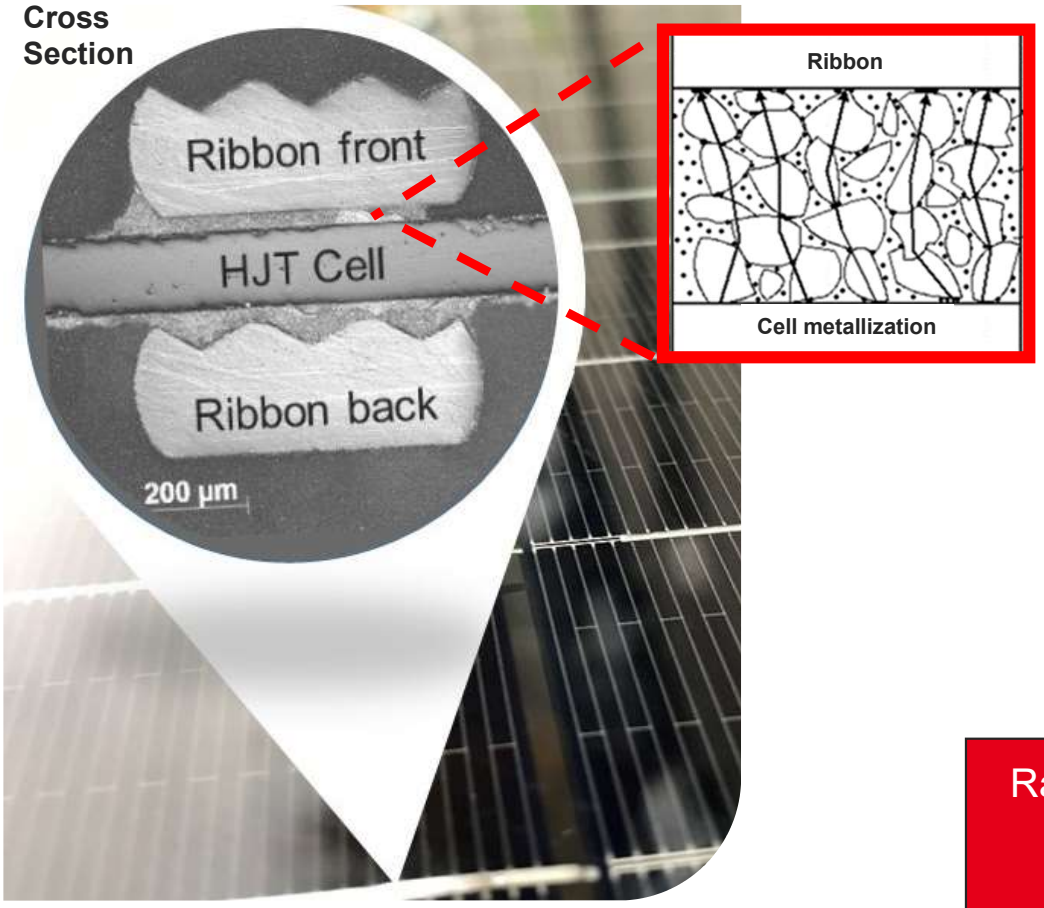
# Towards less than 10 mg/Wp silver consumption in HJT modules with ECA based interconnection

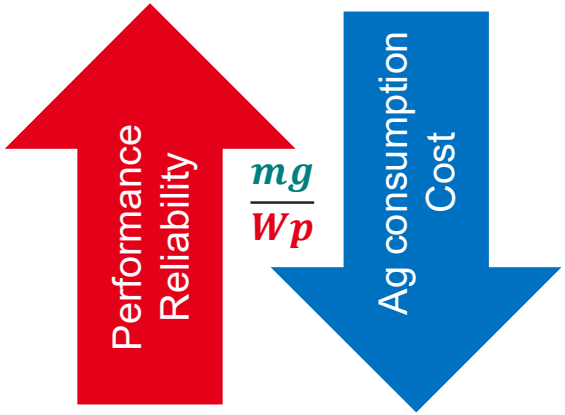
Rémi Monna, Gustavo Rodrigues Lopes, Nathalie Ronayette-Lamoine, Laurent Fonteneau, Anne-Sophie Ozanne, Jules Clerjon, Didier Therme, Johann Jourdan, Bertrand Hladys

# Cell interconnection for HJT cells made with Electrically Conductive Adhesives (ECA)




- ✓ Lead and Bismuth free technology
- ✓ Low T° process and wide window (80 - 200°C)
- ✓ Compatibility with temperature sensitive cells like HJT and Si-Perovskite tandem cells

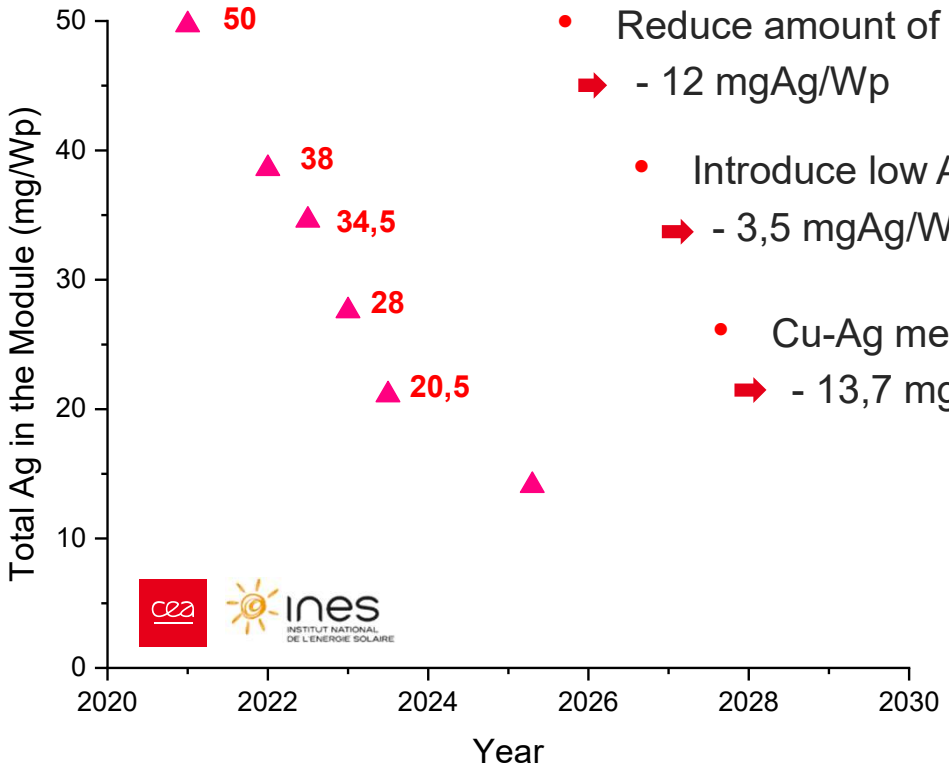
Continue to reduce Ag consumption while maintaining PERFORMANCE and RELIABILITY



