SOLAMET® 索特

Confidential

Metallization Paste Requirements for Advanced TOPCon Emerging Technologies

Solamet Electronic Materials

2026 feb.

Agenda

- Solamet® company introduction
  - ✓ Technical center & Manufacturing site
  - ✓ Solamet intellectual property
- New technology for n-TOPCon
  - ✓ Stencil printing
  - ✓ Laser transfer
  - ✓ Poly finger
  - ✓ Edge passivation
  - ✓ Rear side low cost approaches
    - ✓ Nickel blending
    - ✓ Silver seed layer + Ag/Cu or Cu paste

Introduction - Solamet Materials Science

DuPont™ Solamet® → SOLAMET® 索特

Heritage from DuPont
- R&D and innovation
- Broadest IP coverage
- Global service and support

NEW Solamet
- Flexibility
- Speed

- July 1, 2021, Jiangsu Solamet Electronic Materials Co., Ltd. acquired DuPont Solamet® metallization business, including all products, personnel, intellectual property, and assets worldwide
- Today's Solamet has stronger innovation capabilities, broadest metallization product portfolio, and professional global customer services
- Solamet is the industry innovation leader and holds the broadest portfolio and access to metallization paste intellectual properties

SOLAMET®

1983
- Launched first photovoltaic conductive paste product

1999
- PV145 the world's first commercial fire-through PV metallization paste

2009
- PV41x new low-temperature conductive paste for thin film PV

Intellectual Property

>115

Active Solamet® Patent families

Patented

2011
- Revolutionary PV17x silver paste products based on patented Pb-Te-O frit Technology
- Launched PV3N1 - world's first commercial Ag-Al paste for N-type Solar Cell

2015
- PV76x/PV56x/PV36x complete commercial metallization solution for PREC

2016
- PV3Nx/PV6Nx/PVD2x world's earliest commercial complete n-TOPCon metallization package

2018
- ACS Heroes of Chemistry Award for the enormous contribution of Pb-Te-O frit technology to the PV industry

ACS Awards
Heroes of Chemistry
Pb-Te-O frit chemistry

2021
- **Established Solamet as an independent operating business, opened a new chapter**

2023
- **Launched revolutionary PV3NL TOPCon LECO metallization solution**

Introduction - Solamet Global Presence

- Headquarters:
  - Huzhou-Zhejiang (CN)
  - Shanghai (CN)
- R&D and Technology Centers:
  - Shanghai (CN)
  - Taoyuan (TW)
- Manufacturing Sites:
  - Dongguan (CN), 2000 t/yr
  - Taoyuan (TW), 300 t/yr → Taiwan made certification for US end market since 2023; non FEOC (Foreign Entity of Concern) solution available

Dual Technology Centers both equipped with updated facilities and tools to support fast-paced new product and application development

- R&D and product customization
- New product and application development
- Trouble shooting and customer process simulation
- Advanced technology collaboration

Dual technology centers to strategically serve the China and oversea markets

Shanghai R&D Center

Taiwan Technical Center (Product Development, Technical Service, Production)

Dual Technical Center

- Well-equipped and updated lab facilities to support fast-paced product and application development

