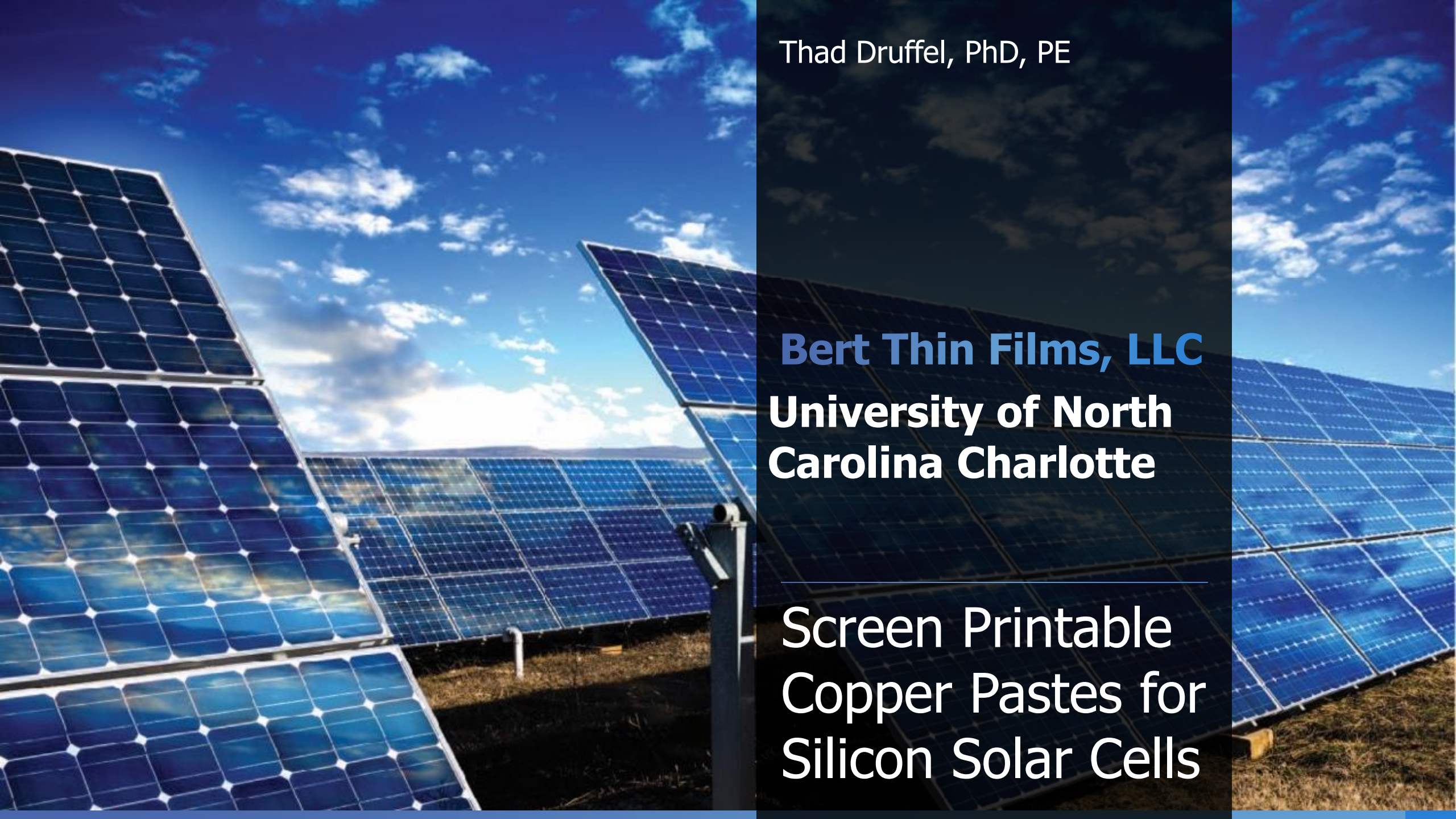


Thad Druffel, PhD, PE

Bert Thin Films, LLC

University of North Carolina Charlotte

Screen Printable Copper Pastes for Silicon Solar Cells

Outline

Copper Screen Printable Pastes for High Temperature Firing

- Silver Metallization
  - Consumption and Costs
  - Screen Printable – Air Fired
- Why Not Copper
  - Issues – oxidation, diffusion
  - Previous approaches
- The Bert Thin Film Approach
  - Screen Printable - Air fired
    - Paste
    - Screen Printing
  - Performance
  - Durability
- Conclusions

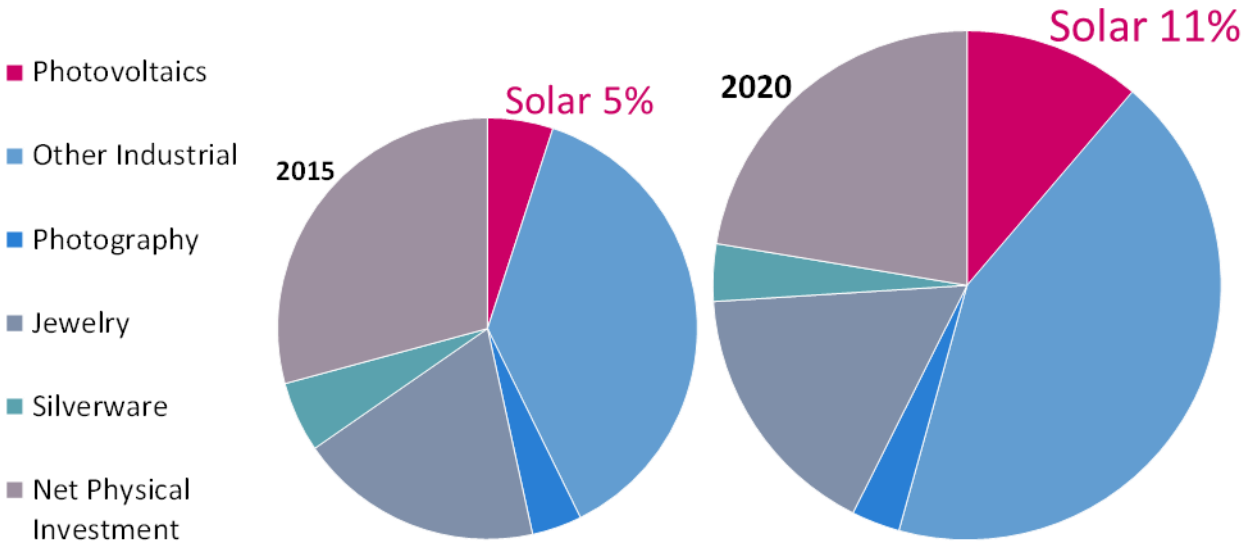
Copper is 800 times more abundant than Silver.

Metallization

A small part of the cell, but a critical part of the performance and cost

Scaling solar to meet the global need for electricity would push the photovoltaic industry to demand all of the silver production at current silver usage.

That is not feasible…



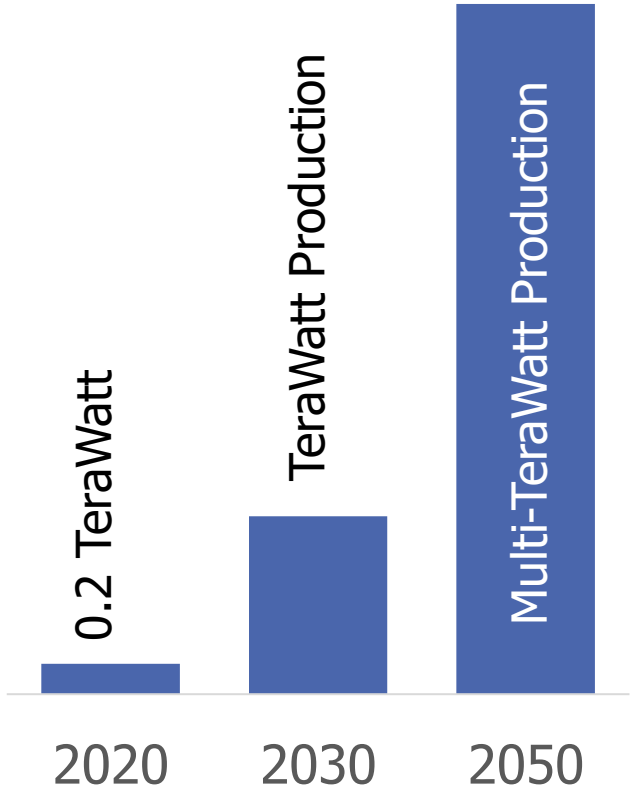
Silver Demand by Sector

www.silverinstitute.org/silver-supply-demand/

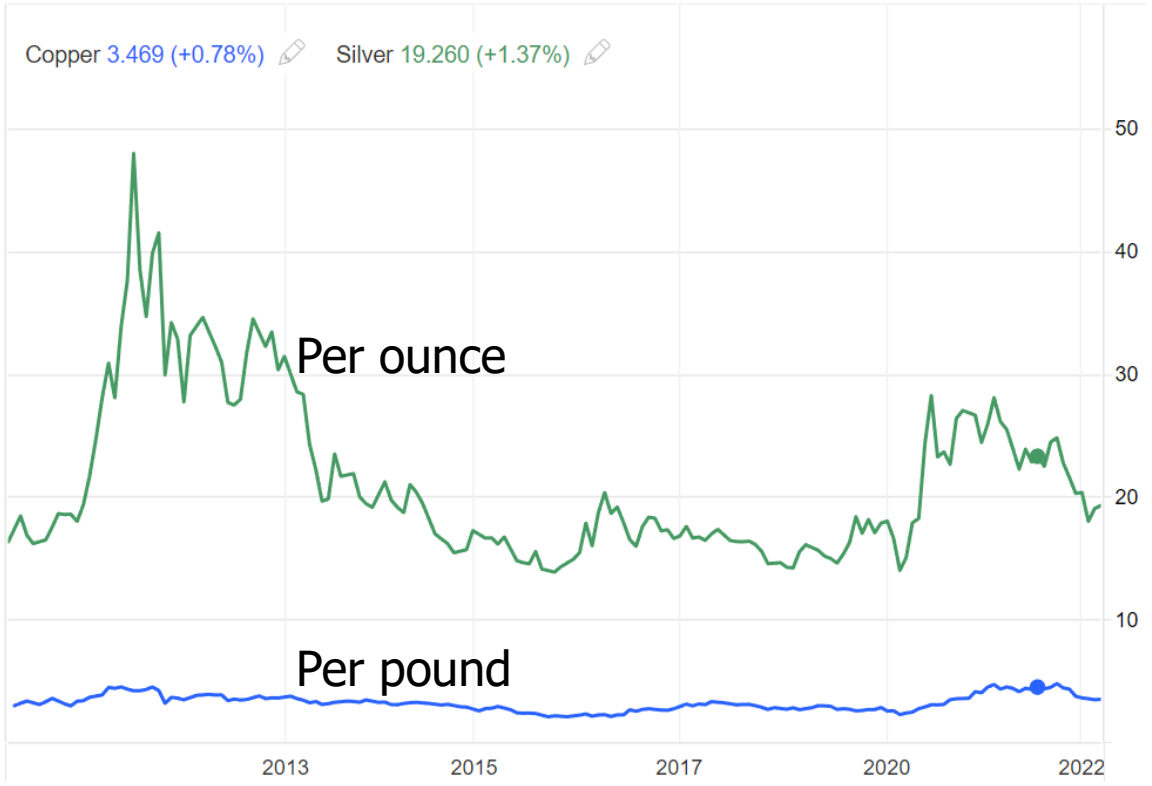
Ag Supply

Newer technologies use more silver.

Structure	Percentage of Global Silver Supply for 1 TW Production
PERC	53
TOPCon	88
SHJ	117



Y. Zhang, M. Kim, L. Wang, P. Verlinden and B.Hallam (2021) "Design considerations for multi-terawatt scale manufacturing of existing and future photovoltaic technologies: challenges and opportunities related to silver, indium and bismuth consumption", Energy Environ. Sci., 2021,14, 5587-5610 DOI 10.1039/D1EE01814K



Cost Comparison

Cost of Silver has increased 67% over the past 6 years and pricing is volatile

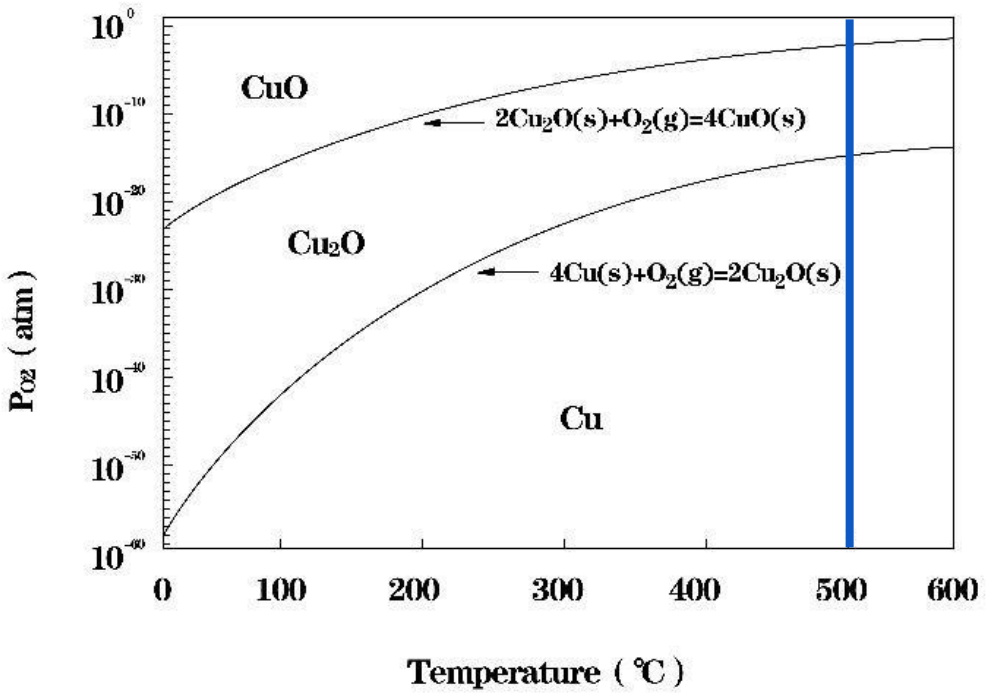
Copper 1/100th the cost of silver

So

- 300 GW Production
- ~10X increase in scale in 10 years
- Most of this CAPEX has not depreciated
- ~90% is screen printed with furnace
- 1 TW by 2030
- Screen printing with furnace is scalable

Why Not Copper? (Or what do we need to overcome?)

Oxidation



Thermodynamic phase transition diagram of Cu to Cu 2 O or CuO

Shang, Shengyan & Kunwar, Anil & Wang, Yanfeng & Yao, Jinye & Ma, Haitao & Wang, Yunpeng. (2018). Influence of Cu nanoparticles on Cu 6 Sn 5 growth behavior at the interface of Sn/Cu solder joints. 10.1109/ICEPT.2018.8480619.

Diffusion

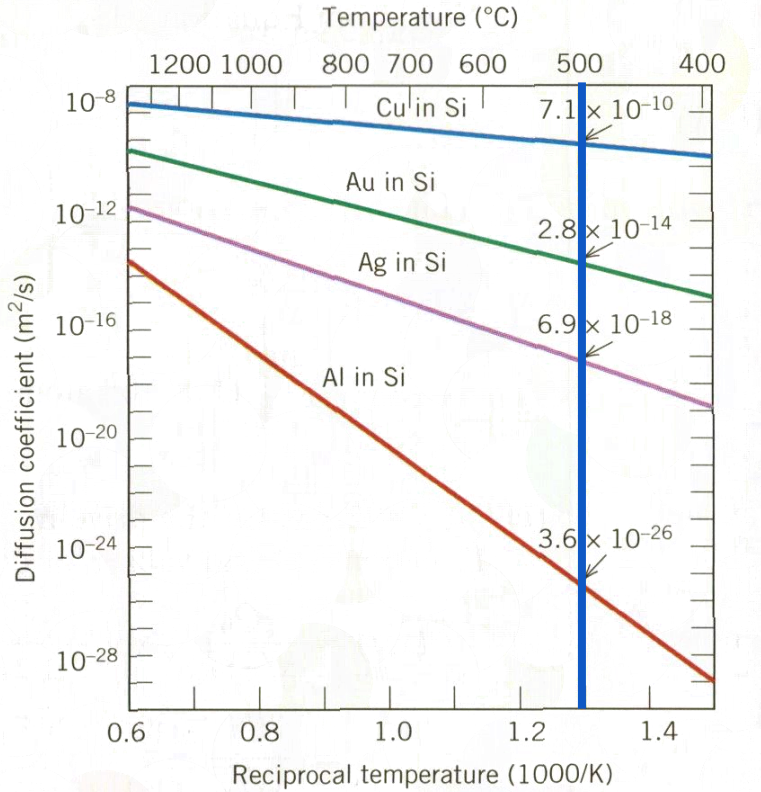
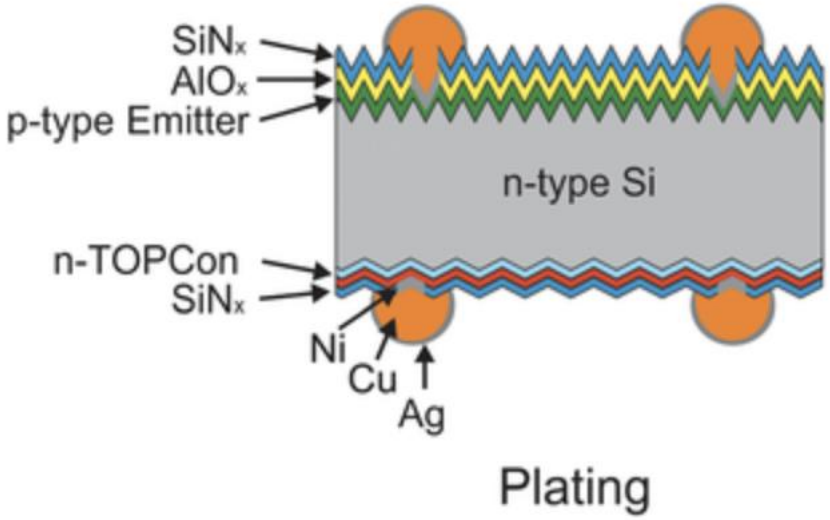


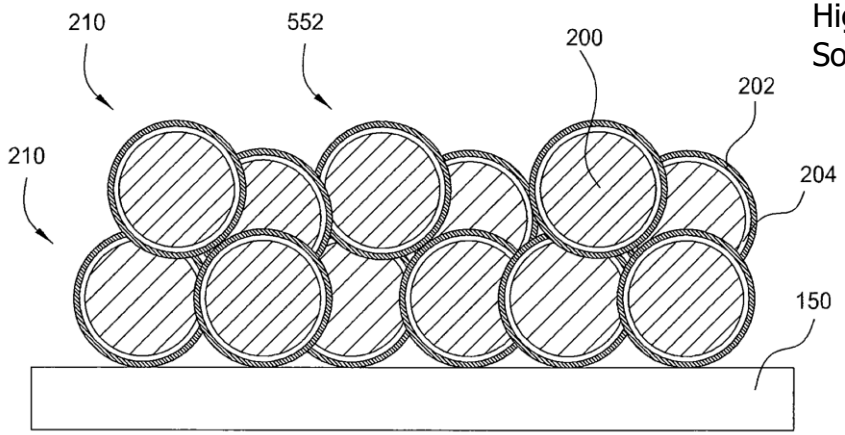
Figure 7.12 Logarithm of D-versus-$1/T$ (K) curves (lines) for the diffusion of copper, gold, silver, and aluminum in silicon. Also noted are D values at 500°C.

Callister, W.D., Rethwisch, D.G., Materials Science and Engineering, 9th Edition, 2014, John Wiley and Sons

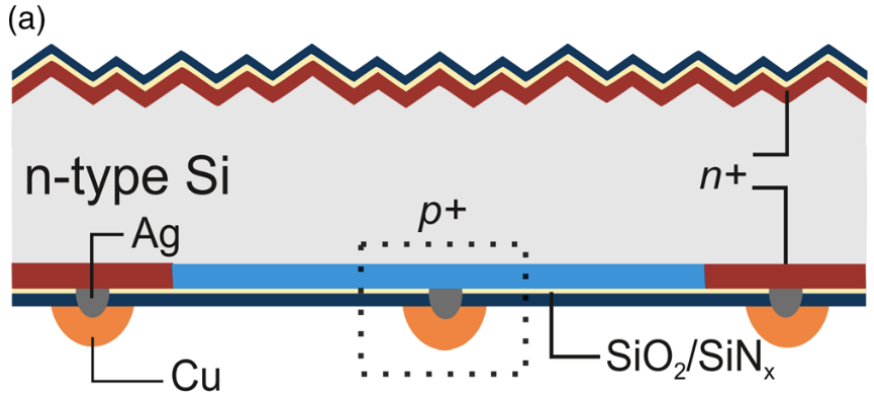
Copper SOA



Grübel B, Cimiotti G, Schmiga C, et al. Direct contact electroplating sequence without initial seed layer for bifacial TOPCon solar cell metallization. *IEEE J Photovolt*. 2021;**11**(3):1-7. doi:10.1109/JPHOTOV.2021.3051636

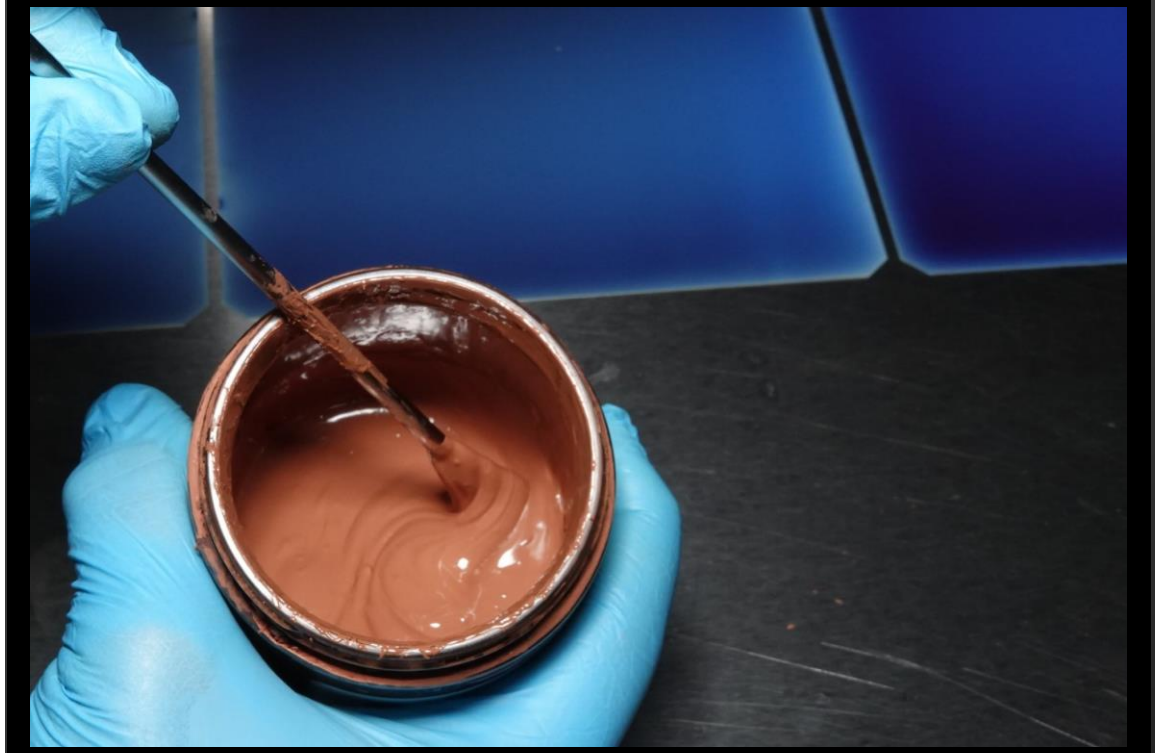


Gee, James, M (2011) Copper Paste Metallization for Silicon Solar Cells, European Patent EP 2 625 722 B1



Chen, N., D. Rudolph, C. Peter, M. Zeman, O. Isabella, Y. Rosen, M. Grouchko, O. Shochet, V. D. Mihailetchi (2023) "Thermal Stable High-Efficiency Copper Screen Printed Back Contact Solar Cells" , Solar RRL, **7**(2) DOI https://doi.org/10.1002/solr.202200874

But All of these use silver



The Solution

CuBert™ – Drop-in Replacement for Silver Pastes

CuBert™

- **No changes to processing.**
- **No new equipment to add.**

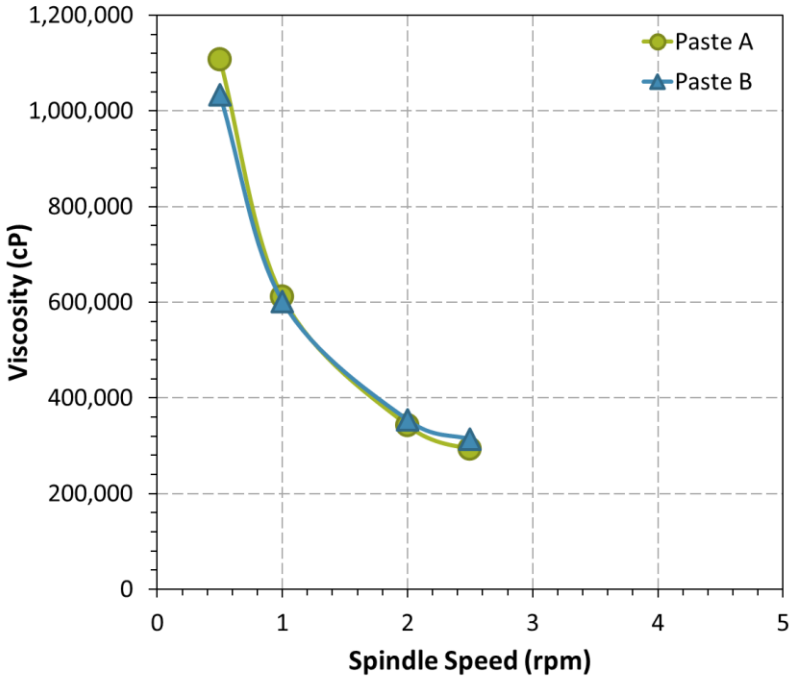
Screen Printable with the same printing technology used in the industry.

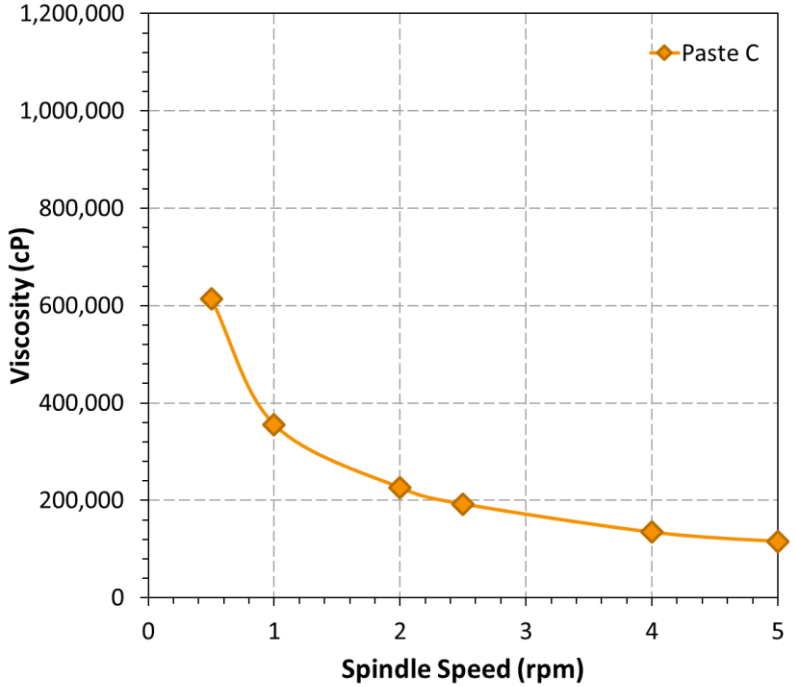
Air Fired in the same belt furnaces used in the industry.

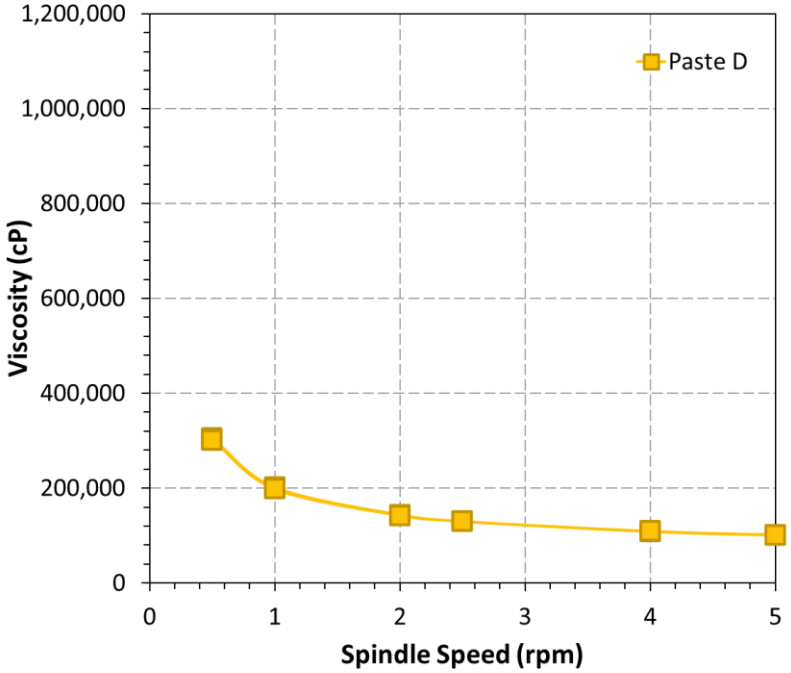
Performance. Functional devices after firing at temperatures up to 600 ˚C.

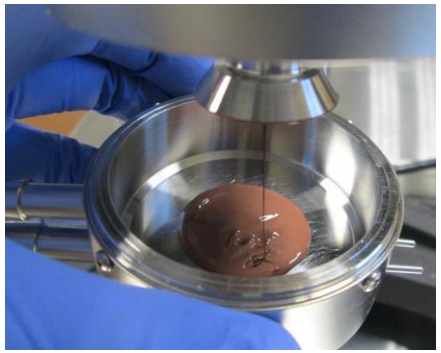
Durability. Demonstrated stable pFF for 1000 hours at 200 ˚C, initial module damp heat.

Paste Rheology







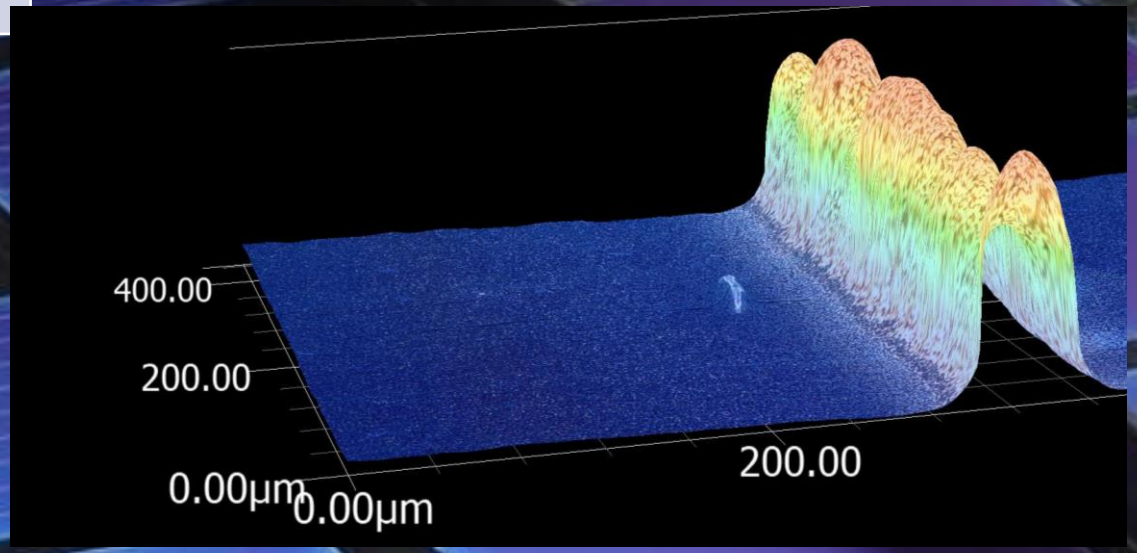


Viscosity can be adjusted.

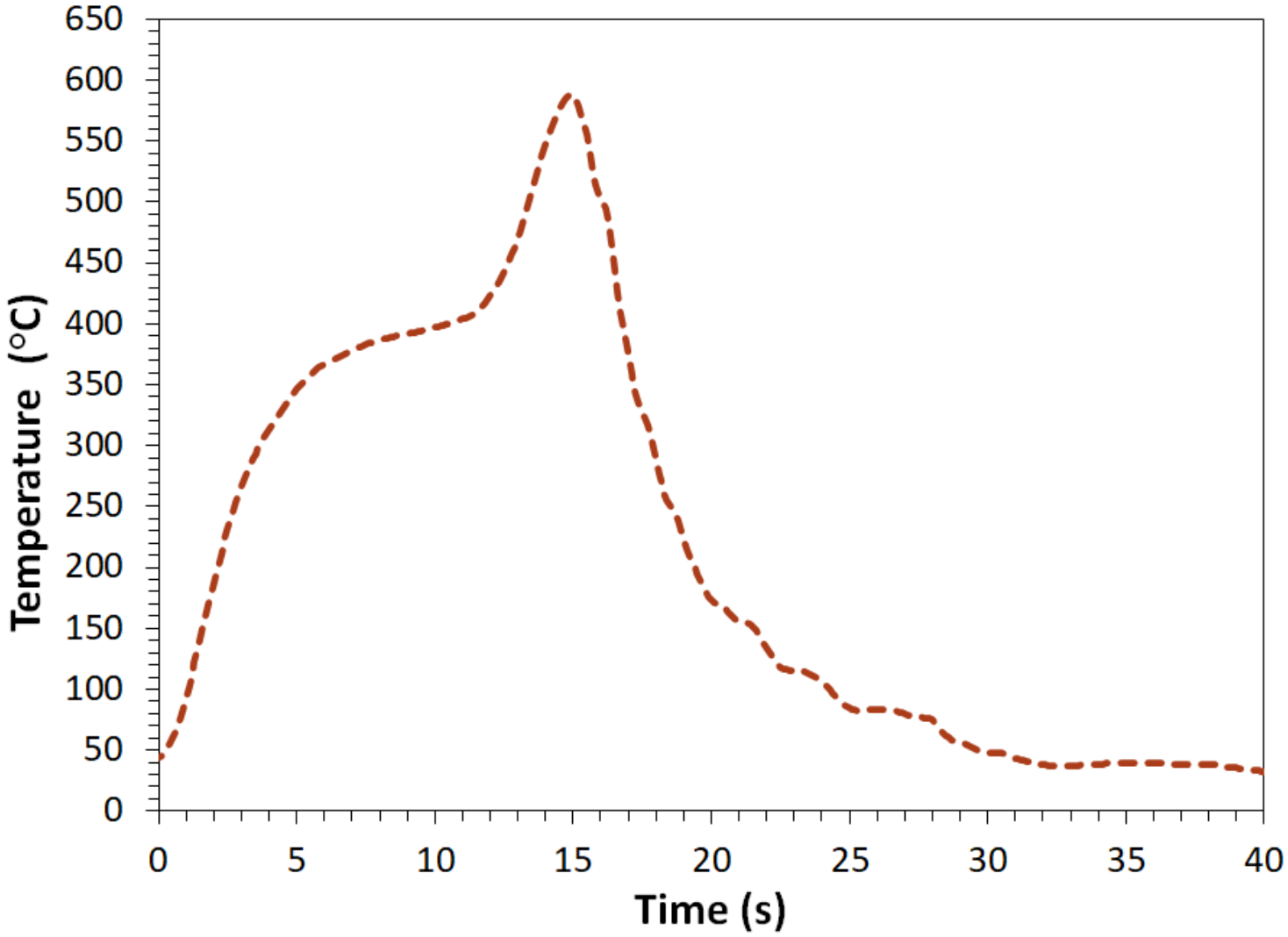
Brookfield Ametek HB Cone and Plate Viscometer with CPA-52Z Spindle.

Screen Printing Parameters

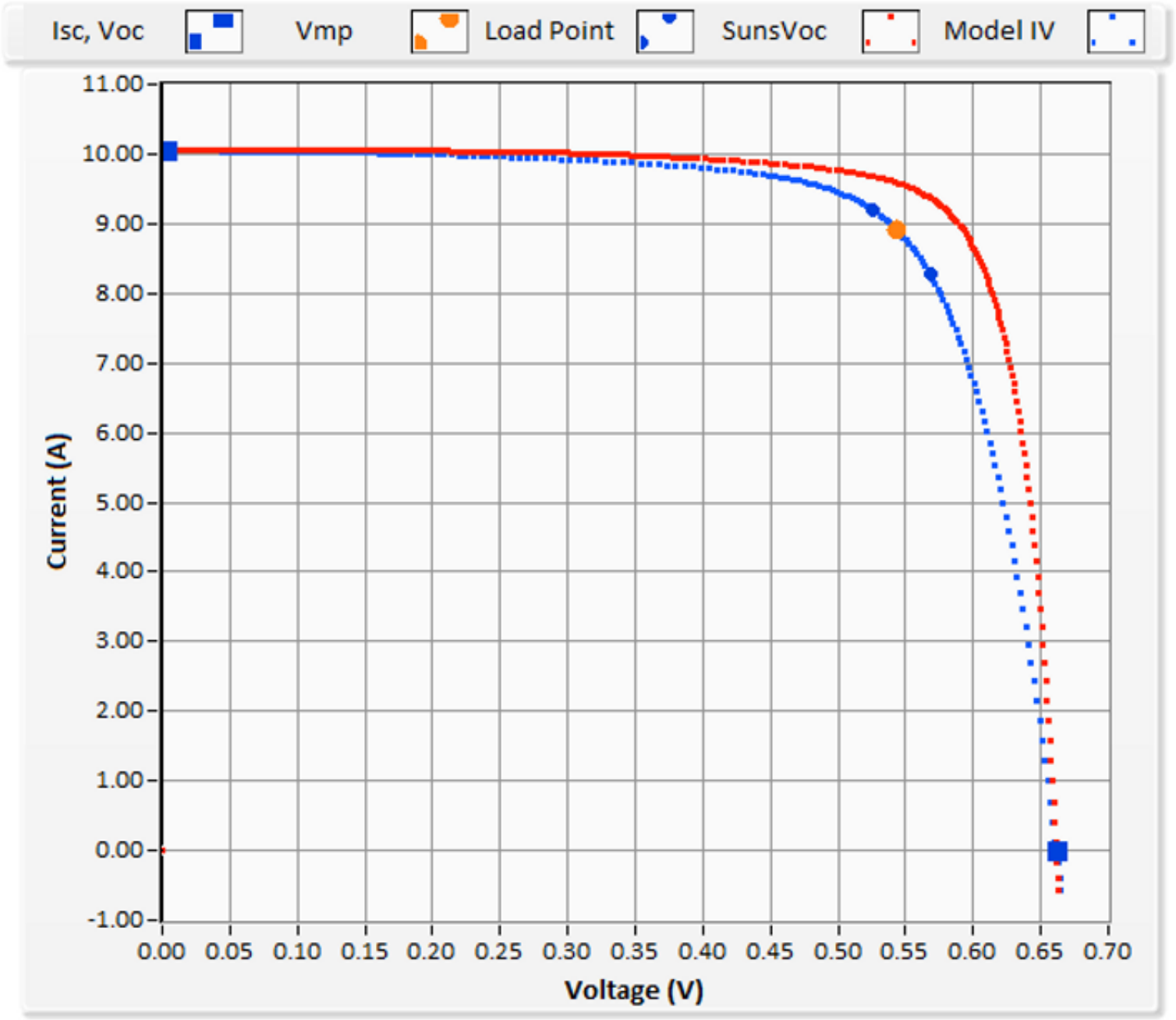
Screen Parameter	Value
Mesh	400-500 mesh, 18 µm wire
Screen tension	16-19 N/cm
Emulsion thickness	12-20 µm
Print gap	1.25-2.0 mm
Print speed	50-150 mm/s
Squeegee pressure	8-10 kg
Squeegee durometer	70-80



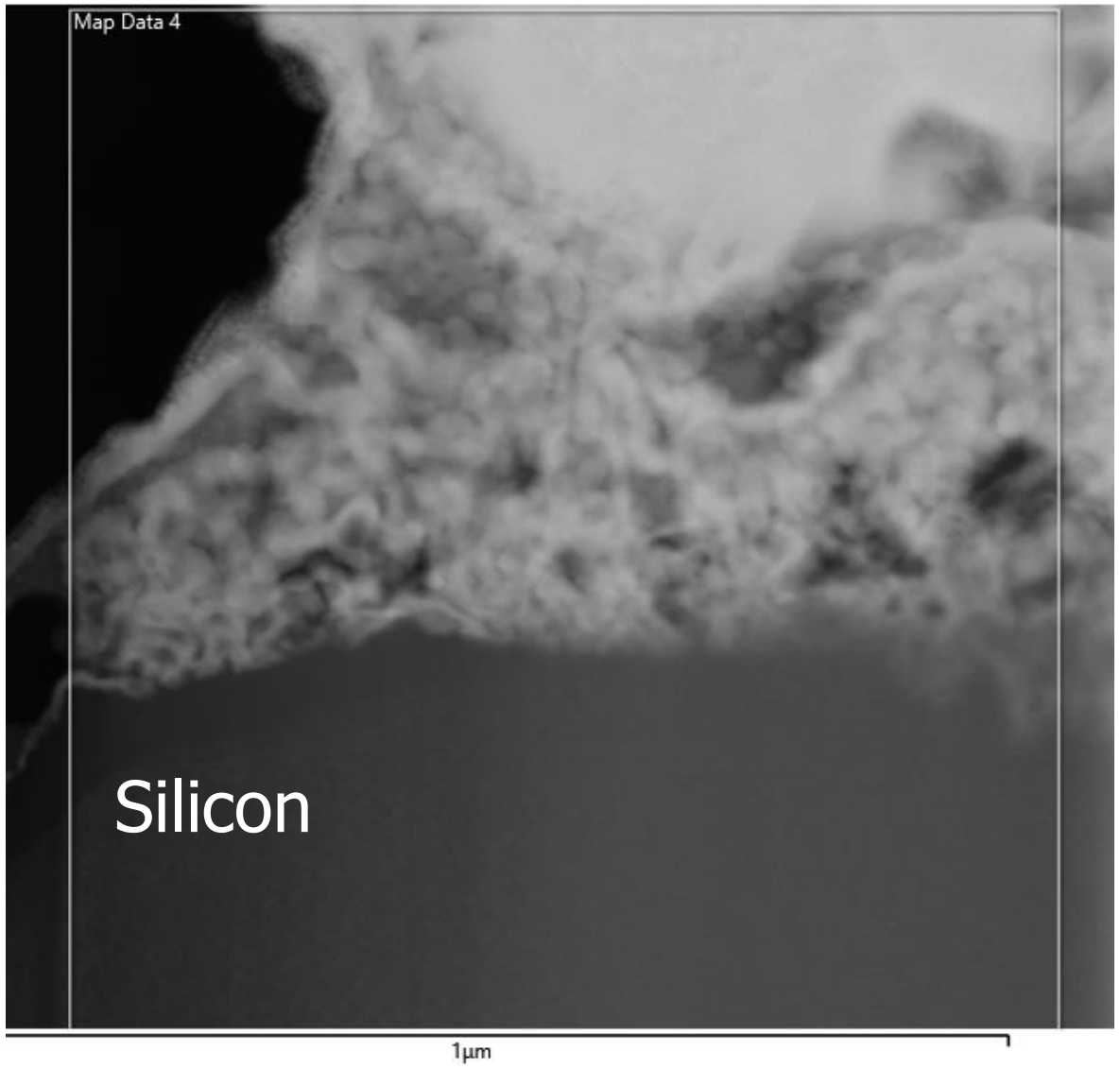
Firing Profile

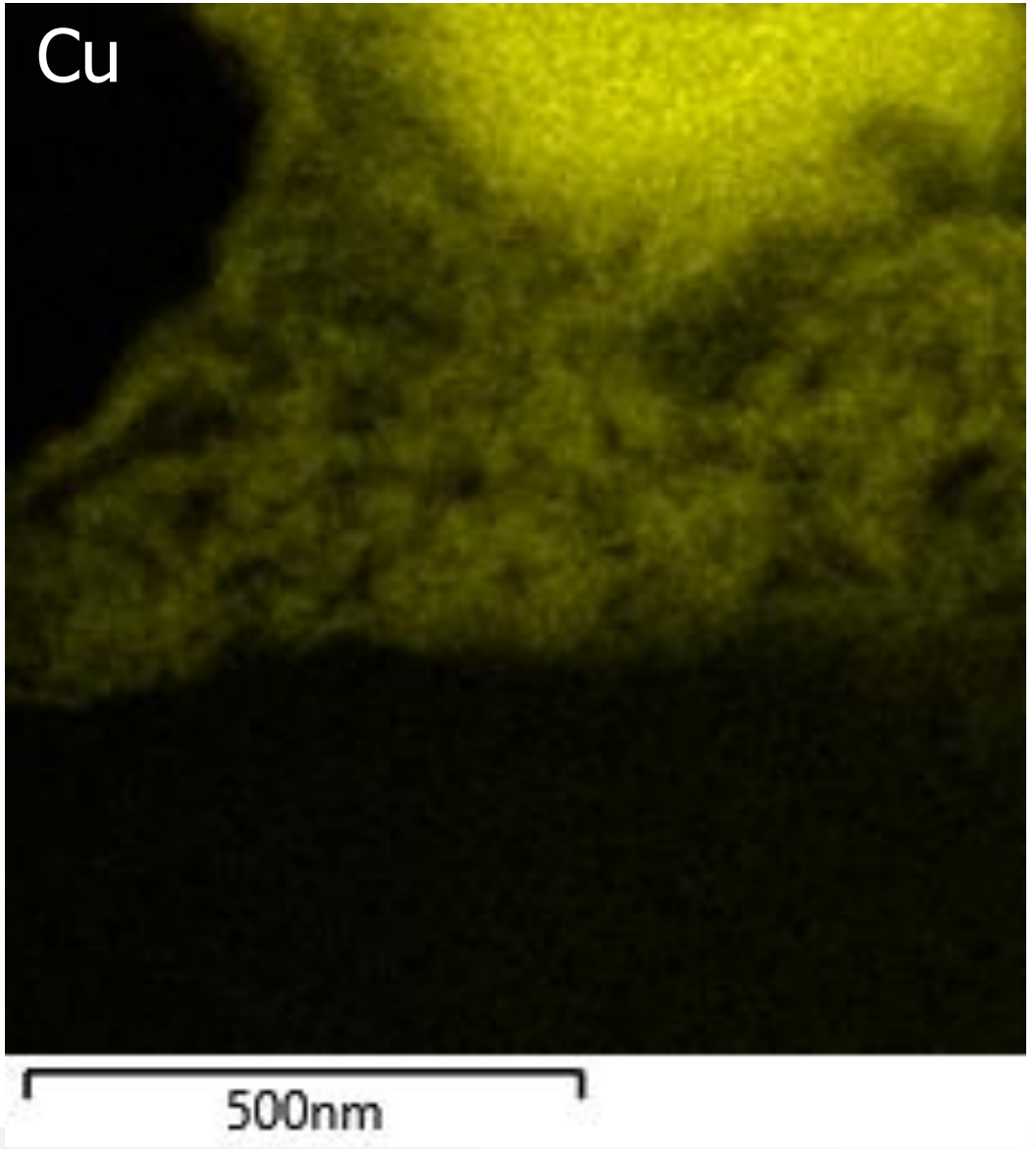


I-V Data


Isc, Voc
Vmp
Load Point
SunsVoc
Model IV
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
Current (A)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
Voltage (V)

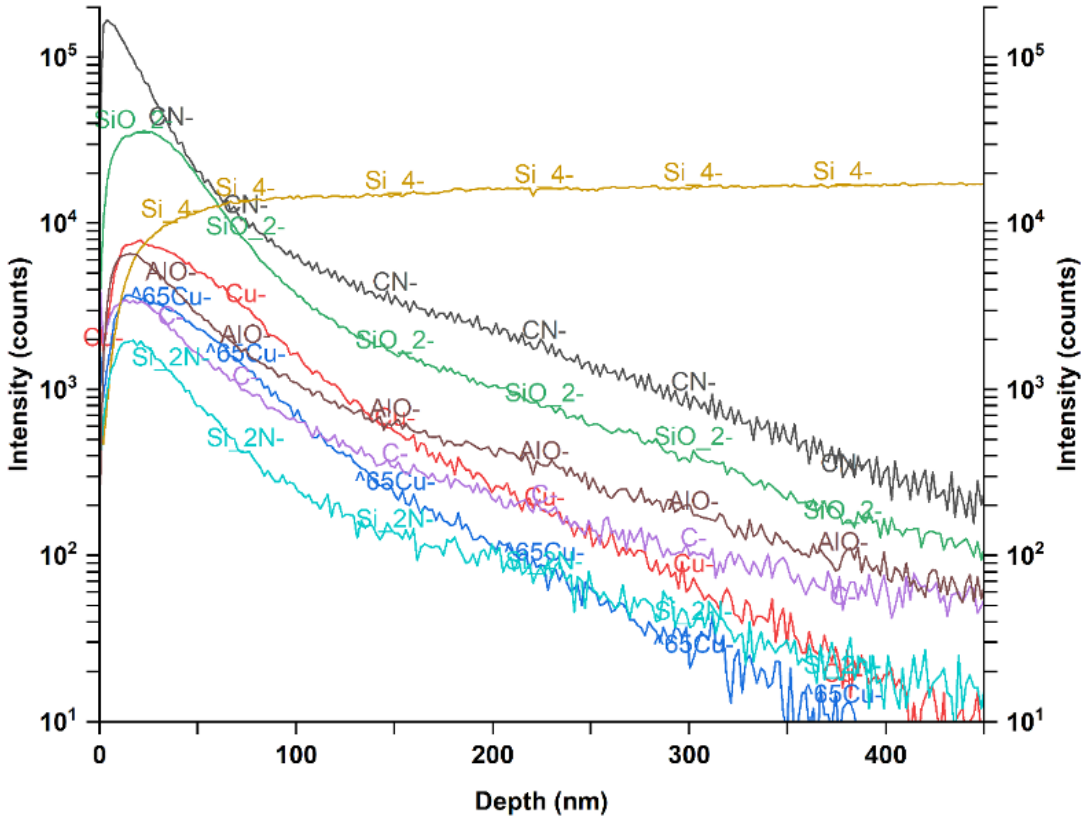
SEM Cross-section

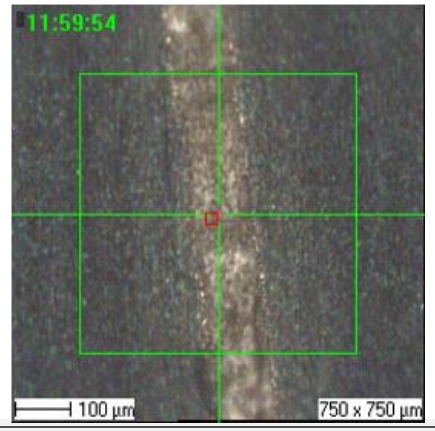


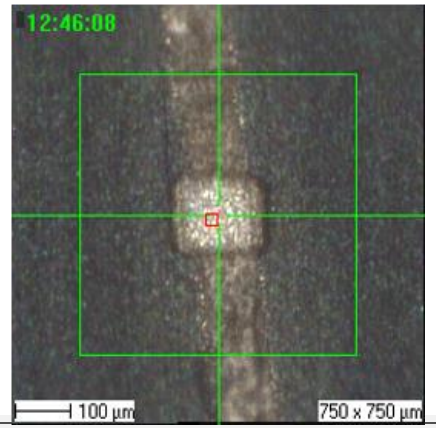


Durability - SIMS

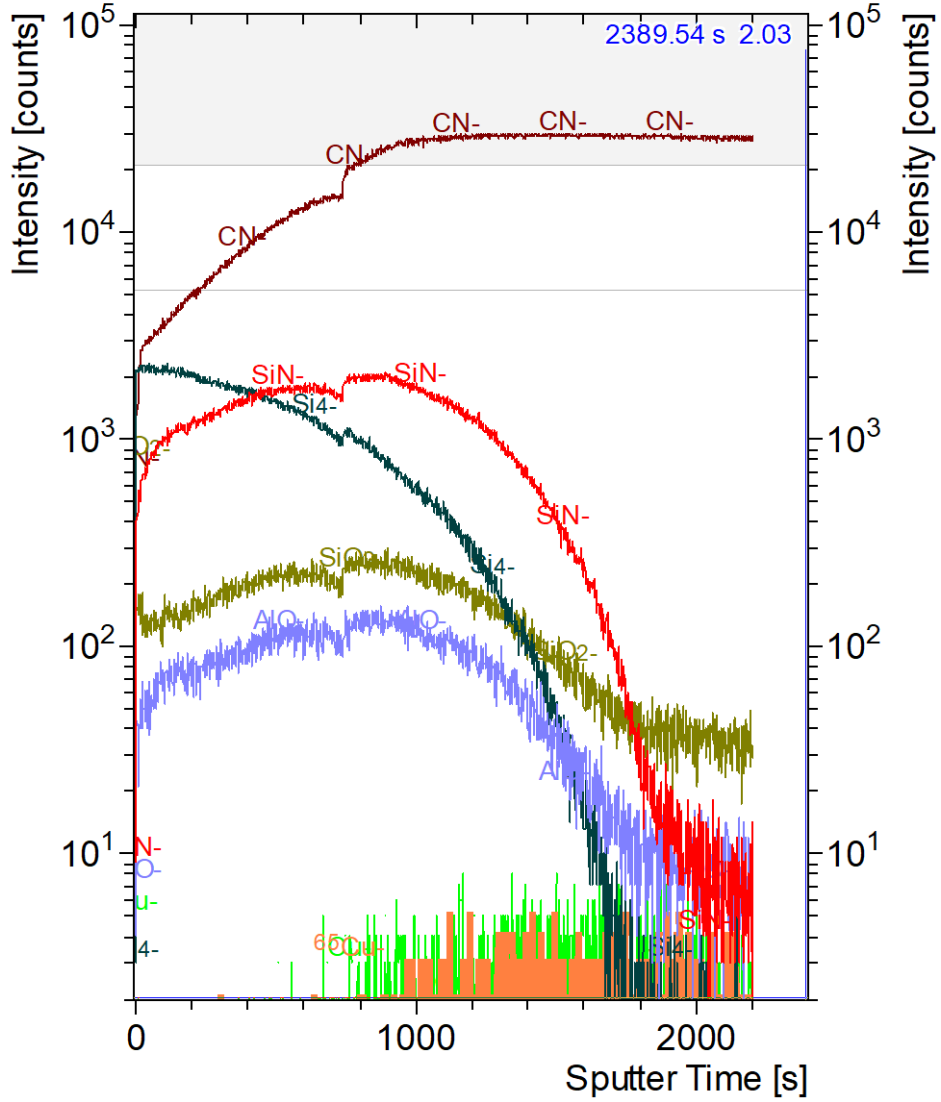
Front



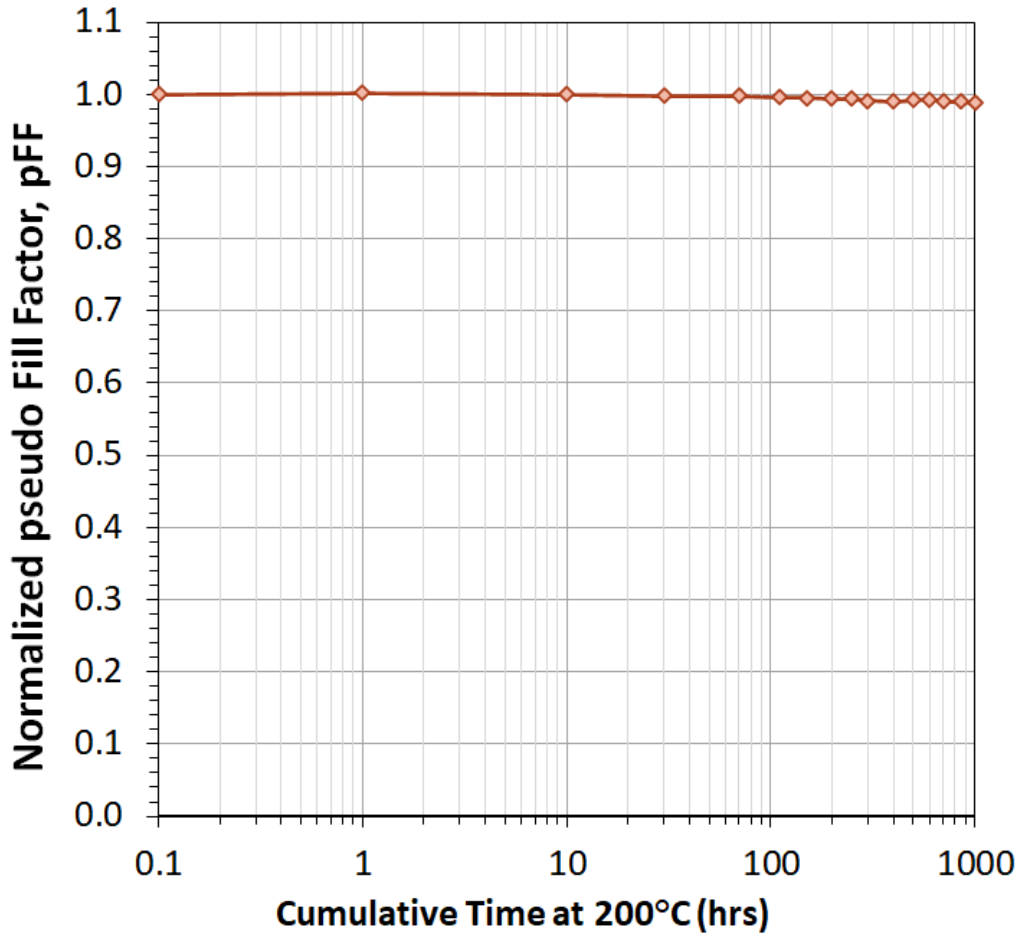


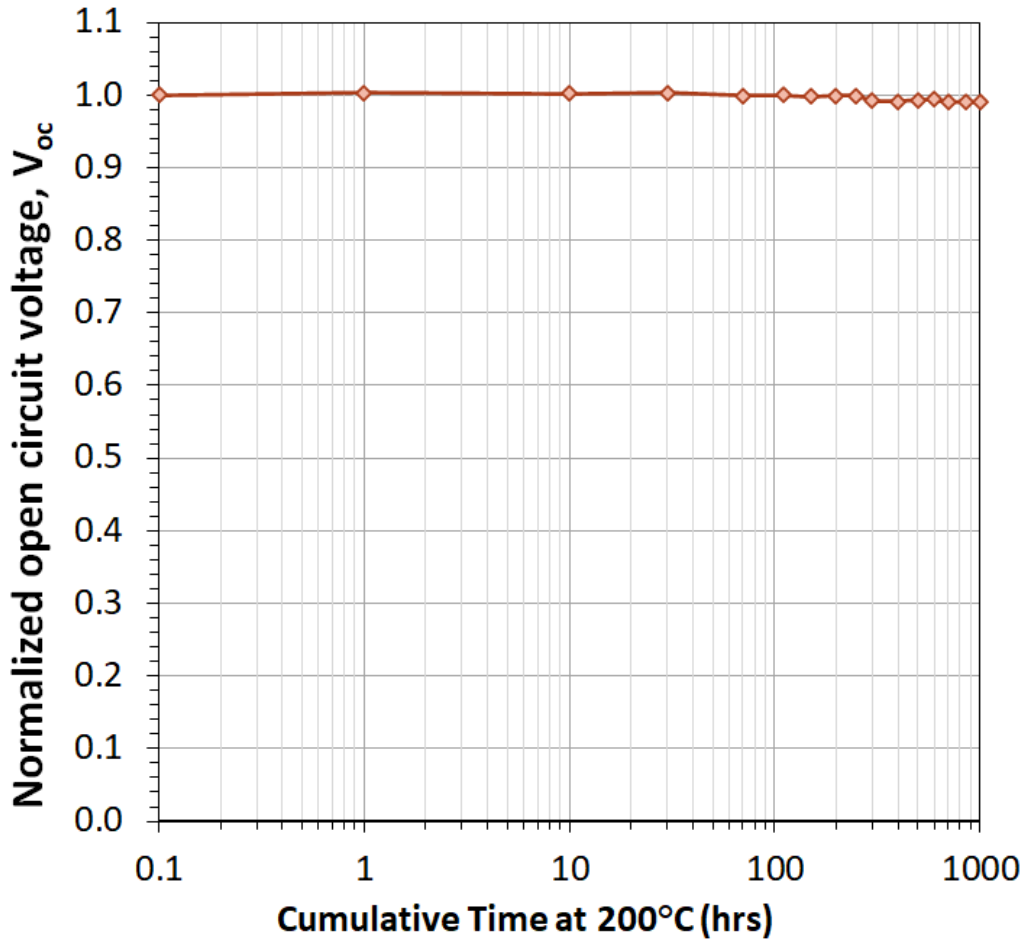


Back

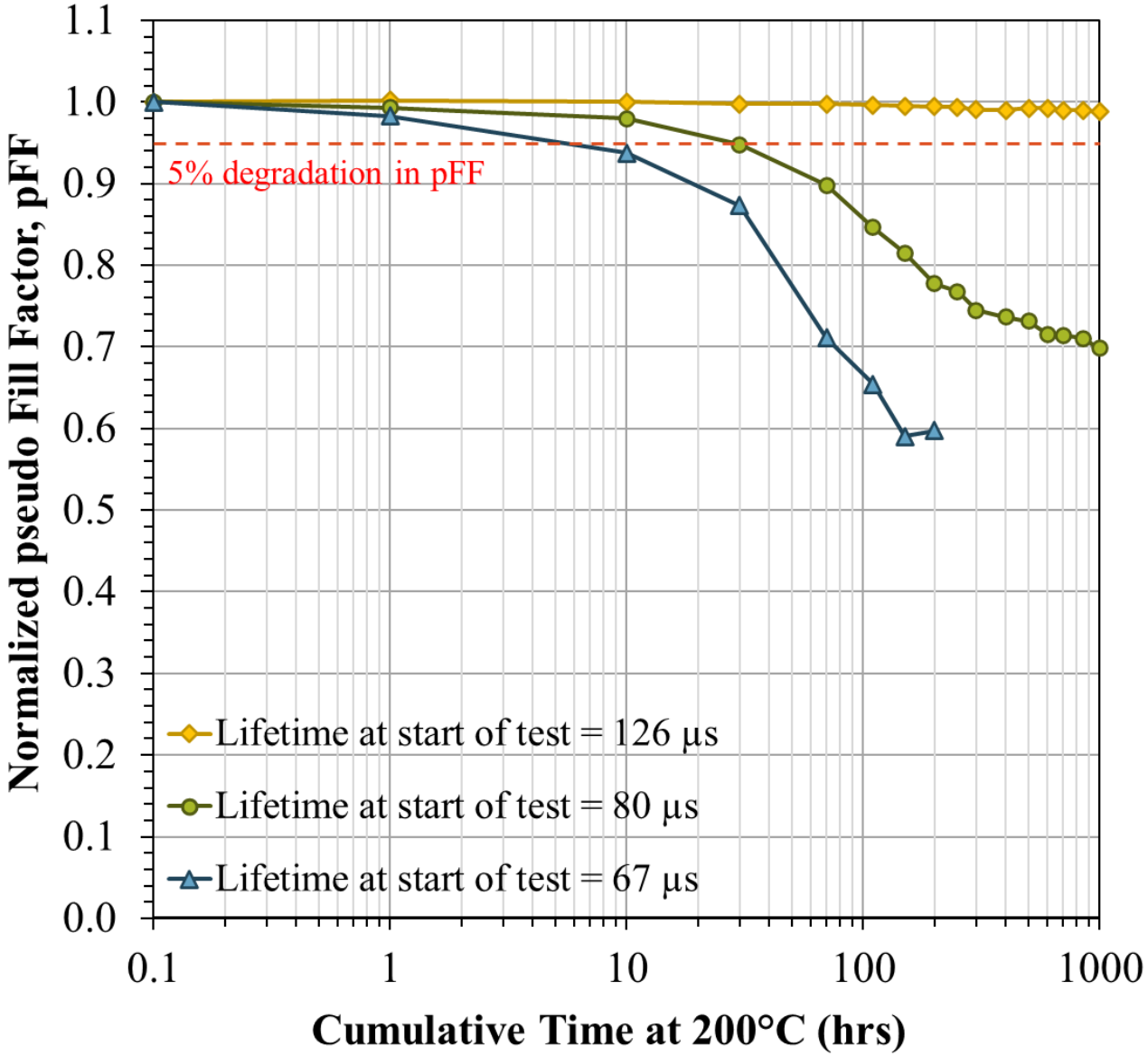


Durability (Dry testing) 200 ˚C 1,000 hrs





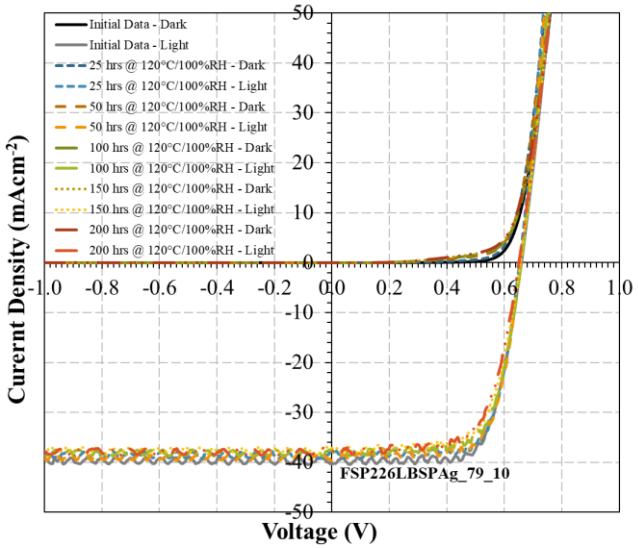
Discussion – Good vs. Bad Cell

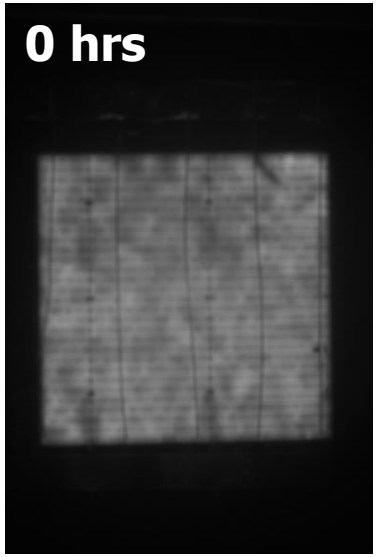


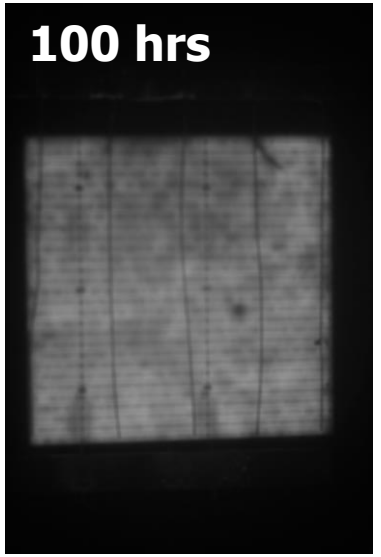
HAST: 120°C/ 100%RH/ 2 Bar (4 × 4 cm²)

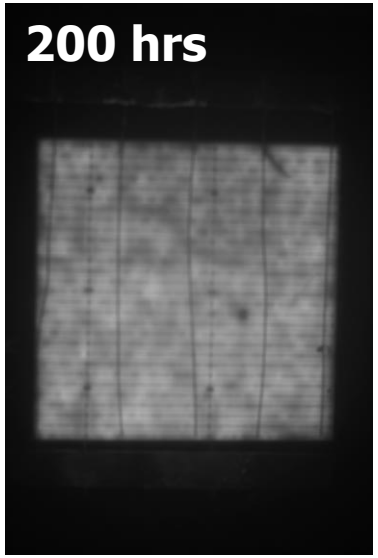
Good Cell:

After 200hrs
Normalized iV_{oc} = 1.00
Normalized pFF = 0.93



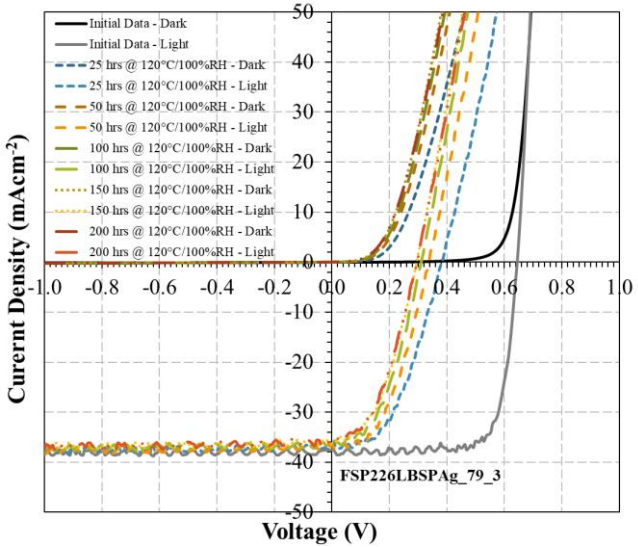


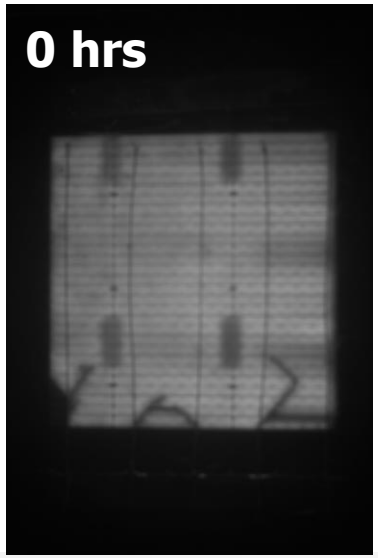


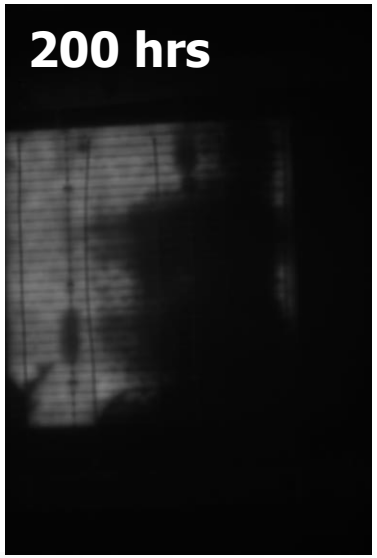


Bad Cell:

After 200hrs
Normalized iV_{oc} = 0.47
Normalized pFF = 0.64

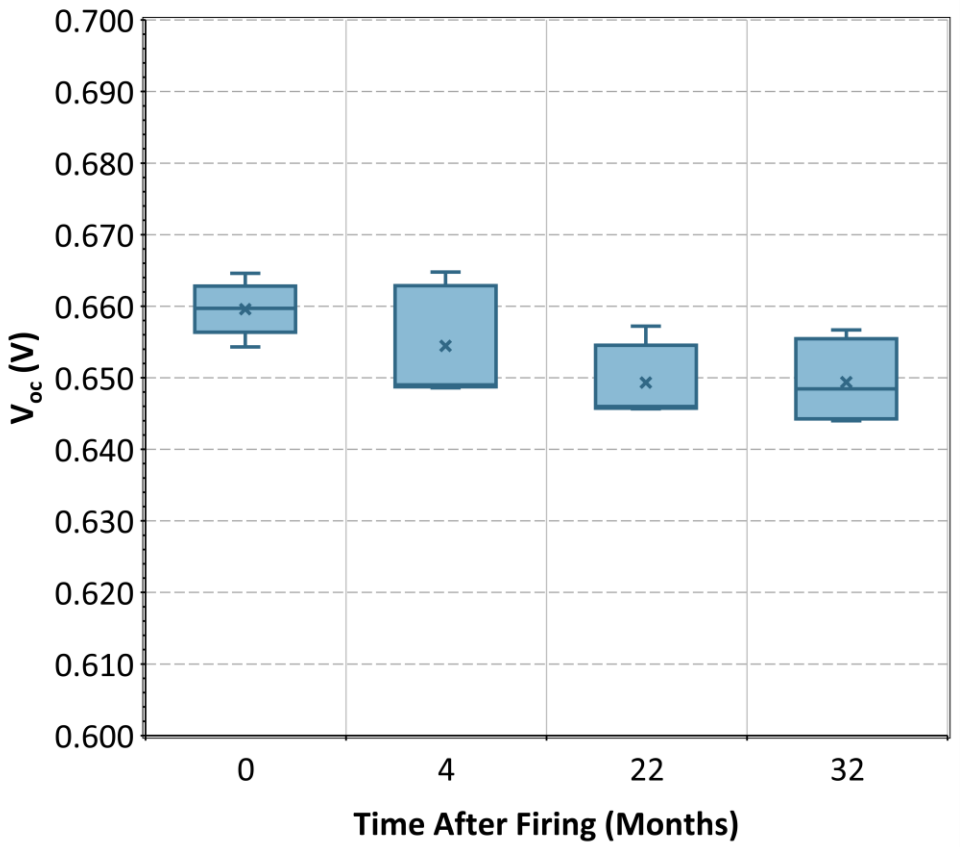


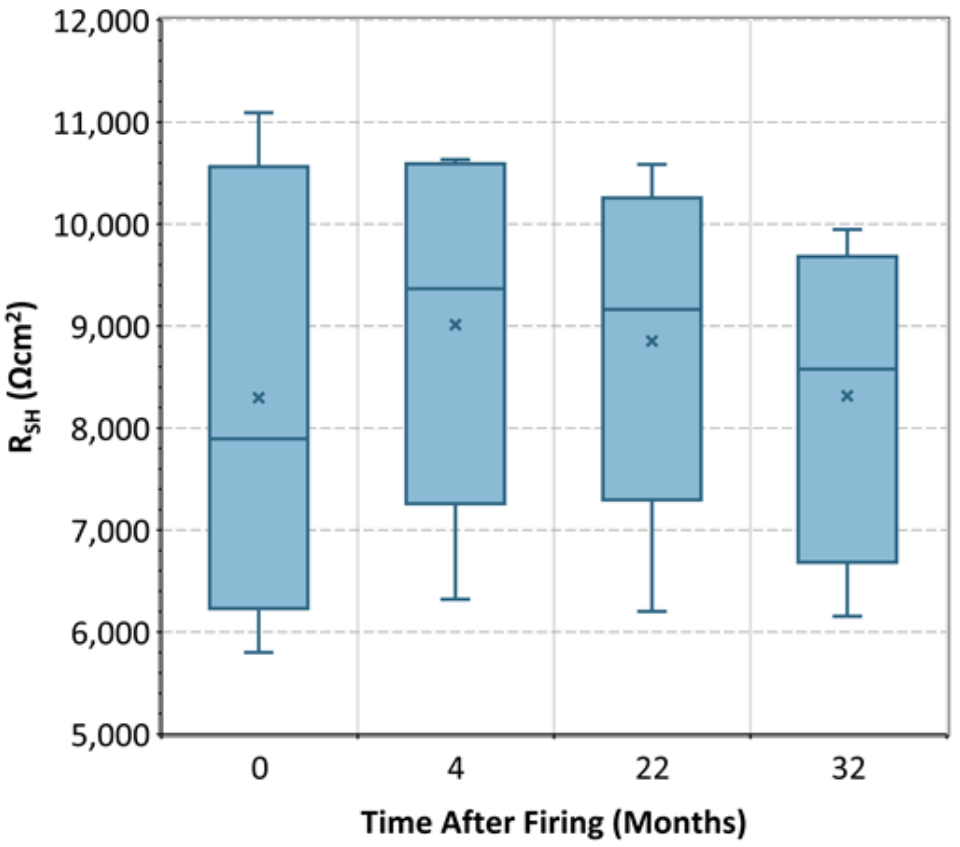




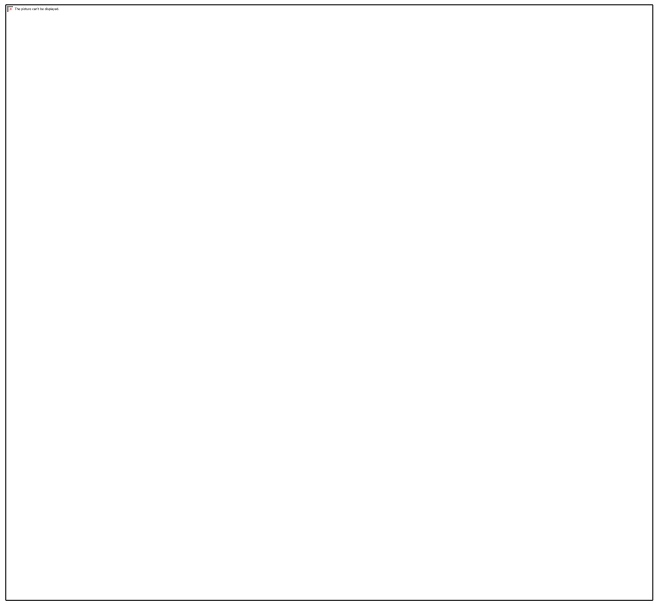
Durability (Ambient Storage)

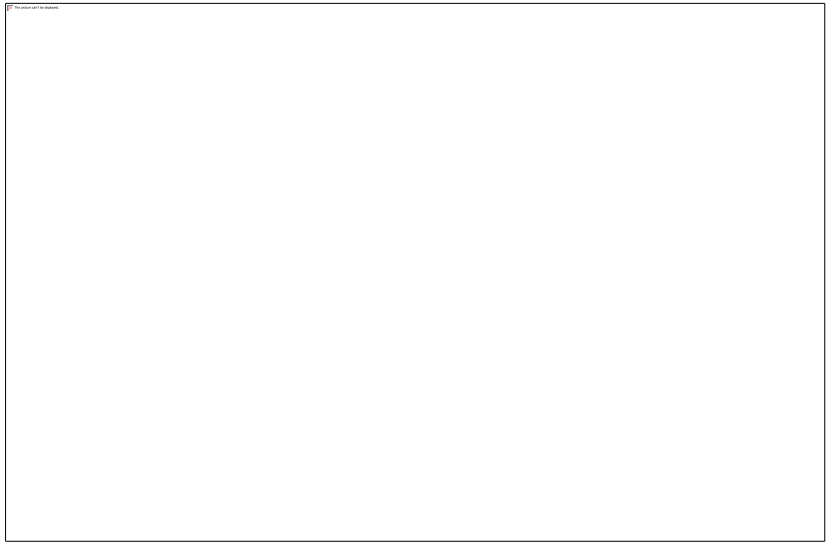
Caveats
1. 5 cells
2. Measured on different IV systems
3. Measured by different people





Solderability (Solderable pads)





Conclusions

Copper Screen Printable Pastes for High Temperature Firing

- Copper paste – no silver
  - Scalable
  - No cold storage
- Screen printed
- Fired in ambient air at 600 ^{o}C
  - Functioning device
  - Controlled etching
- Cell durability
  - Dry cell testing (200 ^{o}C, 1,000 hrs)
  - Encapsulated HAST (120oC, 100% RH, 2 Bar, 200 hrs)
  - Almost 3 years room storage
- Solderability
  - Initial results
- Next Steps

Thank You

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Aba Ebong, PhD
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