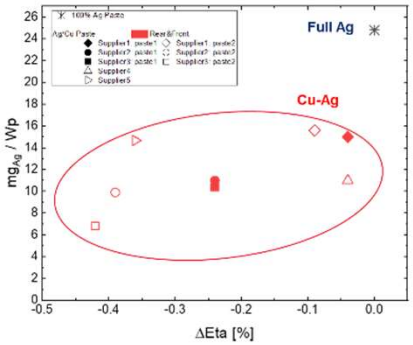

Radical reduction of silver is a must for TW scale manufacturing in PV
Our target < **3 mg/Wp by 2030**

# Ag reduction in the module with ECA interconnection

❖ ***From 50 mg/Wp to 14 mg/Wp in less than 5 years***




- Reduce amount of deposited ECA
  ➡ - 12 mgAg/Wp
- Introduce low Ag content ECAs
  ➡ - 3,5 mgAg/Wp
- Cu-Ag metallization on HJT Cells
  ➡ - 13,7 mgAg/Wp



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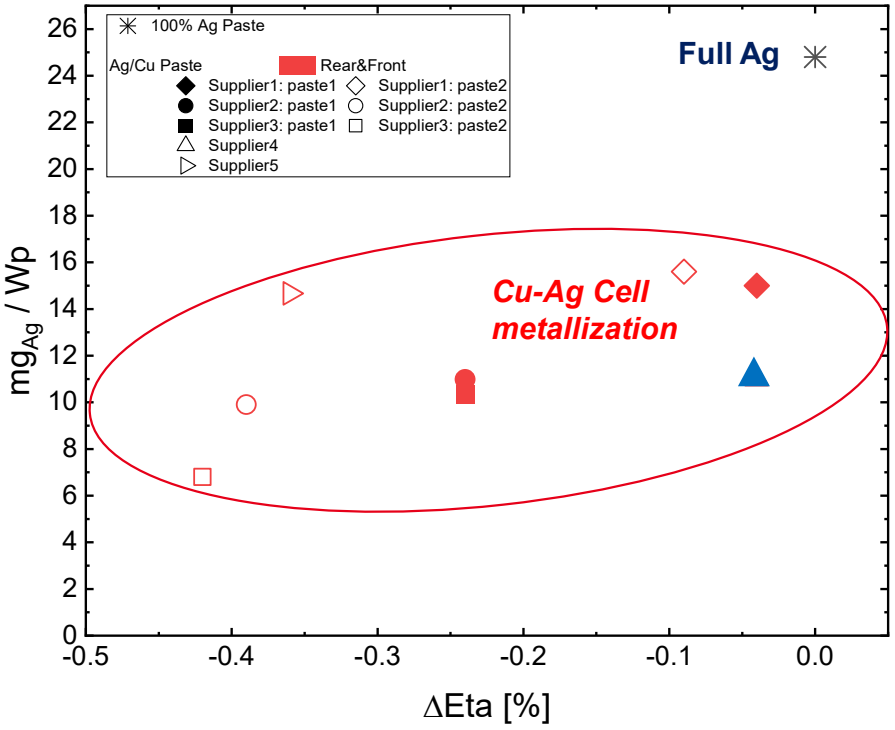
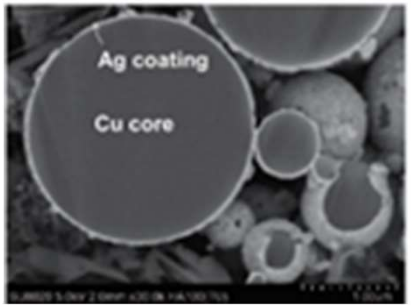



A.Lanterne & al : Copper-based Metallization Approaches for Drastic Reduction of Silver Content in Heterojunction Solar Cells – PVSEC 2024




- ✓ Cu-Ag Cell metallization
  - Cu core particles / Ag coating
  - **11 mgAg/Wp** give a loss of 0.05 % absolute efficiency
  - 7 mgAg/Wp is reachable but with a loss of 0.4 % of absolute efficiency with Cu-Ag Paste

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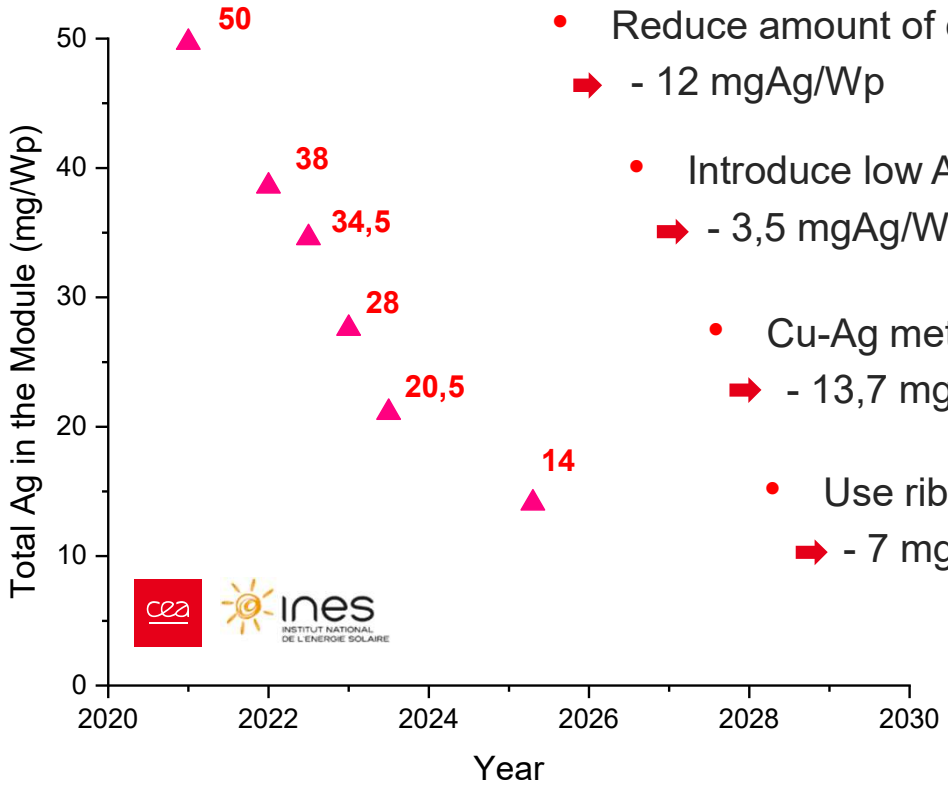


