Lead-Free PV Modules: Industrial Realization and Evaluation of Environmental Impact

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Motivation: PV modules typically contain 8-10 g/m² lead (Pb). The project "BermUDa" demonstrated and evaluated the production of lead-free PV modules using state-of-the-art processes like screen printing and solder interconnection, to improve sustainability and compliance to a possible RoHS[1] revision.

Approach

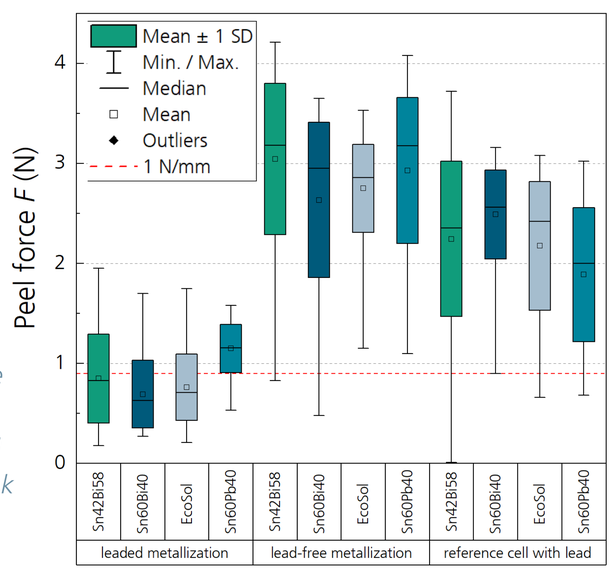
- Demonstration of lead-free PV modules
- Investigation of sustainability
- Module Production
  - Processes: Screen printing and solder interconnection.
  - Metallization on 4500 pre-processed wafers, optimization of firing process
  - Different solder alloys: Sn42Bi58, Sn60Bi40, Ecosol, and Sn60Pb40 (ref.).

Cell Metallization

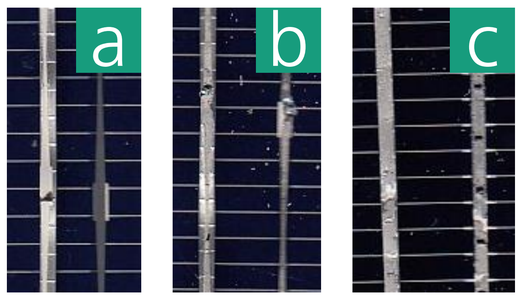
- Lead-free pastes required slightly thicker finger width of 40 vs. 33 µm for lead-containing pastes (results from 2019).
- Efficiency of lead-free cells up to 0.3 $\%_{abs}$ lower compared to leaded ref. cell.

Cell Interconnection

- Lead-free pastes can operate on a comparable or even higher level to lead-containing pastes.
- 90° Peel forces reached > 1 N/mm for a broad range of process parameters.

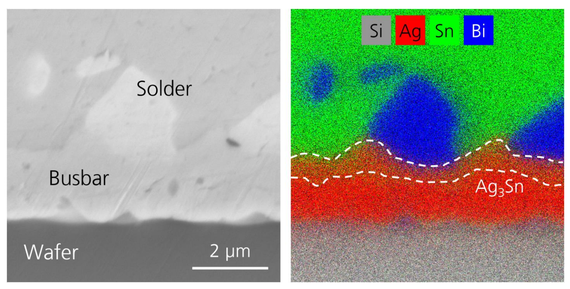


90° peel forces of the cell front side after soldering. For the group with lead-containing paste, the achieved peel forces were limited by the weak cell/metallization interface.