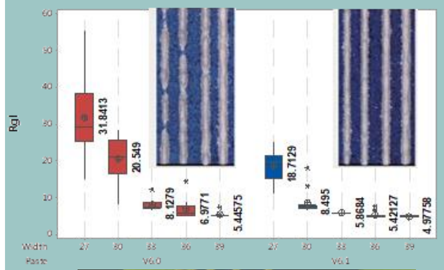
Taiwan

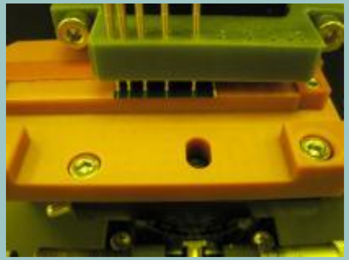
Shanghai

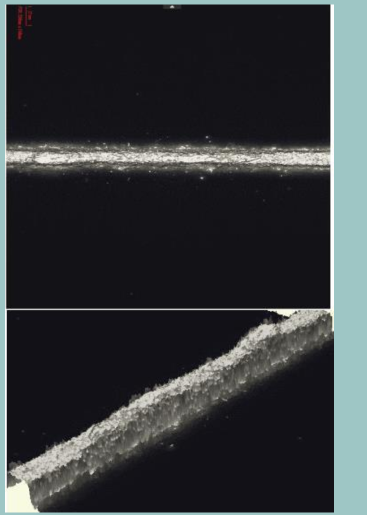
Paste formulation and characterization

Printing and cell performance evaluation

simulation test / measurement







Tasks

- Paste customization to meet specific needs

  产品客制化

- New product development

  新产品开发

- Trouble shooting / customer process simulation

  客户制程平台模拟

- Advanced technology collaboration

  新技术合作开发

Agenda

- Solamet® company introduction
  - ✓ Technical center & Manufacturing site
  - ✓ Solamet intellectual property
- New technology for n-TOPCon
  - ✓ Stencil printing
  - ✓ Laser transfer
  - ✓ Poly finger
  - ✓ Edge passivation
  - ✓ Rear side low cost approaches
    - ✓ Nickel blending
    - ✓ Silver seed layer + Ag/Cu or Cu paste

Solamet® Has Broad Access to PV Paste IP

- The Solamet® business is the industry innovation leader and holds the broadest access to PV paste IP

Solamet® owns an extensive IP portfolio from continuous innovations through the years

>115
patent families

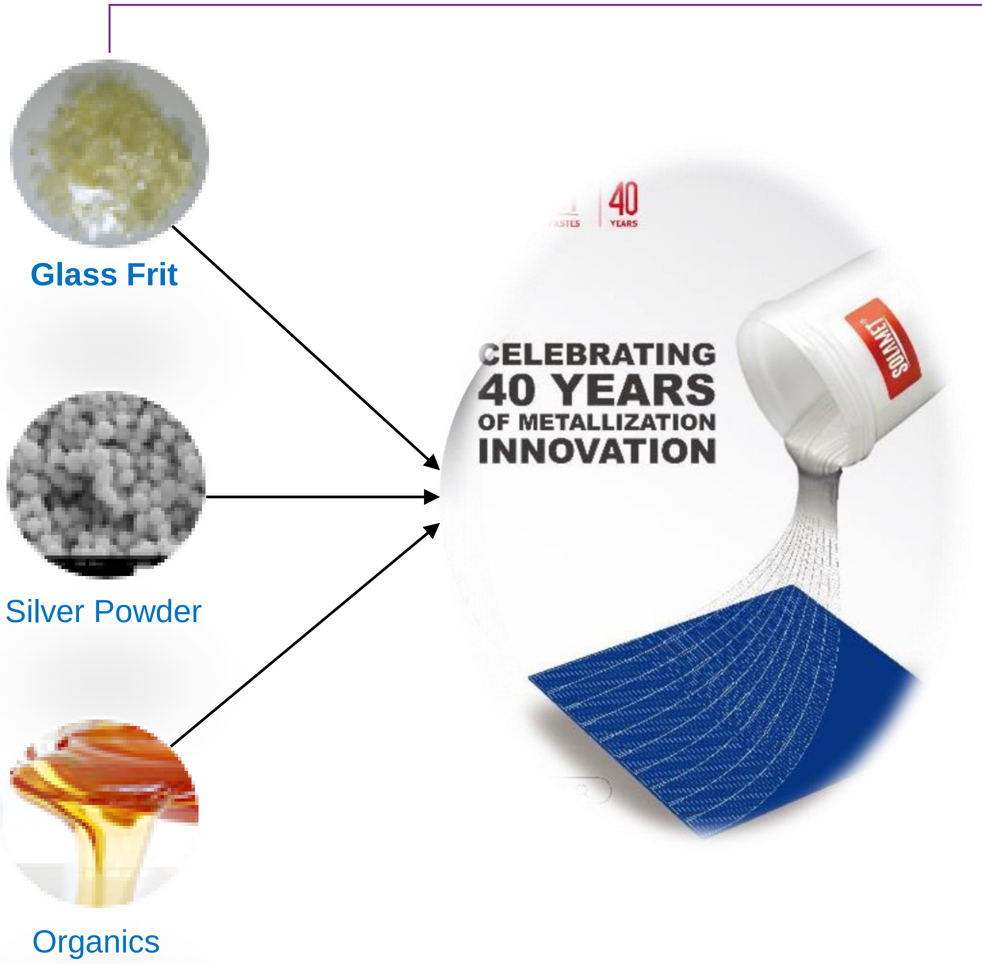
- Key granted patents have >10 years of remaining life
- Solamet® IP based on the Pb-Te-O frit technology is the keystone to the PV paste industry
- Nearly all p-type / n-type Si solar cells today uses Solamet® innovations

