof without solar cells	With HJT or TOPCon solar cells	With back contact (xBC) solar cells
		
		

User benefits

Improved sustainability and comfort



	Plug-free charging	All year thermal comfort	No roller blind required	Maximum CO_2 benefits**	UN Sustainable Development Goals (SDGs)
Laminated solar roofs for passenger cars ($170 < P_{max} < 380$ Wp)	• Up to 3000 km/y EV range extension*	• "Sunshade" in summer • No "cold wall" in winter • Cabin pre-ventilation	• Gain in headspace • Weight, CO_2, and costs savings	• 6-16 g/mi (US EPA) • Up to 7 g/km (EU ECO innovation)	• Affordable and clean energy (SDG7) • Innovation (SDG9) • Climate action (SDG13)
AGC Unique Selling Points	**Selection of the best PV and glass technologies**	**Combination with best-in-class low-E coating** (emissivity< 0.2, reflection <2%)	**Combination with ambient lighting**	**Maximize EU supply chain and local manufacturing**	• **Responsible consumption & production (SDG12)**

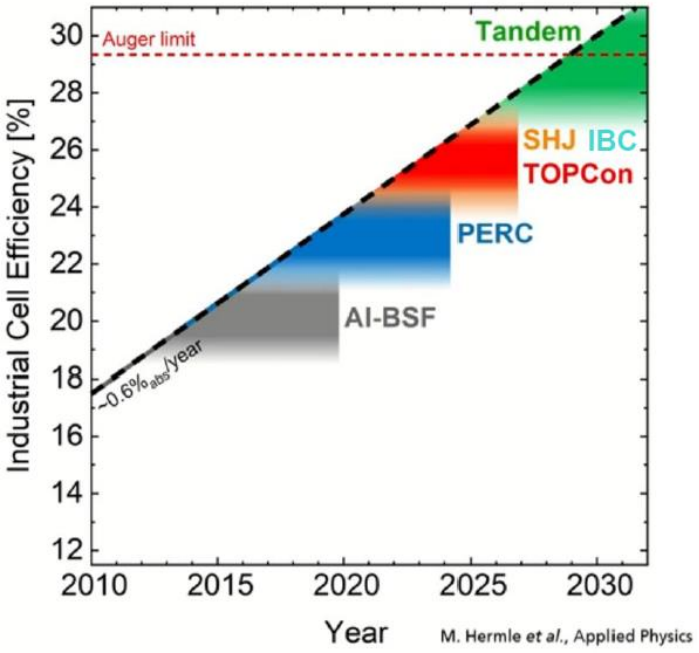
**Depending on reference case, PV roof size, car location, and driving profile*

