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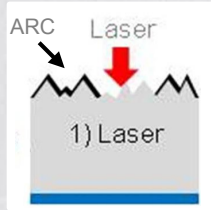
Analytical Controls

Solar Cell Front Contact Plating using Technic Chemistry

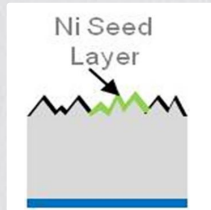


What is Front Contact Plating for Solar?

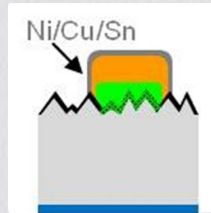
Silver front contact is replaced by plated nickel, copper, and tin on silicon solar cells. Light Induced Plating (LIP) process used in place of silver paste screening & firing



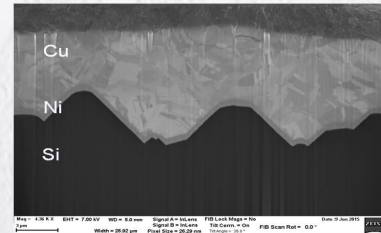
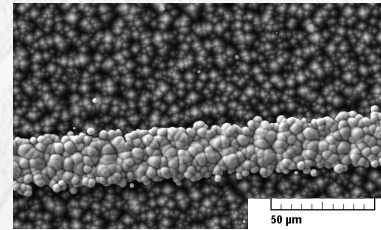
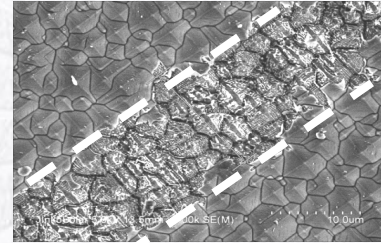
1. *ARC layer must be opened to expose the emitter for plating.*



2. *Light Induced Plating (LIP) is used to deposit nickel metal on the emitter. Nickel silicide ohmic contact formed by low temperature anneal.*

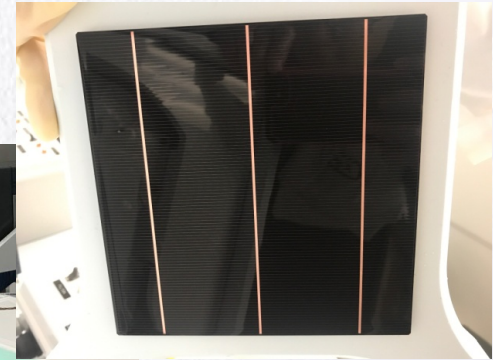
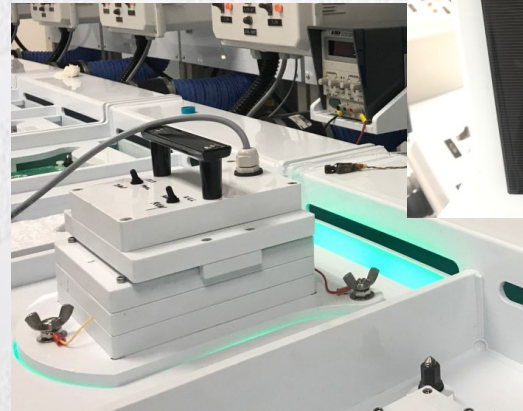
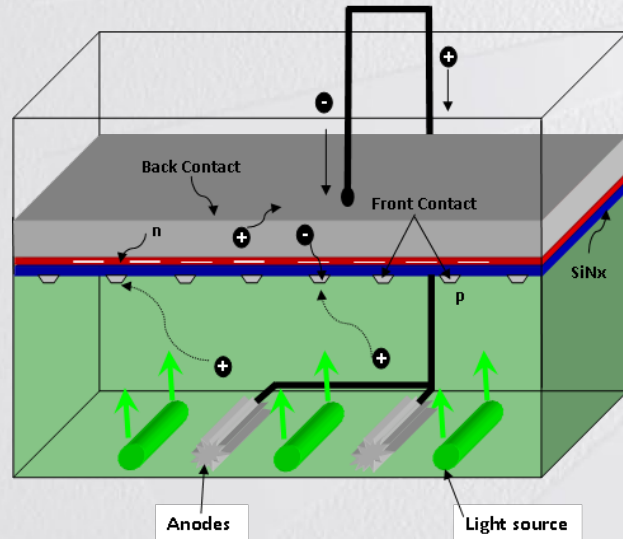


3. *LIP of copper and tin metal increase the conductivity and solderability of the front grid.*



Why Light Induced Plating?

- Illumination induces negative potential on front side.
- Back side connected via external power supply.
- Positively charged metal ions are attracted out of the bath to exposed emitter on front side of solar cell.



Advantages

Reduces Cost & Increases Performance with Ag-free Plated Contacts

Motivation:

Fabricate front grid contacts by plating Ni/Cu/Sn instead of screen printing Ag.

Method:

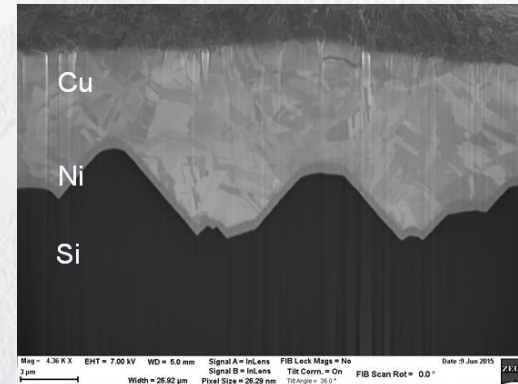
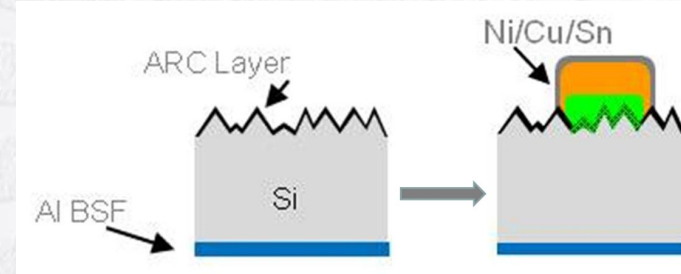
Pattern ARC layer prior to plating: laser ablation and wet etch patterning have been tested.

Results:

Good adhesion, electrical performance, and reliability results have been achieved with plated contacts.

Known Advantage:

Plated contacts have lower contact resistance and better line conductivity than silver paste contacts.



Silver Price Fluctuations

- Silver prices are currently very low ~ \$14 – 14.50 / ounce for the past few months
- In 2011, silver prices hit \$44 / ounce
- Demand for silver is rising ... will this translate into increase silver price?

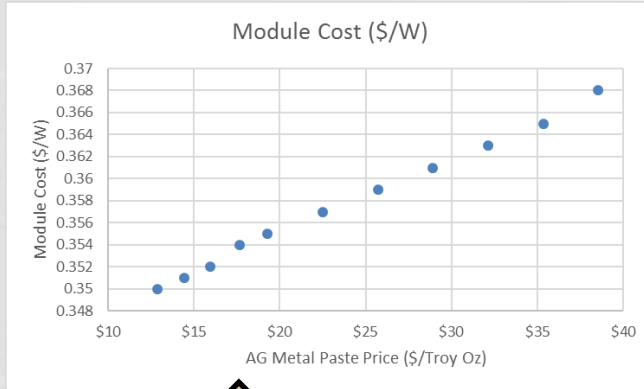


<https://silverprice.org/spot-silver.html>

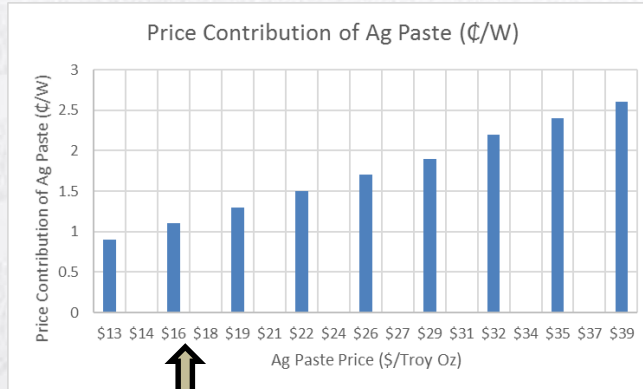
Cost Model Summary*

- Plated Contacts using LIP Ni/Cu/Sn provide a 3.4% Improvement (%/W)
- Direct Materials Costs for plated contacts are 55% less than Ag paste costs
- No margin left to reduce Ag paste costs unless Ag prices drop lower

Silver Paste Cost \cong Silver Price



Today's Price



Today's Price

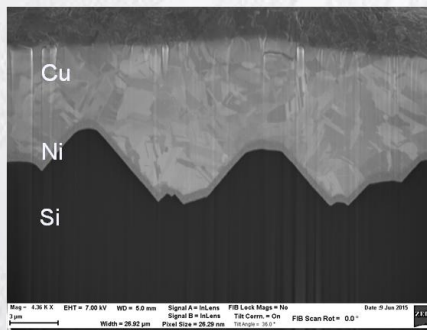
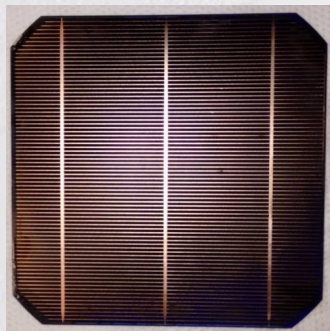
- Plated contacts using Ni/Cu/Sn will not increase in cost with Silver Price

* Based Ag prices and intel from January 2018

Unique Features of Technic Chemistry

- Boric acid free Ni chemistry : **Technisol® Nickel D2428**
Developed for LIP plating
Low maintenance – pH stable
- Low stress Cu chemistry : **Technisol® Cu 3000**
Developed for low stress copper plating at high current density
Technic provides analytical tools to monitor additives – EBA or RTA
- Clear Sn chemistry : **Technisol® Sn D2480**
Developed for LIP plating – solution does not become cloudy over time

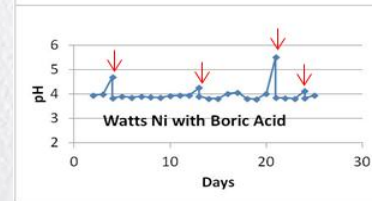
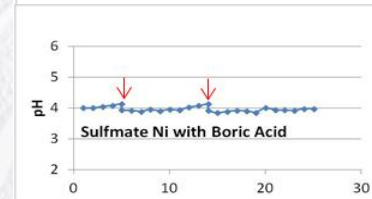
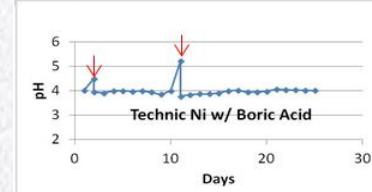
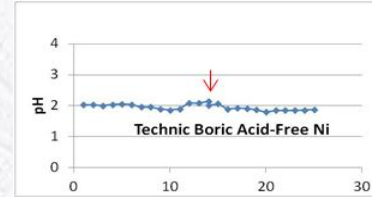
Chemistries co-developed with
LIP tooling for robust solution



Technic Boric Acid-Free Ni

- Technic formulated a unique nickel plating chemistry that can be made with or without boric acid
- The pH and stress were measured over a 5 week study and compared to commercially available Ni baths
- Technic's boric acid-free Ni has the most stable pH
- Technic's nickel bath w/ or w/o boric acid has the lowest internal stress

	Watts Nickel	Nickel Sulfamate	Technic Ni w/ Boric Acid	Technic Boric acid-free Ni
Contains Boric Acid	Yes	Yes	Yes	No
pH target	4.0	4.0	4.0	2.0
Internal Stress over 5 weeks (MPa)	-20 (comp) to 20 (tensile)	-50 (comp) to 40 (tensile)	-15 (comp) to 15 (tensile)	-15 (comp) to 15 (tensile)
LIP w/o rectification	No	No	Yes	Yes
Technic Product Names	Watts Ni Semi bright	Technisol Ni 2420	N/A	Technisol Nickel D2428

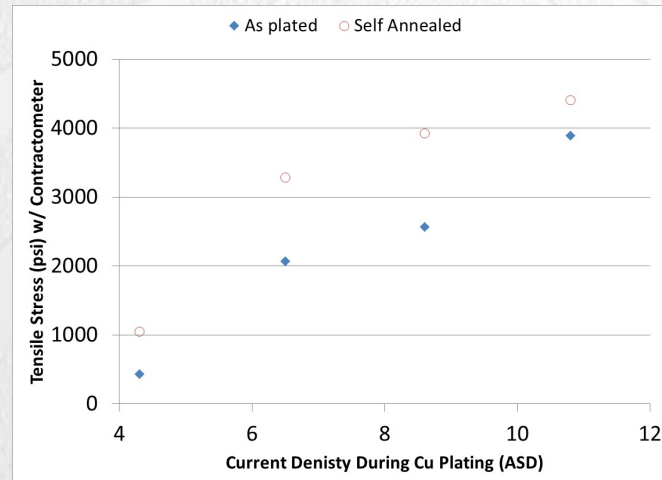
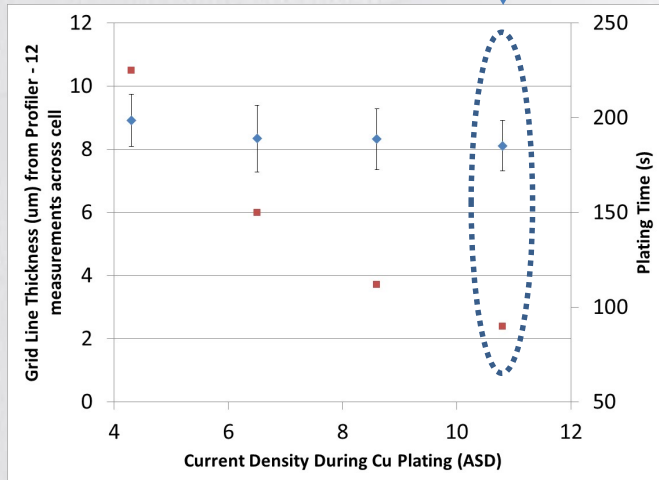


Red arrows indicate pH adjustment

Technic Cu Bath – Low Stress

- Technisol[®] Cu 3000 is easy to maintain with only 2 additives – Brightener & Carrier
- Grid line profile and thickness uniformity across the wafer is similar for low and high current density plating \therefore 10.6 ASD can be used to shorten plating time.
- As expected, stress of the copper deposit increases with increasing current density; however, at 10.6 ASD the Cu stress after self annealing is still <4500 psi.

4-5 $\mu\text{m}/\text{min}$ plating rate



Technic Sn Bath – LIP Possible

Light Induced Plating (LIP) of Sn metal requires that the Sn plating bath remain clear over the life of the bath.

- Typical Sn plating baths become cloudy over operation due to the oxidation product, stannic tin (Sn^{4+}).
- Technisol[®] Sn D2480 specially formulated to remain clear over bath life enabling LIP plating.

LIP plating of Sn over the plated Cu grid line completely removes Ag from the solar cells frontside contact.

- Ag is generally the solderable layer for traditional module making whether using silver paste contacts or plated contacts with immersion silver.
- Using Sn as the solderable layer completely eliminates Ag from the solar cell front grid metallization
- Initial testing indicates adhesion and module reliability similar for Sn versus Ag solderable layer.

Electrical, Adhesion and Reliability Testing

Technic chemistry has been successfully plated on multiple cell architectures from different solar cell suppliers:

- Mono Back Surface Field (BSF)
- Multi Back Surface Field (BSF)
- Mono PERC
- Silicon Heterojunction (SHJ)

Electrical and Reliability testing has been performed on Mono BSF, Multi BSF, and Mono PERC cells plated with Technic Ni, Cu, Sn chemistry.

- IV data for plated cells is similar to IV data for silver paste controls
- Passing results obtained for damp heat and thermal cycling testing on plated cells

Adhesion data has been collected for Mono BSF and Multi BSF to date

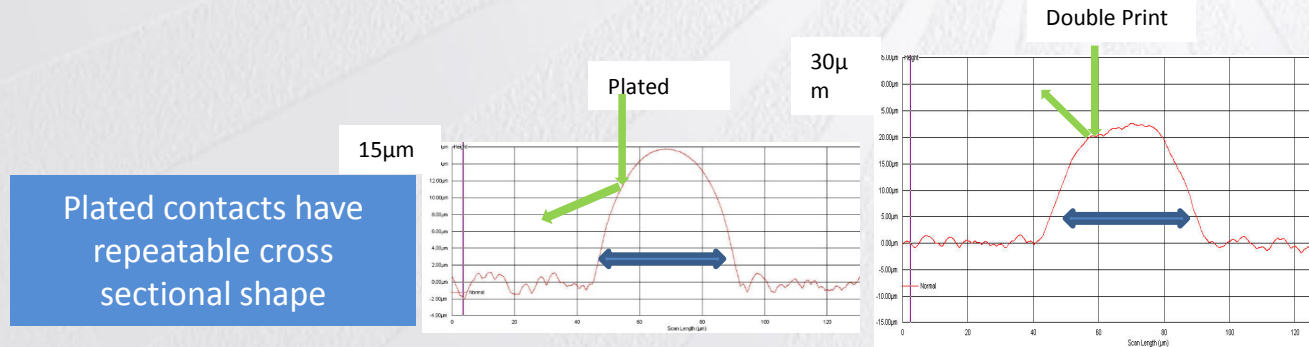
- Pull testing results for Technic plated cells similar to the control cells

Efficiency Results: Plating Cells \cong Ag Paste Cells

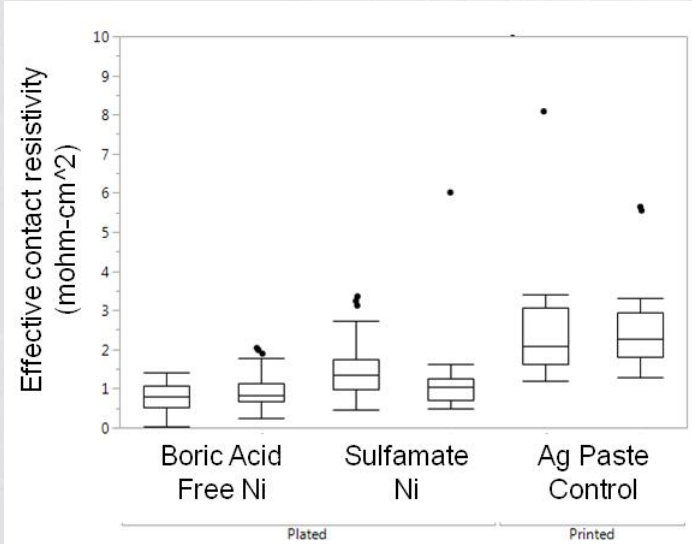
BSF	n	% Eff	% FF	Grid Line Thk (μm)	Grid Line Width (μm)
Plated	10	19.19 ± 0.22	78.83 ± 0.52	11.9 ± 0.7	40 ± 1
Ag Paste	10*	19.24 ± 0.19	79.17 ± 0.64	21.8 ± 1.2	42 ± 3

* n=4 for Ag paste grid line thickness & width, cells purchased from Fraunhofer ISE: laser ablated (patterned) @ Fraunhofer, Plated @ Technic

Mono-PERC	n	% Eff	% FF	Voc	Grid Line Thk (μm)	Grid Line Width (μm)
Plated*	25	21.04 ± 0.23	78.25 ± 0.63	654 ± 2	7.6 ± 1.5	49 ± 4
Ag Paste	26	21.38 ± 0.32	80.16 ± 0.51	657 ± 5	16.7 ± 1.6	62 ± 4



