RoHS-Compliant Interconnection of TOPCon Solar Cells

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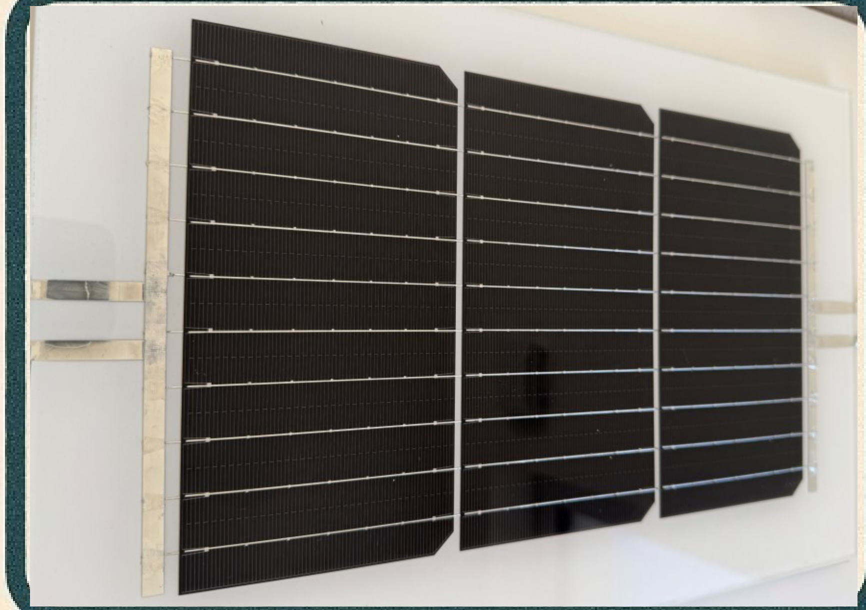
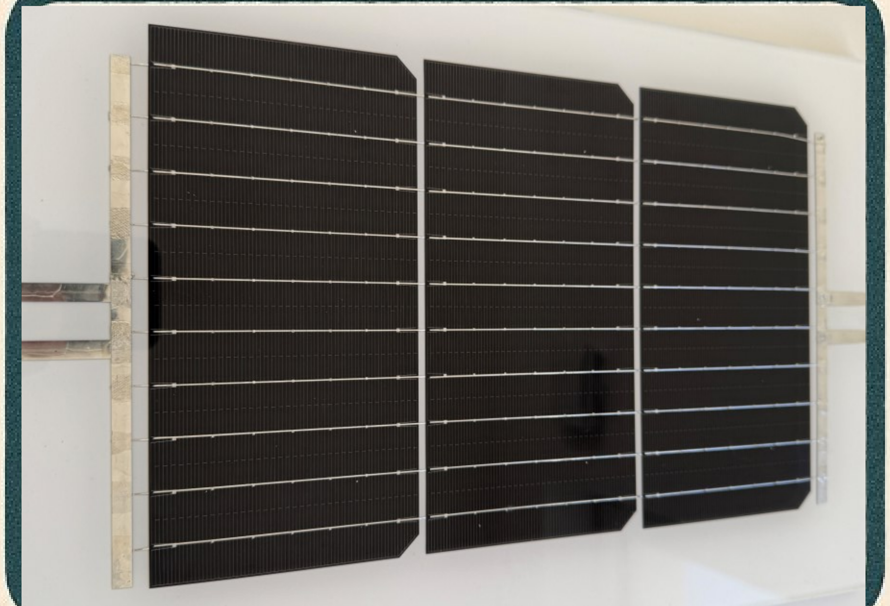
13th Metallization and Interconnection Workshop

FIND THE DIFFERENCE

99% CAN'T FIND THE DIFFERENCE





NEW GAME COMING SOON

Frame design created using AI tools.

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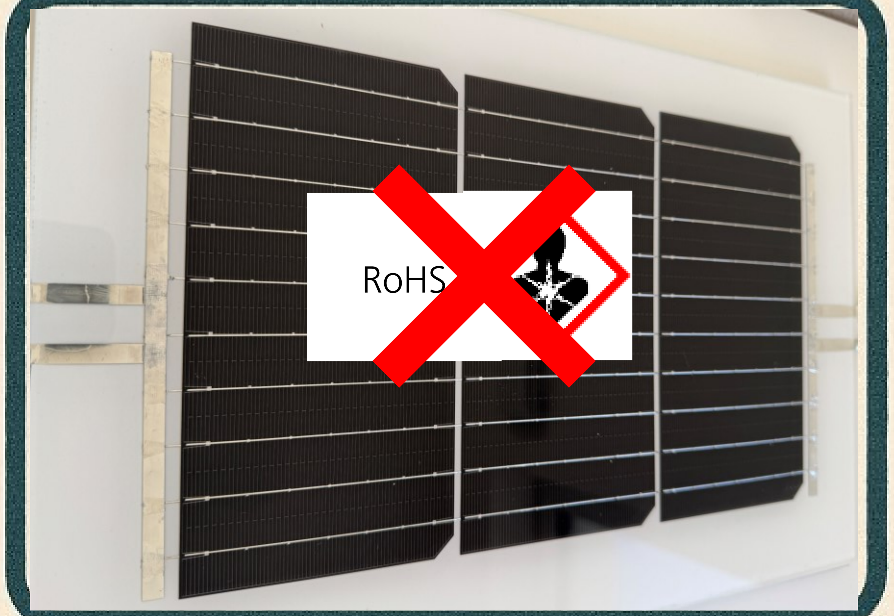
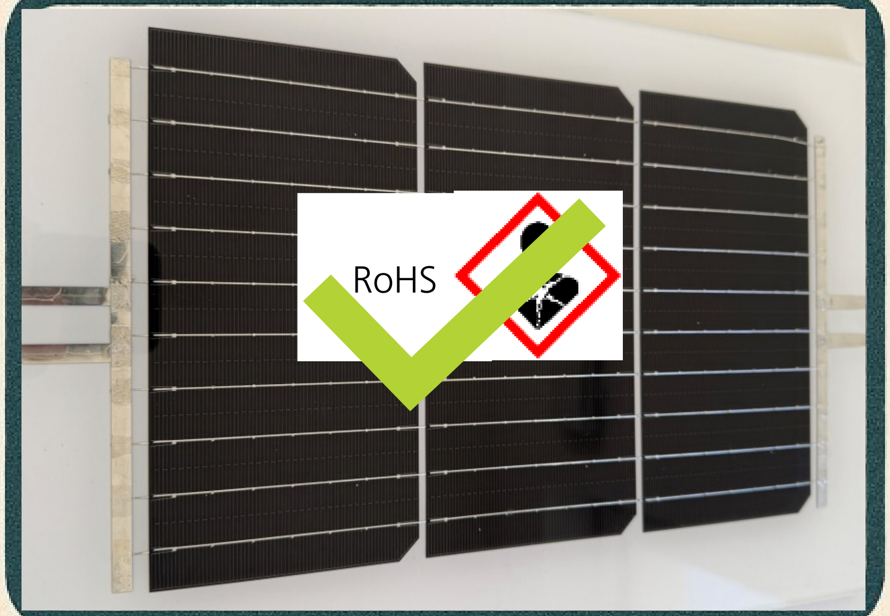




NEW GAME COMING SOON

Frame design created using AI tools.

