3D lamination for flexible manufacturing of variously curved PV modules

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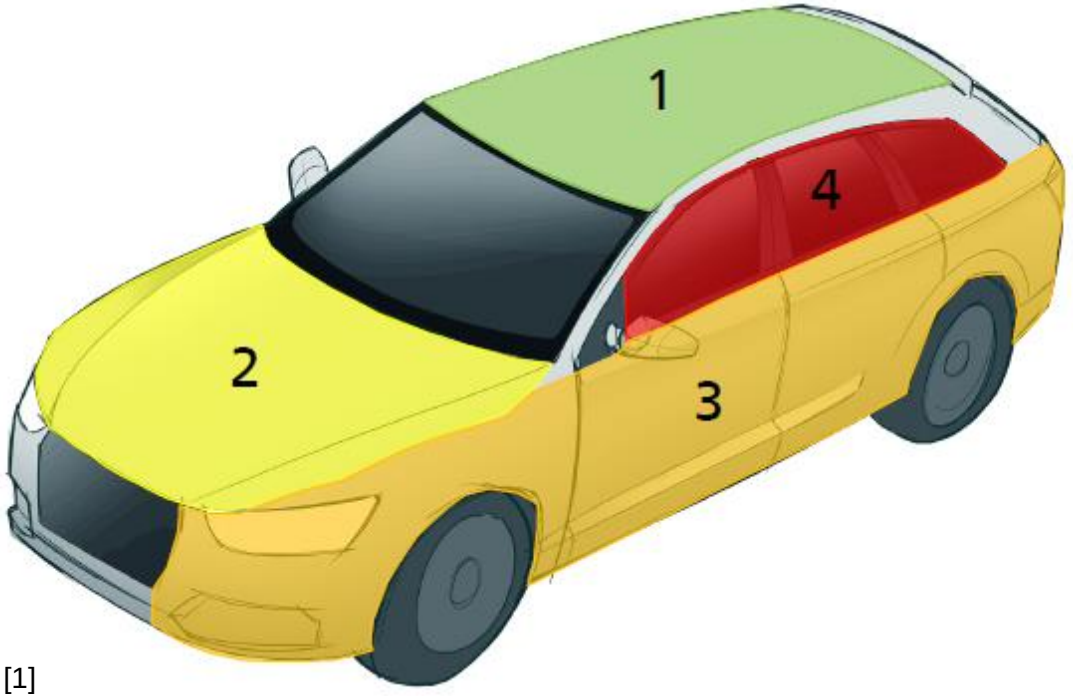
PV potential of electric passenger cars

