

Faculty of Engineering
School of Photovoltaic and Renewable Energy Engineering



Progress in Silver-Lean Screen-Printing Metallisation Technology for Industrial Silicon Solar Cells

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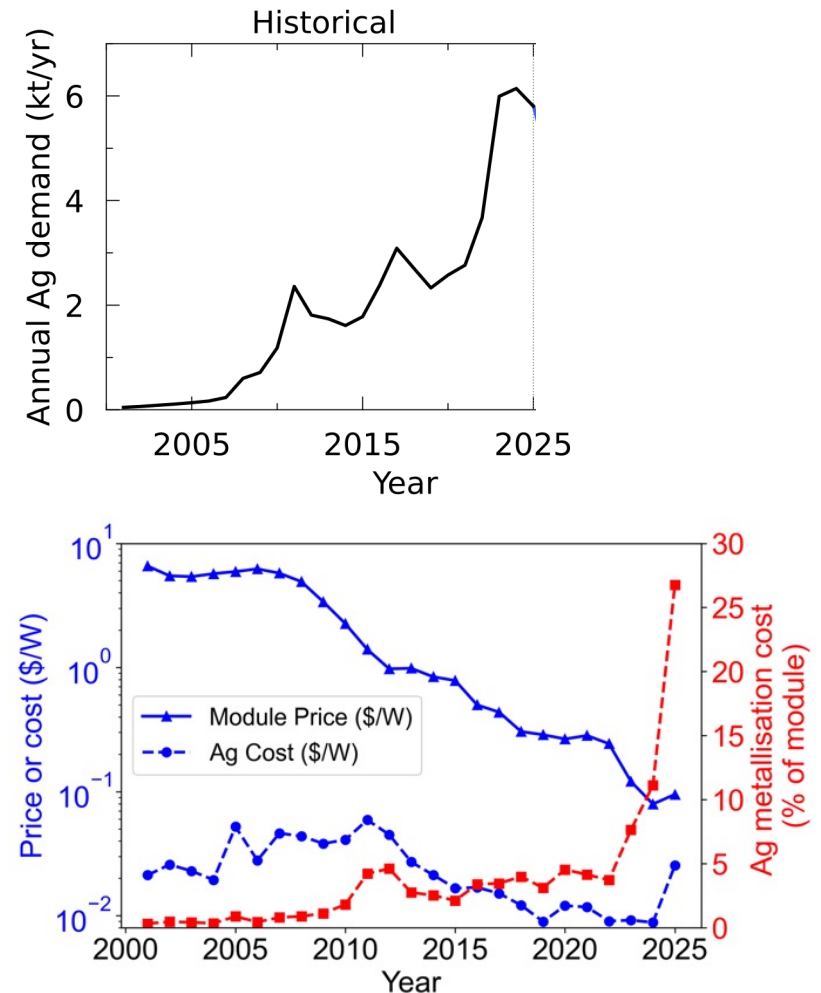
School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Australia

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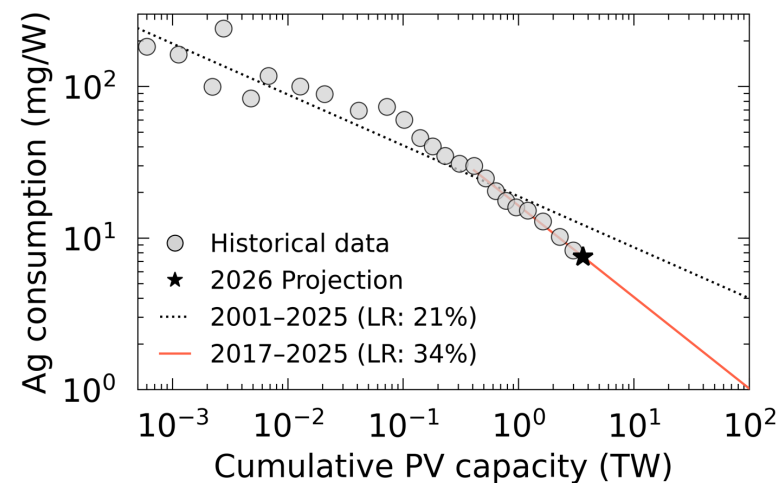
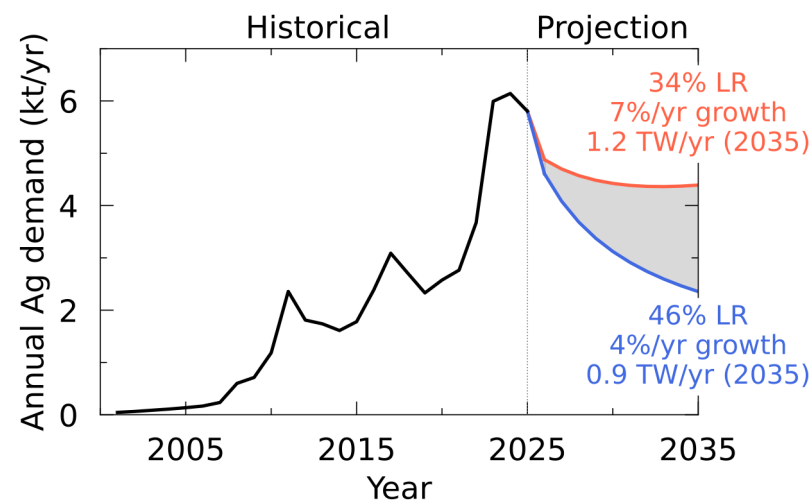
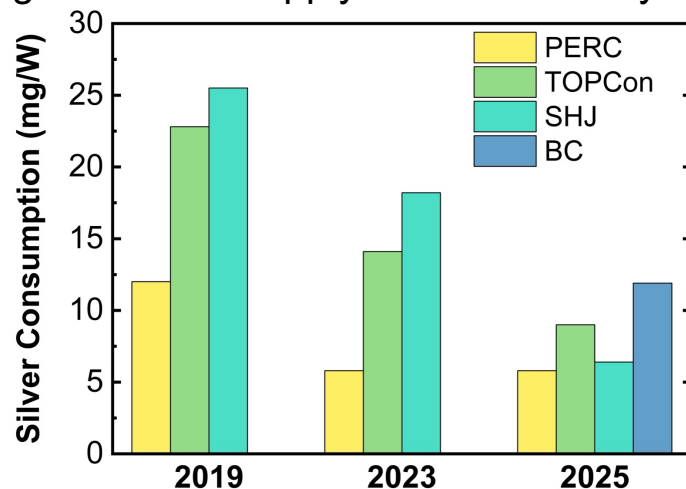
Silver – An Issue for Sustainability and Cost

- **Renewable energy transition creates a shift from fuel intensive to material intensive technologies**
 - Silver is a key material issue for PV, using >20% of global silver supply each year since 2023
 - 2025 demand of ~5300 tons
- **Despite falling consumption, silver price spikes are increasing silver's cost share in modules**
 - Can represent more than 10% of module cost
 - This is driving PV manufacturers to accelerate efforts to reduce silver consumption



Silver – An Issue for Sustainability and Cost

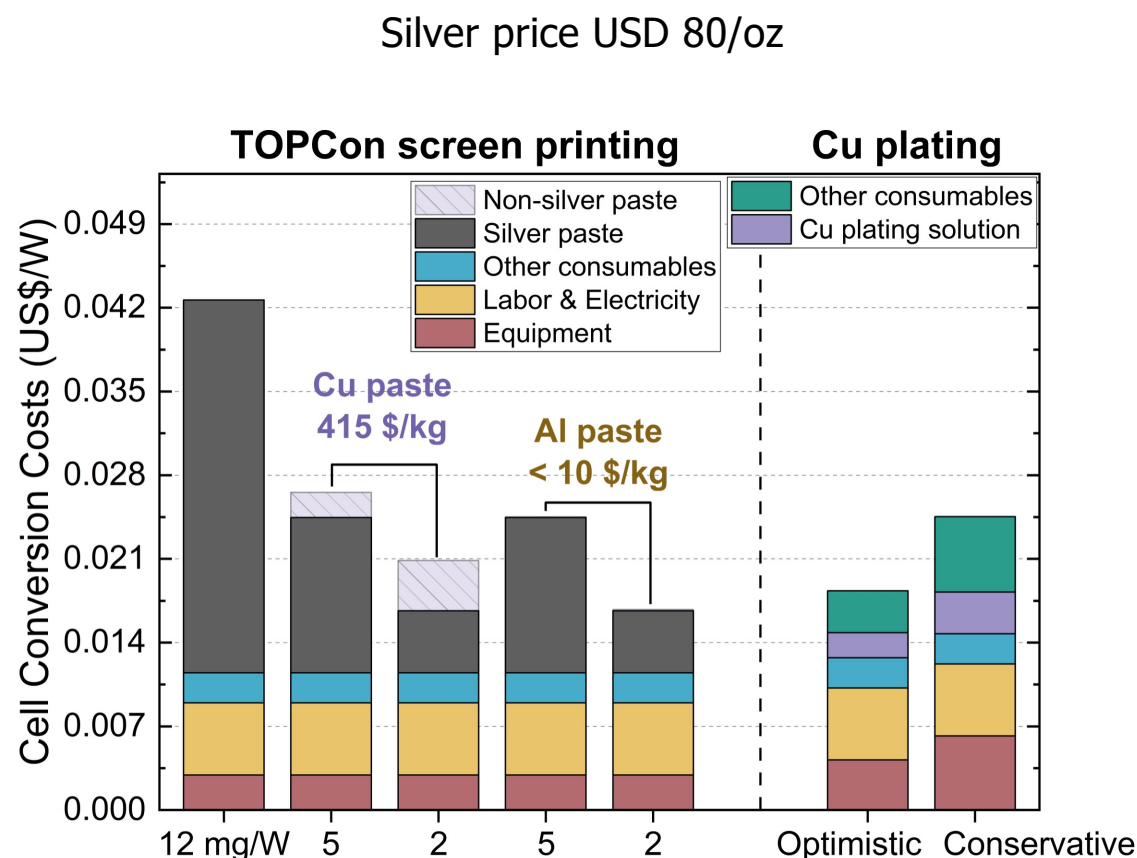
- Solar cell manufacturers continue with aggressive silver reduction efforts
- **The Silver Learning Rate is Accelerating**
 - Despite the industry's transition from PERC to TOPCon, which requires more silver, the silver learning rate has accelerated to $\approx 34\%$
 - With continued silver learning, we can stay below 20% of global silver supply even for 2 TW/year



[1] <https://www.pv-magazine.com/2026/04/15/silver-demand-from-pv-industry-expected-to-drop-19-this-year/>
 [2] Mineral Commodity Summaries 2026 by U.S. Geological Survey (USGS); presented at 2024 Silicon Workshop.

Why printing? – “It’s sticking with what we know”

- Two key approaches for reducing silver
 - **Screen-printing (dominant)**
 - Decades of expertise in technology and paste development
 - Rapid commercialisation
 - Low capex
 - Bankability
 - **Cu plating**
 - Can be done but complex and high CAPEX
 - Concerns over reliability and bankability
 - Management of liquid metallic waste
 - 1.1 mg/W with $\eta = 24\%$ [1]



[1] <https://www.ise.fraunhofer.de/en/press-media/news/2026/silver-consumption-in-topcon-solar-cells-reduced-by-factor-ten.html>

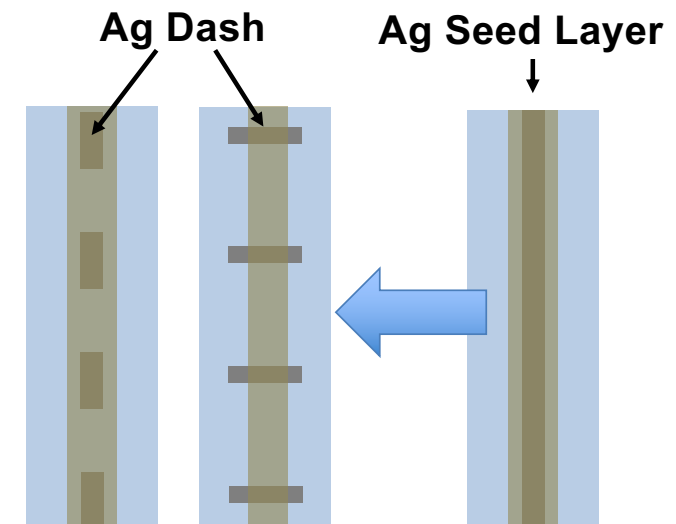
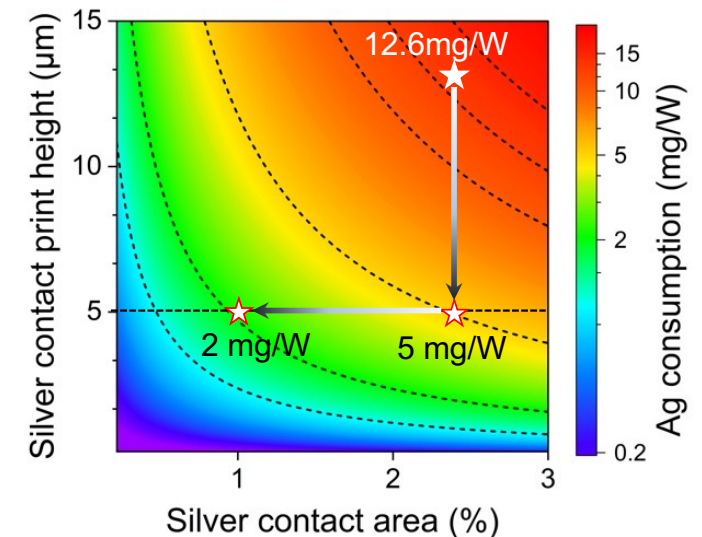
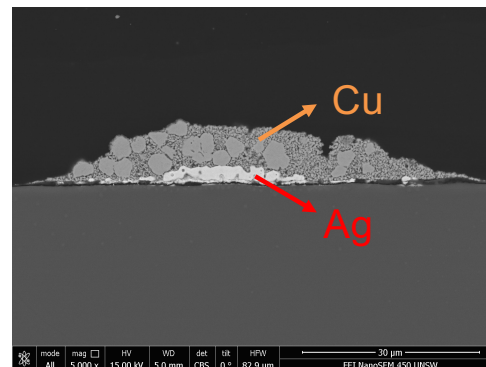
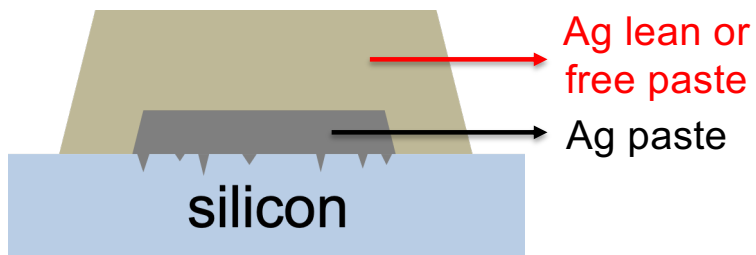
UNSW Silver-Lean Screen Printing

Double print fingers with Ag seed layers

- Key features:
 - Thin Ag seed layers for contact formation
 - Floating silver-lean or silver-free fingers
- 5 μm height of Ag $\rightarrow$ $\sim 5 \text{ mg/W}$ Ag usage for TOPCon

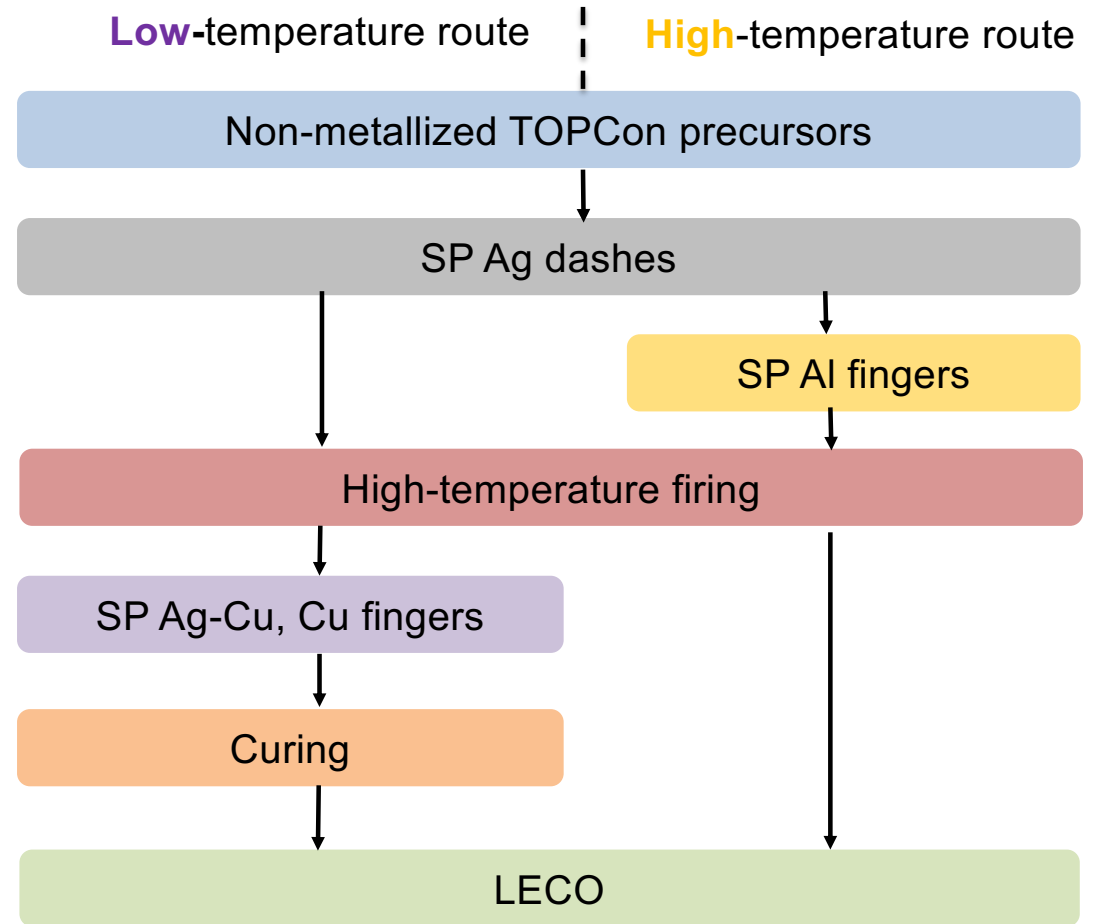
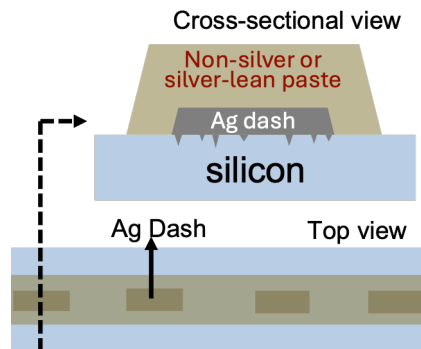
UNSW dash metallization design

- Replace continuous Ag seed layer with Ag dash
 - Reduced coverage of silver, independent of print width
 - Ultra-low Ag usage $< 2 \text{ mg/W}$ TOPCon, 1 mg/W for PERC
 - **Scope to increase efficiency**



Experimental Work

- Non-metallised industrial TOPCon precursors
- Ag dashes printed on the front/rear surface
- Silver-lean fingers/busbars
 - **Low**-temperature route (firing + curing):
 - Ag-coated Cu pastes
 - Pure Cu pastes
 - **High**-temperature route (co-firing):
 - Aluminium paste



UNSW Silver Reduction Progress (Low Temperature Route)

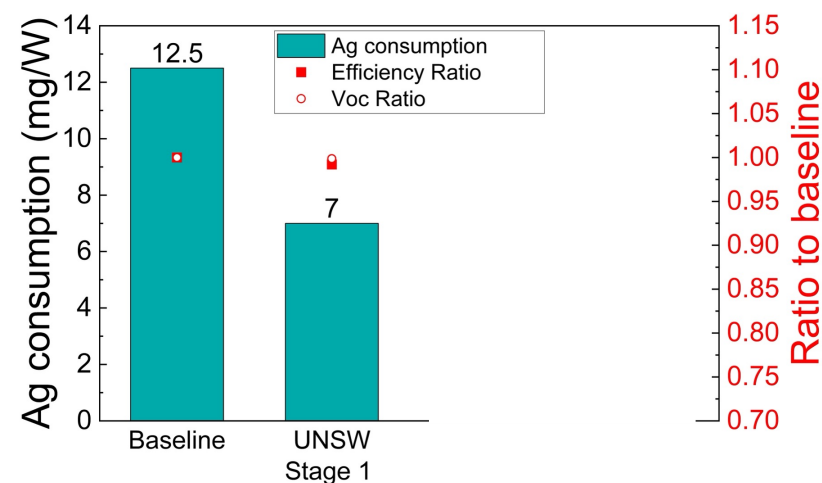
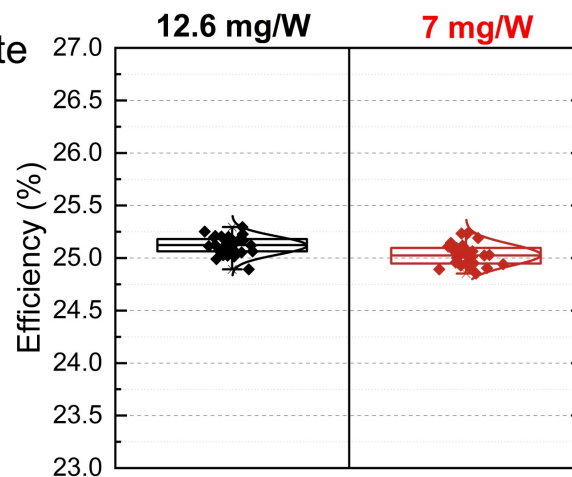
Staged implementation approach

Stage 1: Rear only

Stage 1: Rear only

- Rear Ag dash + Ag-lean paste
- 7 mg/W achieved
- $\Delta\eta$ to ref < 0.1%_{abs}

**85% silver
reduction on rear**



UNSW Silver Reduction Progress (Low Temperature Route)

Staged implementation approach

Stage 1:
Rear only

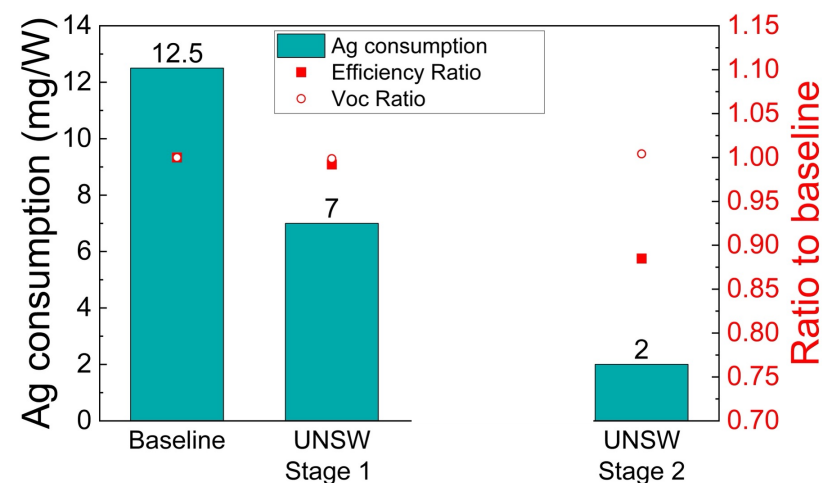
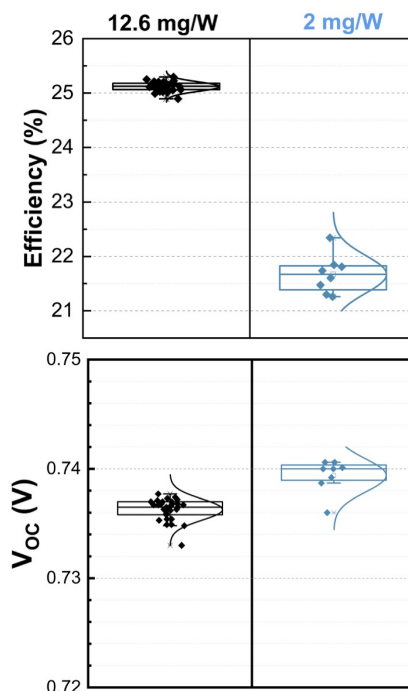


Stage 2:
Front + rear

Stage 2: Front + rear

- Dual Ag dash + Ag-lean paste
- 2 mg/W achieved
- $\Delta\eta$ to Ref > 2.8%_{abs}
- Challenges:
 - Finger width 60 μm
 - Processing issues

**83% silver
reduction on front**



UNSW Silver Reduction Progress (Low Temperature Route)

Staged implementation approach

Stage 1:
Rear only

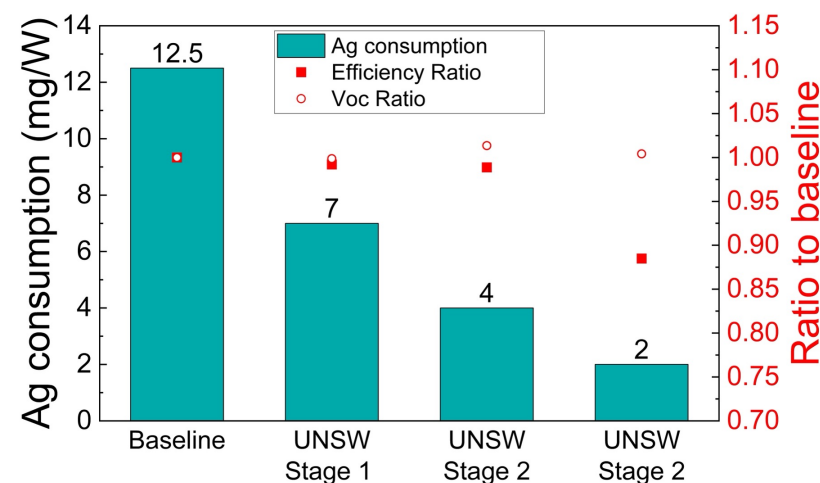
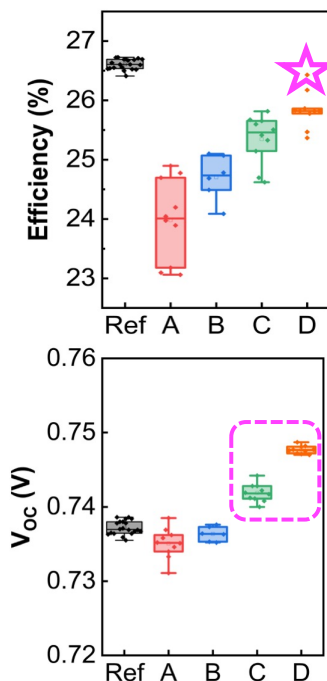


Stage 2:
Front + rear

Stage 2: Front + rear

- Dual Ag dash + Ag-lean paste
- 4 mg/W achieved
- $\Delta\eta$ to Ref < 0.2%_{abs}
- $\eta > 26.4\%^*$ (not yet optimised)
- $V_{OC} >$ Reference (Up to 10 mV gain)
 - 7 mV gain demonstrated for PERC
- Finger width $\approx 40\ \mu\text{m}$

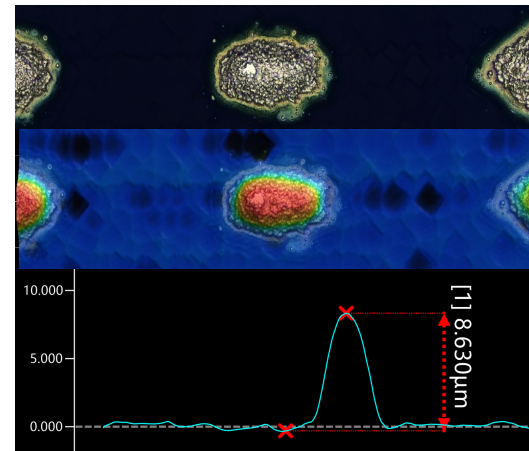
**35% silver
reduction on front**



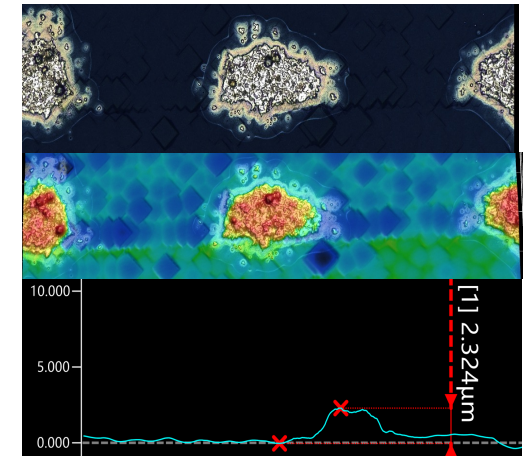
* Efficiency was measured at industry pilot line

Continuing Improvements

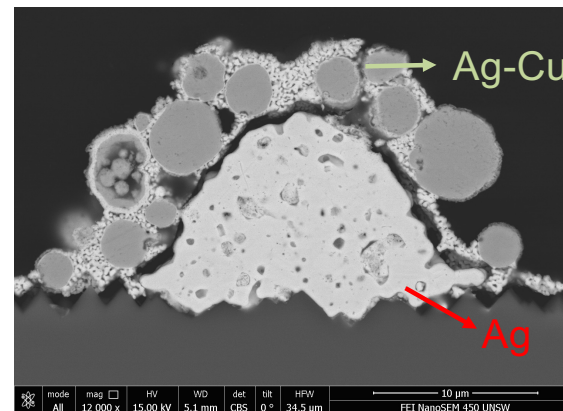
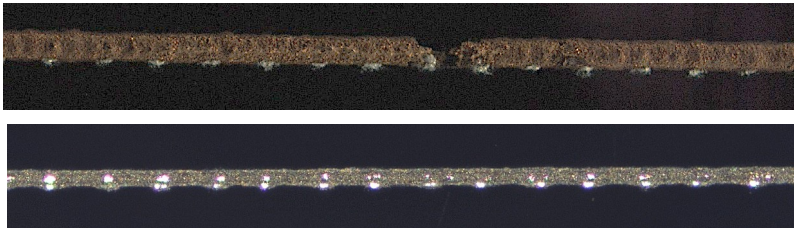
- Ongoing work:
 - Reduce front Ag dash laydown
 - Paste optimization
 - Printing optimization/line width
 - Further process optimization
 - Addressing challenges for stage 2 and beyond



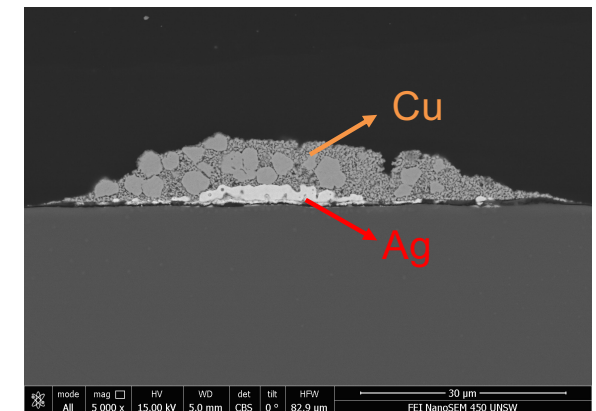
Old rear Ag dash paste



New rear Ag dash paste



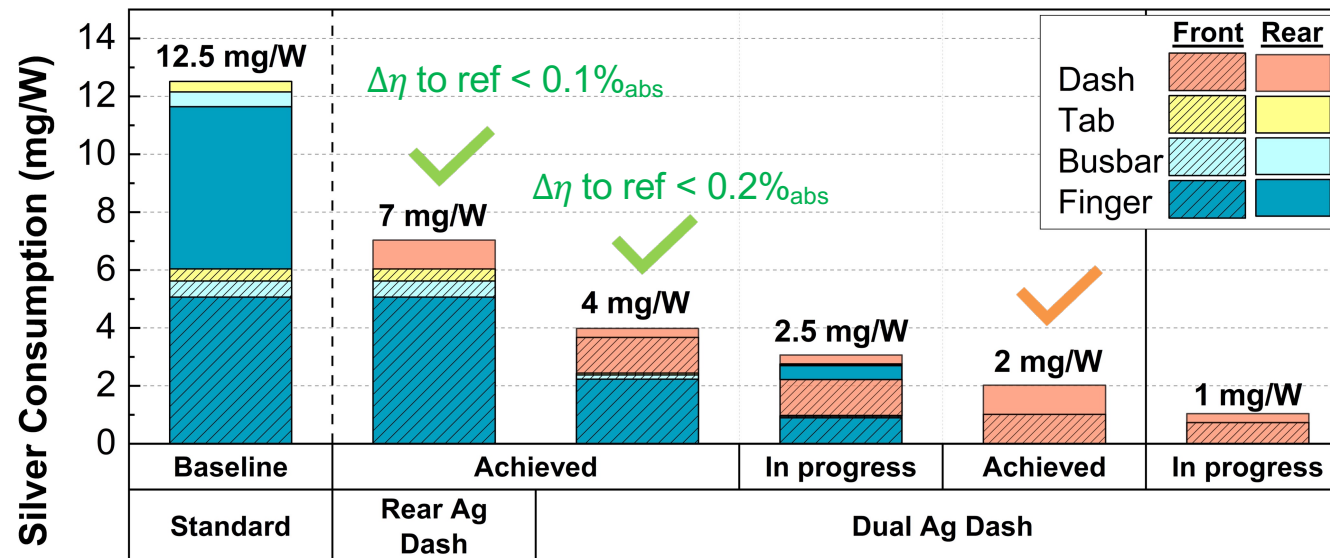
Front side



Rear side

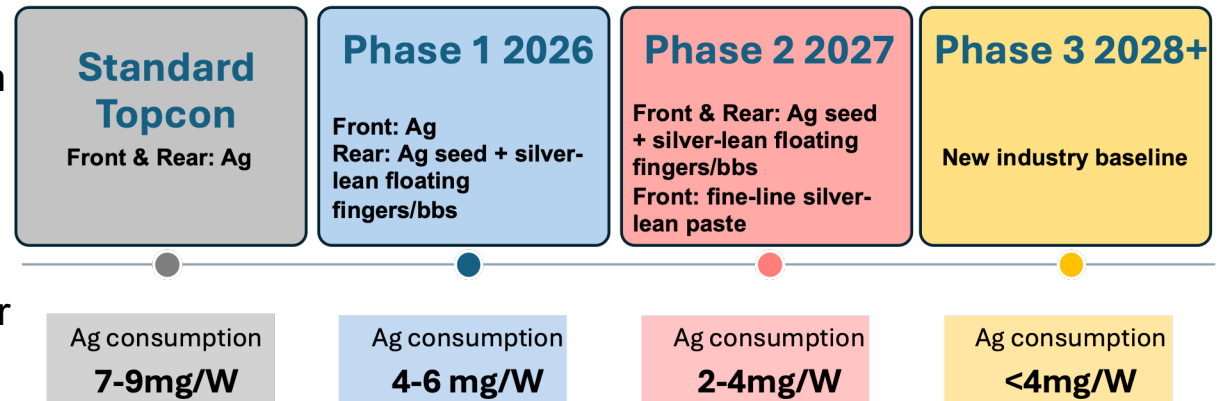
Scope to reduce silver consumption to 1 mg/W for TOPCon

- 4 mg/W already achieved with minimal impact on efficiency
- 2 mg/W demonstrated, working to increase efficiency
- Pathway to 1 mg/W identified and working towards progress



