

Achieving Module Ready Silver-Lean TOPCon Cells with Copper Electroplating



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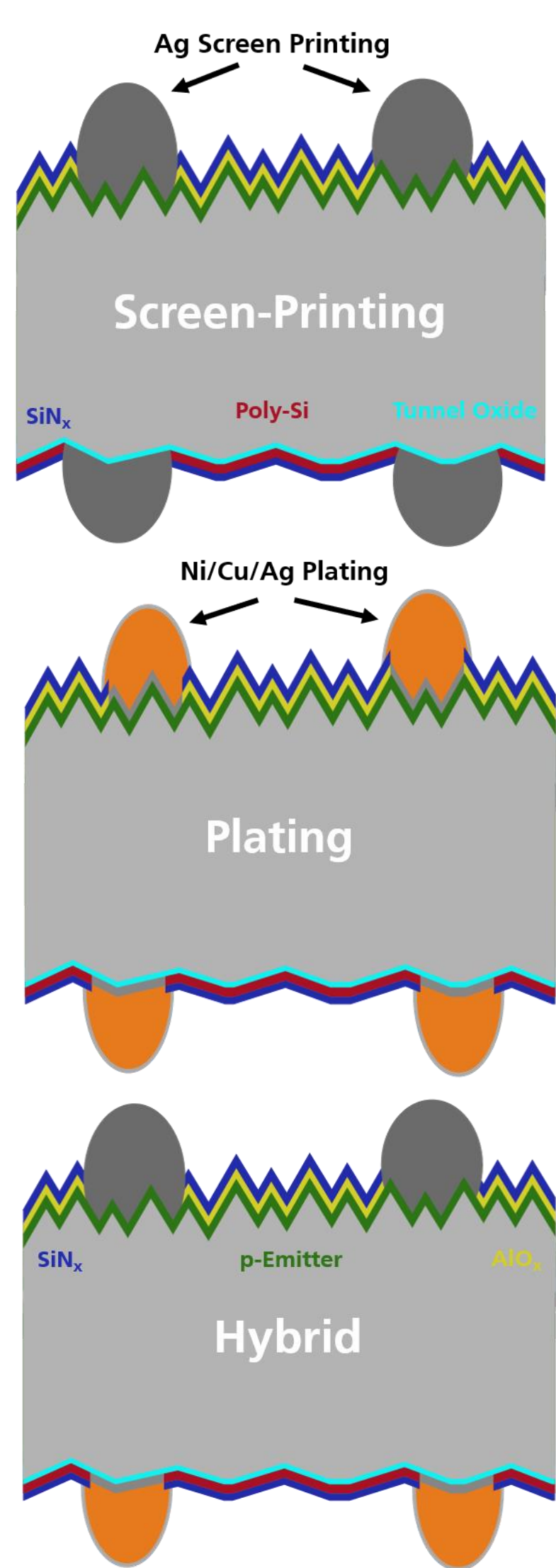
Motivation

- **Primary Cost Driver:** Silver remains the dominant cost factor in industrial solar cell manufacturing
- **Market Volatility:** Extreme price fluctuations from 40 \$/oz to 110 \$/oz over the past 12 months highlight the economic risk of silver dependency
- **TOPCon Vulnerability:** Reducing silver content in TOPCon cells is particularly challenging due to high-temperature processing requirements and the risk of copper-induced degradation
- **Promising Solution:** Nickel/copper (Ni/Cu) electroplating emerges as a highly promising metallization route to address these challenges and advance TOPCon cell technology

Evaluation of silver lean metallization routes

Electrical TOPCon champion cell performance and corresponding silver consumption (this work)