Solamet® also has licenses to practice IP through cross-licensing arrangements

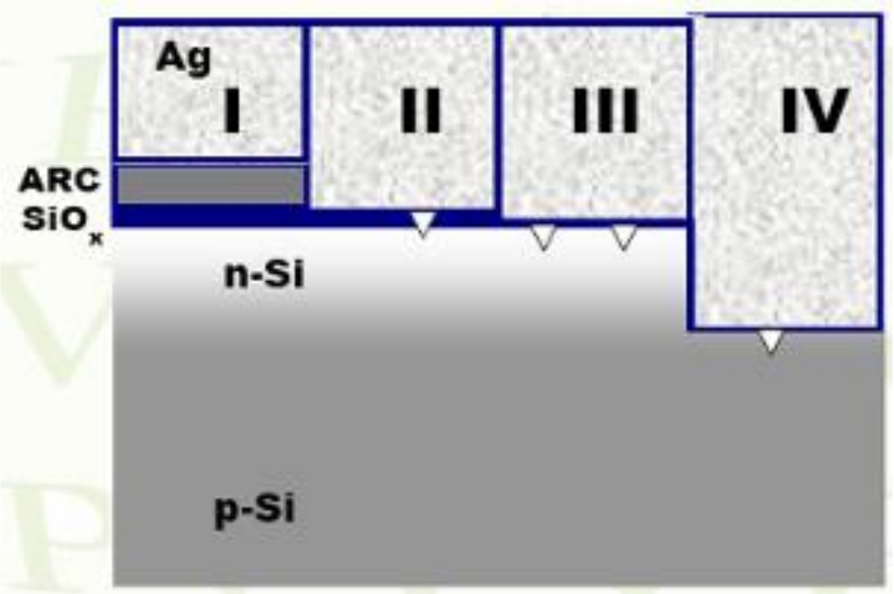
> 35
patent families

- Expanded access to practice for the mainstream p-type & n-type market segment
- Broader options for the growing n-type segment, including n-TOPCon and HJT applications

Frit is the Key for Firing Metallization Process

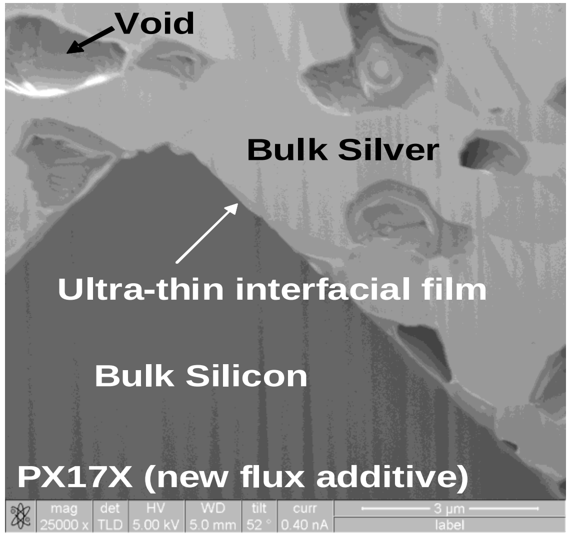


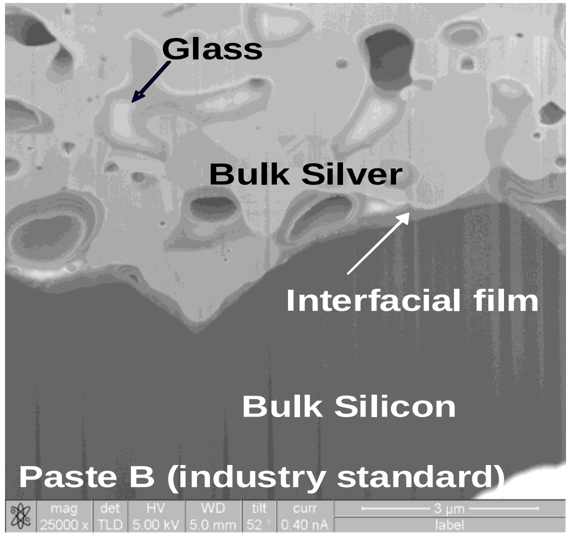
Progressive
Ag-Si Interaction
Ideal State = III

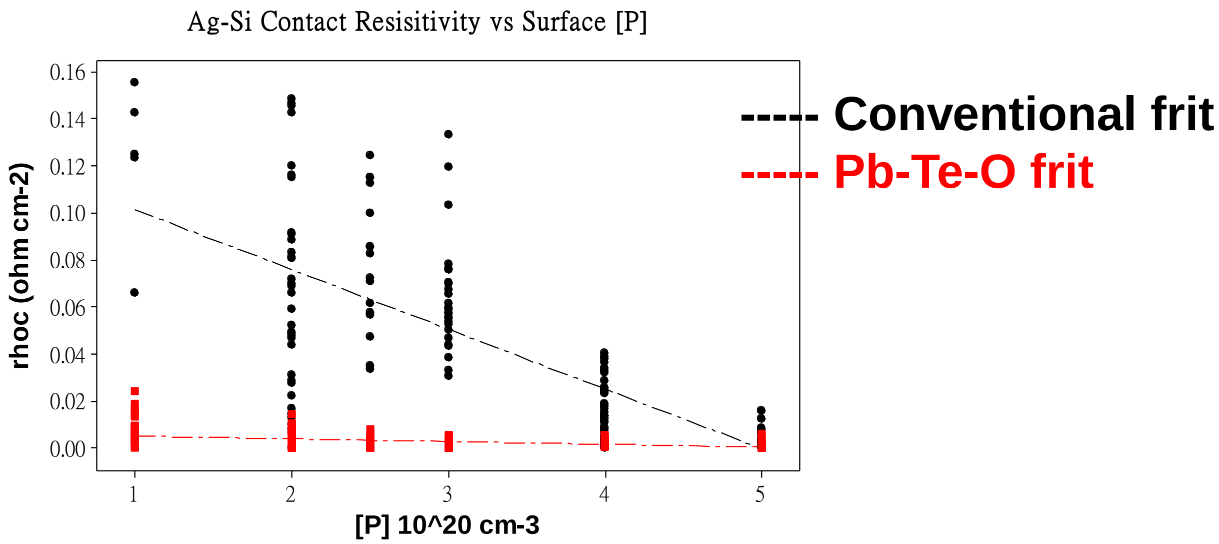


- Etch through ARC in a <u>controlled manner</u> ➔ Uniformly remove SiN_x:H at high temperature
- Contact emitter with <u>thin interfacial films</u> ➔ Reduce $R_{contact}$, reduce R_{series};

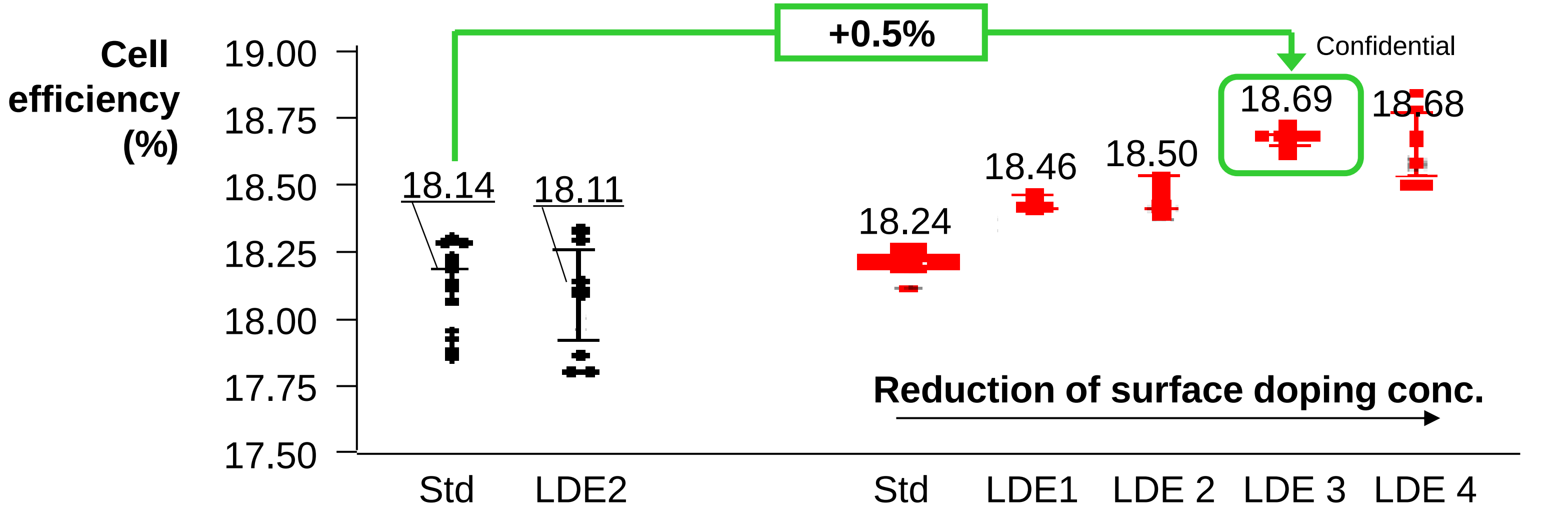
Pb-Te-O Frit Enable LDE with Significant Eff. Improvement