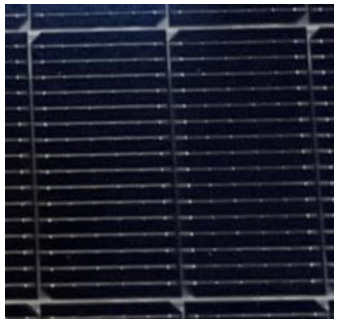
** 2024 values

Selection of best PV technologies

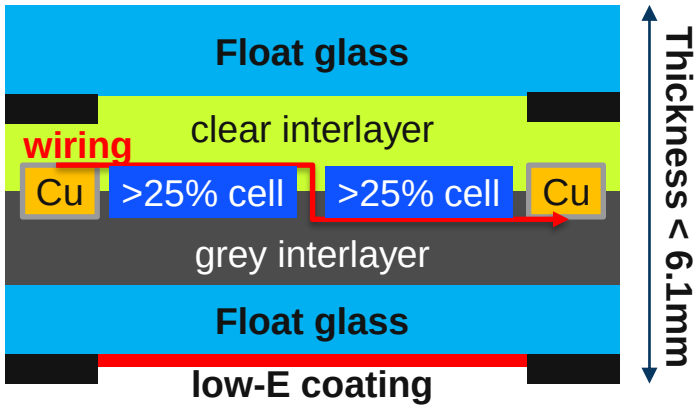
>25% efficient PV solar cells

Industrial silicon cell efficiency [%] roadmap



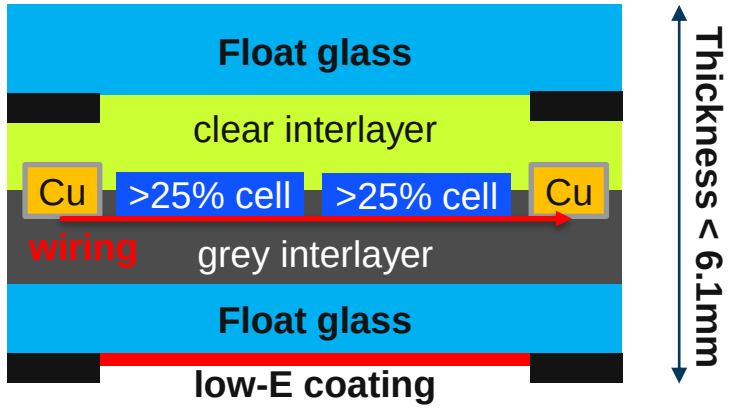


HJT / TOPCon solar cells (mainstream, lower cost)



Design validation plan (DVP) passed successfully

IBC solar cells (next-gen, premium)



Key DVP tests in progress

Selection of best interlayers / encapsulants

Automotive PVB recommended for panoramic solar roofs in cars

Why automotive PVB:

- **high penetration resistance** (ECE R43 safety requirements)
- **high impact absorption** (stone impact, head impact, etc.)
- excellent **acoustical performance** (sound attenuation)
- **very low haze** (ratio diffuse/total transmittance) <1%
- **excellent control of thickness** (no glass edge pinching, etc.)
- very wide range of **PVB with different colors and transmission values** in UV, visible, and near-infrared (depending on application requirements)
- **excellent durability** (against UV, solar radiation, etc.)
- **lower cost** than alternative encapsulants for automotive products
- **established supply chain & manufacturing** sequence (autoclaving, etc.)
- etc.

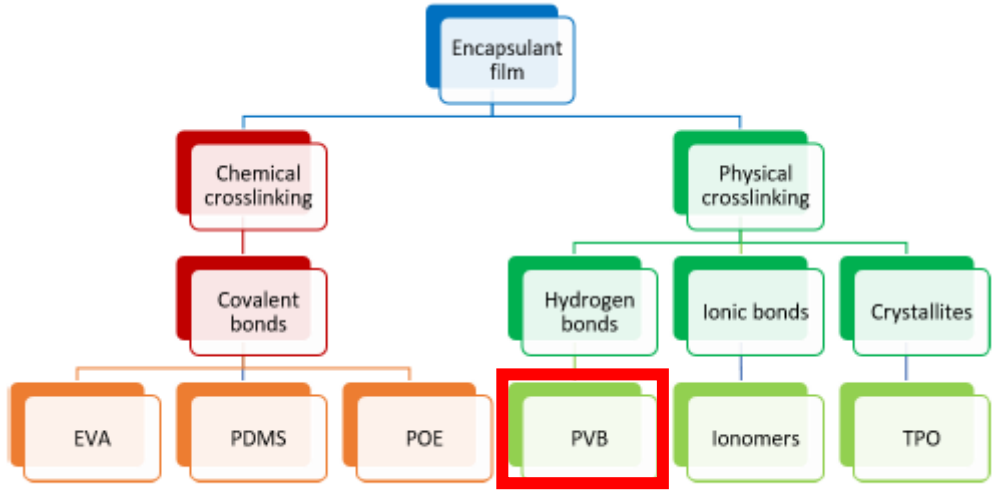


Figure 2: Typical encapsulants and their main characteristics.

Source: Report IEA-PVPS T13-13:2021

Safety qualification mandatory before market entry

Different standards for terrestrial PV modules and automotive components

Certification of Terrestrial Photovoltaic (PV):

- **IEC 61730:** PV module safety qualification
  - Part1: Requirements for construction
  - Part2: Requirements for testing
- **IEC 61215:** Design qualification and type approval
- **IEC 61701:** Salt mist corrosion testing
- **IEC 61215:** Ammonia corrosion testing

Safety qualification of automotive components:

- **ECE R43:** Safety glazing materials and their installation on vehicles
- **ISO 16750 -(1 5):** Safety for electrical and electronic equipment
- **JASO D 902:** Automotive parts – Electronic equipment – Durability testing methods
- **JIS R 3212:2015:** Test methods of safety glazing materials for road vehicles

Table 3.4-1 Reliability assessment items for terrestrial PV and automotive components