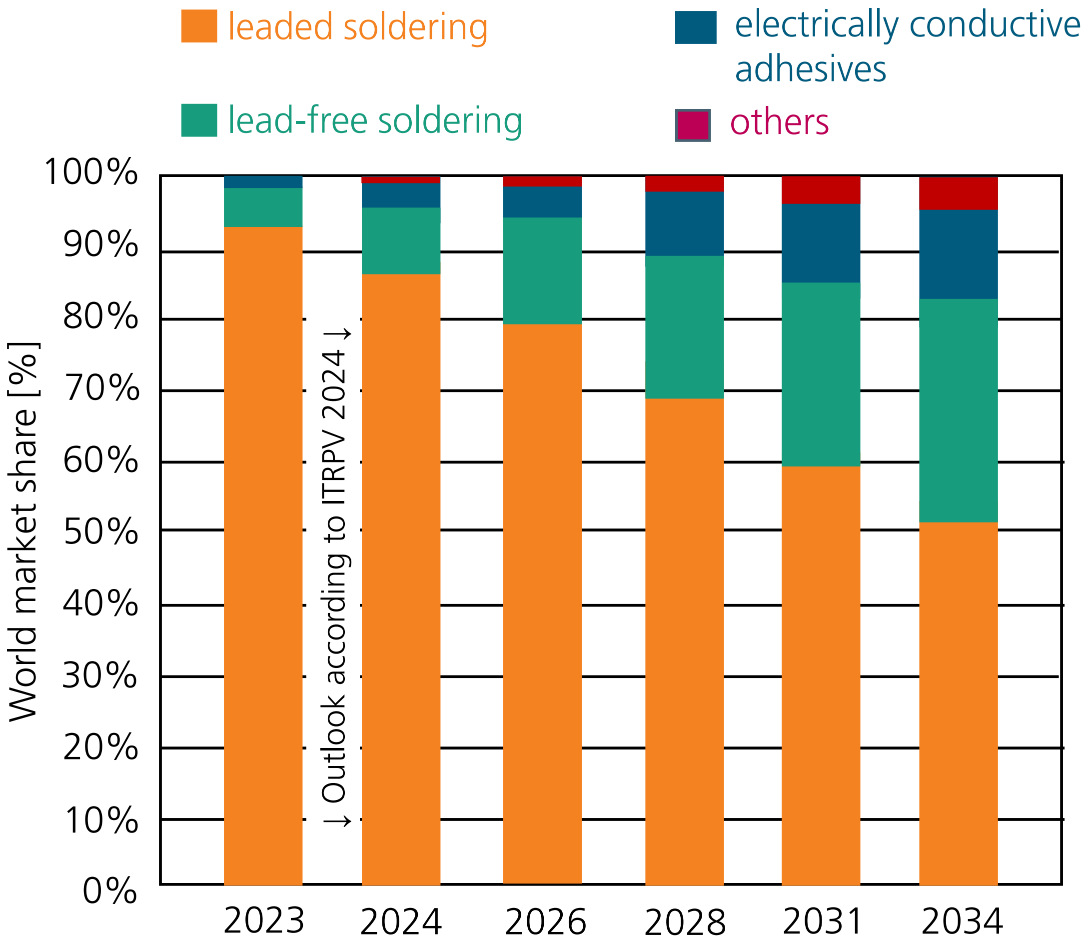
State of the Art

Interconnection technologies in PV modules

Standard: Busbar interconnection

- Currently soldering with Sn60Pb40 coated ribbons [1]
- Alternative lead-free (Pb-free) technologies
  - Lead-free soldering
  - Lead-free glueing
  - Others (*e.g.*, taping, back contact-related solutions)

Pb – isn't its use restricted by European regulations? So why are we still using it?



[1] ITRPV 15th, 2024.

ITRPV: International Technology Roadmap for Photovoltaic
PV: Photovoltaic

Why do we still use Pb-containing solders?

The problem with lead (Pb)

RoHS = Restriction of Hazardous Substances [1]

- EU directive since 2006
- Appendix II: Restricted substances accord. Article 4(1) with **max. concentration** in homogenous materials **in weight percent (%$_{wt.}$)**
  - Lead (0.1%)
  - ...

02011L0065 — EN — 15.07.2016 — 005.002 — 1

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►B DIRECTIVE 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 8 June 2011

on the restriction of the use of certain hazardous substances in electrical and electronic equipment

(recast)

(Text with EEA relevance)

(OJ L 174, 1.7.2011, p. 88)

Amended by:

		Official Journal		
		No	page	date
►M1	Commission Delegated Directive 2012/50/EU of 10 October 2012	L 348	16	18.12.2012
►M2	Commis			
►M3	Commis			

02011L0065 — EN — 15.07.2016 — 005.002 — 20

▼B

ANNEX II

Restricted substances referred to in Article 4(1) and maximum concentration values tolerated by weight in homogeneous materials

Lead (0,1 %)

Mercury (0,1 %)

Cadmium (0,01 %)

Hexavalent chromium (0,1 %)

Polybrominated biphenyls (PBB) (0,1 %)

Polybrominated diphenyl ethers (PBDE) (0,1 %)

[1] RoHS-Richtlinie, 2011/65/EU.

RoHS: Restriction of Hazardous Substances (in Europe)

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  - **Lead (0.1%)**
  - …

→ (4) This **directive does not apply** to:
(i) photovoltaic modules intended to be used in a system designed,…

4. This Directive does not apply to:

(a) equipment which is necessary for the protection of the essential interests of the security of Member States, including arms, munitions and war material intended for specifically military purposes;

(b) equipment designed to be sent into space;

(c) equipment which is specifically designed, and is to be installed, as part of another type of equipment that is excluded or does not fall within the scope of this Directive, which can fulfil its function only if it is part of that equipment, and which can be replaced only by the same specifically designed equipment;

(d) large-scale stationary industrial tools;

(e) large-scale fixed installations;

(f)

(g)

(h)

(i) photovoltaic panels intended to be used in a system that is designed, assembled and installed by professionals for permanent use at a defined location to produce energy from solar light for public, commercial, industrial and residential applications;

(j) equipment specifically designed solely for the purposes of research and development only made available on a business-to-business basis.

[1] RoHS-Richtlinie, 2011/65/EU.