Lower Contact and Line Resistivity



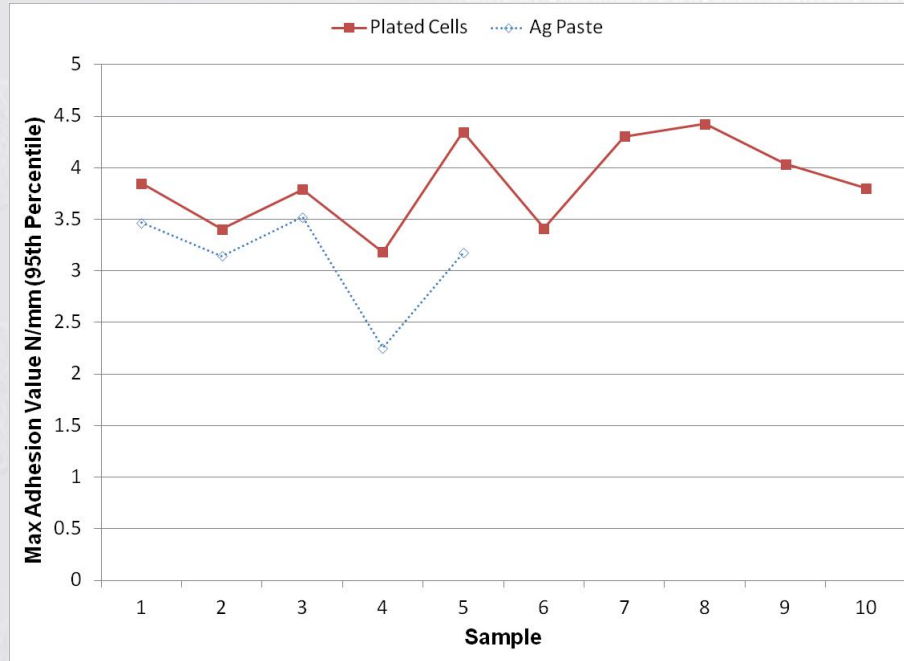
- Plated contacts are approximately half the contact resistance of Ag paste contacts.
 - Ag paste control cells from Fraunhofer ISE – high quality!
- Line resistivity of plated lines < Ag paste lines even with less volume of material.
 - Plated lines are shorter than silver paste lines but are more conductive!

	Line Resistivity (ohm-m)	Grid line height / width (microns)
Ag Paste Control	$5.0 \pm 0.4 \times 10^{-8}$	$21.3 \pm 4.9 / 45.5 \pm 9.4$
Plated Boric Acid-Free Ni	$1.9 \pm 0.1 \times 10^{-8}$	$12.5 \pm 1.2 / 41.4 \pm 3.2$
Plated from Sulfamate Ni	$2.2 \pm 0.1 \times 10^{-8}$	$13.2 \pm 1.5 / 45.5 \pm 3.5$
Pure Copper [2]	1.72×10^{-8}	

*Measurements made using ContactSpot tool (TLM method)

Excellent Adhesion Results

- All 10 plated samples tested show max adhesion > 3 N/mm
- 4 of the 10 plated samples have max adhesion ≥ 4 N/mm
- All 5 Ag paste samples show adhesion ≤ 3.5 N/mm