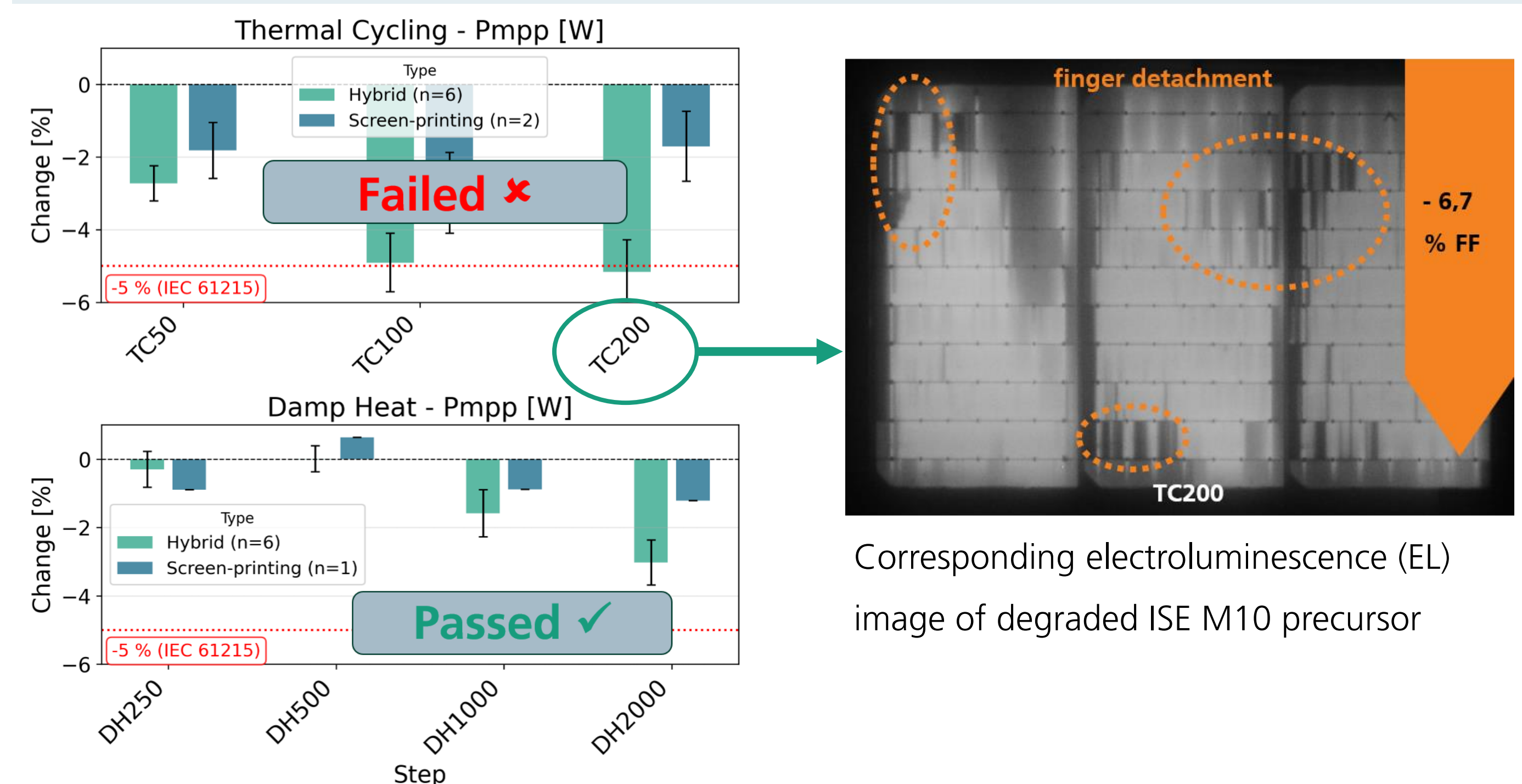
Metallization route	Screen-Printing	Hybrid	Plating
Eta [%]	24.13	24.04	23.13
FF	81.15	81.13	80.48
J _{SC} [mA/cm ²]	40.75	40.64	40.97
V _{OC} [mV]	730	727	702
Silver usage [mg/Wp]	17.4	9	1.03



- 😊 Excellent electrical performance
- 😊 Industrial standard = high throughput and established technology
- 😞 High silver consumption and price fluctuation vulnerability
- 😊 Excellent module reliability showcased recently [1]
- 😊 1.1 mg/Wp silver consumption - potentially silver free technology [2,3]
- 😞 Mediocre electrical performance
- 😊 Comparable electrical performance to Screen-Printing
- 😊 Silver consumption is halved
- 😞 Two metallization tools and techniques required

- Module reliability for hybrid metallization route is investigated on two precursor types in this work:
- ISE internal (M10) precursors: 3 half-cell mini modules in TC and DH
 - Industry 1 (M10) precursors: Infrared soldering and peel test