Category	Reliability assessment items	Terrestrial PV				Automobile components					
		IEC 61730	IEC 61215	IEC 61701	IEC 62716	ISO 16750 -2	ISO 16750 -3	ISO 16750 -4	ISO 16750 -5	JASO D902	JIS R 3212
Mechanical	Surface strength	MST 12					4.4				
	Hail / Steel ball falling		MQT 17								5.4
	Static mechanical load	MST 34	MQT 16								
	Vibration						4.1			6.4	
	Mechanical shock						4.2				
	Gravel bombardment						4.5				
Climatic	Steady-state temperature	MST 37, 55, 56						5.1			5.19
	Dump heat	MST 53	MQT 13					5.7		6.3	5.10
	Thermal cycling	MST 51	MQT 11					5.3.1			
	Humid heat cycle	MST 52	MQT 12					5.6			
	Solar radiation	MST 54	MQT 10					5.9			5.17
	Outdoor exposure		MQT 08								
	Salt corrosion			○				5.5			
	Ammonia corrosion				○						
	Thermal shock							5.2, 5.4 5.3.2		6.2	
	Mixed gas corrosion							5.8			
Electrical	Hot-spot endurance	MST 22	MQT 09								
	EMC					4.13					
Chemical									○		5.15

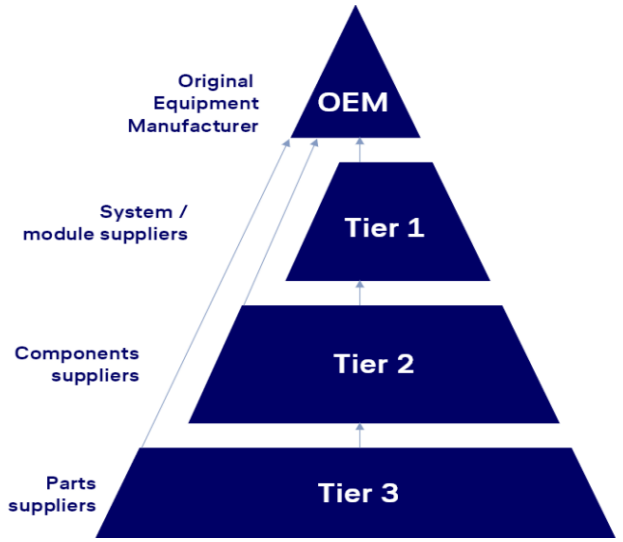
Source: NEDO PV-Powered Vehicle Strategy Committee Interim Report (3) - February 2023

Experience from Tier-1 supplier like AGC

Automotive experience mandatory to succeed

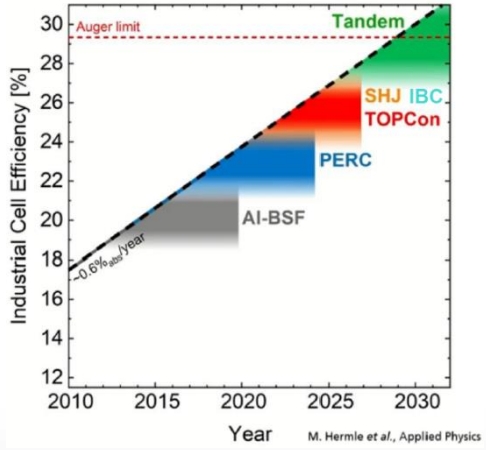
- Experience of automotive supply chains and quality controls is mandatory:
  - **IATF 16949:2016:** International Standard for Automotive Quality Management Systems
  - **Automotive SPICE (A-SPICE)** for complex systems including software
  - **Production Part Approval Process (PPAP)**

  => Achieving those certifications is no easy feat and represents an important entry barrier for new suppliers



- Car manufacturers (OEM) follow their **own design / product validation plans (DVP / PVP) programs**:
  - Some OEM are doing **efforts to standardize DVP/PVP for each product family** (e.g. windshields, panoramic fixed sunroof, etc.)
  - Need close collaboration with OEM during product pre-development

  => It takes several years to develop a new automotive product and technology choices must be done very carefully



Main challenge

Identify / develop sequence of tests to ensure safety of panoramic solar roofs

Non-exhaustive list of real-world conditions that must be considered:

Material requirements

Resistance to solar radiation (UV, high T)

Resistance to high humidity

Mechanical loads

Dynamic load during robot assembly

Vibrations during rough road driving

Heavy snow load in winter

Wind load at high driving speeds

Environmental tests

Resistance to chemicals, high pressure, abrasion

High operating temperatures + thermal cycling (day/night)