The unique chemistry and *excellent Si-Ag contact* of Pb-Te-O technology *enables wider range of diffusion optimization* and higher cell efficiency



Conventional paste

Solamet® Pb-Te-O frit (PV17x) in 2012

SOLAMET®

2018

ACS Awards
Heroes of Chemistry

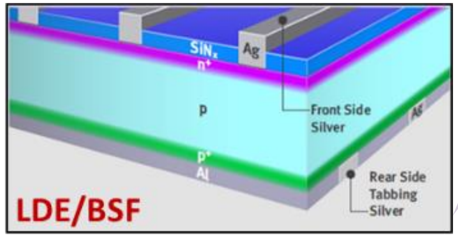
Pb-Te-O frit chemistry

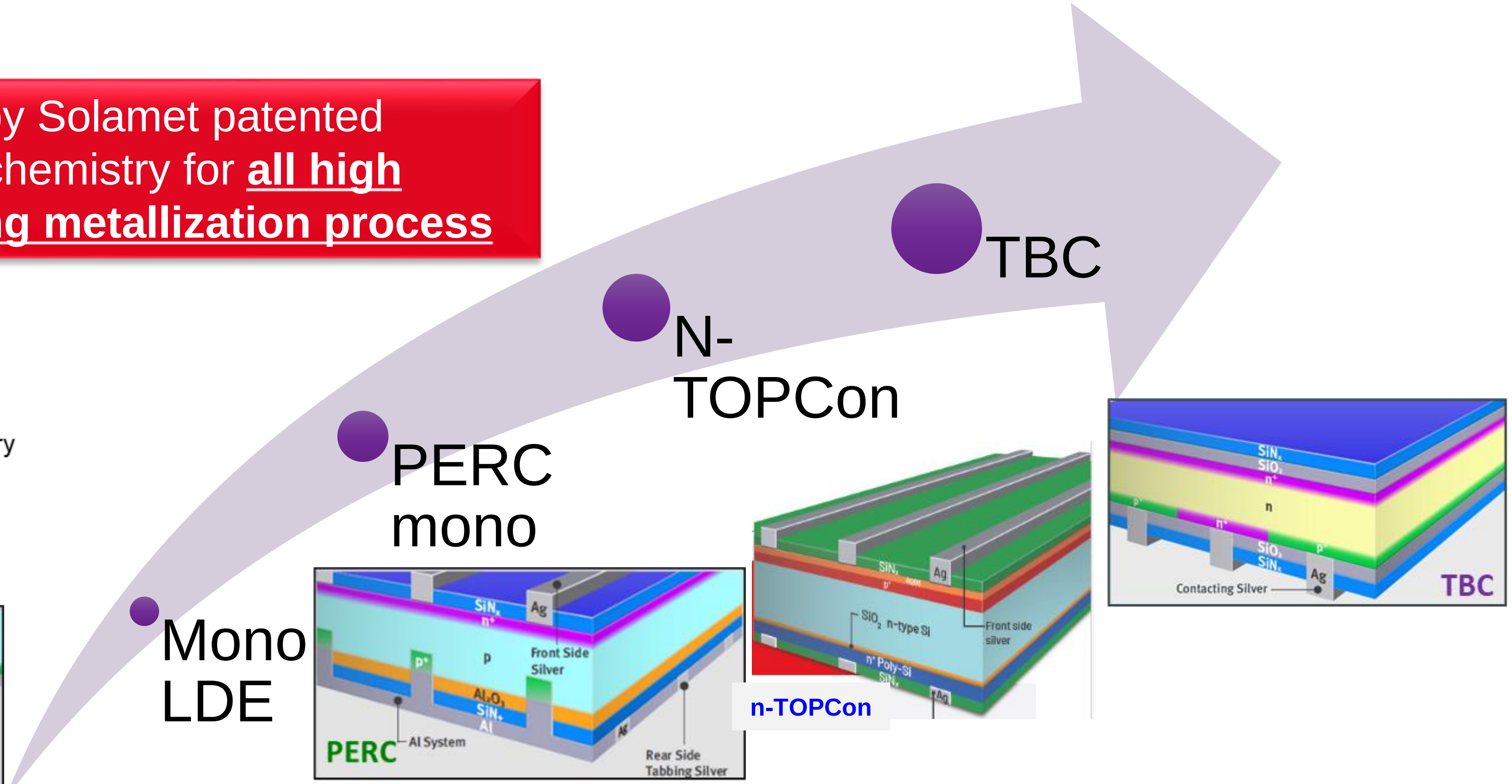
DuPont Scientists won the prestigious America Chemistry Society "Heroes of Chemistry" award in 2018, on the invention of the PbTeO frit chemistry and its successful application in PV industry