Commercialisation Progress & Expectation

- **First US Patent in family has been granted**
 - Covering both PERC, TOPCon and BC
- **Commercial pastes for silver-lean design are now available for TOPCon:**
 - Key opportunity for US supply chain
 - Ag pastes for Ag dashes
 - Can act as a copper diffusion barrier
 - Silver-lean paste:
 - Ag-coated Cu, pure Cu
 - Others under development
- **Managing Capex and bankability risks**
 - Rapid and phased commercialisation
 - Aligned with existing manufacturing processes and equipment
 - Minimal Capex additions

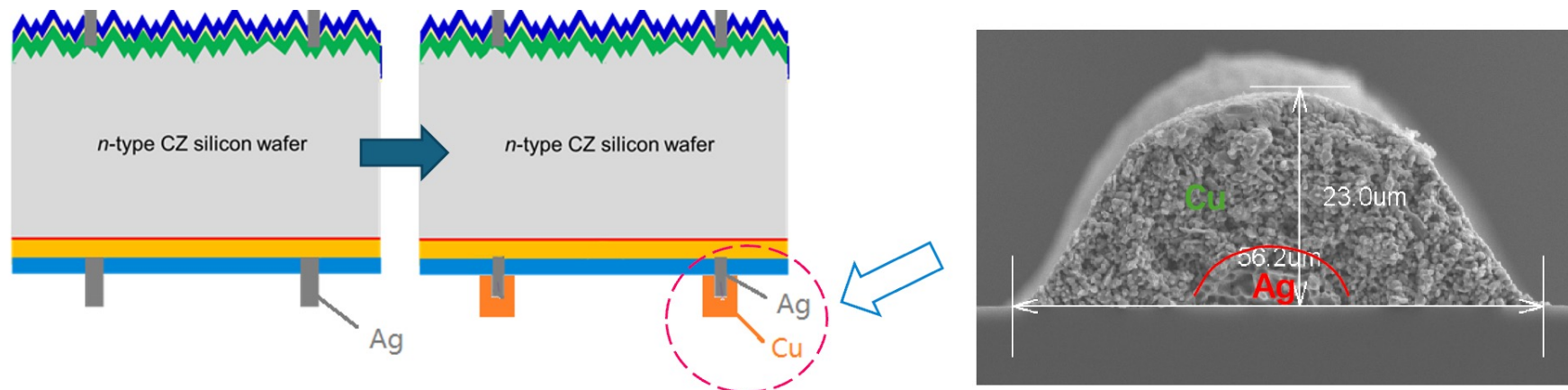


Collaboration, licensing and technology transfer options available for PERC, TOPCon and BC enabling < 2 mg/W

Commercialisation Progress & Expectation

- Multiple companies in GW scale technology production trials
- Example data from Trina

Trina solar



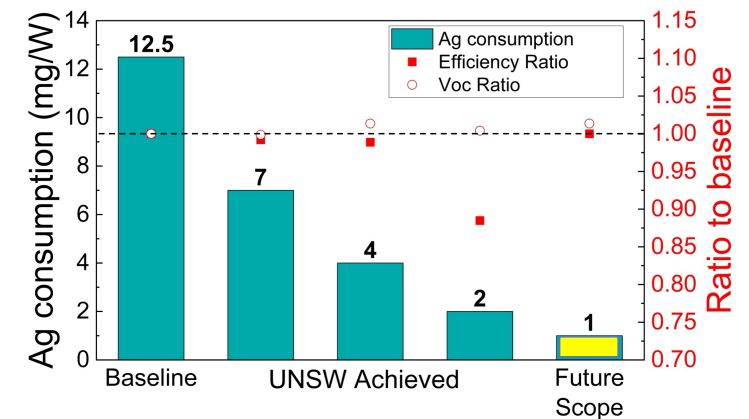
Finger type	Qty.	J_{sc} (mA/cm ²)	V_{oc} (V)	FF (%)	<i>Eta</i> (%)	Ag consumption mg/W	Cu consumption mg/W
Ag	936	41.25	737.1	83.26	25.32	BL	0
Cu	1255	41.27	737.5	83.11	25.30	BL-2.5	13.5

□ Silver consumption **save 2.5 mg/W.**

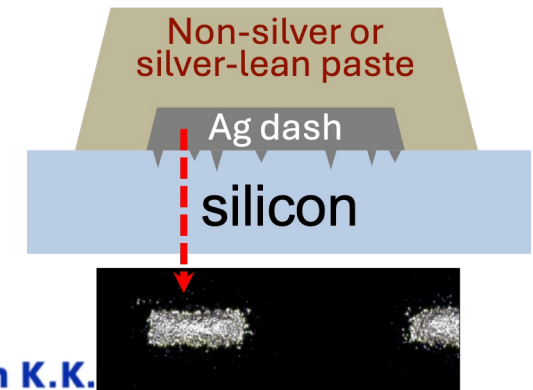
□ **Almost same efficiency.**

Conclusion

- Silver is a key sustainability and cost concern for PV production
- Patented UNSW silver-lean metallisation can achieve 2 mg/W
 - Compatible with PERC, TOPCon and BC
 - Currently 4 mg/W ($V_{OC} > \text{ref}$, best Eff 0.2%_{abs} lower)
 - Ongoing work with high temperature Al paste, maintaining V_{OC}
 - Future scope:
 - Further paste & process optimisation
 - Continue collaborating with the PV industry towards commercialisation
 - Minimal Capex additions and phased integration approach for bankability



UNSW Ag-lean dash design



JOLYWOOD



Toyol Aluminium K.K.

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