Salt corrosion in winter

Leaves in fall or bird drops… = risks of hot spots formation

Possible approach

Use program combining various standards

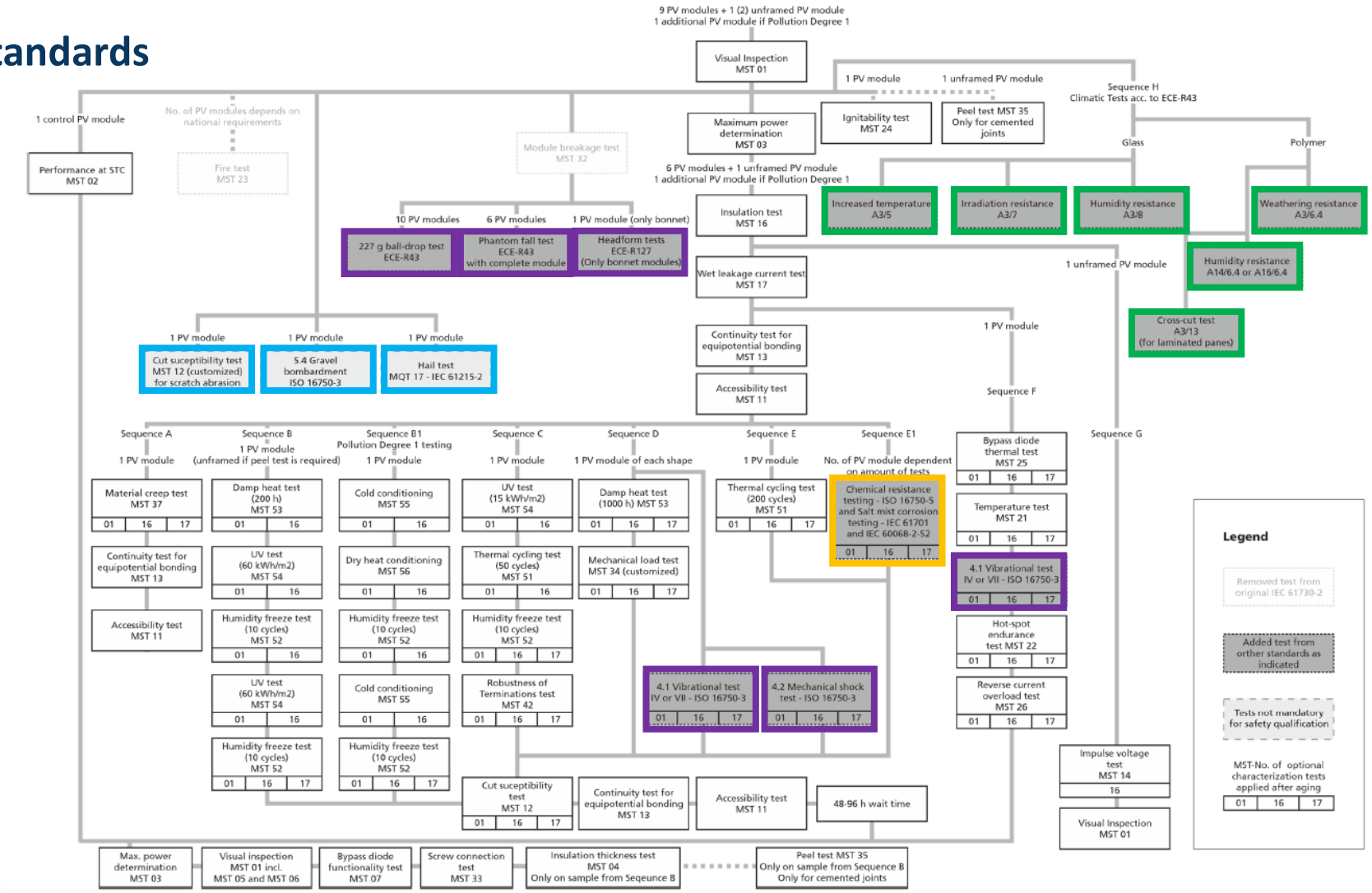
Safety & performance tests

Material requirements

Mechanical load tests

Qualitative tests

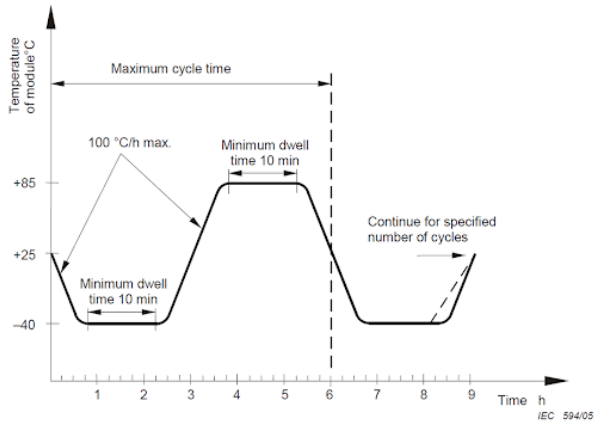
Chemical load tests



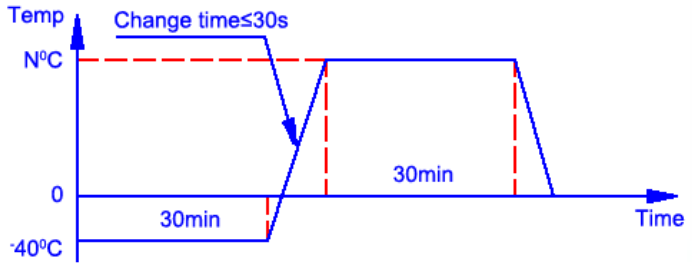
Source: J. Markert et al. Proposal for a Safety Qualification Program for Vehicle-Integrated PV Modules, https://doi.org/10.3390/su132313341

Key reliability aspects

1) Thermal cycles are not the same as thermal shocks!



- **Thermal cycling test according to IEC61215 MQT11 (terrestrial PV modules)**:
  - Used to detect early failures like broken interconnect, broken PV cell, etc.
  - **200 cycles <u>in 1 test chamber</u> from -40°C to +85°C with max. <u>100°C/h</u>**
  - Current application with I ~ I_{mpp} at +25°C or higher