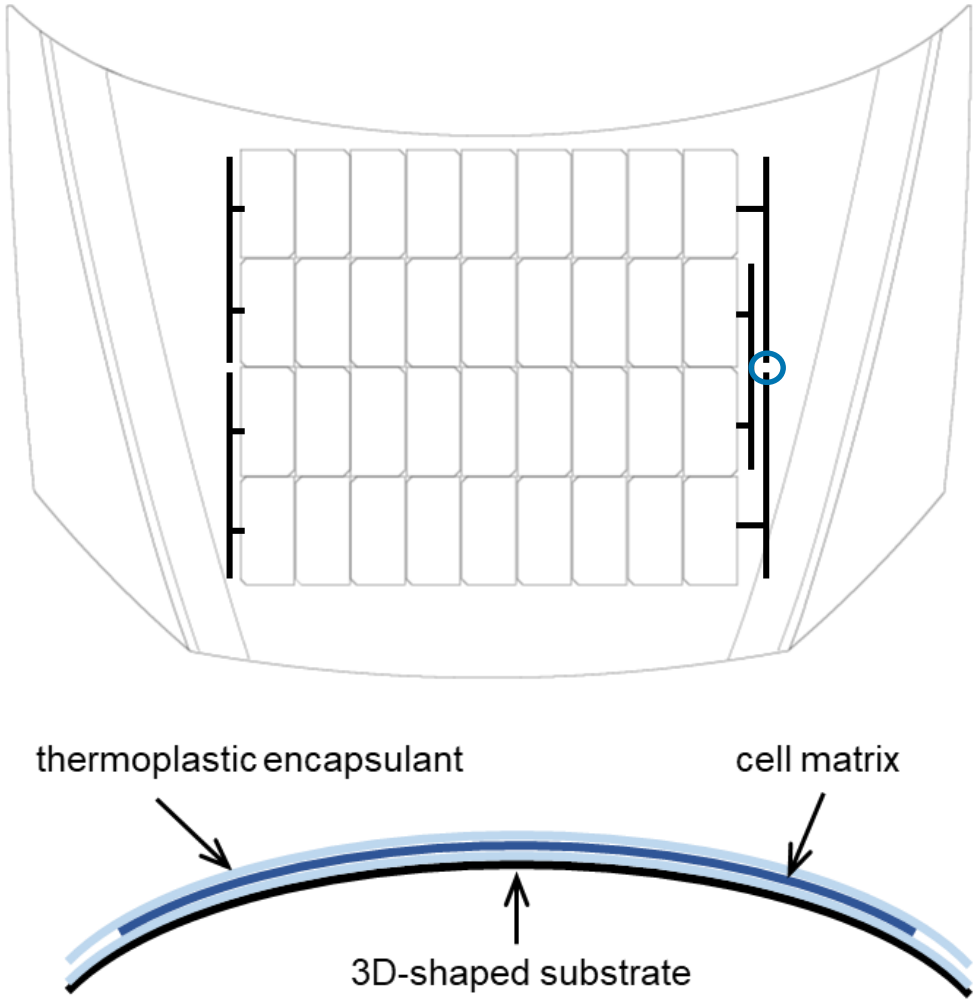


[1]

- Increase annual driving range with vehicle-integrated PV (VIPV)
- Potential solar range is ca. 5000 km per year for roof, hood and trunk [1]
- IBC cells advantageous for VIPV due to:
  - High efficiencies [2,3]
  - Thin modules due to one-sided and foil-based interconnection [4]
  - Aesthetic appearance [5]
- Challenge: 3D-shaped substrates

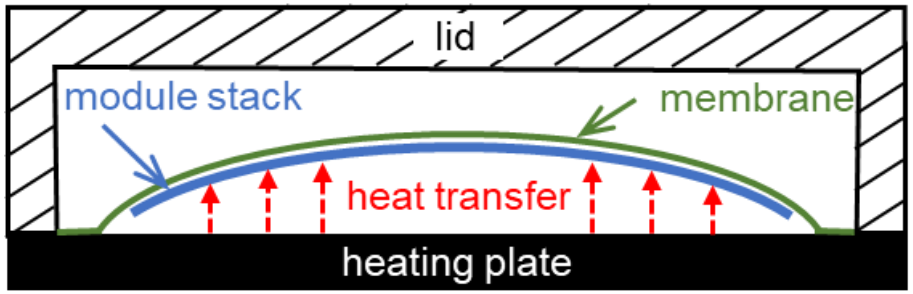
[1] M. Heinrich et al., 37th EUPVSEC, 2020
[2] F. Haase et al., Sol. Energy Mater. Sol. Cells, vol. 186, pp. 184-193, 2018
[3] K. Yoshikawa et al., Nat. Energy 2, 17032, 2017
[4] H. Schulte-Huxel et al., IEEE Journal of Photovoltaics, vol. 3, no. 1, pp. 77–82, 2013
[5] J.C. Ortiz Lizcano et al., Progress in Photovoltaics Vol. 30, pp.401-435, 2022

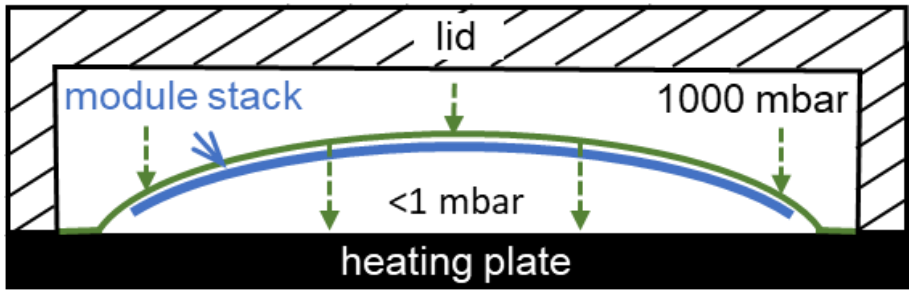
VIPV module layout

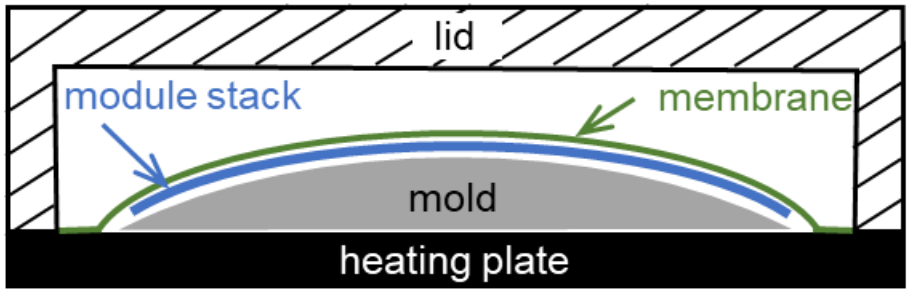


- Substrate: passenger car hood
- Matrix of 4x9 half-cut IBC cells
- Both contacts fed through one hole
- Electrical isolation by substrate primer and double layer of encapsulant

Challenges for lamination of 3D-shaped modules

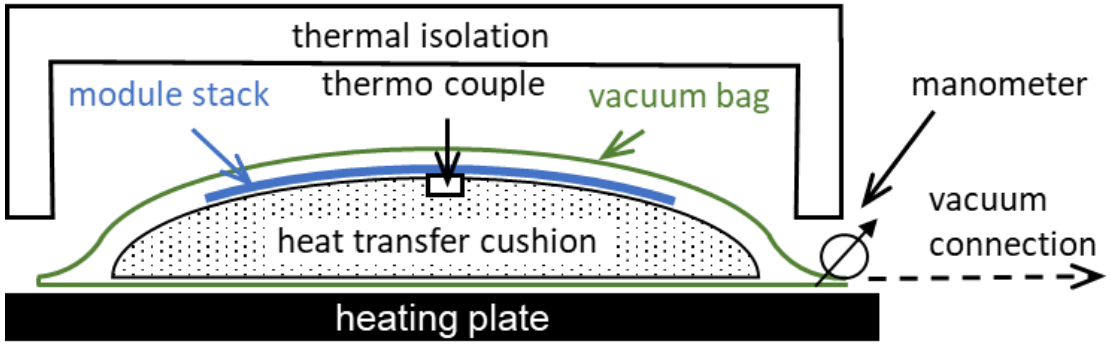






- Evacuated space between flat heating plate and curved module stack hinders heat transfer
- Module substrate could be deformed due to membrane pressure
- Specific mold for every module shape required

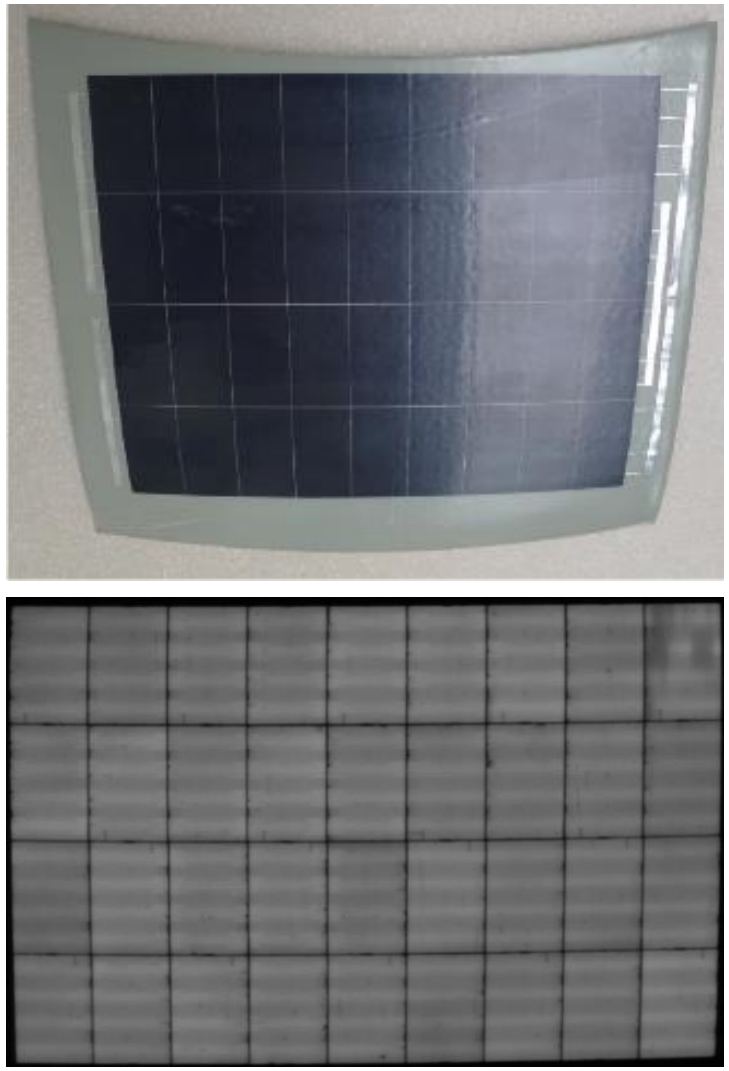
Flexible Heat Transfer Mold



- Heat transfer cushions as flexible heat transfer mold (FlexHTM) [1,2]
- Cushions made from heat resistant textiles or polymer foils and filled with aluminum granulate
- Applicable in standard vacuum lamination processes

[1] J. Eilrich, A. Morlier, patent number DE 10 2022 104 261 B3
[2] W. Wirtz et al., 40th EUPVSEC, 2023

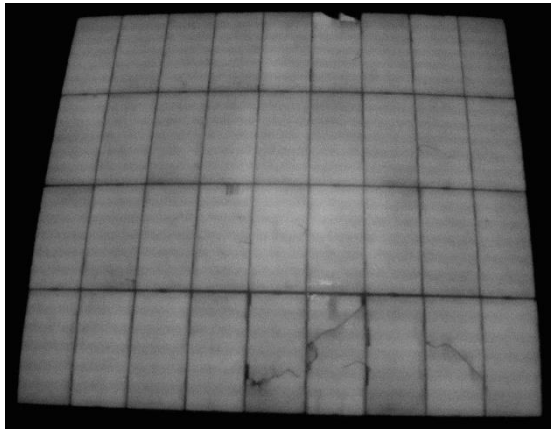
Passenger car hood cutout



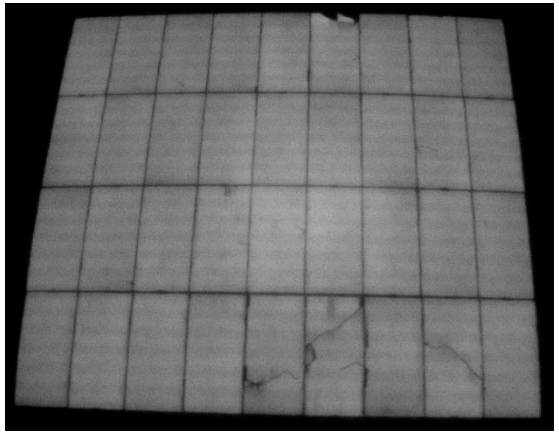
- 0.7 m² with 8 cm height difference
- Encapsulant melted evenly on whole area
- Electrical insulation works
- No cell cracks after lamination observable in electroluminescence image
- **Successful lamination of PV module on curved metal substrate**

Passenger car hood for automotive vibration test

before vibration test



after vibration test



- Heat transfer cushions avoid deformation of the steel substrate during lamination
- No mechanical or electrical degradation after 24h automotive vibration test [1,2]

[1] Markert et al., Sustainability 2021, 13, 13341
[2] “Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 3: Mechanical loads”, ISO/FDIS 16750-3:2007

Aesthetically appealing VIPV module

- Reuse of flexible heat transfer mold
- Uniform bluish-black appearance due to IBC cells on black hood and scattering encapsulant
- No additional coloring layer needed
- Cross connectors hidden behind dummy cells

Demonstrator VIPV modules from passenger car hoods

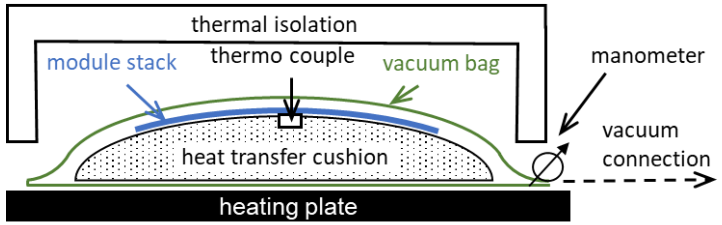
cutout

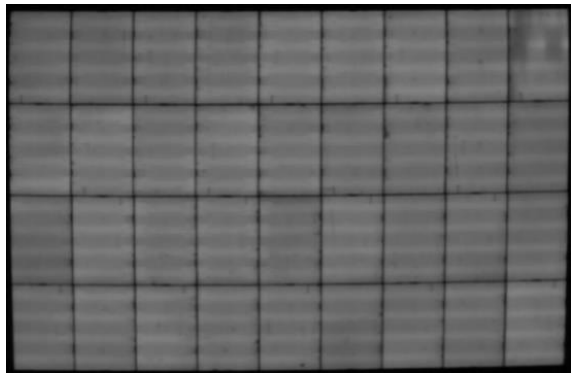
grey

black

Module	A [m²]	A_{active}[m²]	I_{sc} [A]	V_{oc} [V]	FF [%]	P_{mpp} [W]	η_{active} [%]
Cutout	0.70	0.46	4.9	24.8	79.3	95.5	20.8
Grey	1.13	0.46	4.9	24.8	80.1	97.8	21.3
Black	1.13	0.46	4.9	24.7	80.6	97.6	21.3

Summary





- 3D lamination with flexible heat transfer mold
- Successful lamination of VIPV modules from passenger car hoods and IBC cells
- Crack-free lamination
- Automotive vibration test passed
- Aesthetically appealing

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Thank you for your attention!

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