Solamet®'s Pb-Te-O Frit Chemistry Continues to Contribute for Next Generation PV Cell

Supported by Solamet patented
Pb-Te-O frit chemistry for **<u>all high temperature firing metallization process</u>**

2018
ACS Awards
Heroes of Chemistry
Pb-Te-O frit chemistry





<u>PbTeO frit chemistry</u> enabled mono LDE, and continue to be the chosen frit system in current PERC mono/n-TOPCon and future BC platform **<u>for phosphorus (n) emitter</u>**

SOLAMET®

Selected Solamet® Patents on Te Frit Technology

US Patents

US8497420
US8889980
US8895843
US9722100
US10069020
US10468542
US10559703
US10658528
US11043605

South Korea Patents

KR10-1569566
KR10-1569567
KR10-1569568
KR10-2031570
KR10-2048388
KR10-2177050

European Patents

EP2566823
EP2566824
EP2566826

Summary of previous U.S. litigation involving Solamet's IP

Item	Case name	Court	Case no.	Filing date	Patents asserted
1	E.I. DuPont de Nemours & Co. v. Heraeus Precious Metals North America Conshohocken LLC	U.S. District Court, District of Delaware	1:11-cv-00773-SLR-CJB (also referenced as Civ. No. 11-773-SLR)	Sept 2, 2011	U.S. Patent No. 7,767,254 B2 (and related Solamet patents)
2	E.I. DuPont de Nemours & Co. v. Heraeus Materials Technology, LLC & SolarWorld Industries America, Inc.	U.S. District Court, District of Oregon	No. 3:12-cv-01104-HU	June 2012	U.S. Patent No. 8,158,504 B2 (and related Solamet patents)
3	E.I. DuPont de Nemours & Co. v. SunEdison, Inc. & NVT, LLC	U.S. District Court, District of Delaware	1:2014cv01078	Aug 21, 2014	U.S. Patent No. 8,497,420 (and related patents)
4	Solar Paste, LLC v. Changzhou Fusion New Material Co., Ltd.; Risen Solar Co., Ltd.; Risen Energy America, Inc.	U.S. District Court, District of Delaware	1:21-cv-01257-LPS	Sept 1, 2021	U.S. Patents: 7,767,254; 8,497,420; 8,889,979; 8,889,980; 8,895,843