RoHS: Restriction of Hazardous Substances (in Europe)

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RoHS - Directive

The problem with lead (Pb)

Calculation

- 13.4 g Pb (for Sn60Pb40) inside one PV module
- ~30 kg module weight

⇨ 0.0134 kg / 30 kg ≈ 0.04 $\%_{wt.}$ < 0.1 $\%_{wt.}$

[1] RoHS-Richtlinie, 2011/65/EU.

RoHS - Directive

The problem with lead (Pb)

Is a PV module a homogenous material? [1]

- No, BUT:
  - Solder alloy = homogeneous material
  - Metallization = homogeneous material
  - …
- Therefore: The max. concentration of 0.1 $\%_{wt.}$ refers to the **solder alloy itself**

Calculation

- 13.4 g Pb (for Sn60Pb40) inside one PV module
- ~30 kg module weight

⇨ 0.0134 kg / 30 kg ≈ 0.04 $\%_{wt.}$ < 0.1 $\%_{wt.}$

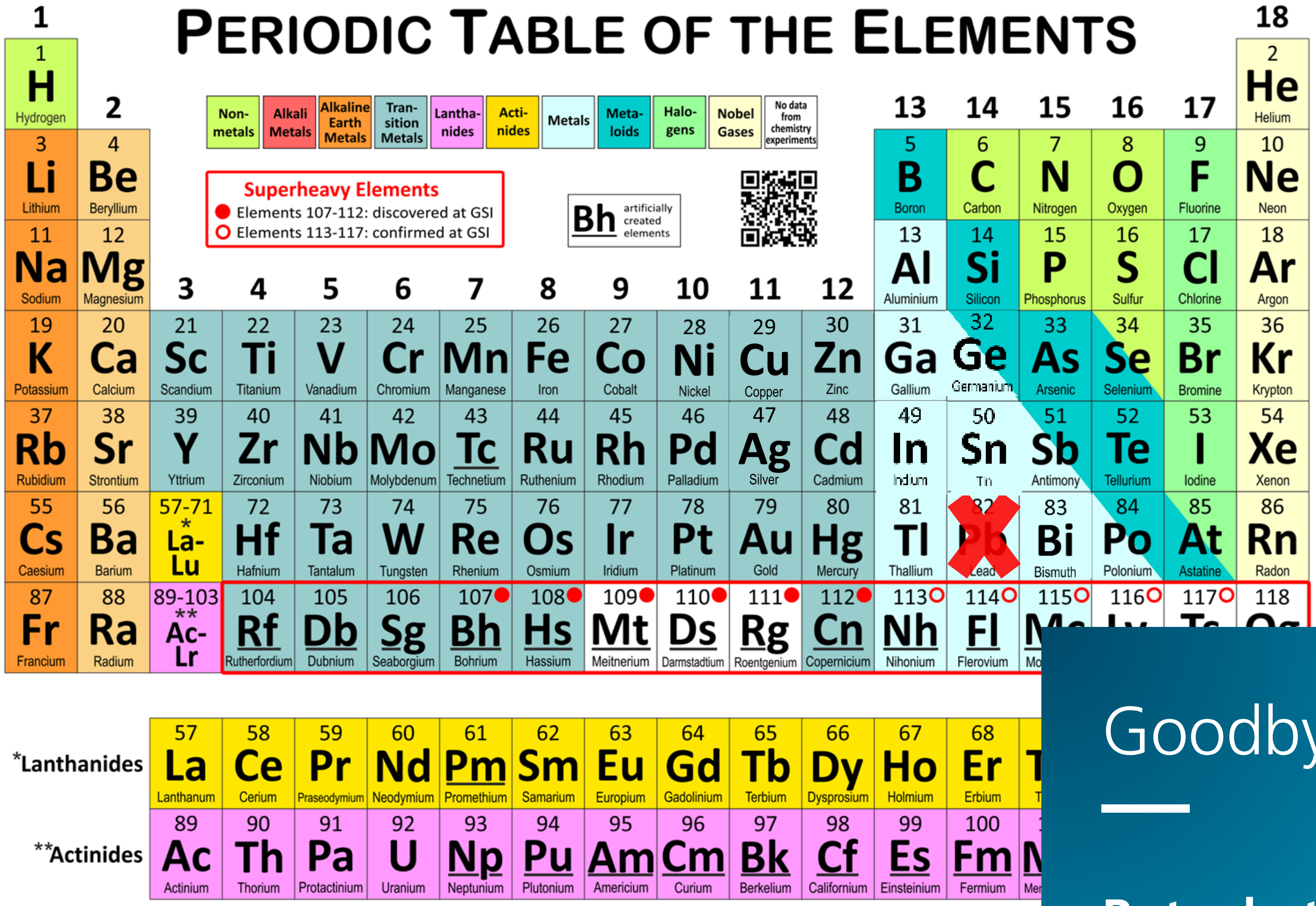
Correct calculation

- 34 g solder alloy inside one PV module

⇨ 13.4 g / 34 g ≈ 40 $\%_{wt.}$ ≫ 0.1 $\%_{wt.}$

→ Current RoHS exemption is under revision – Pb content exceed 0.1 $\%_{wt.}$ limit
→ Developing Pb-free solutions to stay prepared for future requirements.

[1] RoHS-Richtlinie, 2011/65/EU.



Goodbye, Lead!

But what‘s next?