- Reduce amount of deposited ECA
  ➡ - 12 mgAg/Wp
- Introduce low Ag content ECAs
  ➡ - 3,5 mgAg/Wp
- Cu-Ag metallization on HJT Cells
  ➡ - 13,7 mgAg/Wp
- Use ribbons without Ag coating (Bare)
  ➡ - 7 mgAg/Wp

# Ag reduction in the module with ECA interconnection

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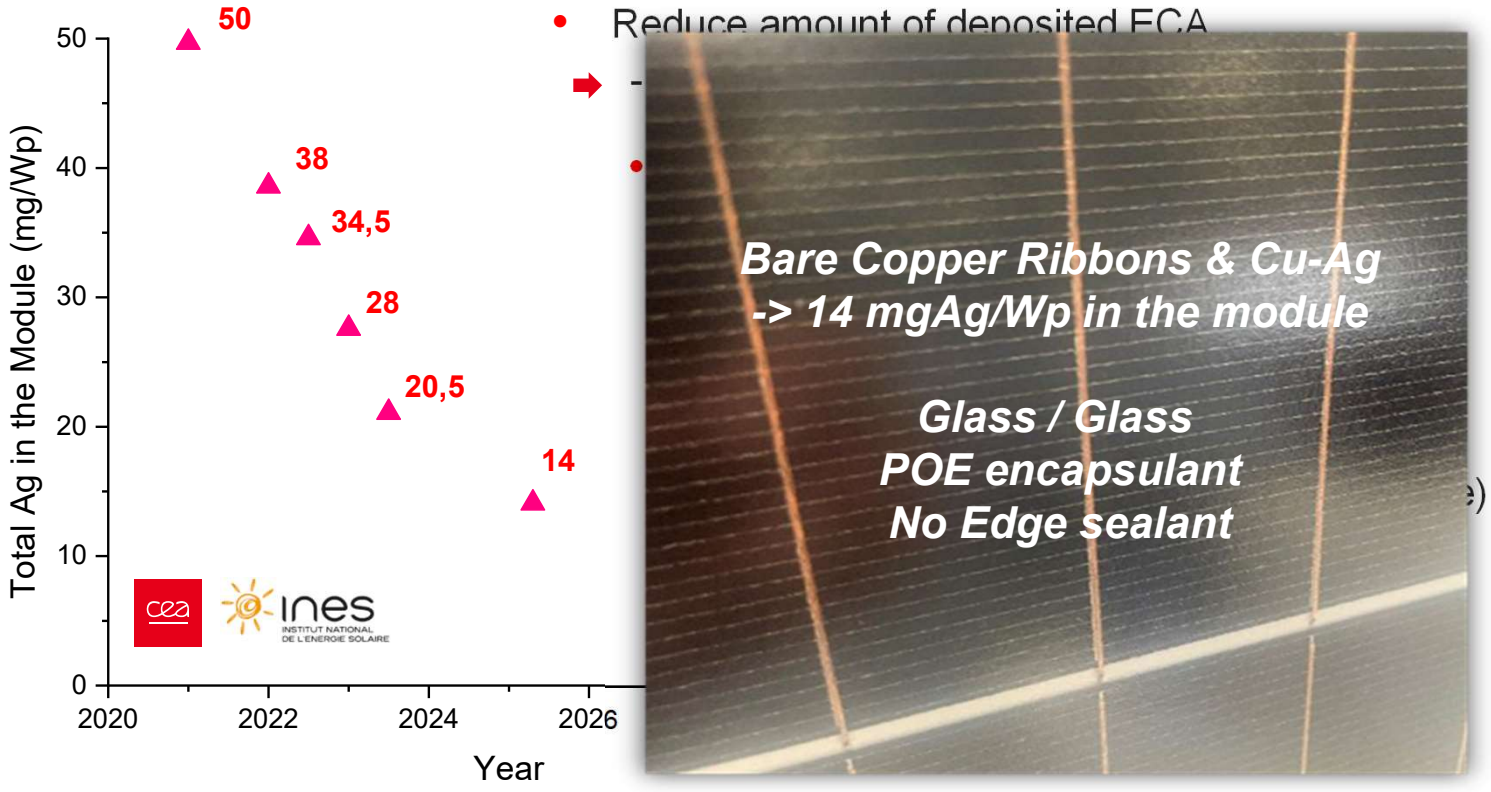
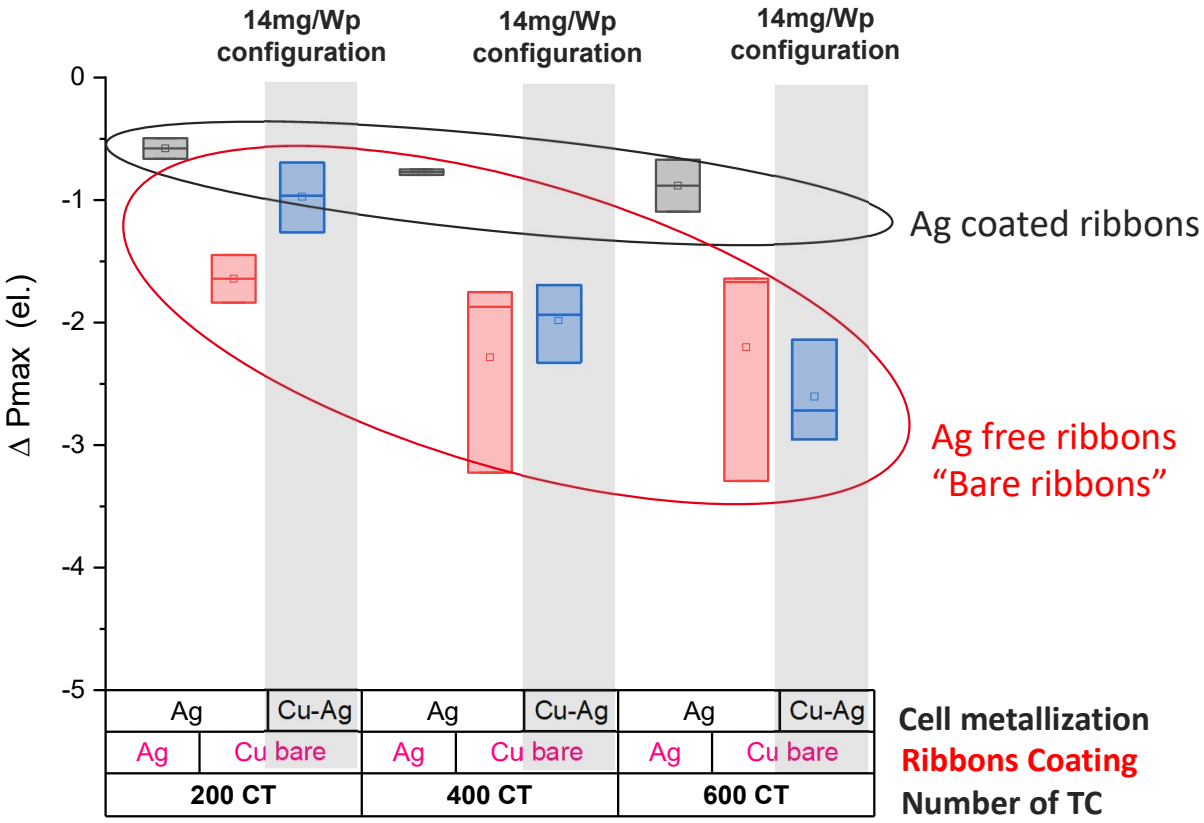