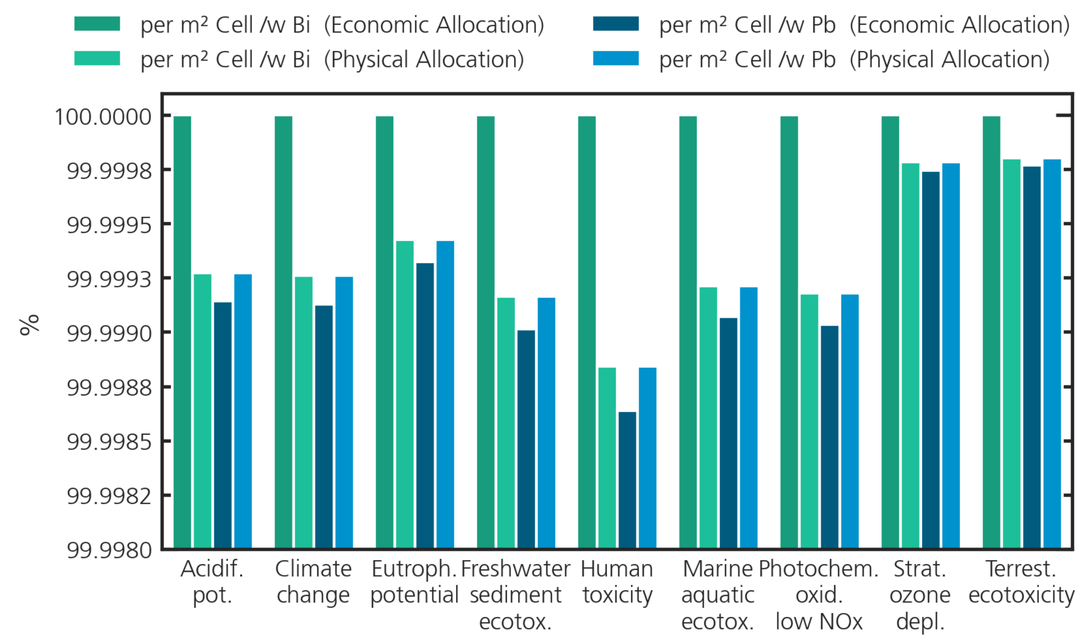
Cell metallization / solder alloy

Fracture pattern of a) leaded cell metallization, b) lead-free cell metallization and c) commercial reference cell.



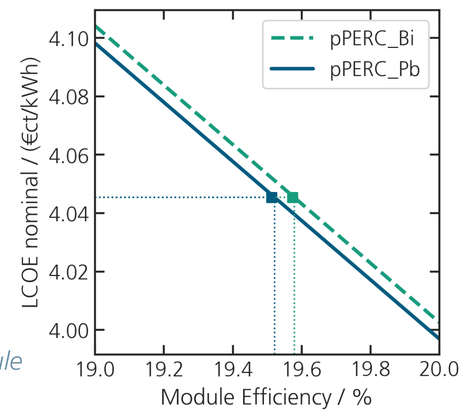
SEM and EDX images of a cross section of a lead-free solder joint with An Ag_3Sn phase at the interface between solder and Ag.

Life Cycle Analysis (LCA) and Cost Analysis



Life-cycle assessment of lead-containing and lead-free solar cells across different categories.

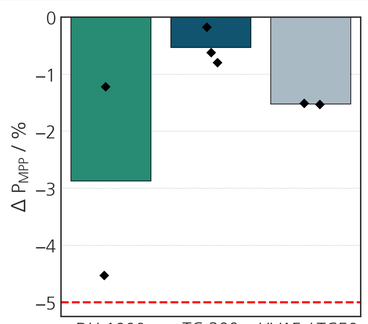
- Bi not necessarily more sustainable:
- Coupled production processes of Pb and Bi requires allocation.
- Small difference between materials and allocations.
- Total Cost of Ownership (TCO) analysis shows small (< 0.5 %) difference for module production costs.



Sensitivity analysis of the influence of module efficiency on the LCOE at Freiburg

Module Reliability

- The modules pass the tests with a good margin to the pass-fail criterion (-5 %).



Power loss of lead-free modules after reliability tests according to IEC 61215-2:2016.

DH 1000 TC 200 UV15 / TC50 / HF10

[1] Restriction of the use of certain hazardous substances, Directive 2011/65/EU: RoHS, 2011.

The authors acknowledge the funding from the German Federal Ministry for Economic Affairs and Climate Action (FKz.: 0324362 "BermUDa").

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag