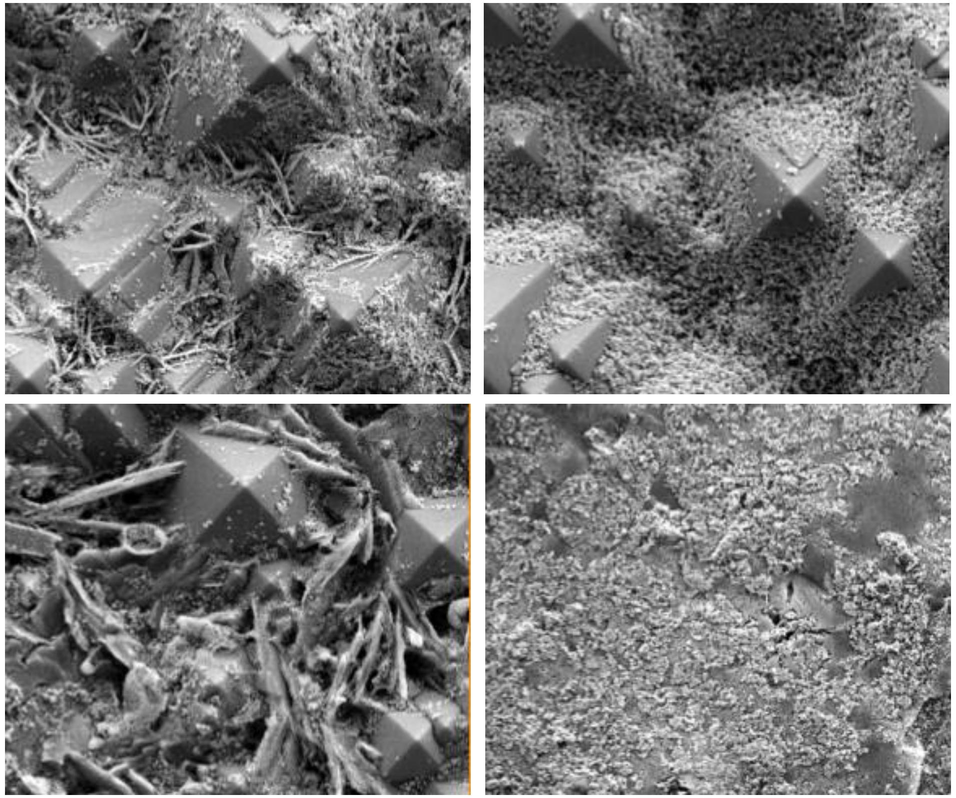
Performance and Accelerated Testing of Reactive Silver Inks Metallization of SHJ with 90% less Silver



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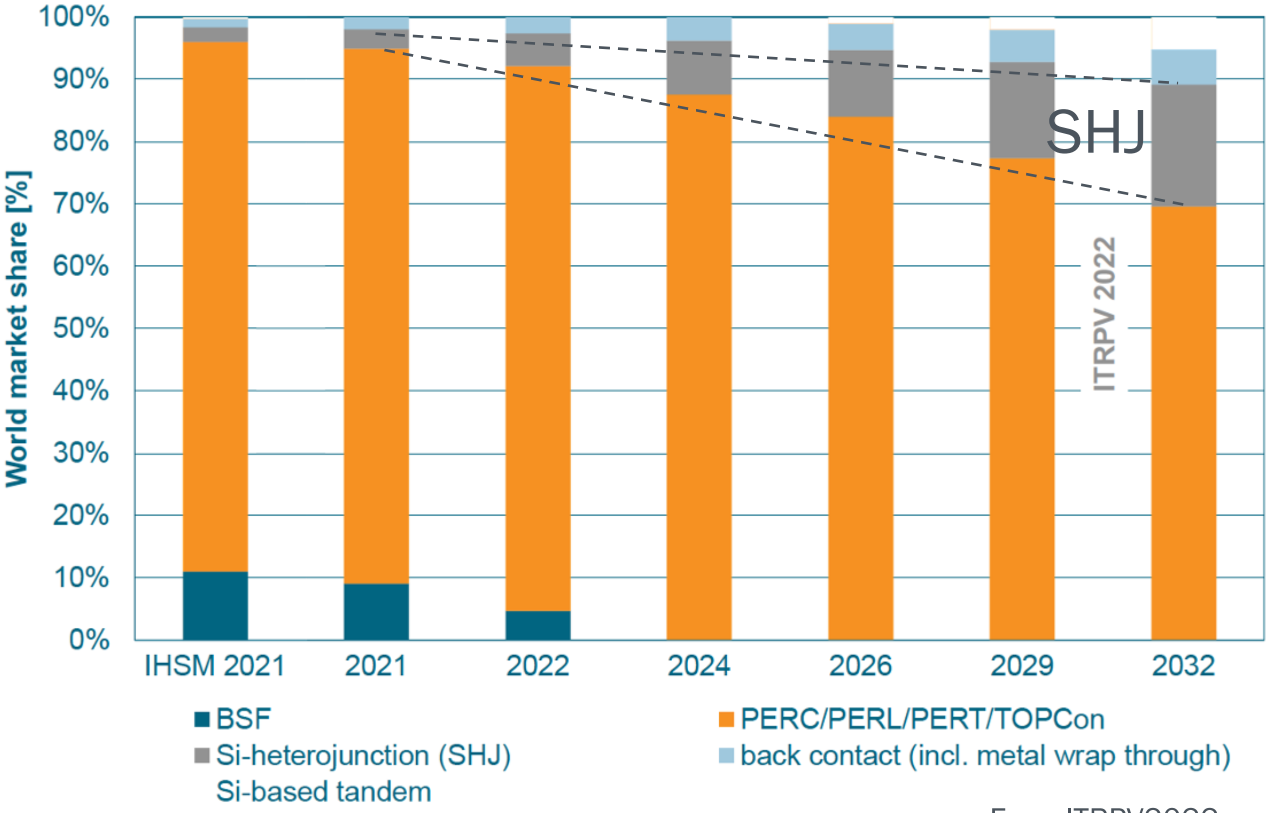
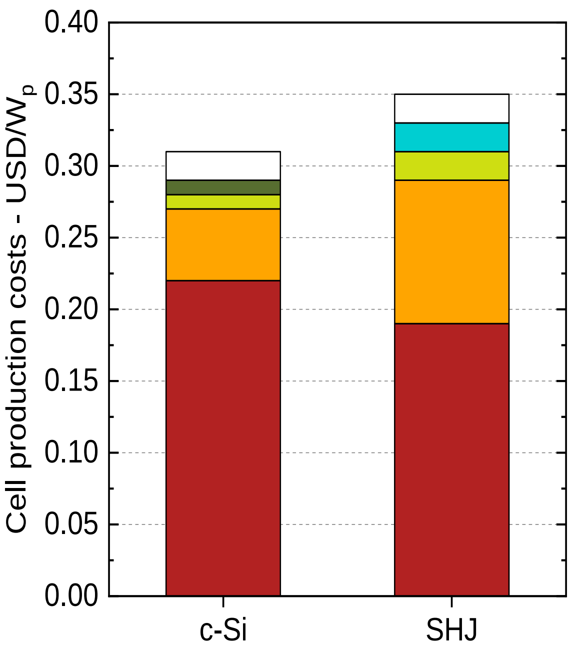
11th MIW 2023
Neuchâtel
May 8th, 2023

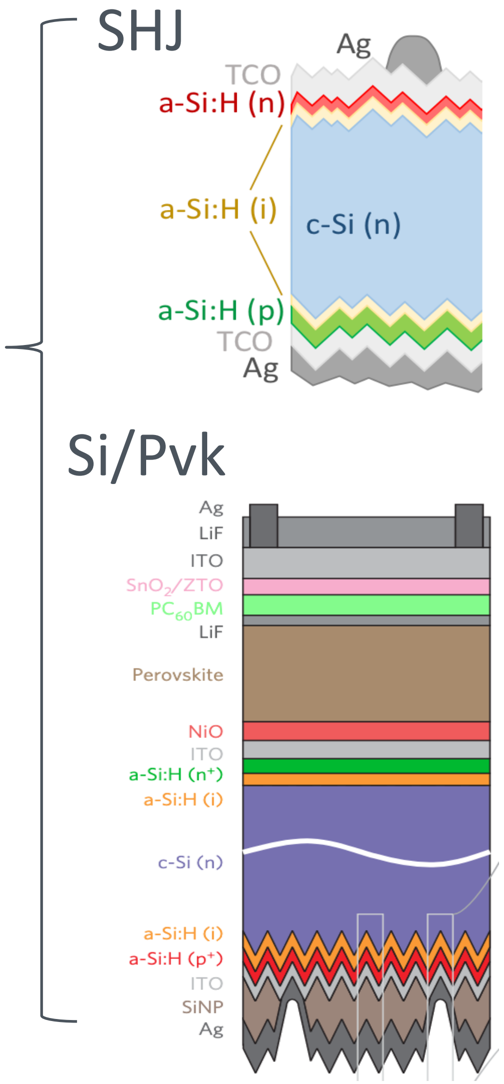
Motivation



From ITRPV2022

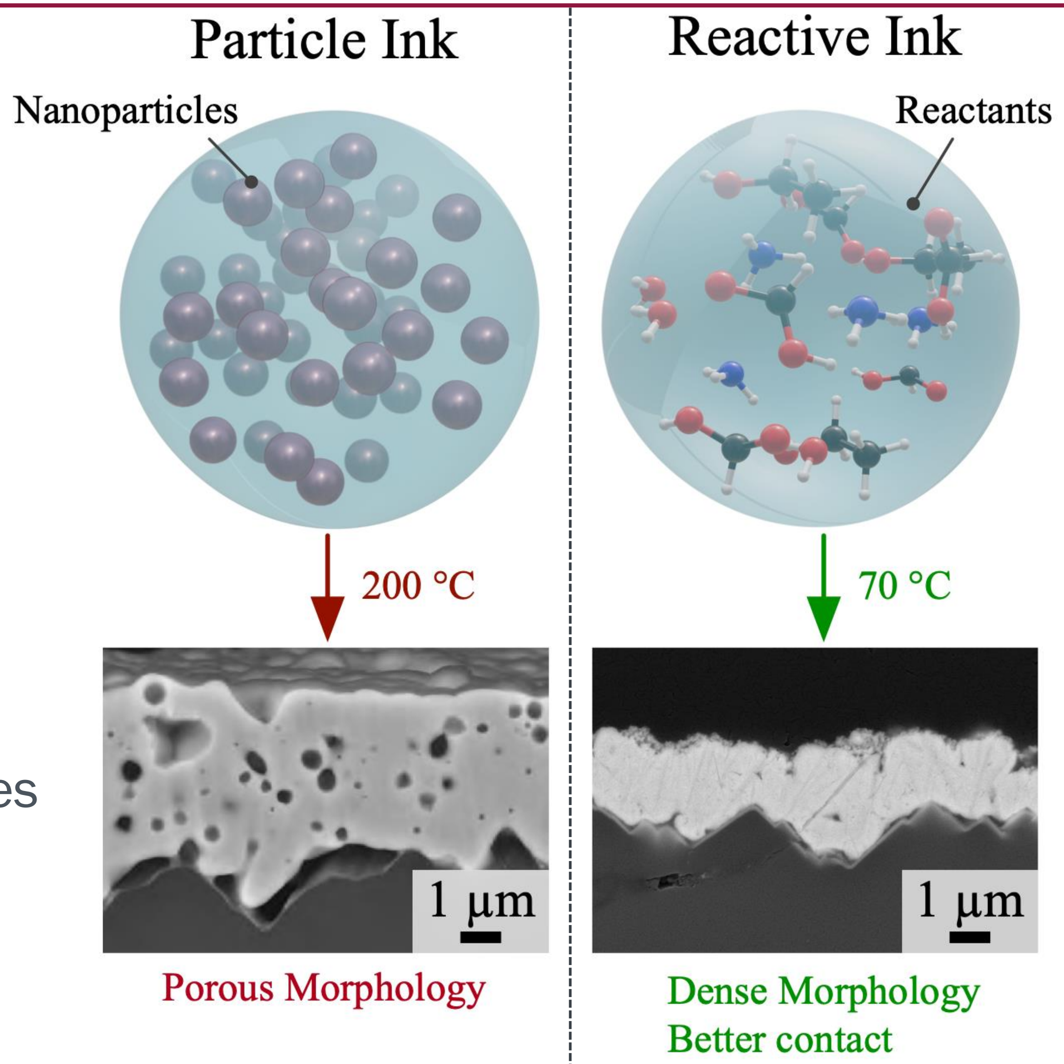


- Metallization is 30% cost
- Processing Temperature



Approach

- High Ag loading
- High resistivity
  - 10-20 μΩ.cm for LT-SP
- Processing Temperatures
  - 200°C for LT-SP
- High mechanical stress printing and waste



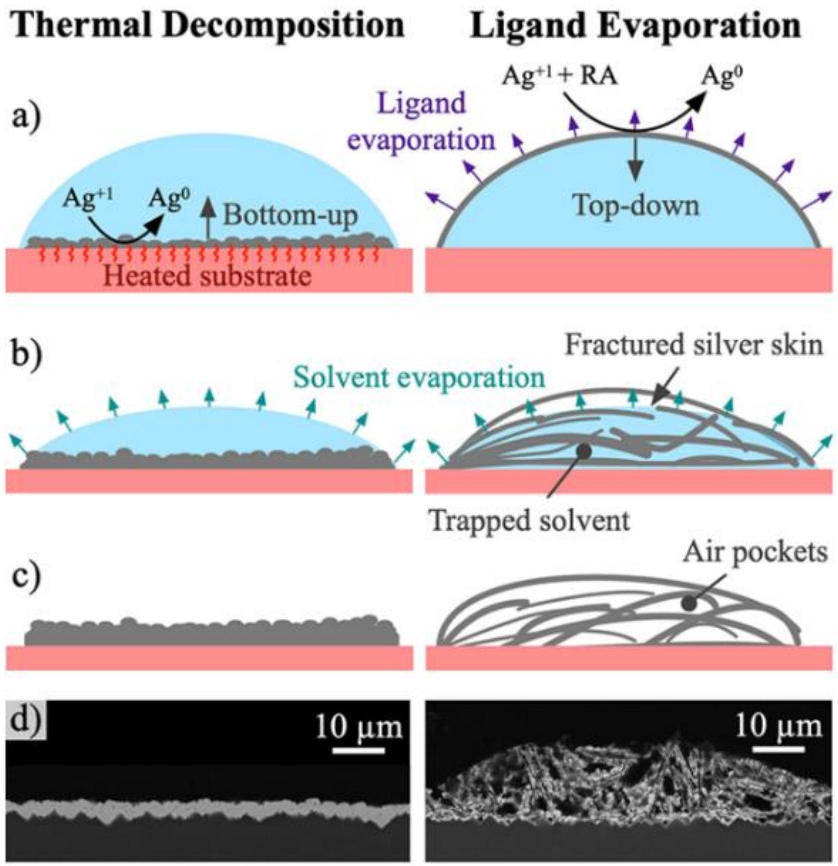
Hildreth, Bertoni US20180099520A1
Hildreth, Bertoni US11077664B2

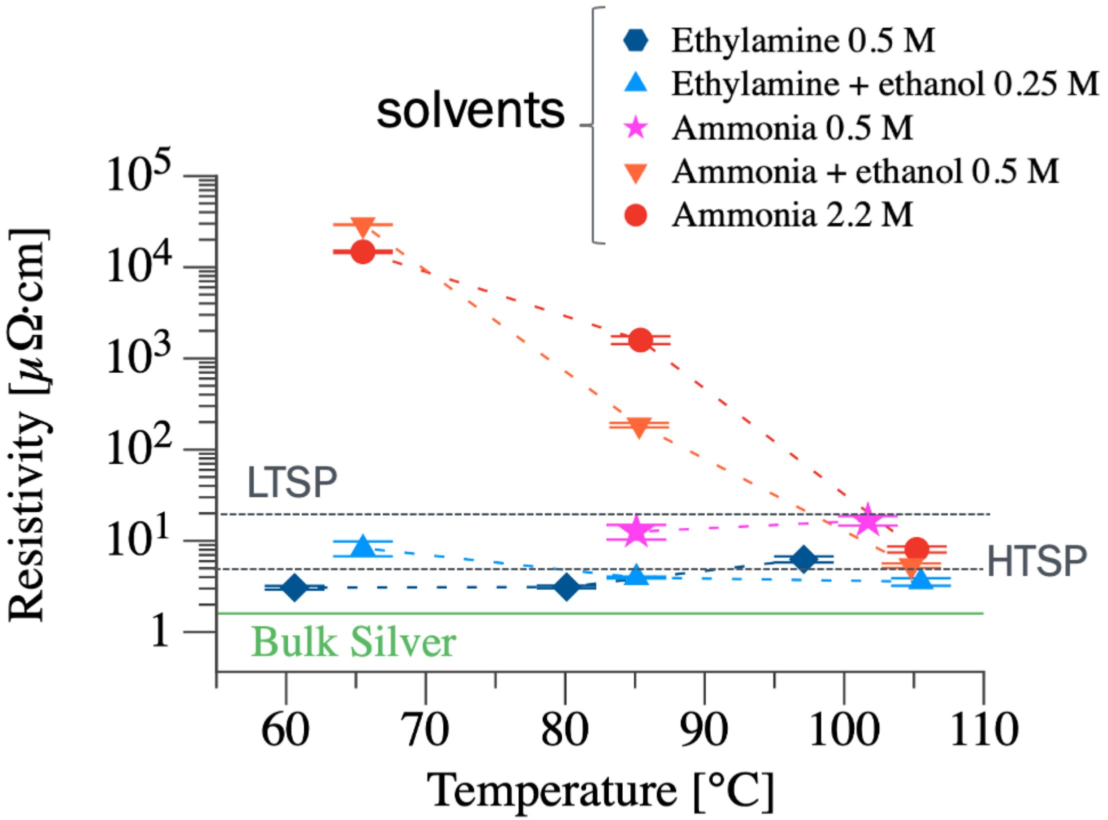
$AgC_2H_3O_2 + CH_2O_2 + solvent$

- Low resistivity
  - 3.0 μΩ•cm
- Low temp processing
  - 50/120°C
- Low mechanical stress printing
- Low amount of waste
- Process sensitivity

Ink Formulations

$$AgC_2H_3O_2 + CH_2O_2 + solvent$$

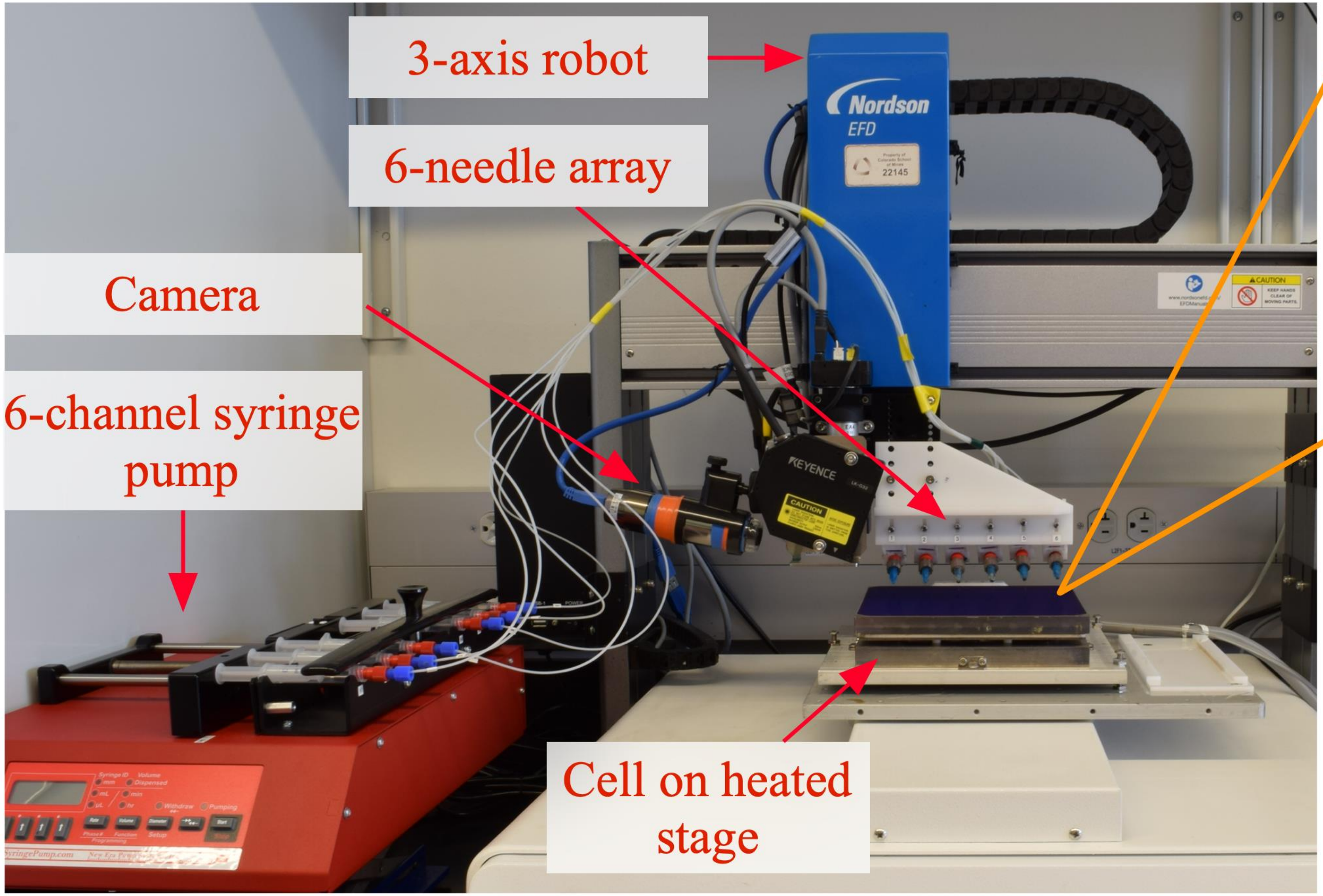


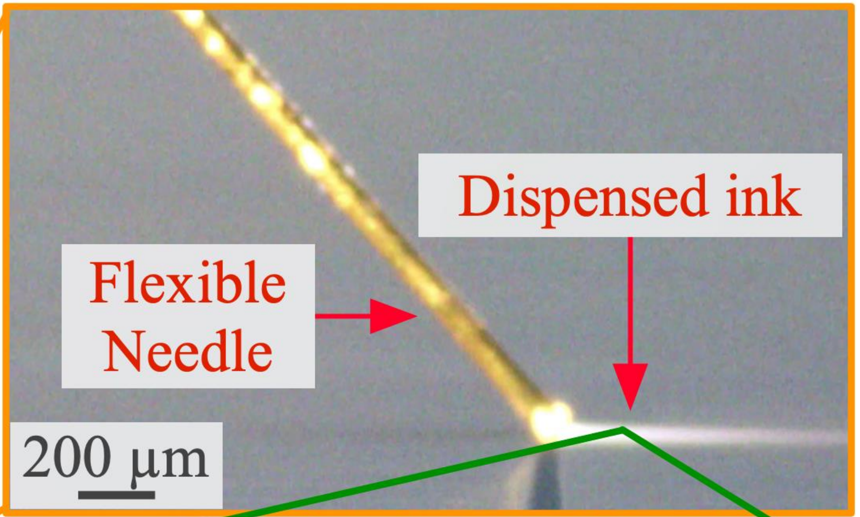


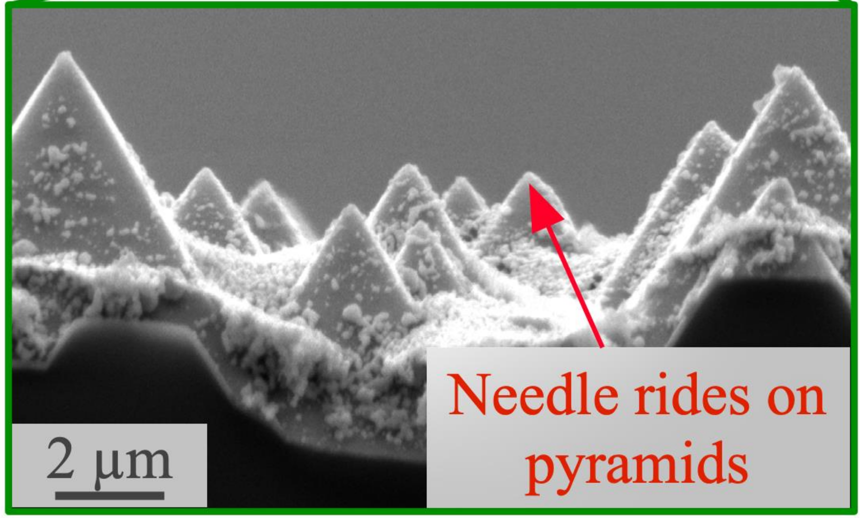
	Media Resistivity (Ω cm)	Contact Resistivity (Ω cm²)
SP	20×10^{-6}	10×10^{-3}
RSI	2.4×10^{-6}	3.1×10^{-3}

DiGregorio, S. J., et al *ACS Appl Energy Mater* **6**, 2747–2757 (2023).

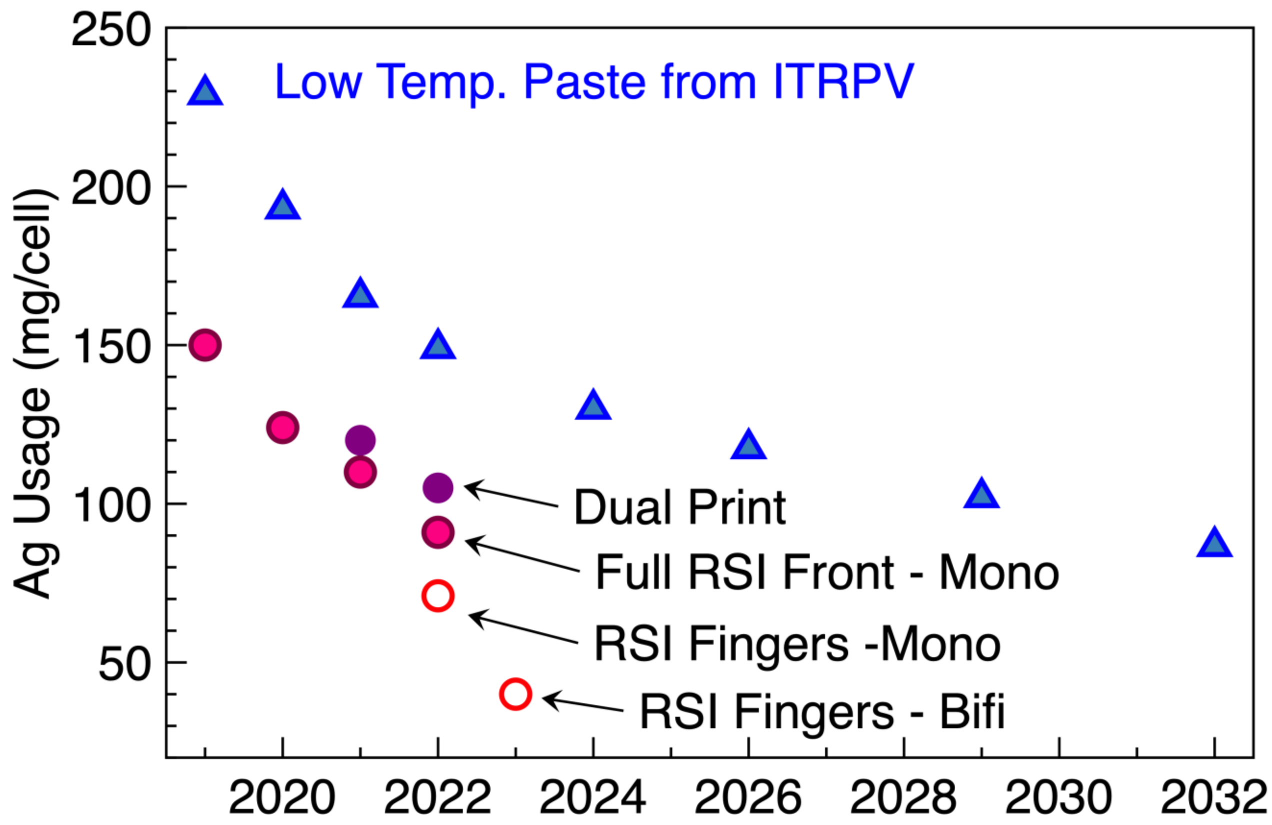
Printing Process (@CSM)



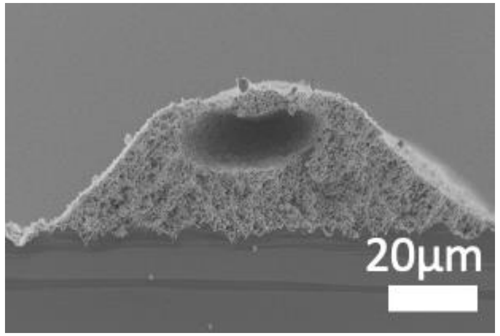




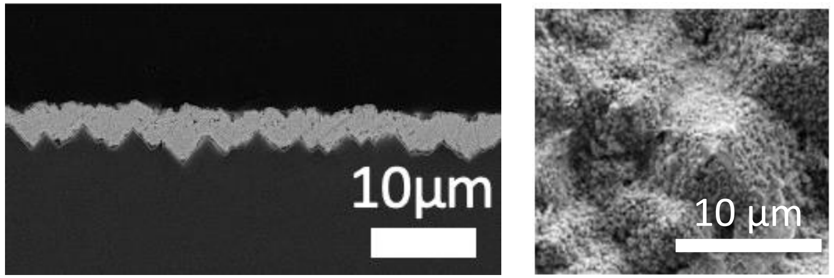
Silver Usage



LT Ag Paste



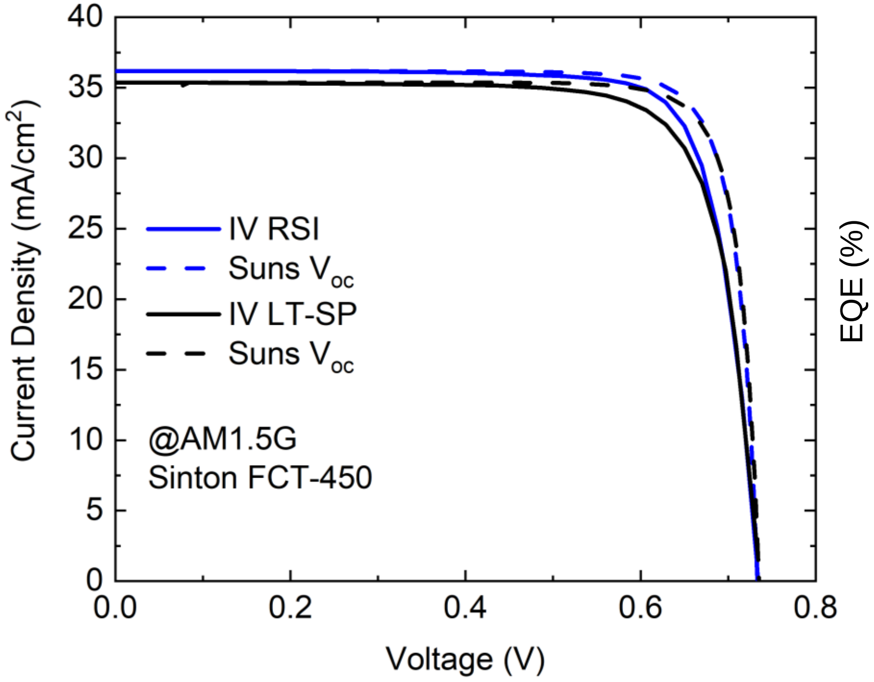
RSI Metallization

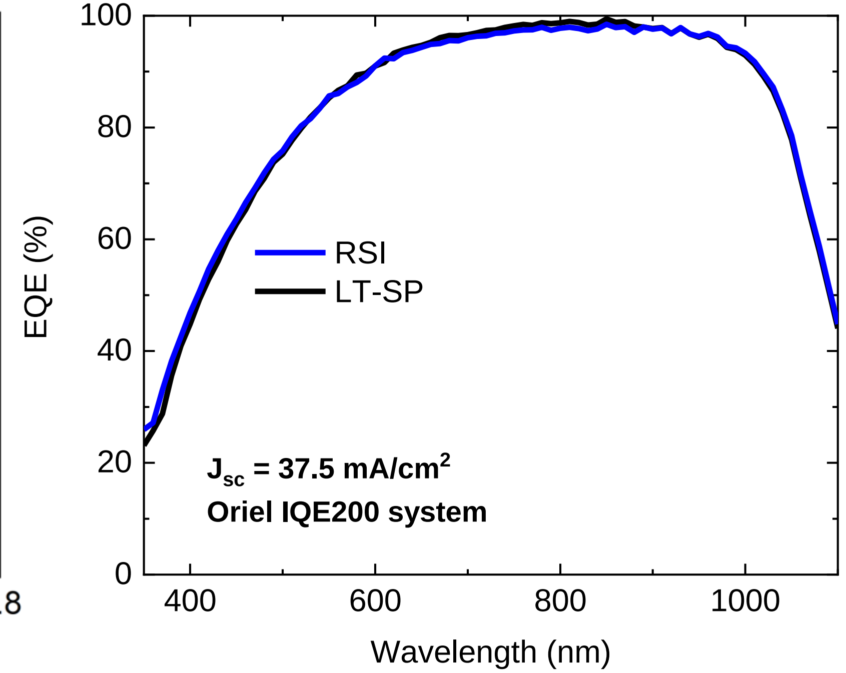


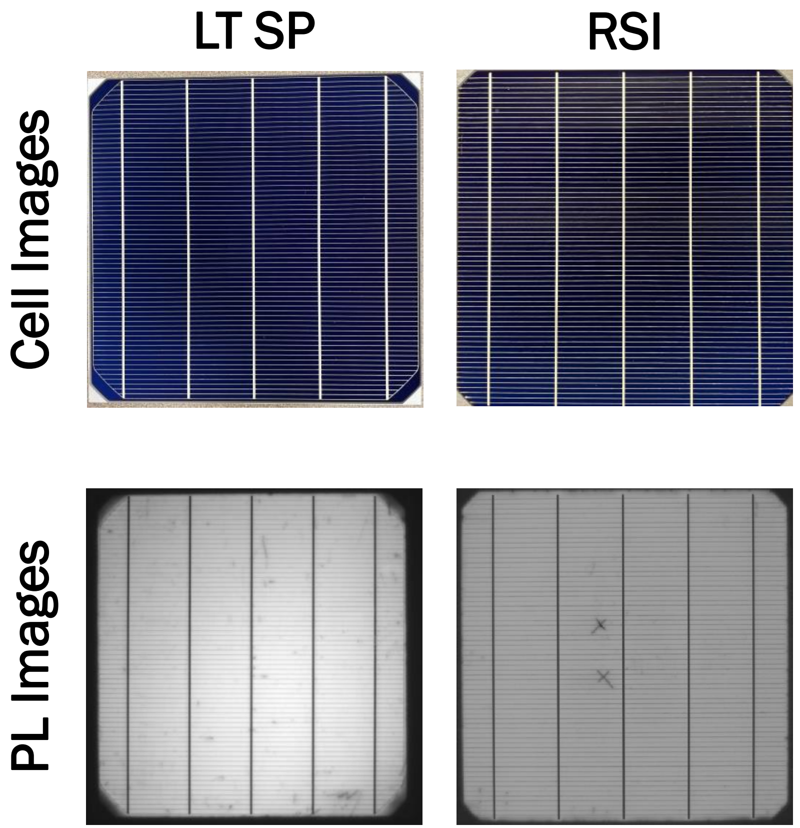
- Fingers only: 20 mg Ag per side

Cell Fabrication

@ ASU Solar Fabrication Lab.







Cell Type Top and Rear Cont. HJ	Eff %	Voc (V)	Jsc (mA/cm²)	FF%
M2, Monofac., LT SP	21.2	734	36.2	78.2
M2, Monofac., RSI	21.3	732	36.1	80.4

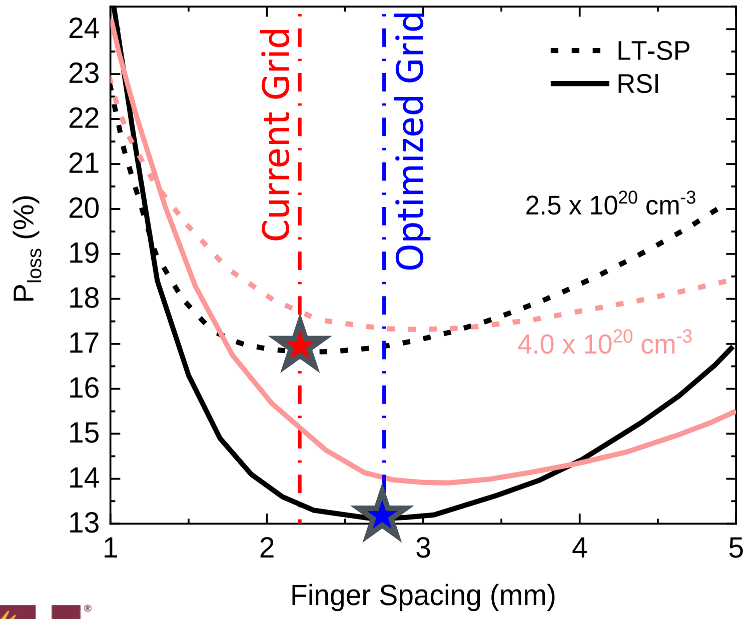
DiGregorio, S. J., et al *ACS Appl Energy Mater* **6**, 2747–2757 (2023).

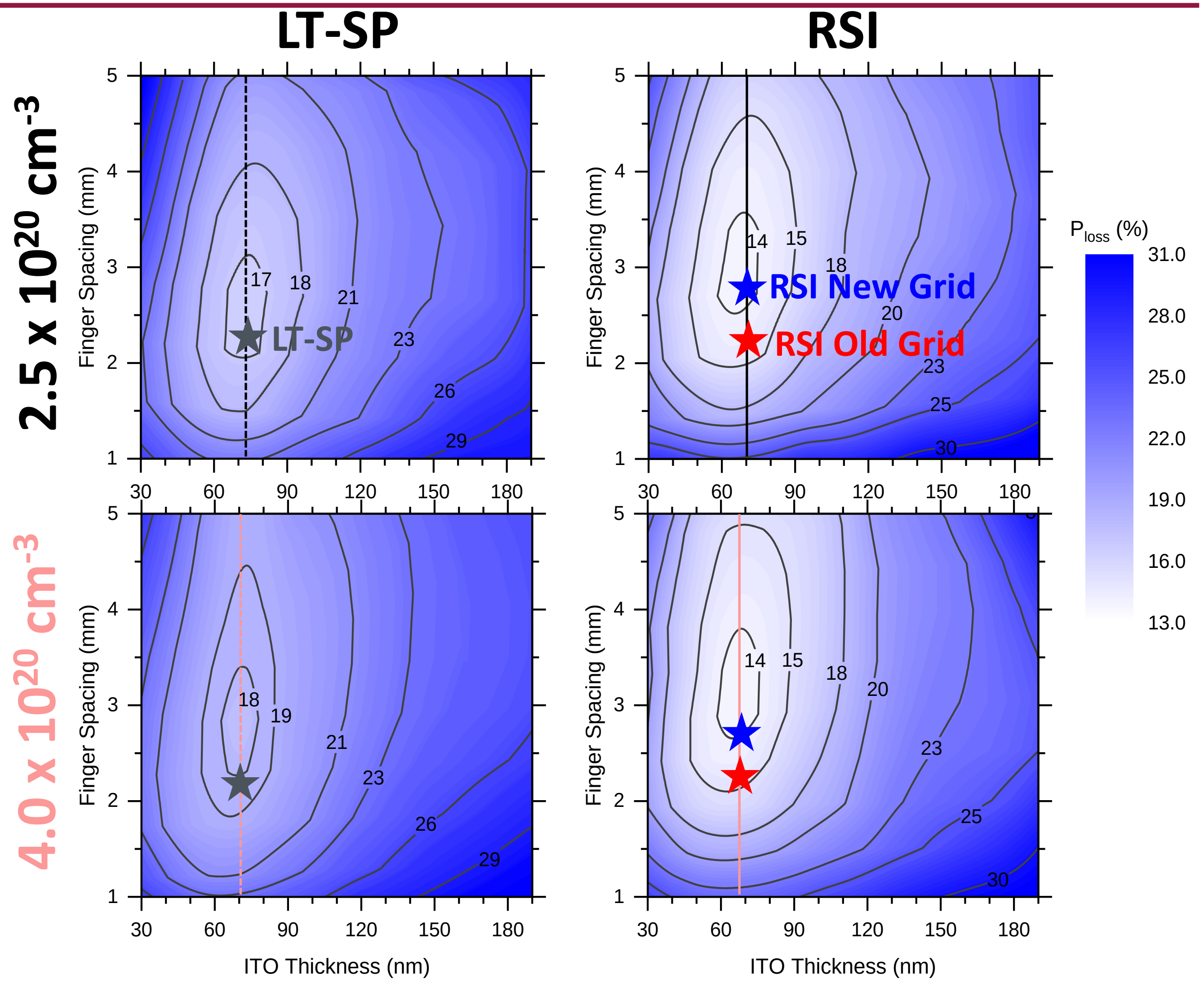
Power Losses

Power loss differences

- LT-SP: 17.3 → 16.8= **- 0.5%**
- RSI: 13.9→ 13.1 = **- 0.8%**
- RSI electrical properties enable higher benefit from reduced carrier density

LT-SP vs RSI Power Loss

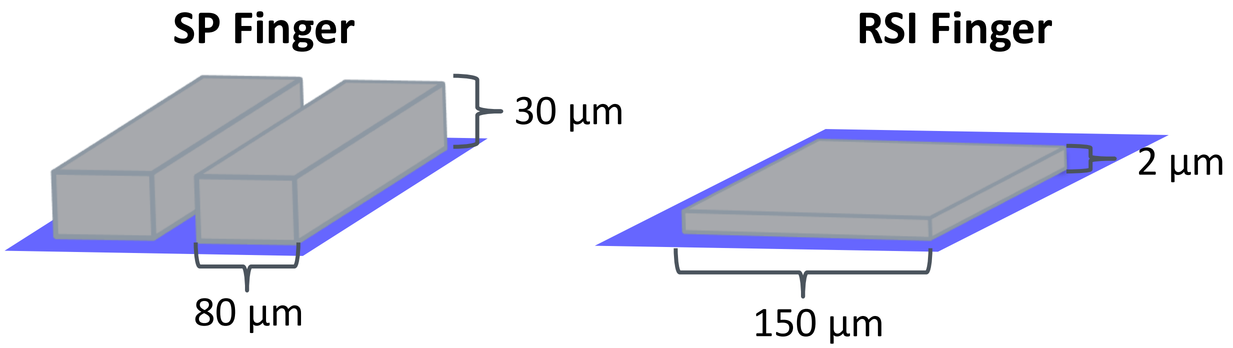




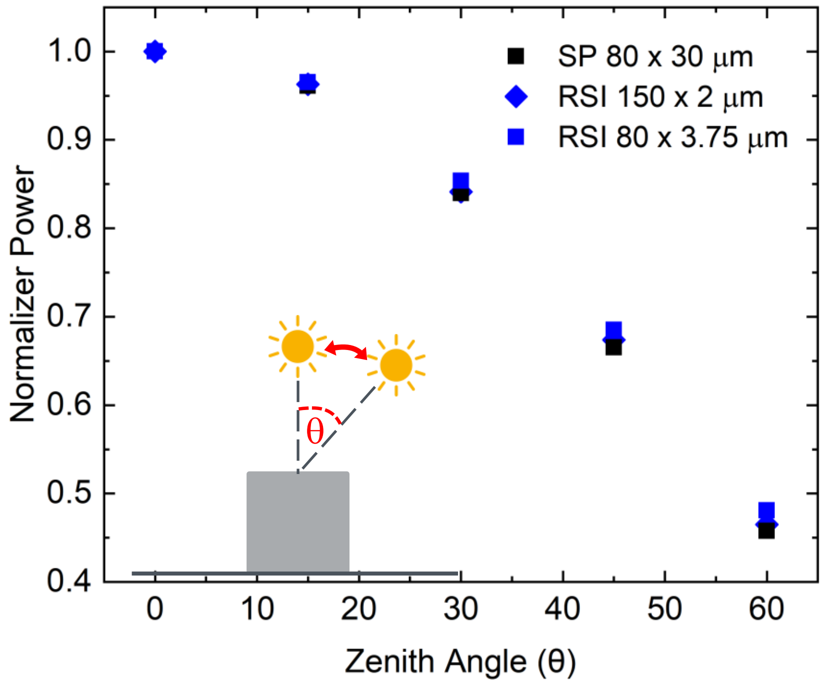
M. Martinez-Szewczyk, et al *Adv. Energy Mat,* submitted (2023).

Benefits of New Form Factor

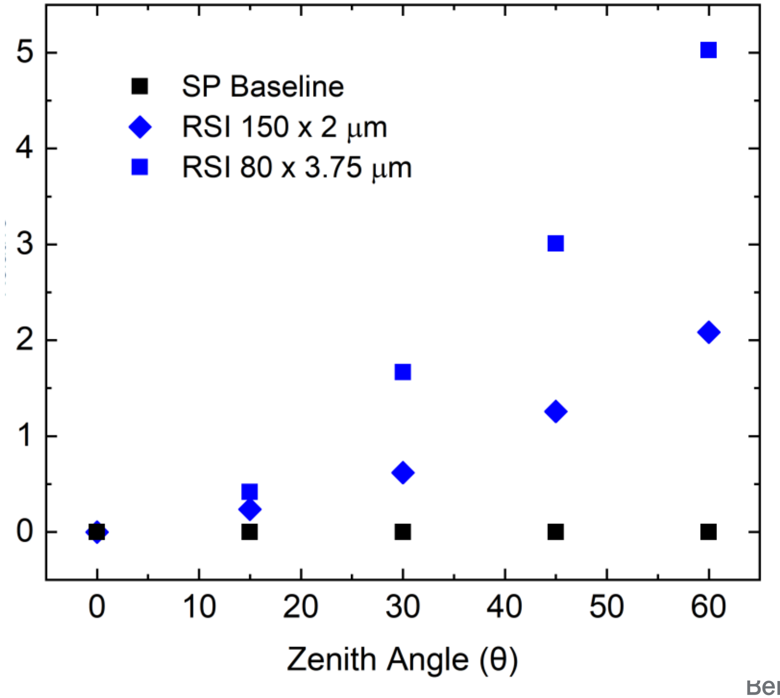
- RSI 150 µm x 2 µm:
  - **0.25-2%** increase in power
- RSI 80 µm x 3.75 µm:
  - **0.5-5%** increase in power



Normalized Power vs Zenith Angle



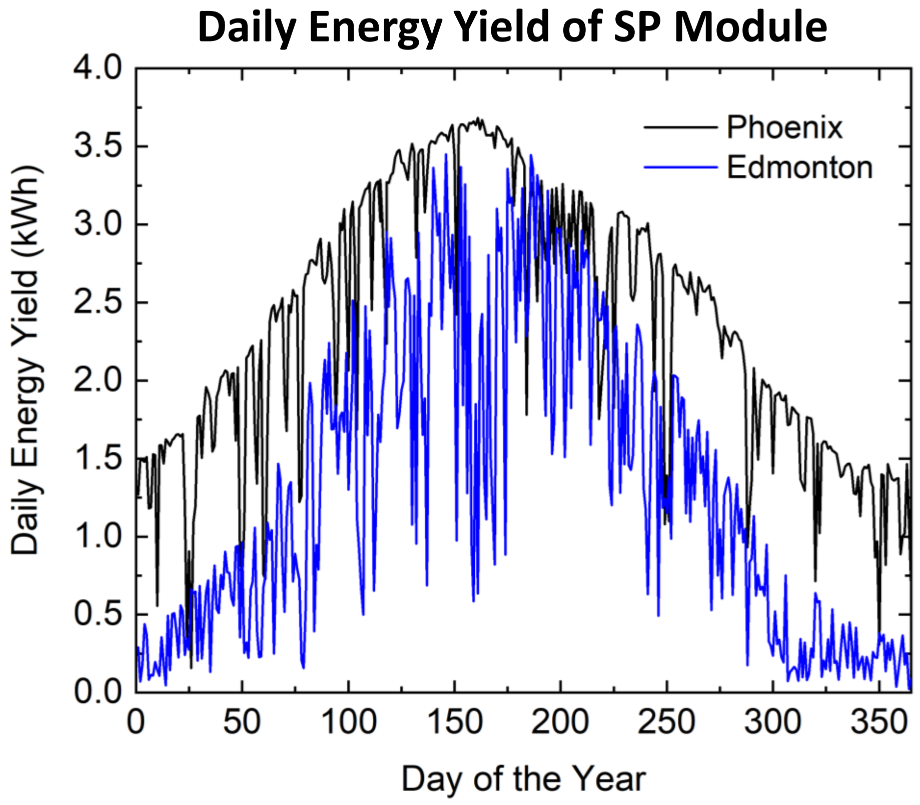
Change in Power vs Zenith Angle



Module Yearly Energy Yield

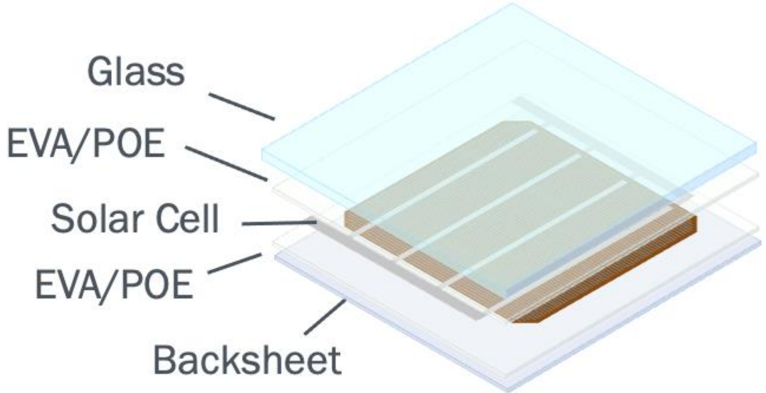
- 72 monofacial cell, Single-axis tracker modules
- Phoenix: **3.7%** increase in energy for RSI
- Edmonton: **10.7%** increase in energy for RSI
- Reduced height of RSI overcomes increased finger width shading
  - Becomes more pronounced at higher latitudes
- **3.6-9.7%** lower LCOE using RSI modules

Metallization	Location	Energy Yield at STC (W)	Yearly Energy Yield (kWh)
SP	Phoenix, AZ	328	754
RSI	Phoenix, AZ	321	782
SP	Edmonton, AL	328	512
RSI	Edmonton, AL	321	567



M. Martinez-Szewczyk, in preparation (2023).

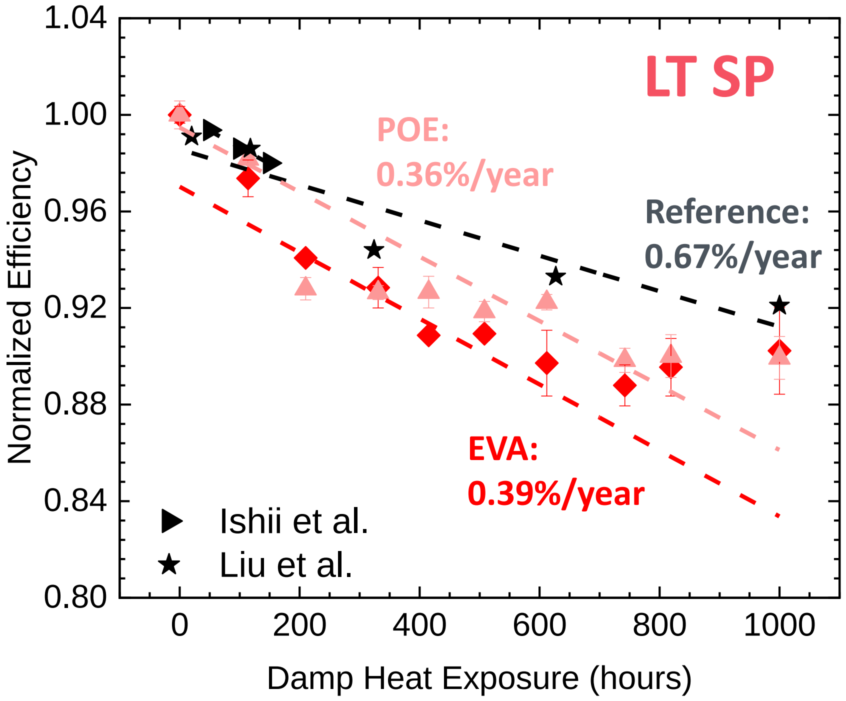
Minimodule Damp Heat Degradation

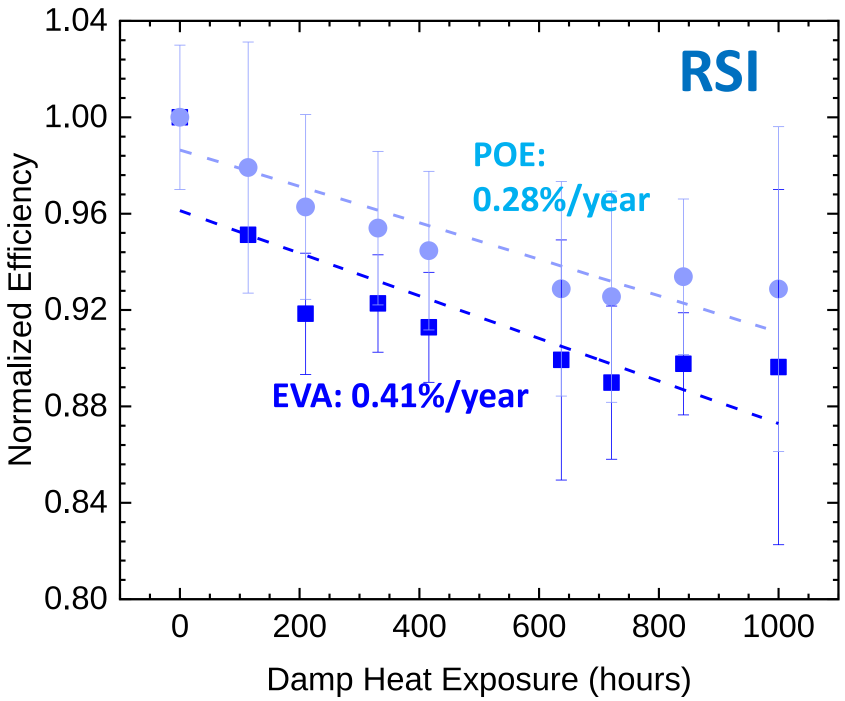


10 Minimodules per set

Sisters at NREL for validation

- Comparable degradation rates for different metallizations and encapsulants

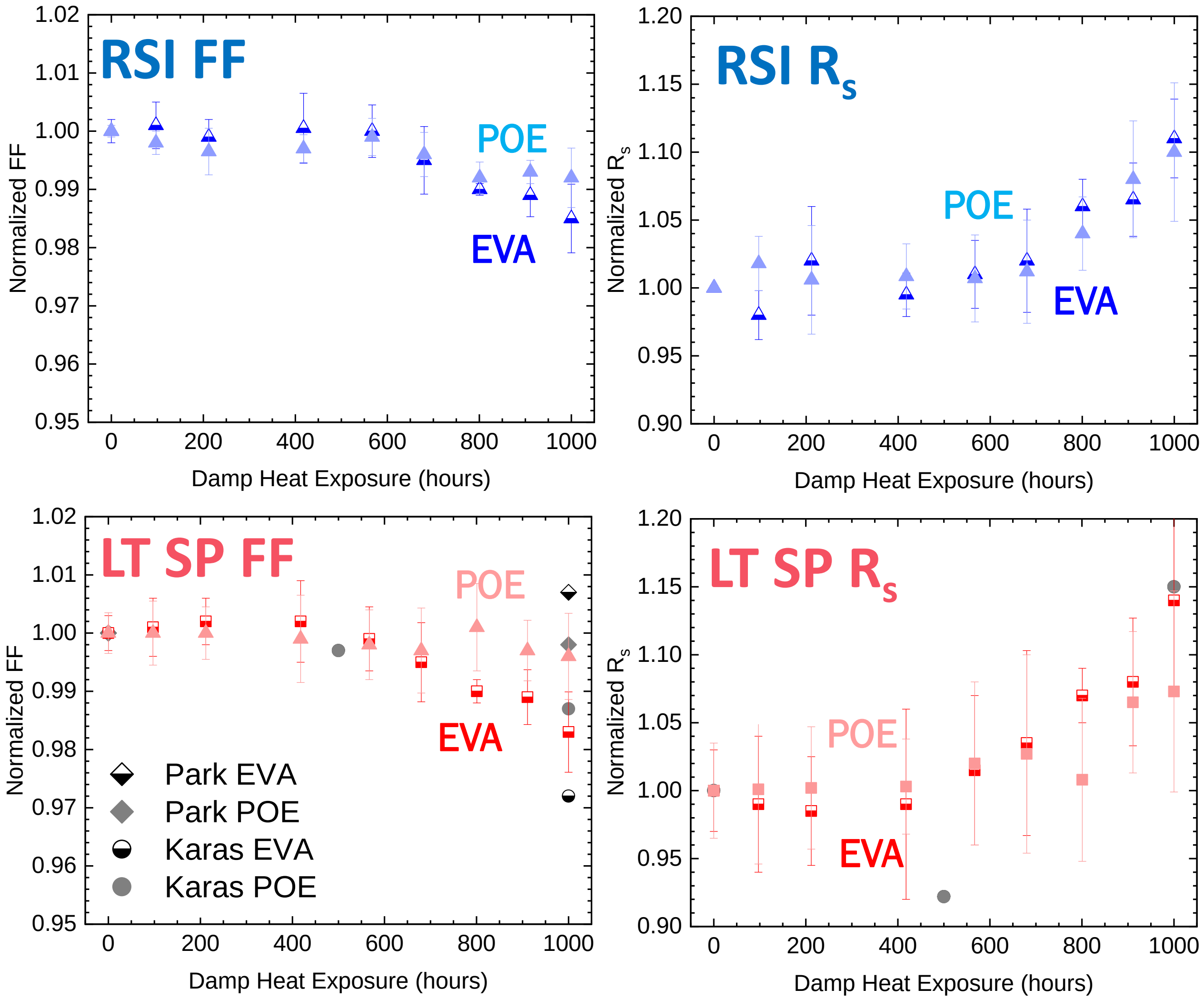


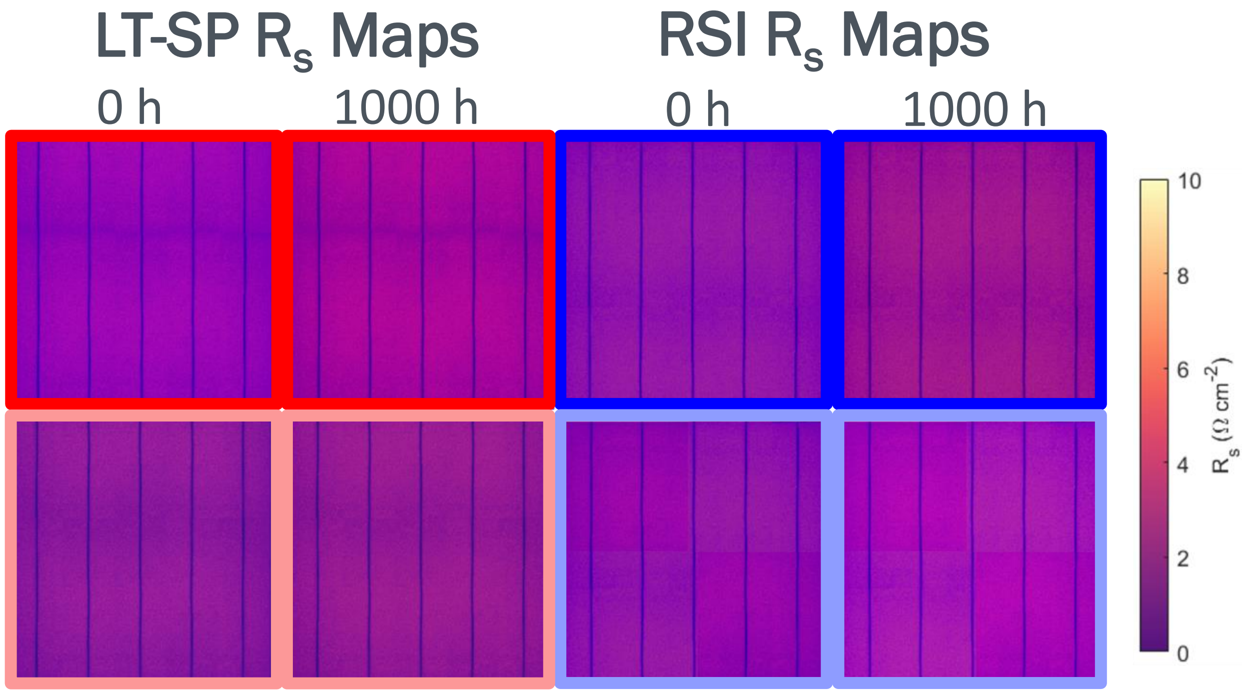


[1] Liu et al. "Damp-Heat-Stable, High-Efficiency, Industrial-Size Silicon Heterojunction Solar Cells", joule 4(4) (2020).
[2] Ishii et al, "Annual degradation rates of recent crystalline silicon photovoltaic modules", Prog. Photovolt: Res. Appl;25:953–967 (2017).

M. Martinez-Szewczyk, in preparation (2023).

FF and R_s Degradation



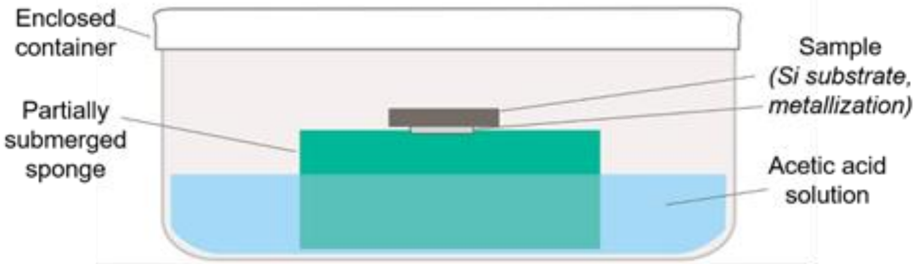


- No disconnected fingers or observable corrosion
- Similar R_s trend regardless of metallization

M. Martinez-Szewczyk, in preparation (2023).

Corrosion Results

Experiment Schematic



0-7 Hours

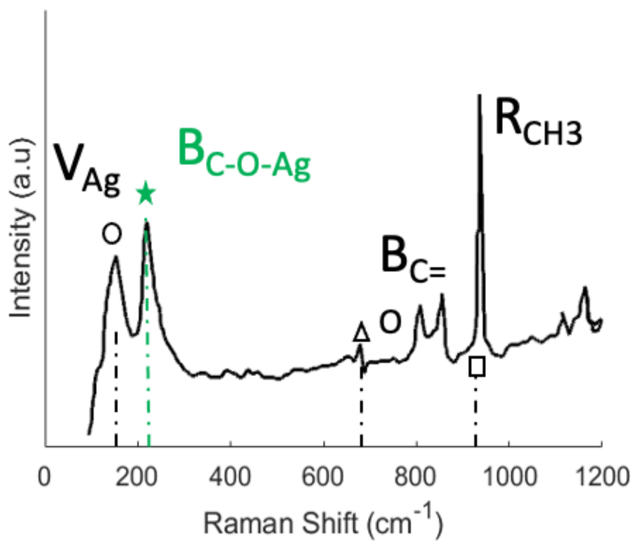
$$CH_3COO^- + Ag^+ \leftrightarrow AgCH_3COO$$

7+ Hours

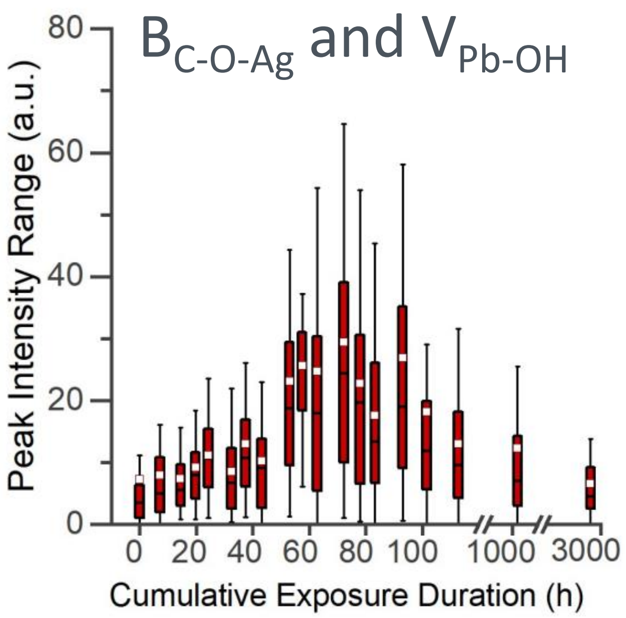
$$AgCH_3COO + CH_3COOH + H_2O \leftrightarrow Ag^+ + 2CH_3COO^- + H_3O^{+}*$$

*Silver acetate solubility decreases as pH decreases

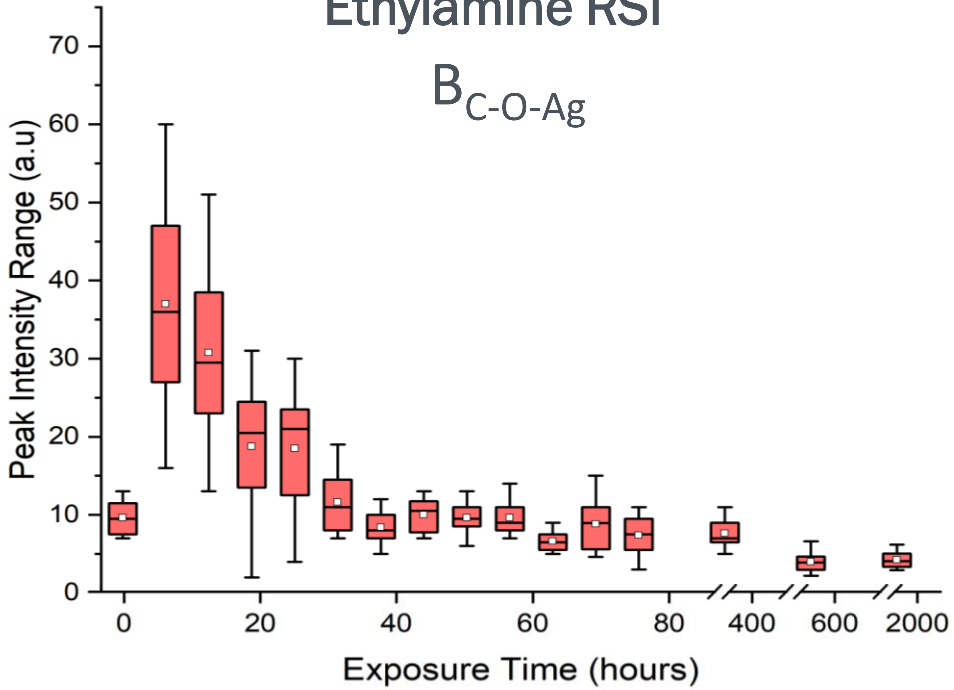
99% Silver Acetate Raman Spectrum



Baseline HT Ag Paste



Ethylamine RSI



Jeffries, A. M., et al. *Solar Energy Materials and Solar Cells* **223**, 110900 (2021).

Summary

- Lower vapor pressure complexing agents result in thermal-driven silver precipitation
  - More dense and conformal metallization
- RSI shows comparable performance vs LT-SP cells with up to 90% less finger silver content
  - Silver usage can be further reduced with multiwire approaches
- Improved electrical properties of RSI allows for optimized TCO
- V_{oc} drops by about 0.3% in a year consistent across structures due to changes in the defect density at the interface
- No corrosion or failure of the metallization is observed

Acknowledgements

Work done by

Michael Martinez-Szewczyk

Jorge Ochoa

Collaborators:

Owen Hildreth (CSM)

Steven Di Gregorio (CSM)

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