PSE image: https://superheavies.uni-mainz.de/periodic-tables/

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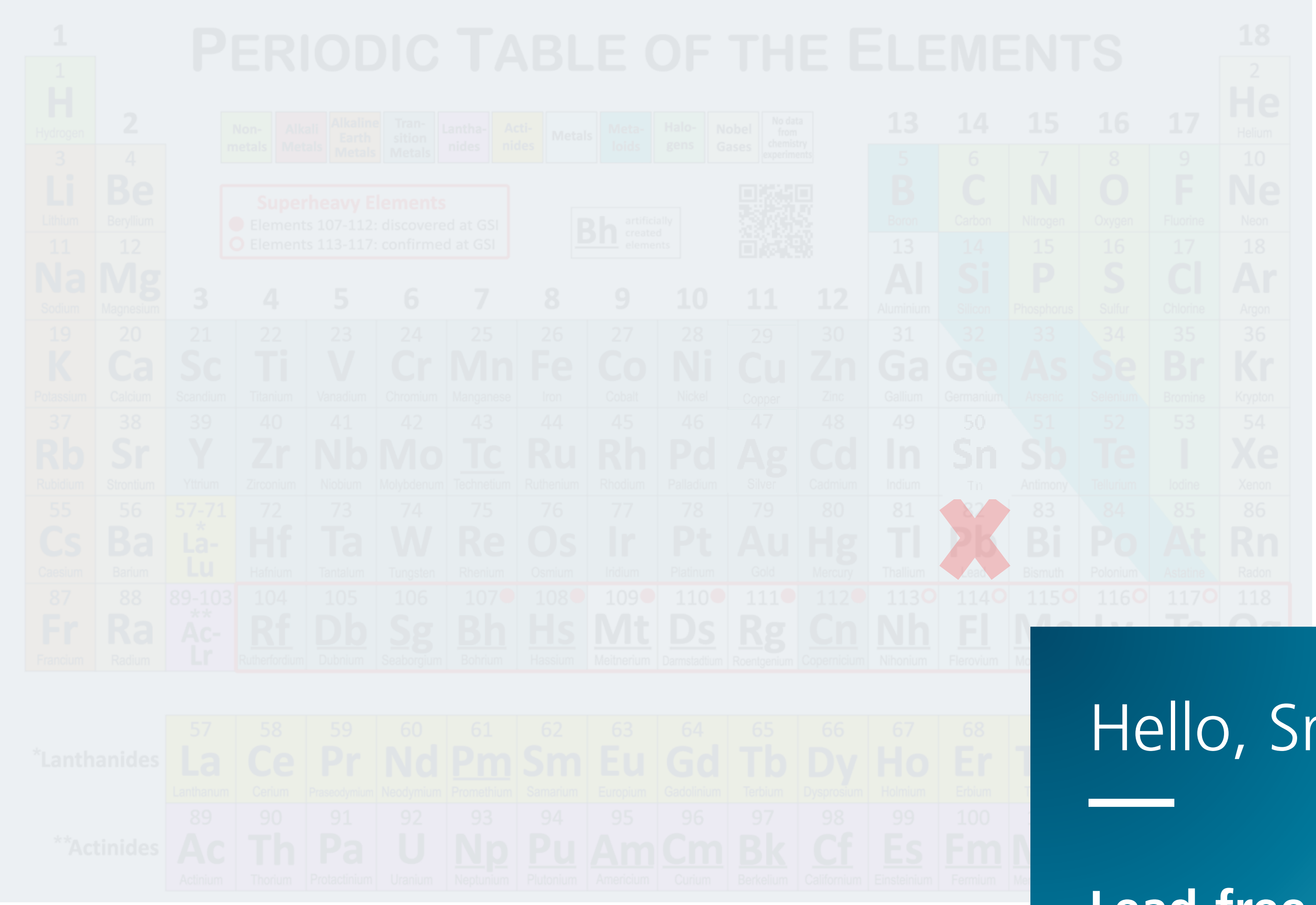

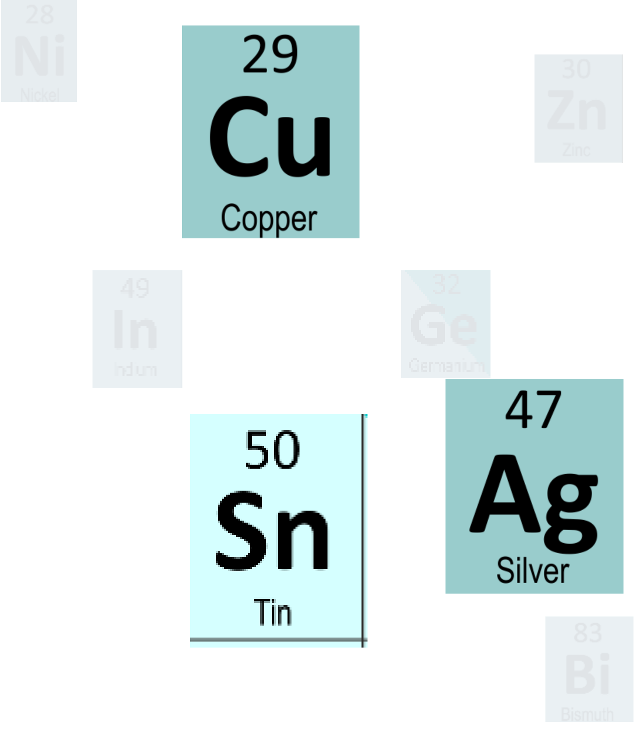

Hello, SnCuAg!

Lead-free, but full of potential

PSE image: https://superheavies.uni-mainz.de/periodic-tables/

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Tin-Silver-Copper Solder

Pb-free alloys in electronics & research gaps for PV

50 Sn Tin | 47 Ag Silver | 29 Cu Copper

Short Profile of SnAgCu (SAC) alloys:

- Typically used composition **SAC305**:
  - **Sn96.5Ag3.0Cu0.5** ($\%_{wt.}$) - $T_{m,\ SAC305}$ = 217-219 °C [1]
- Widely used in electronic industry
  - Replacement of SnPb alloys after restrictions
- Sufficient mechanical, electrical and long-term reliability properties[3-6]
  - Good wetting and solderability on Cu surfaces
  - High thermal fatigue resistance and mechanical stability under cyclic loading


[2]

[1] H. Baker, ASM Handbook, 1992.
[2] Image created using AI tools

T_m : Melting Point

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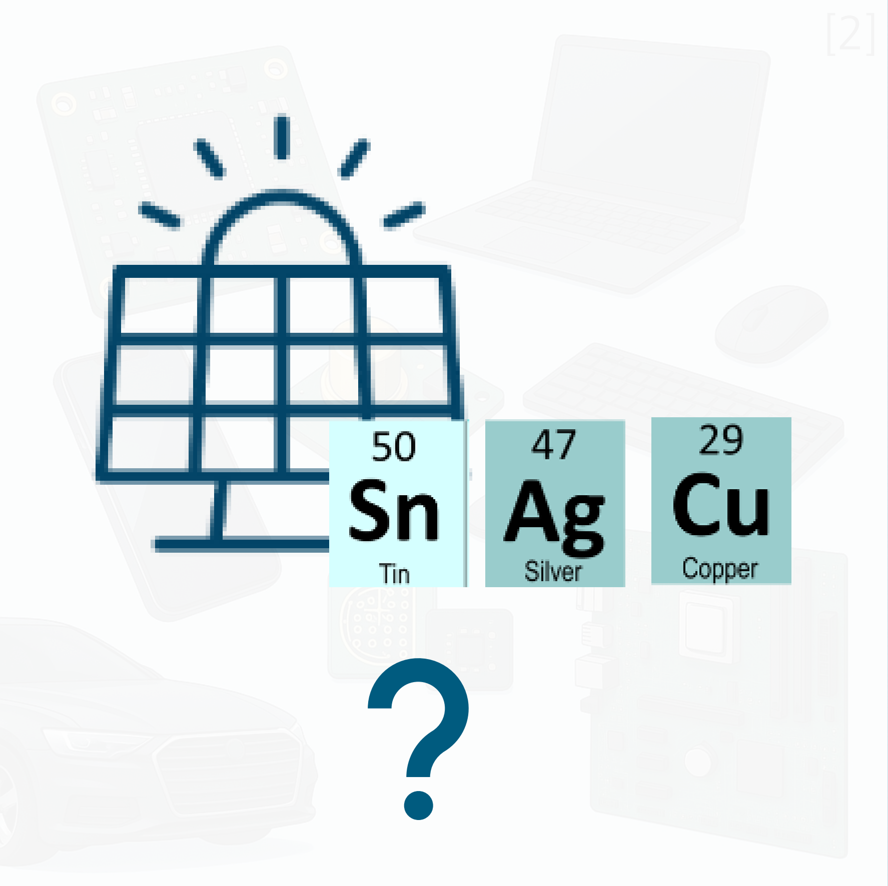
Previous PV-related SAC studies are limited – mostly outdated and not focused on feasibility and current technologies