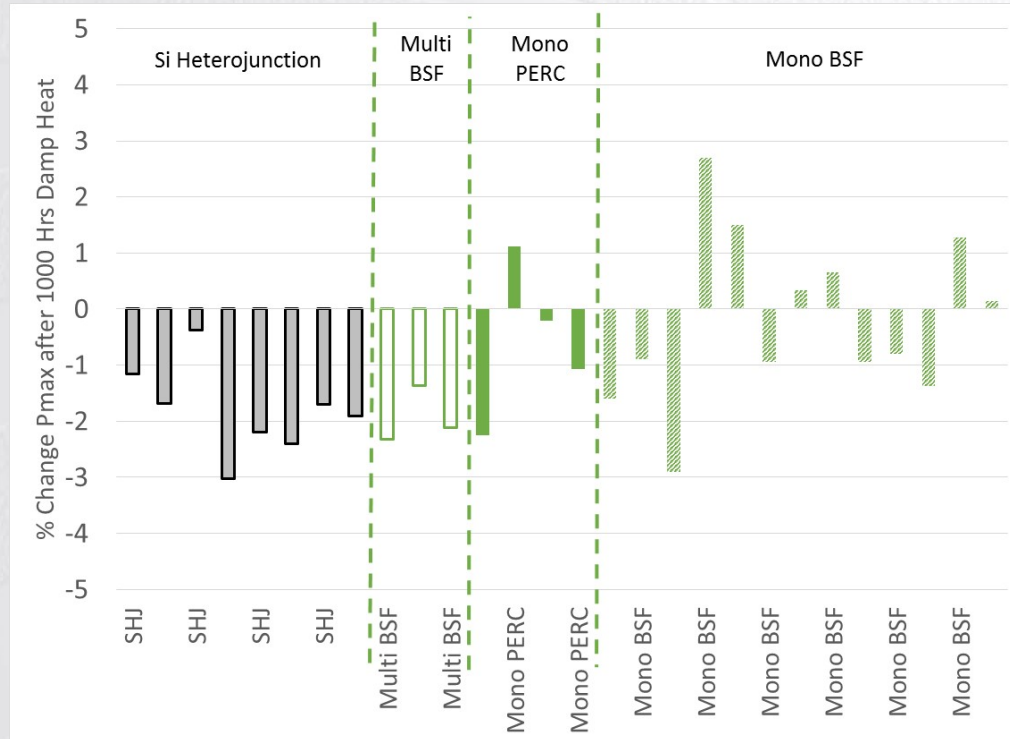


Plated Cell Pass 1000 Hours Damp Heat

Cells from different architectures were plated and made into single cell modules:

- Silicon Heterojunction (SHJ)
- Multi BSF
- Mono PERC
- Mono BSF

All modules considered passing!

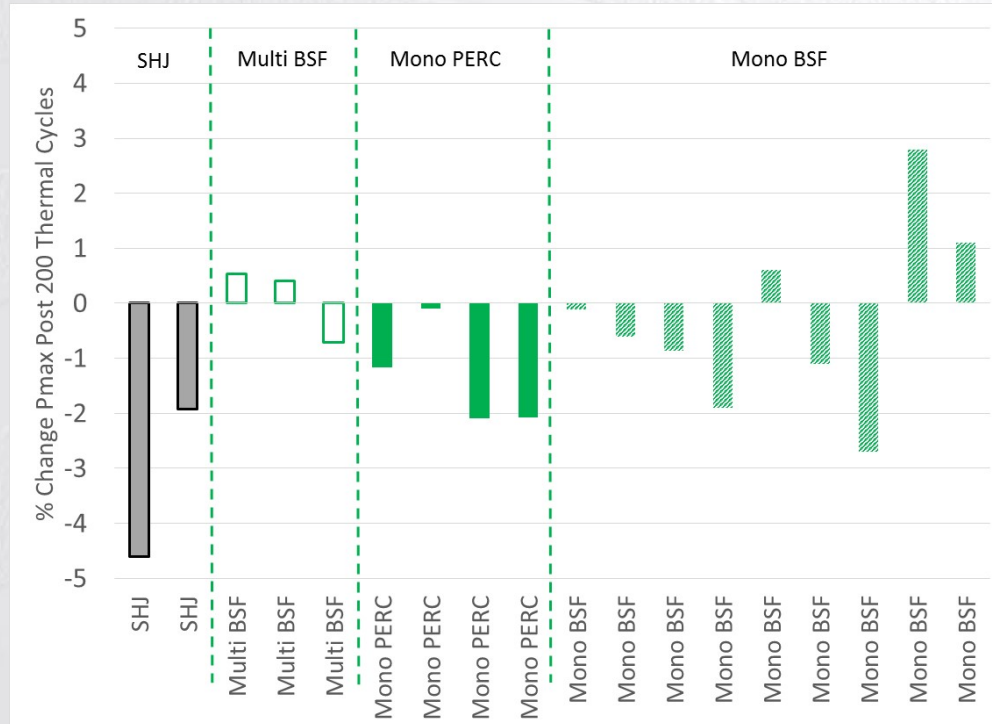


Plated Cell Pass 200 Thermal Cycles

Cells from different architectures were plated and made into single cell modules:

- Silicon Heterojunction (SHJ)
- Multi BSF
- Mono PERC
- Mono BSF

All modules considered passing!



Conclusions

Technic supplies a unique boric acid-free nickel plating chemistry has been specifically designed for plating on solar cells - including the use of Light Induced Plating (LIP)
(Less safety concerns and better pH stability)

Technic offers Cu & Sn plating chemistries have been formulated for plating on solar cells using LIP.

Technic is ready to work with solar cell manufacturers to evaluate the chemistry.

Thank you



photovoltaics
research laboratory