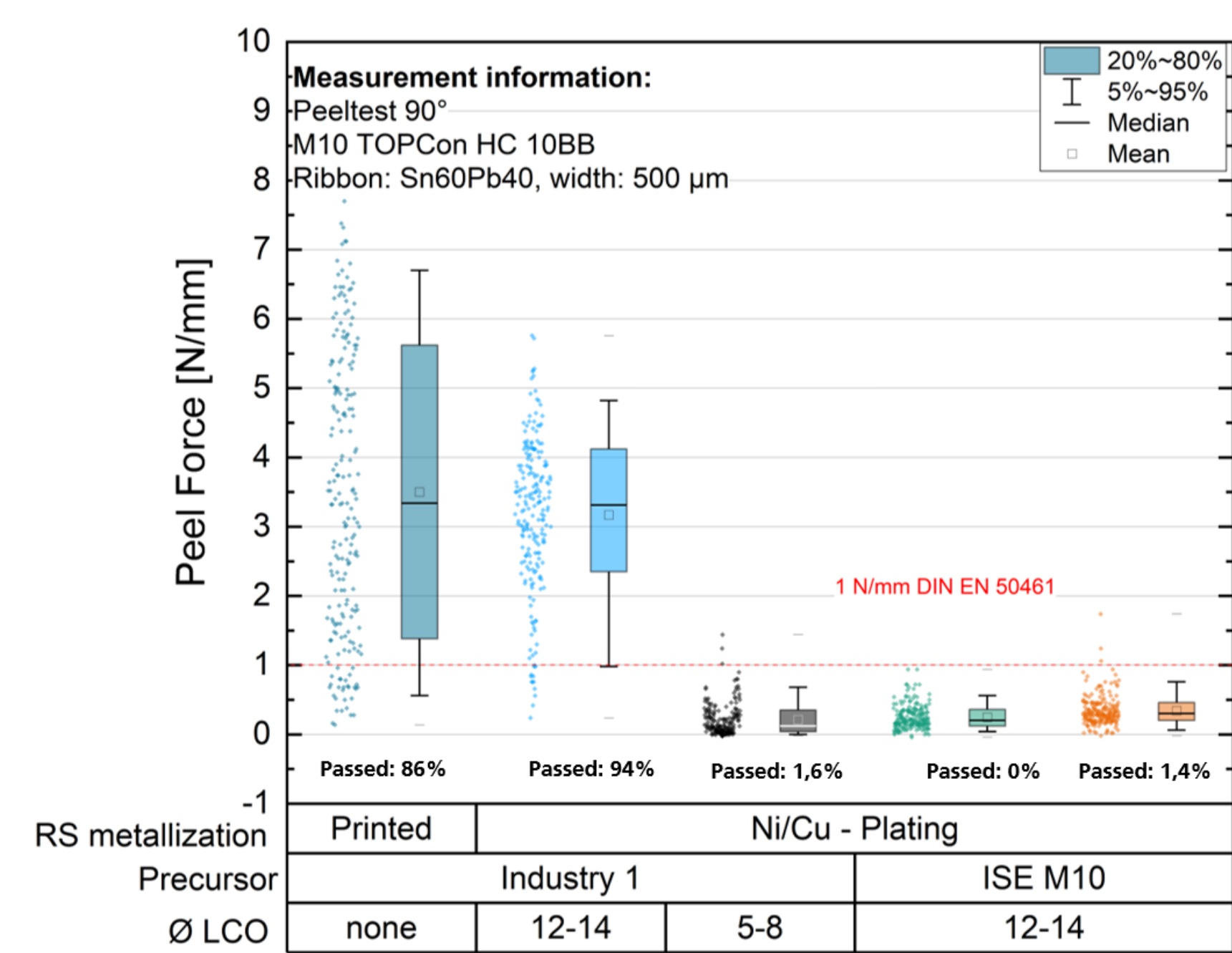
Module reliability of initial hybrid TOPCon cells



→ Fill factor and power degradation due to finger detachment on TOPCon rear

Influences on mechanical rear side adhesion

Mechanical (busbar-pad) adhesion peel test according to DIN EN 50461



- ✓ Plated contacts with excellent adhesion
- 🔍 Precursor differences:
 - 😊 Industry 1
 - 😞 ISE
 - 🔍 LCO – diameter:
 - 😊 Line pitch overlap
 - 😞 No pitch adaption

Precursor differences:

- Industry 1 precursors achieve excellent adhesion, surpassing 3 N/mm on average and are in the same range as screen printing
- TOPCon (rear) sides differentiate in layer stack composition, thicknesses and morphology
- Laser ablation mechanism highly sensible to these changes

LCO diameter influence:

- Due to small diameter no LCO overlap in pad and busbar region (line pitch)
- Plating metallization not merged into continuous solder pad
- Absolute contact area at Si/ Ni and finger/ribbon is reduced and the peel force distribution is limited

Summary

Identified multiple rear side (TOPCON) adhesion influences and showcased **excellent adhesion** – on par with screen printing – while **halving silver consumption without significant efficiency loss**.



[1] Z. Wang, G. Cheng, H. Liu, Z. Wang, K. Wu, D. Chen, Y. Chen, S. Liu, J. Gao, and J. Ding, "Study on excellent contact performance of double-sided copper-plated metallization," J Mater Sci: Mater Electron, vol. 36, no. 4, 2025
[2] A. Lorenz, D. Ourinson, F. Maarouf, S. Kluska, J. Bartsch, S. Mack, J. Eckert, R. Haberstroh, R. Dharmadasa, T. Druffel, J. D. Huyeng, F. Clement, and R. Preu, "Breaking the Barrier: Unveiling the Potential of Copper for Solar Cell Metallization," in 2024 IEEE 52nd Photovoltaic Specialist Conference (PVSC), Seattle, WA, USA, 2024, pp. 161–166
[3] J. Eckert and S. Kluska, "Inline plating of Ni/Cu contacts for industrial TOPCon Si solar cells - Status and outlook," JPV, 2026.

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