[1] H. Baker, ASM Handbook, 1992.
[2] Image created using AI tools
[3] B. Szyszka *et al.*, Curr Appl Phys, vol. 12, pp. 2–11, 2012, doi: 10.1016/j.cap.2012.07.022.
[4] A. Arazna *et al.*, in IEEE 8th ESTC, pp. 1–6, 2020.
[5] L. Zhang *et al.*, ELTE & IMAPS/CPMT, vol. 52, no. 3, pp. 559–578, 2012, doi: 10.1016/j.microrel.2011.10.006.
[6] Z. Cai et al., ECTC, pp. 1493–1511, 2010.

T_m : Melting Point

SAC in PV modules

Research question & experimental approach

Can SAC305 provide reliable interconnections while remaining compatible with standard industrial processes despite its higher melting point?

Experimental approach:

- Mechanical evaluation of strings
  - Wetting behavior using 90° peel test[1]
- Electrical characterization of PV modules
  - I-V measurements[2]
- Long-term reliability of PV modules
  - Thermal cycling & Damp heat tests[3]

Variation of IR lamps set temperature:

$T_{ref,\ SnPb}$	190 °C / 220 °C
T_{Medium}	200 °C / 230 °C
T_{High}	210 °C / 240 °C

Materials:

- Cell technology: TOPCon, M10, hc, bifacial, 10BB
- Solder of ribbons (Cu core + solder):
  - Reference (Sn60Pb40)
  - SAC305

[1] Solarzellen - Datenblattangaben und Angaben zum Produkt für kristalline Silicium-Solarzellen (DIN EN 50461:2007-03), 2007.
[2] IEC 60904-3, Photovoltaic devices: Part 3: measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data, in: IEC 60904-3:2019, 2019.
[3] Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 2: Test Procedures, IEC 61215-2:2016, 2016.

Hot enough for SAC?

Feasibility of SAC305 on industrial stringer

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First Quality Check after Stringing Process

Microstructure of the solder joint on TOPCon metallization

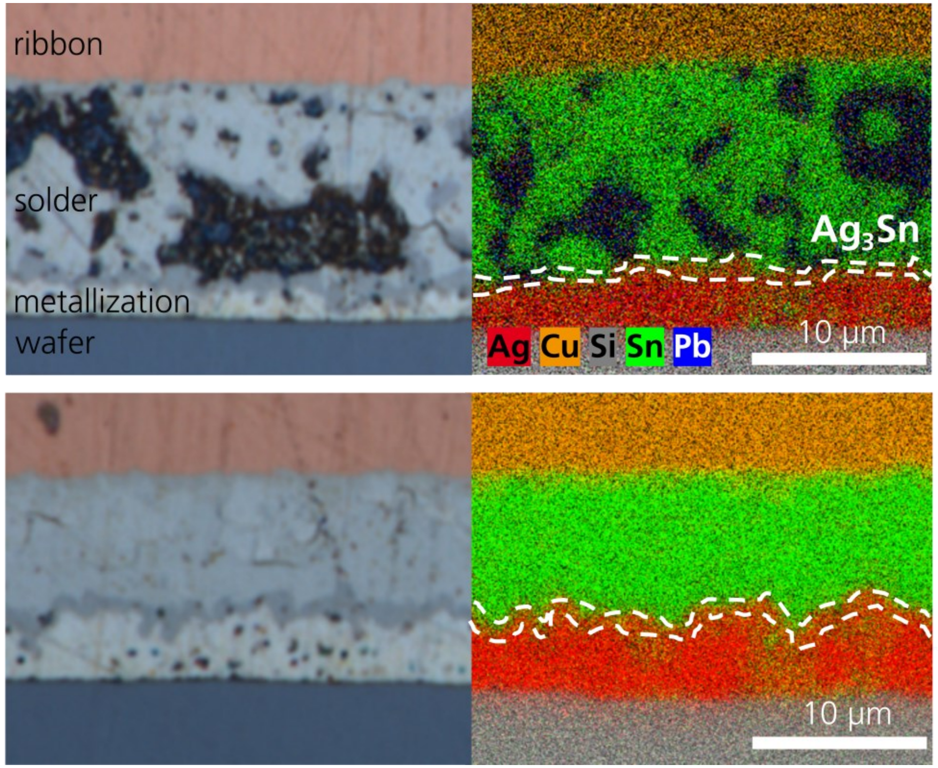
Required diffusion zones between solder and busbar

- An indicator of successful wetting and optimal electrical contact
- Formation of intermetallic phase consisting of Sn and Ag (Ag_3Sn) [1]

Cross-sections of solder joints on TOPcon solar cells

Sn60Pb40 (ref.)

SAC305



Digital microscope EDX element mappings

[1] H. Baker, ASM Handbook, 1992.