  - 5 N weight hanging from the junction box



- **Thermal shock test according to AEC-Q100 (automotive)**:
  - Used for Integrated Circuits used in automotive applications
  - **500 cycles <u>in 2 test chambers</u> (hot and cold) from -40°C +85°C or more (depending on grade) with <u>max. 30s to move between chambers</u>**

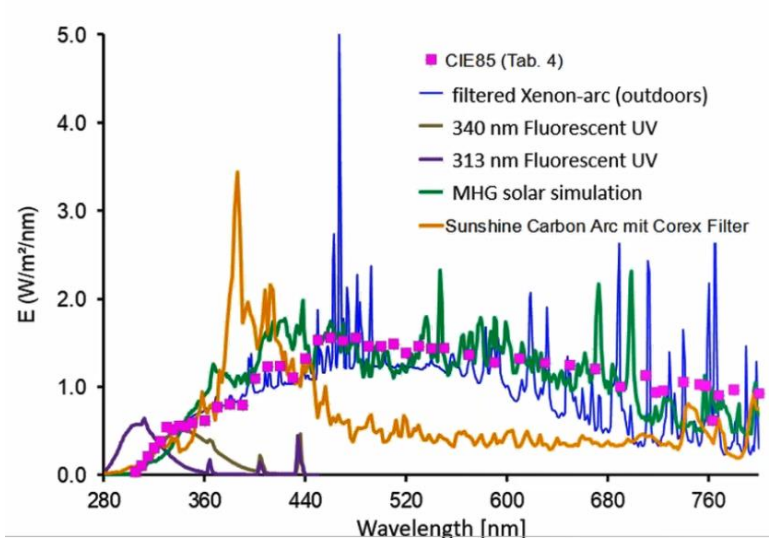
AEC-Q100	Ambient Operating Temperature Range
Grade 0	-40°C to +150°C
Grade 1	-40°C to +125°C
Grade 2	-40°C to +105°C
Grade 3	-40°C to + 85°C

- **In practice, for automotive PV roofs**:
  - **Pb-free interconnect mandatory** for EU End-of-Life (EOL) regulation
  - Thermal shock testing is required by several OEM (different test conditions)

=> **key test done on small PV roof sample (area<0.5m²) with connectors**

Key reliability aspects

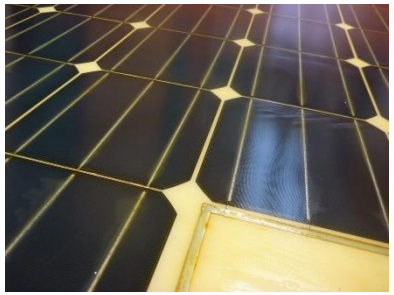
2) A UV test is not a fully capable weathering test