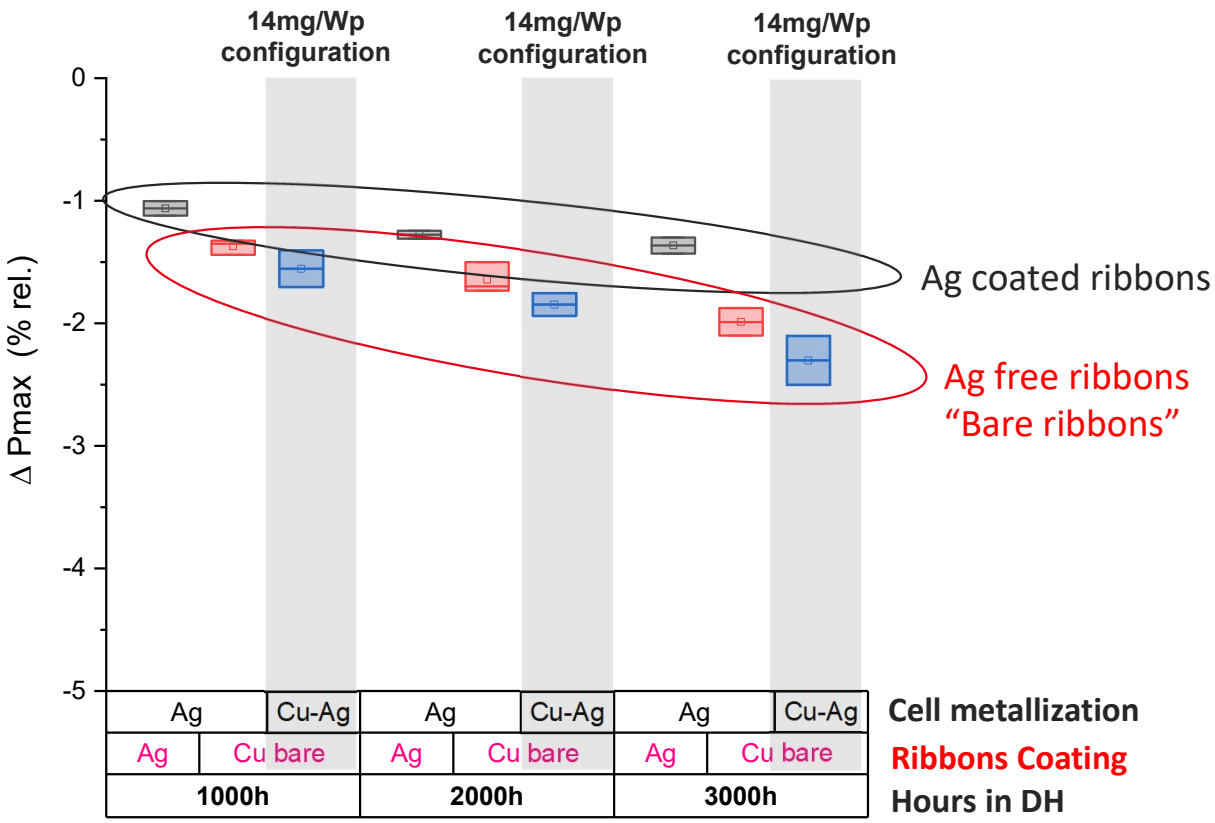
# TC Ageing results




R.Monna & Al , Use of Cu ribbons and Cu-Ag HJT cell metallization on ECA based interconnection for PV modules, Solar Energy Materials and Solar Cells, Volume 287, 1 August 2025, 113594

- ✓ The degradation is more pronounced on the modules with "bare ribbons"
- ✓ No difference observed between Ag and Cu-Ag Cell metallization
- ✓ Less than 3 % degradation after 600 TC
- ✓ Degradation only due to FF
  - No $I_{sc}$ & $V_{oc}$ change