EDX: Energy-dispersive X-ray spectroscopy

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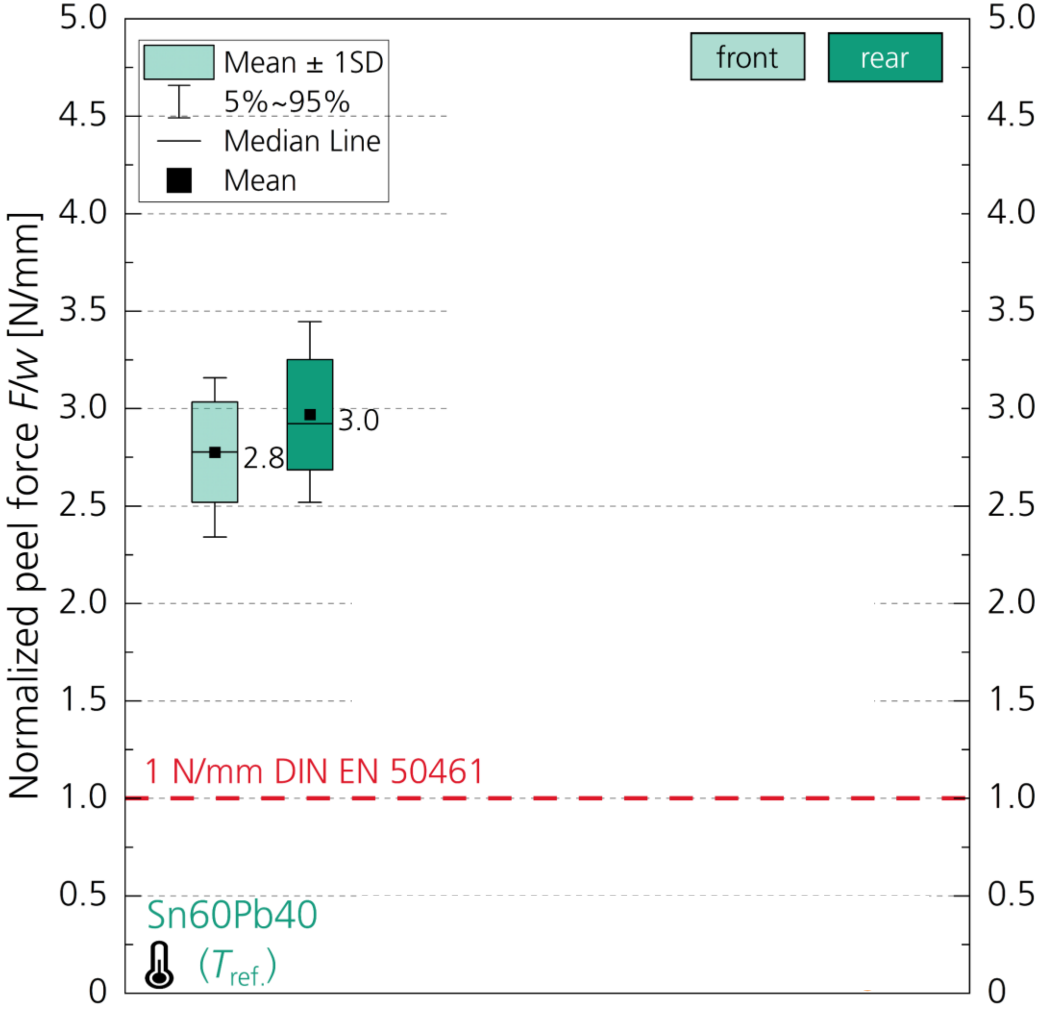
What is the influence of process temperature on the wetting behavior and mechanical adhesion of the ribbons?

Normalized peel forces should exceed 1 N/mm cirterion [1] for sufficient mechanical adhesion

- Peel forces of reference solder are higher than 1 N/mm
- Differences front and rear are expected & normal



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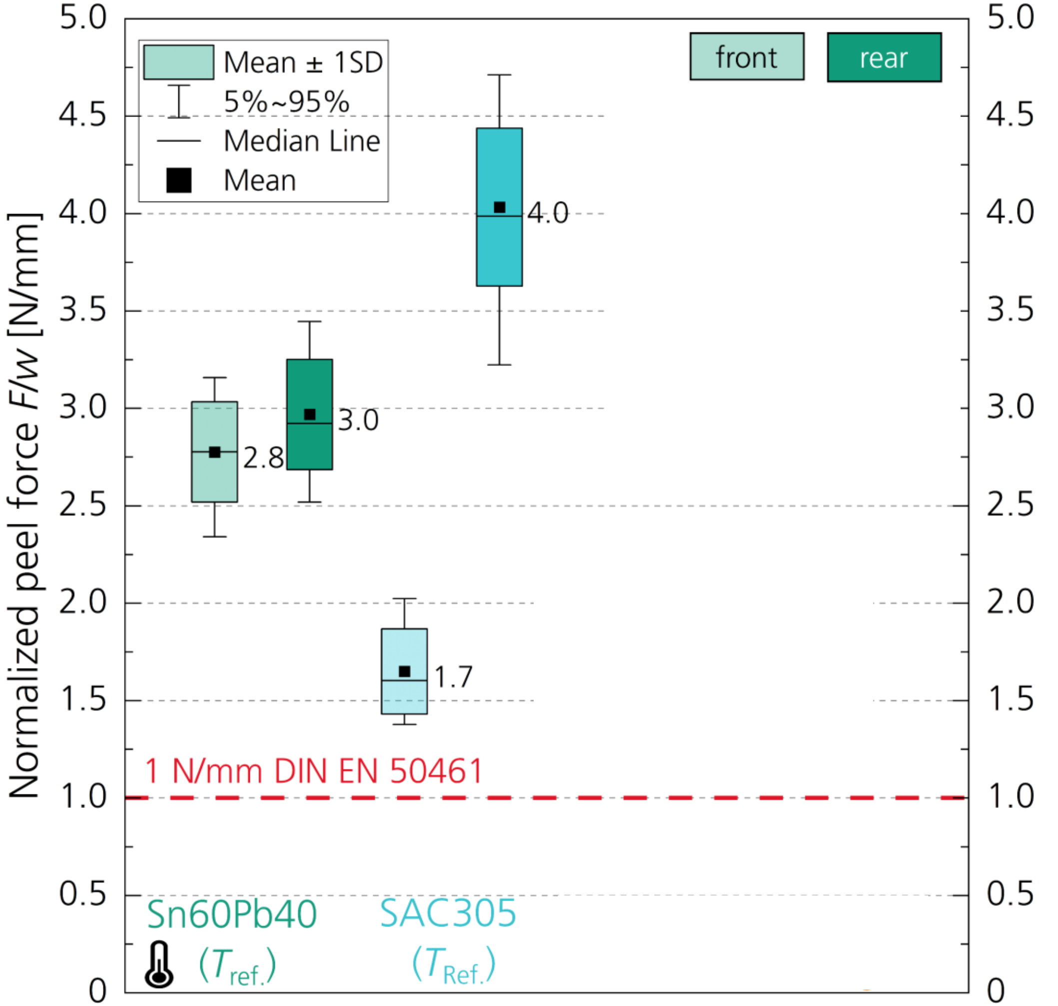
- Comparison of peel forces: SAC305 vs. Sn60Pb40
  - **Peel forces of SAC ribbons > 1 N/mm**
  - **Peel forces on rear side of SAC ribbons are higher SnPb values**

→ Standard process temperature ($T_{ref.}$) for SAC alloys exceed very good wetting