- **Laboratory light source** :
  - **Filtered Xenon arc:** most realistic, used in Weatherometer (WOM)
  - **UVA-340 and UVB-313** : fluorescent lamps commonly used for low-cost tests
  - **Carbon arc:** outdated technology, temperature dependent spectral irradiance
  - **Metal halide:** used for extra large / custom testing, spectral irradiance depends on power

- **UV "pre-conditioning" test according to IEC61730 (for terrestrial PV modules)**
  - Used to detect early failures like delamination, discoloration, cracking, loss of performance
  - Total dose of 60 kWh/m^2 with 3-10% in UV-B range (280-320nm) and T = 60±5°C

  => equivalent to <200 days of real-world exposure to UV so no guarantee of >20y lifetime!



- In practice, for automotive PV roofs:
  - **Up to 3*1500h WOM testing in 2 climates** (Florida: hot/humid; Kalahari: hot/dry)
  - Indoor weathering on full vehicle in sun simulator chamber (DIN 75220)
  - **Up to 2 years of outdoor weathering** of final components in 2 climates

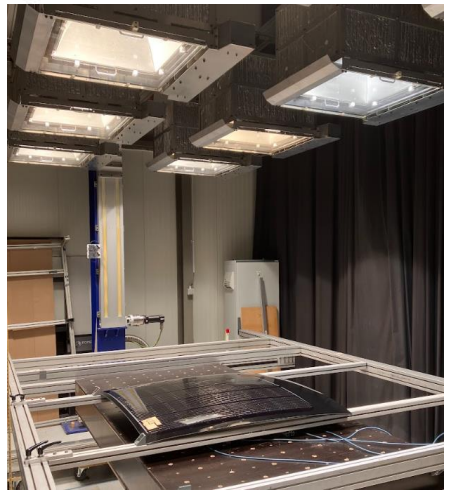
  => very expensive to qualify materials and validate full products for automotive use

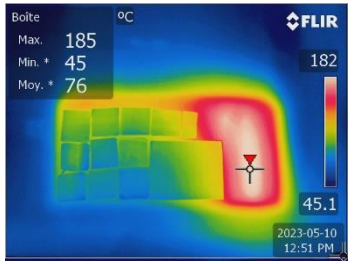
Key reliability aspects

3) Resistance to hot spots is a major topic

- **Cars parked in the sun get hot:**
  - Glass temperatures can reach up to 80°C in the worst areas (black enamel)
  - Risk of permanent damage to panoramic solar roof (visual defect, loss of function)
  - **Risk of injury for passengers (burning, fire safety) => critical risk!**

- **PVB interlayers can create bubbles at elevated temperatures (T>140°C)**:
  - Aggregation of small level of moisture that is contained in PVB interlayers
  - PV cells can lead to hot spots Temp. >180°C under specific conditions

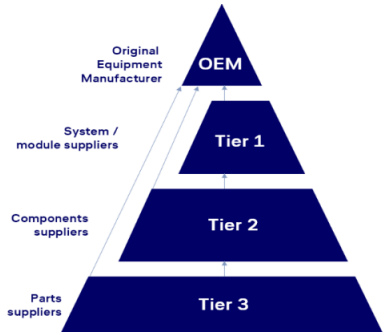




- In practice, for automotive PV roofs:
  - Select the right PV cell characteristics to minimize the risks of hot spots
  - Optimize PV roof layout and bill of materials
  - Perform extended tests to check tolerance to hot spots (high module temperatures, partial shading, etc.)

Summary and conclusions

- **AGC's next generation SolaRoof:**
  - Panoramic sunroof with PV cells inside glass-glass sandwich
  - **Improved sustainability and comfort**
  - **Design validation plan (DVP) passed successfully** with standard HJT/TOPCon cells and in progress with premium IBC cells



- **Safety qualification mandatory before market entry:**
  - Different standards for terrestrial PV modules and automotive components
  - Automotive experience mandatory to succeed given the demands from OEM

- **Key reliability aspects for automotive PV roofs:**
  - Thermal cycles are not the same as thermal shocks!
  - A UV test is not a fully capable weathering test
  - Resistance to hot spots is a major topic