# DH ageing results




- ✓ The degradation is more pronounced on the modules with "bare ribbons"
- ✓ Cu-Ag Cell metallization seems to degrade a little bit more
- ✓ Less than 3 % degradation after 3000 h DH
- ✓ Degradation mainly due to FF
  - Minor $V_{oc}$ degradation

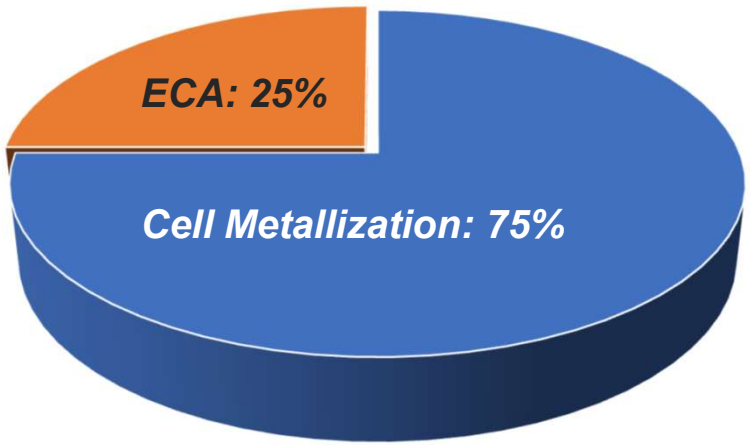
Combining Cu-Ag metallized cells with bare Cu ribbons allows to reach a **total Ag consumption in the MODULE of 14 mg/Wp** with a degradation of less than 3 % after 3000h DH and 600 TC

# How can we decrease more the Ag consumption ?

- ✓ ECA represent 25 % of the Ag consumption
  - Reduce the deposited weight -> ECA dots or pads
  - Reduce the amount of Silver in the ECA

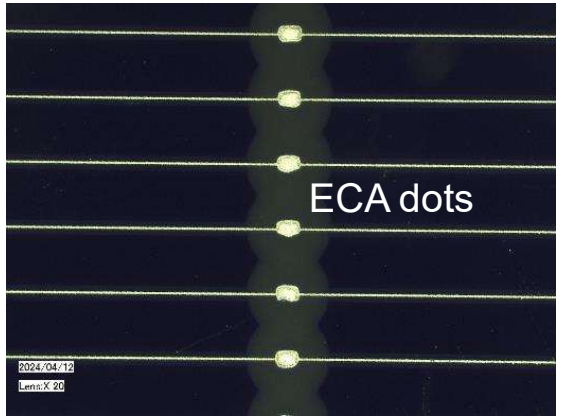
- ✓ The cell represent more than 75%
  - Go to full Cu Cell metallization
  - Introduce ZBB cells

❖ ***Ag consumption in the Module***

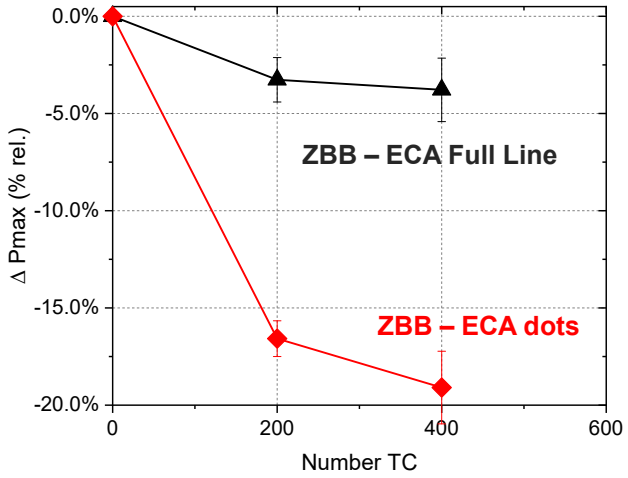


# To ZBB interconnection

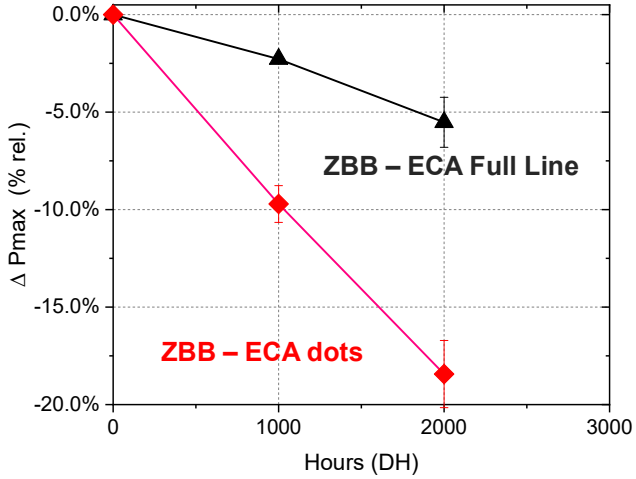
- ✓ Possibility to gain 1.1 mg/Wp with ZBB cells (Cu-Ag metallization)
- ✓ Possibility to gain 1.9 mg/Wp with ECA dots deposition