Introduction to Solamet Electronic Materials

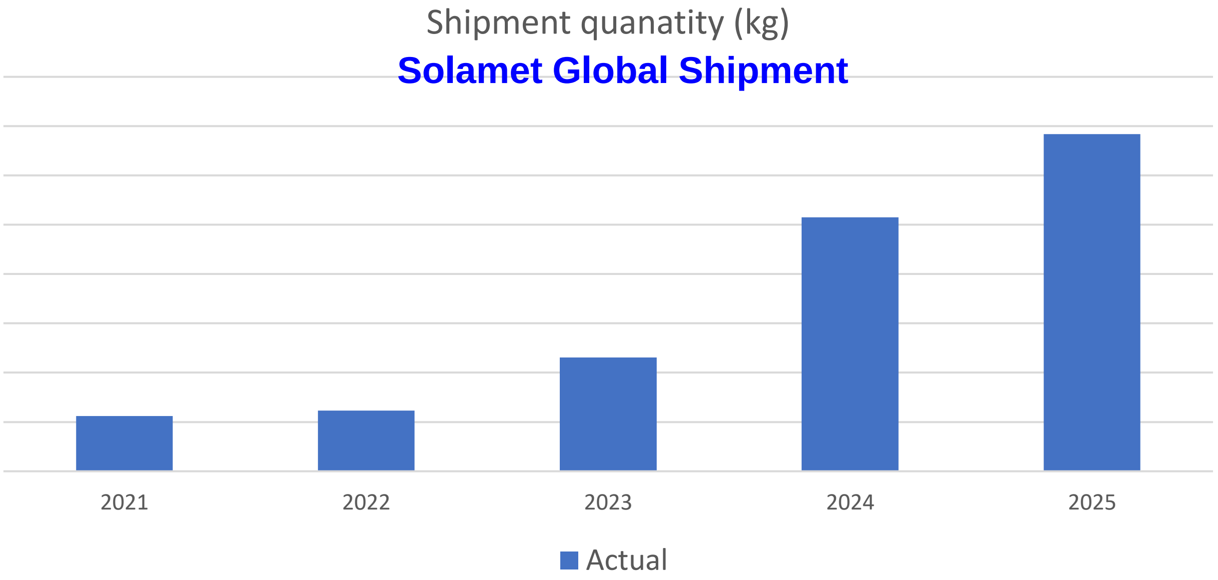
3 key Solamet Facts

- **Paste supplier with strongest IP position all over the world**

ACS Awards
Heroes of Chemistry
Pb-Te-O frit chemistry

- **Top 3 paste supplier globally**

- **Double paste shipment for 2024 vs. 2023 by strong n-TOPCon performance; continuous growth in 2025**