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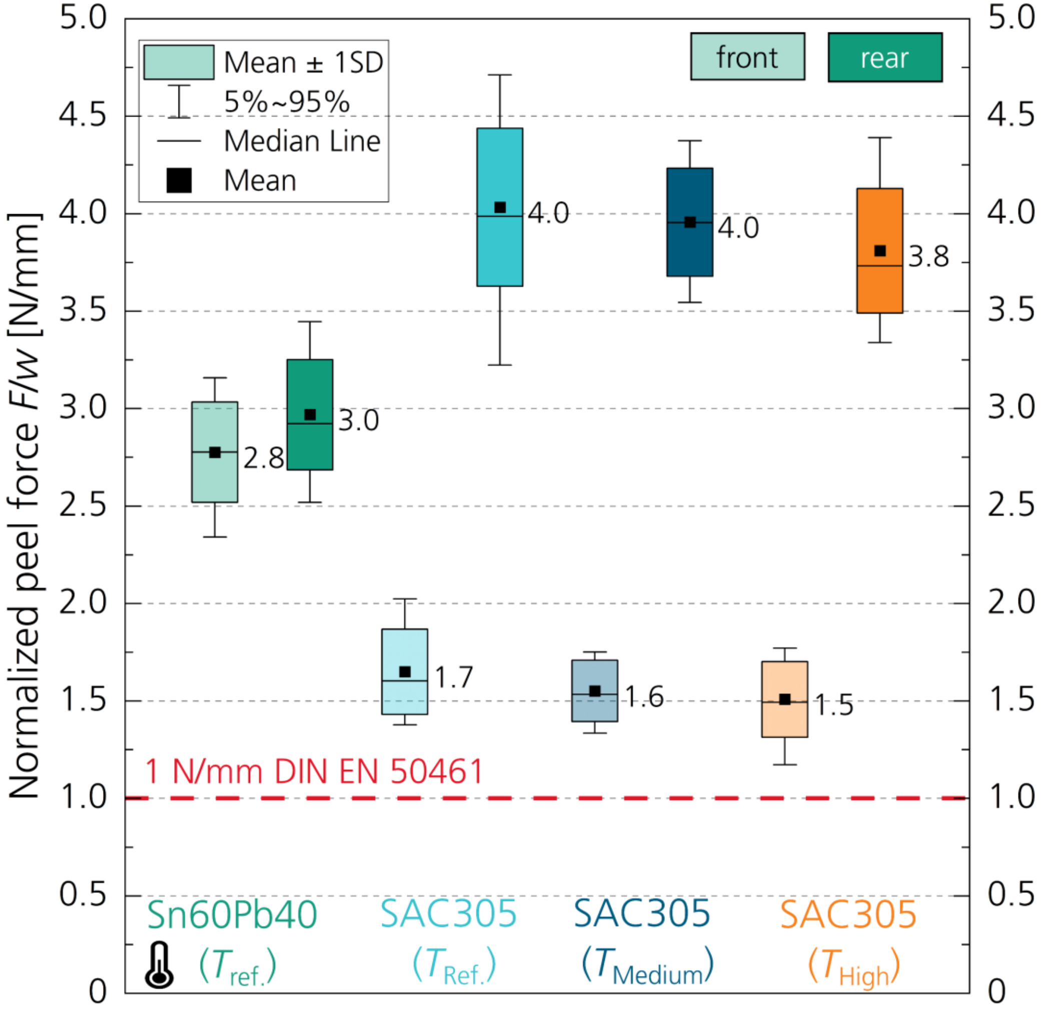
- Impact of different process temperatures on wetting behavior of alloys SAC305
  - **Higher melting point SAC is more noticeable on the front side**



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Adhesion of Pb/Bi-free solder on TOPCon comparable to reference and in part better than reference solder

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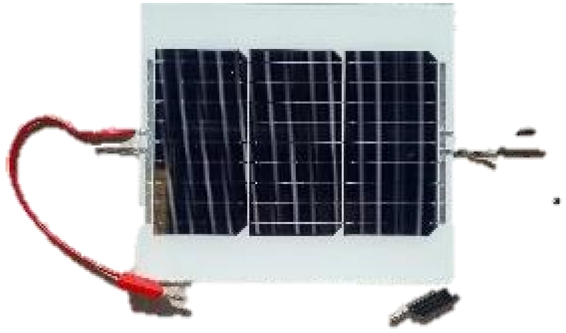
Module Integration

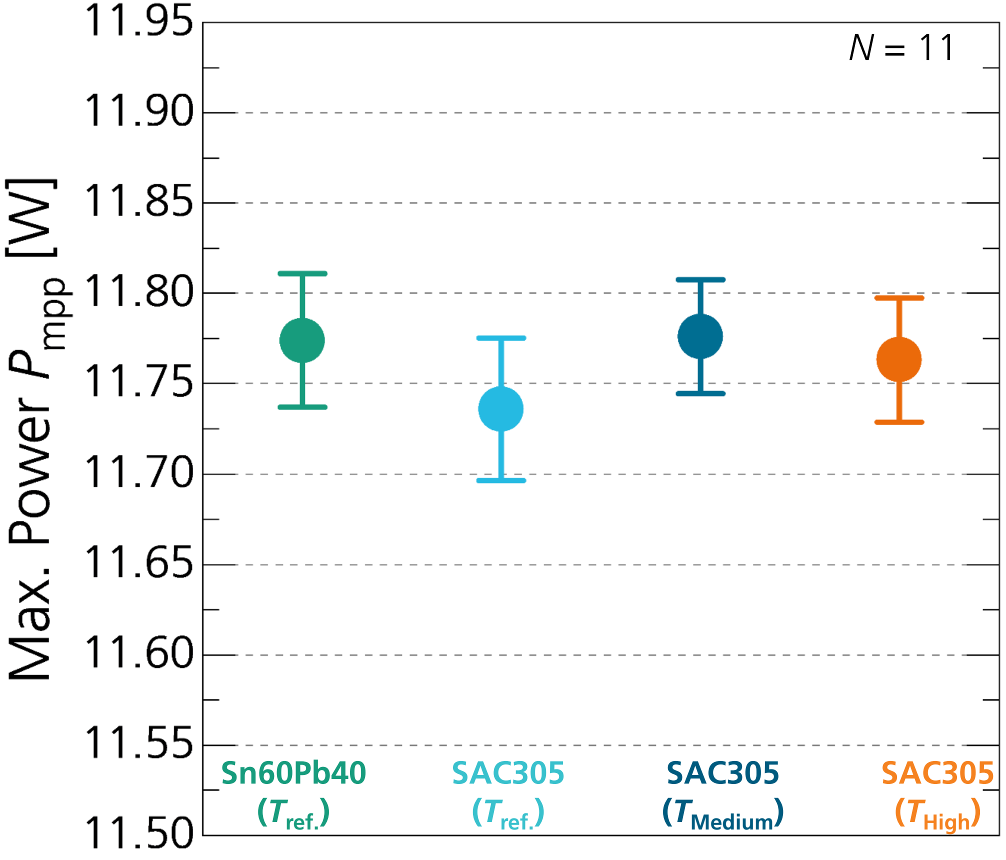
Module performance initial

Initial *I-V* performance:

- Data confirms functional operation of all modules
- Fill factor *FF* stands out, as all module groups exhibit a high fill factor above 80 %, which is indicative of a good interconnection technique

- **No significant differences** observed between process temperatures and solder alloys