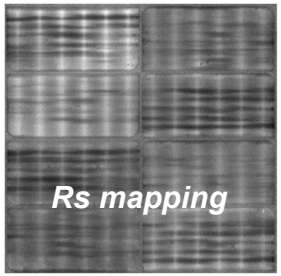



❖ ***TC ageing results***




❖ ***DH ageing results***



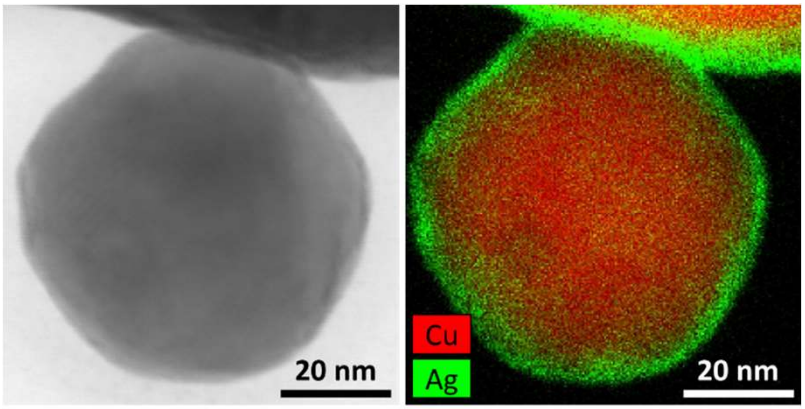




**Significant power decrease (> 15%) with ECA dots on ZBB cells after thermal cycling and damp heat**

- ✓ Issue with pad alignment that increases series resistance

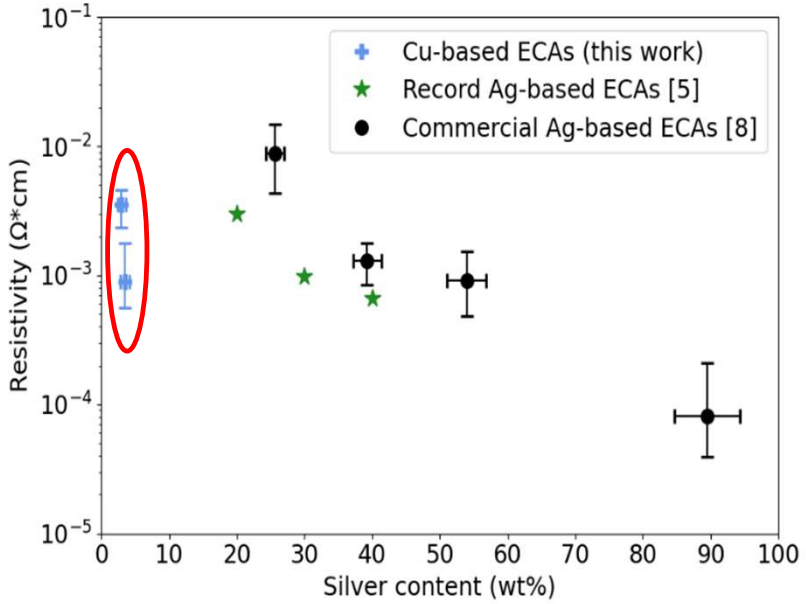
# To Cu-based ECAs

- ***Home-made Cu-Ag nanoparticles ****




- ✓ Core-Shell copper-silver particles
- ✓ $T_{onset}$ = 178 ± 2 °C

* Nathalie Ronayette & Al, Reduction of silver content in Electrically Conductive Adhesives for low-temperature interconnection of solar cells, Solar Energy Materials and Solar Cells, Volume 292, 15 October 2025, 113762




- ✓ Resistivities from 3.5 x $10^{-3}$ to 9.0 x $10^{-4}$ Ω.cm comparable to commercial ECAs
- ✓ Ag content < 10 wt%

**2.5 mgAg/Wp gain (ECA)**
**Ageing tests on progress**

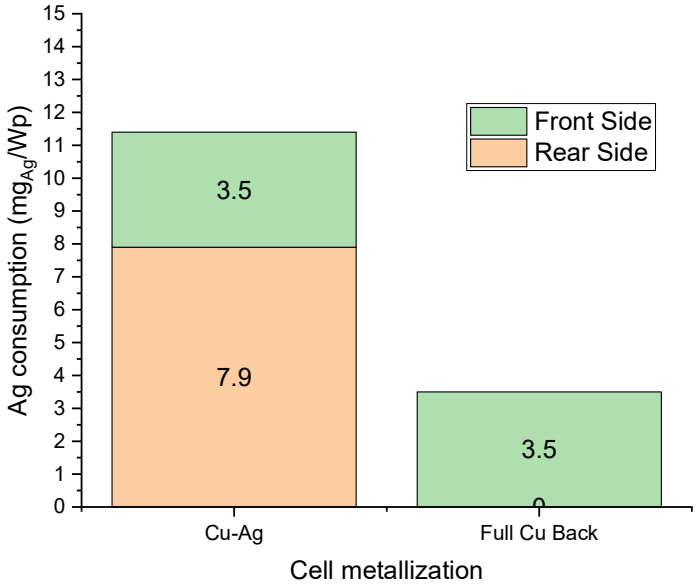
# Rear Side Full Cu metallization as a strategy towards lower Ag consumption

### *Full Copper on the Backside*

- ✓ Front Side: Cu-Ag (~40 wt% Ag) screen-printing metallization
- ✓ Rear Side: Full Cu screen-printing metallization
  - Larger screen-opening for optimal results
  - Heating press used for Cu paste annealing