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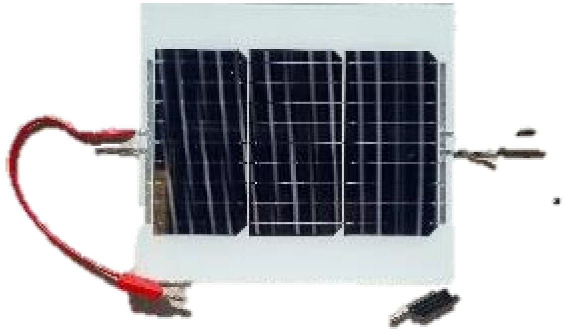
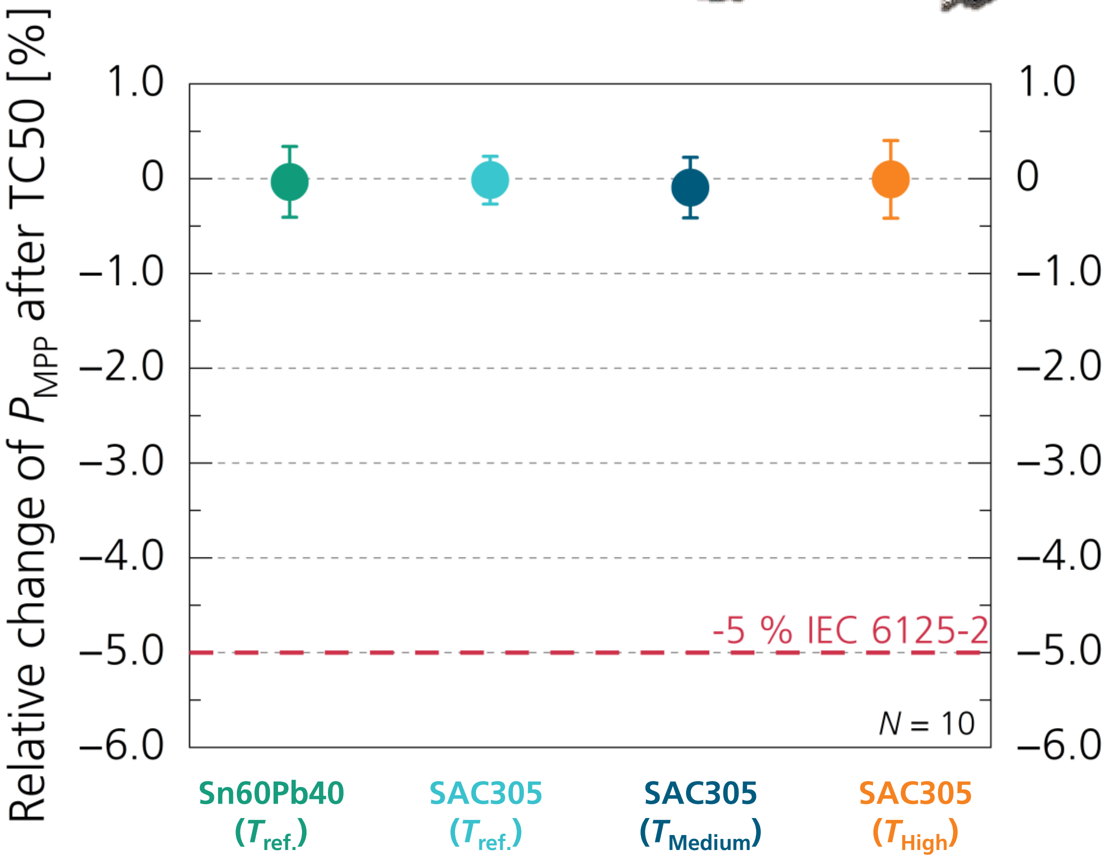
Module Integration

Module performance after TC50

TC50 *I-V* performance:

- Data confirms functional operation of all modules after TC 50
- Parameter degradation TC50 < -1 $\%_{rel.}$
- No unusual changes seen in EL images
- TC200 is still running





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RoHS Readiness & Process Feasibility of SAC305

No Pb, No Bi, No Ag? What's next?

RoHS compliance will require complete phase-out of SnPb solder

→ Current SnPb-based modules exceed upcoming RoHS Pb limits
→ PV industry should be prepared for lead-free interconnection

SAC305 tested on fired Ag contacts of industrial TOPCon cells

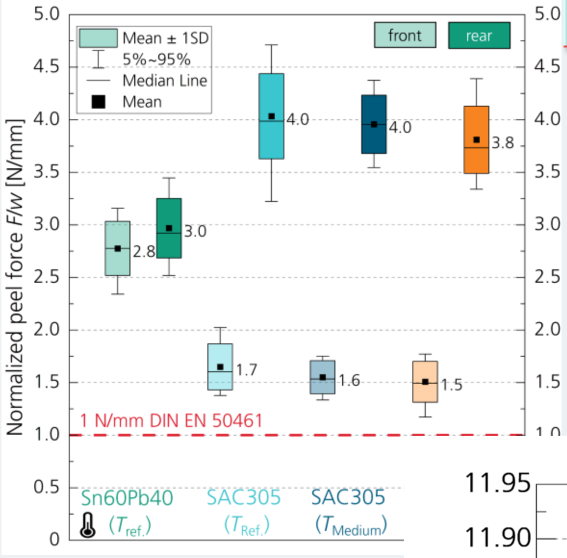
→ Interconnection with industrial stringer and standard process successful
→ Peel forces comparable or better than SnPb (1.5 – 4.0 N/mm)
→ Module integration successful: Fill factors > 80 %
→ *I-V* data, Initial and TC50, show stable performance

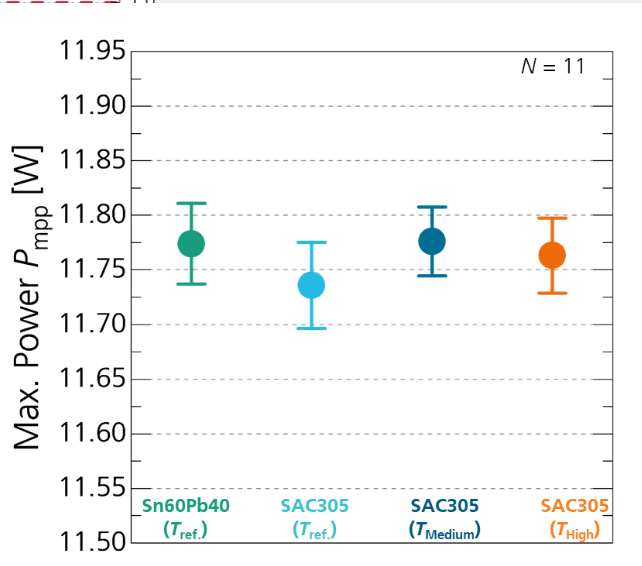
SAC305 proves technically and process-wise suitable as a Pb-free alternative for TOPCon technology.

Yet, the question remains — when compliance becomes mandatory, will cost still be the deciding factor or will there be another choice?

§

RoHS [1]
REACH EC [2]
China RoHS 2 [3]
China REACH 2 [4]
TSCA [5]
...





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Thank you for your attention!

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