**7 mgAg/Wp in the module with BARE Cu ribbons**

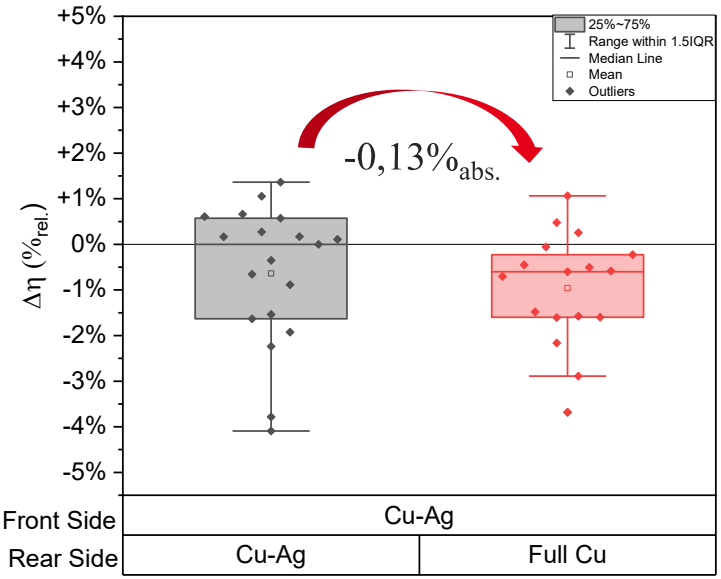
### *Ag consumption on the Cells*



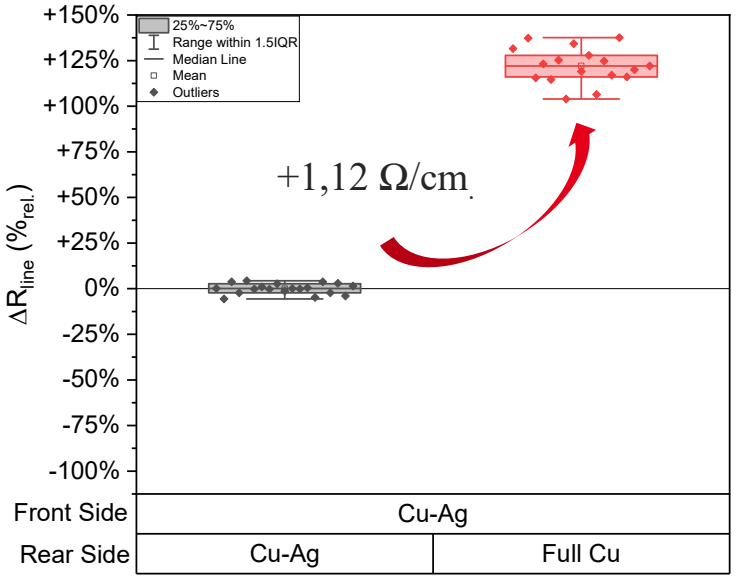

- ✓ 3.5 mgAg/Wp on the cell

# Rear Side Full Cu metallization as a strategy towards lower Ag consumption

### *Cell Efficiency*




### *$R_{line}$ – Rear Side*

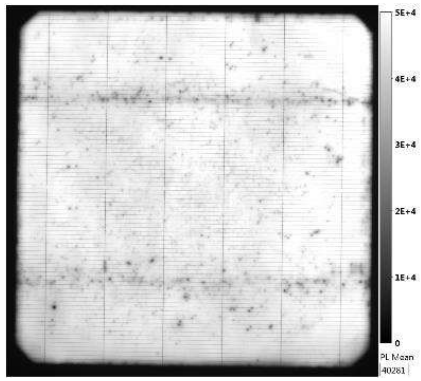



- ✓ Efficiency loss reduced to 0.13 % absolute / Cu-Ag metallization
- ✓ Increase of the line resistance on the backside

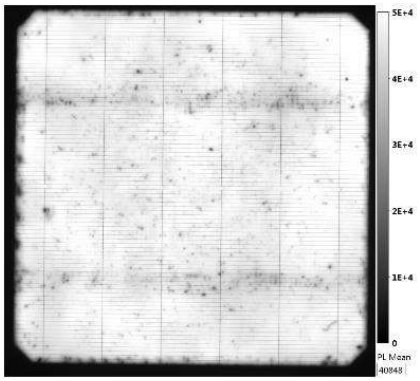
# TCO as a barrier layer against Cu diffusion

- ✓ TCOs are well documented as a relatively effective barrier to Cu diffusion at moderate temperatures (≤ 300°C)
- ✓ No lifetime degradation observed after metallization annealing
- ✓ The long-term stability still needs to be investigated at the module level

❖ ***PL images***



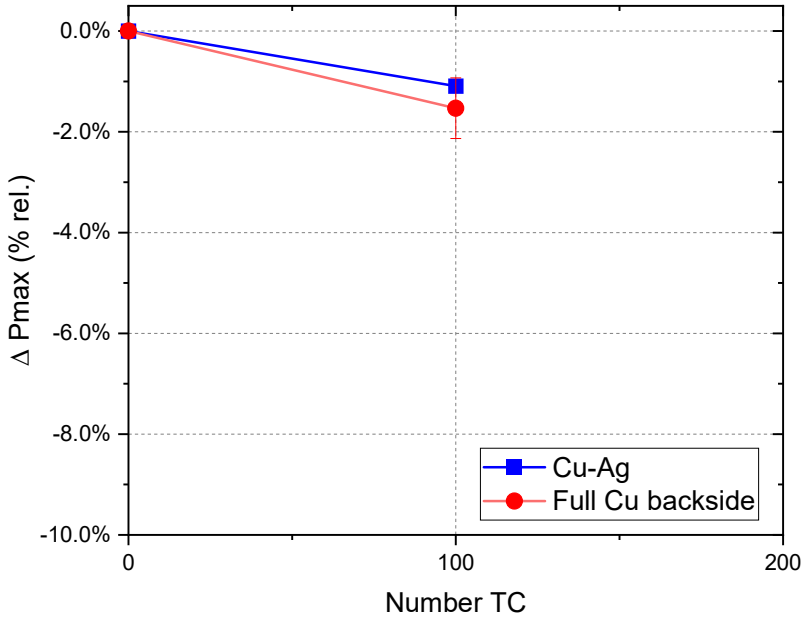

Cu-Ag Front & Back




Full Cu Back

# Rear Side Full Cu metallization as a strategy towards lower Ag consumption

### *TC ageing results on modules*

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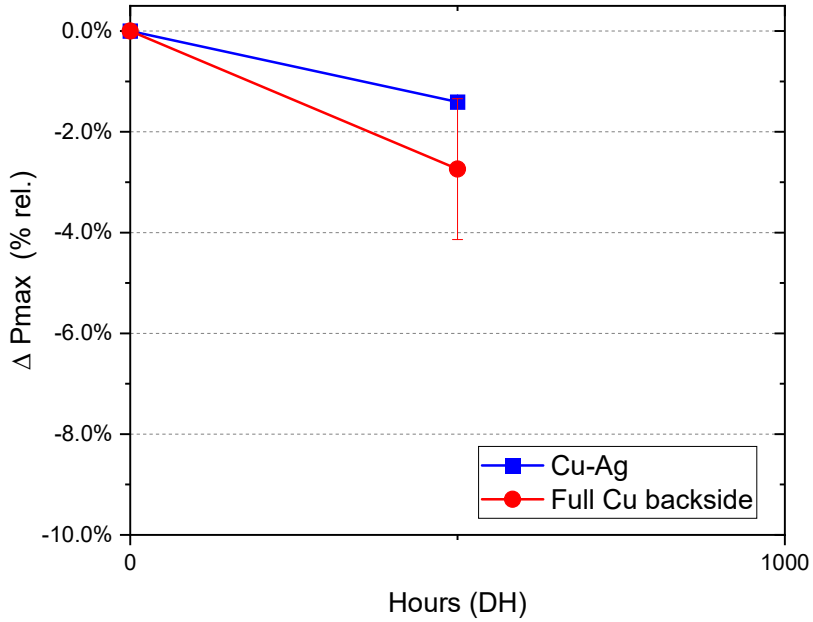
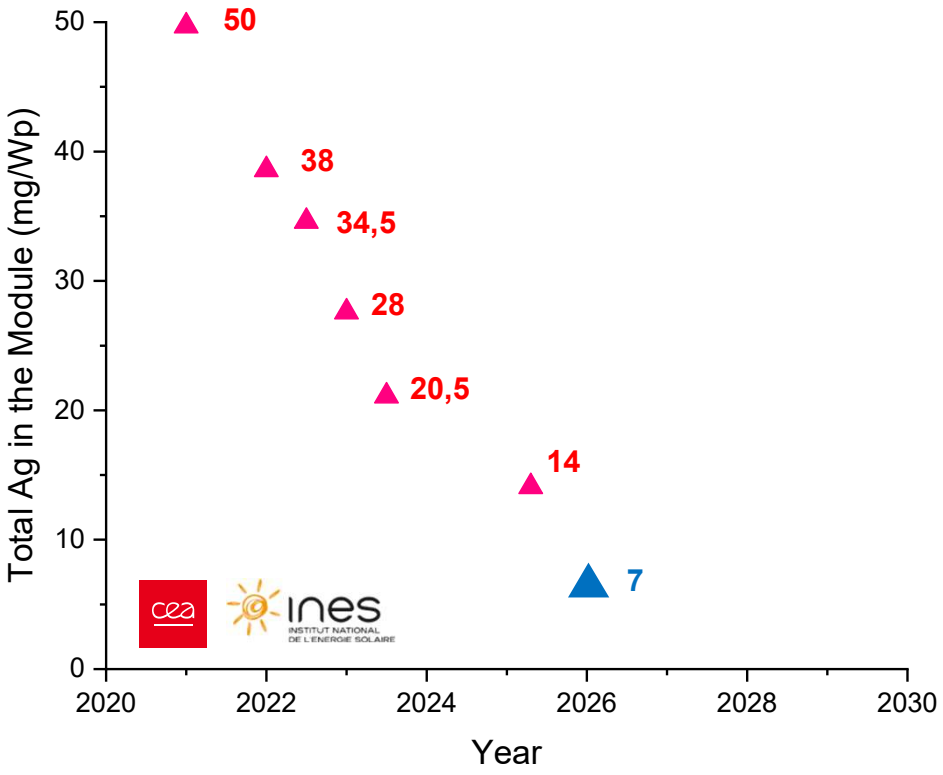



- ✓ Good results on CT ageing compared to our reference Cu-Ag
- ✓ Slightly elevated degradation after 500 hours of DH

# Conclusion of the study

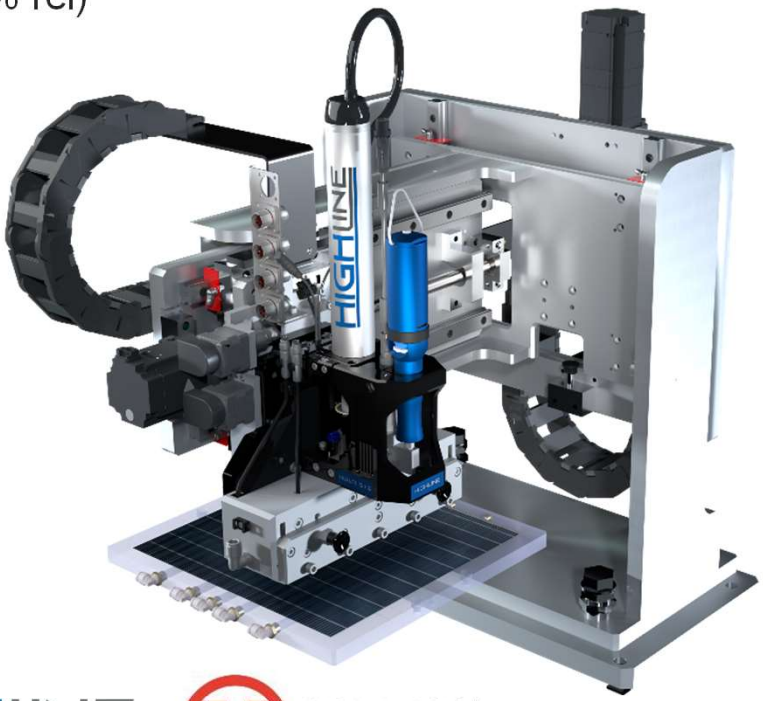



- ✓ **14 mgAg/Wp** reached **on module** by interconnecting Cu-Ag metallized HJT cells with bare Cu ribbons and ECA
  - Less than 3 % degradation after 600 TC and after 3000 h DH (3x IEC passed)
- ✓ Significant power losses with ECA dots after thermal cycling and damp heat
  - Reducing silver consumption in the ECA should rather be achieved through a decrease in the Ag concentration in the ECA
- ✓ HJT cells with Full Cu metallization on the Backside
  - **7 mg/Wp silver consumption in the module**
  - Encouraging initial aging tests; Some issues in DH which has to be solved

# Upcoming developments

- ✓ Make reliable HJT modules with full Cu metallized Cells – Edge Sealant will probably be necessary
- ✓ Front and Back 100 % Cu Cell metallization to obtain a consumption of 3 mg/Wp in the module
- ✓ Reduce electrical losses with Cu pastes and bare Cu ribbons (-2 % rel)
- ✓ Interconnexion with Wires (needs mechanical strengthening)

- ✓ **Novel ECA deposition** – Cell stringing up to ½ G12 Cells
  - ✓ Put down ECA with the « Highline » dispensing head
    - Reduces ECA consumption: More than 15% reduction in material usage.
    - Increases throughput: More than 20% increase in throughput.
    - Versatility: Capable of handling various materials incl. emerging technologies
    - No contact with the cell -> Advantageous for Tandem Cells

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# Thank you


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