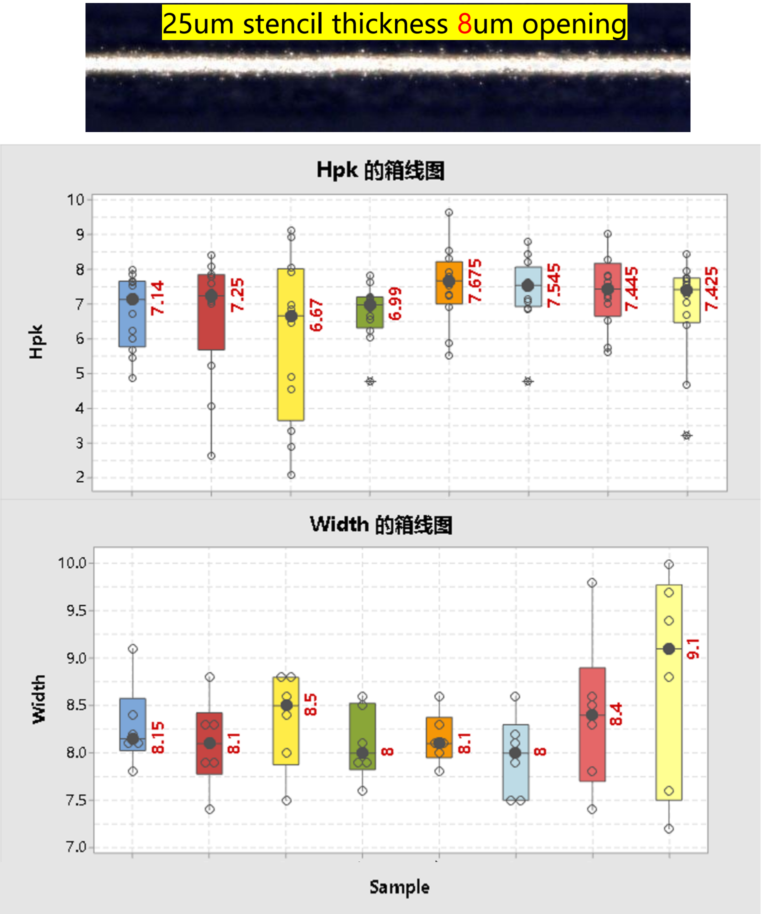


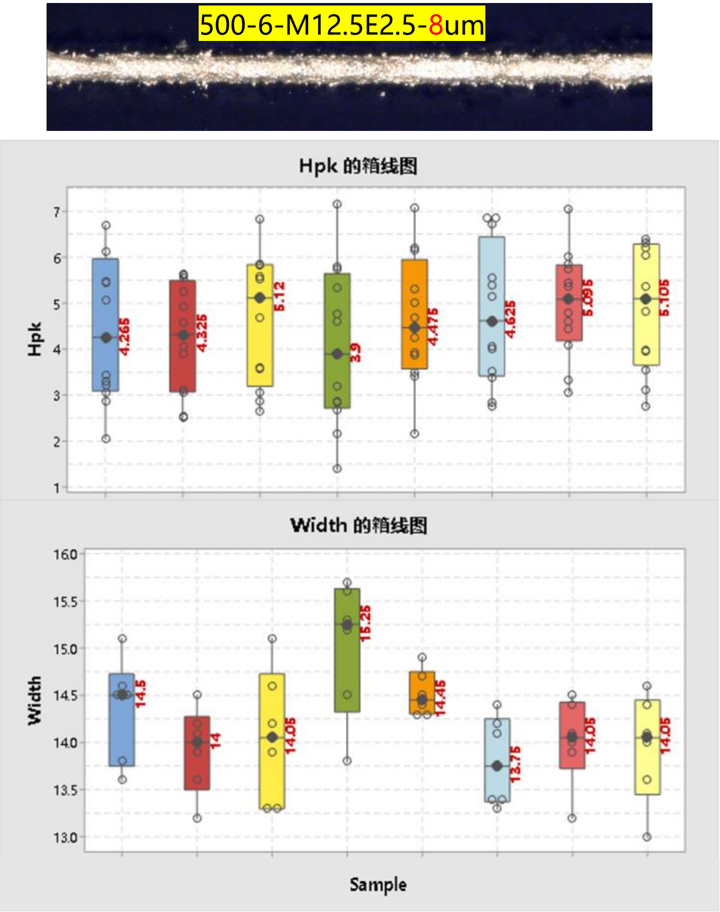
SOLAMET®

Agenda

- Solamet® company introduction
  - ✓ Technical center & Manufacturing site
  - ✓ Solamet intellectual property
- New technology for n-TOPCon
  - ✓ Stencil printing
  - ✓ Laser transfer
  - ✓ Poly finger
  - ✓ Edge passivation
  - ✓ Rear side low cost approaches
    - ✓ Nickel blending
    - ✓ Silver seed layer + Ag/Cu or Cu paste

Solamet® TOPCon PV3NL- Stencil Fine Line

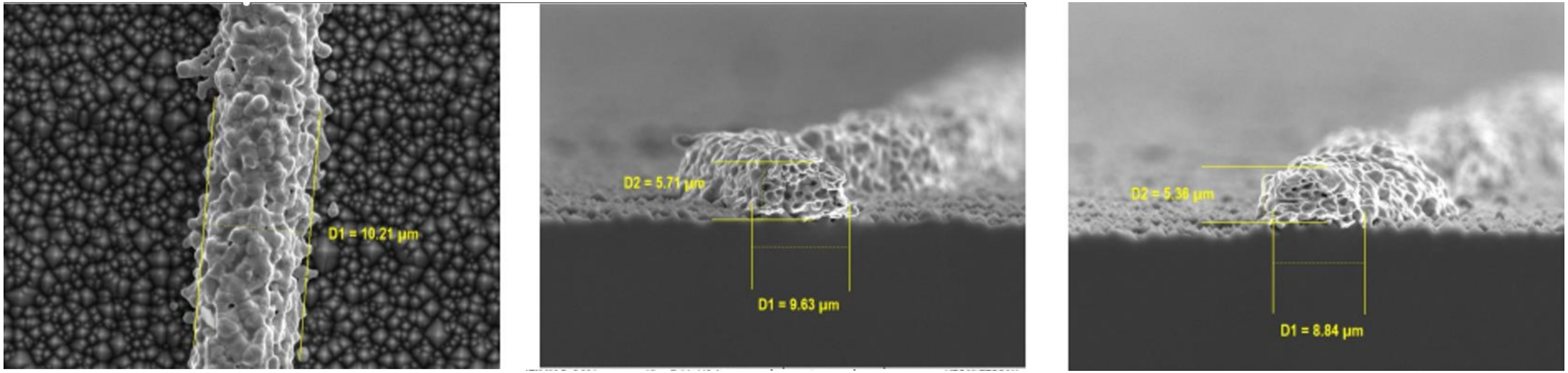


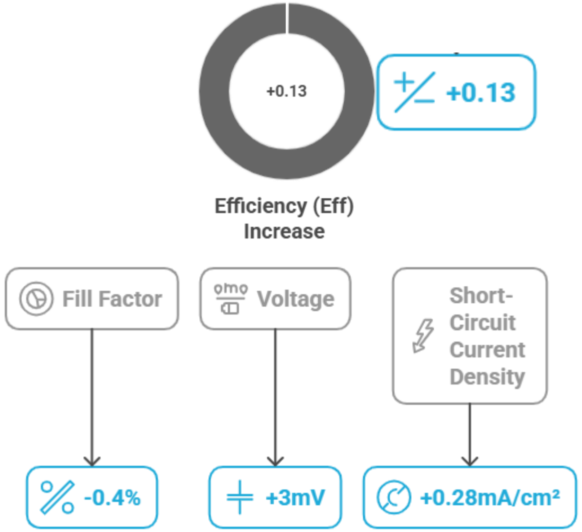


- Compared to high-mesh screens, stencils offer advantages in line morphology: narrower widths <9μm and higher heights >7μm.
- By optimizing the finger number and opening of stencils, significantly improved Isc can be achieved for TOPCon. Simultaneously, the reduced metallization area reduces recombination and improves Voc.
- Similarly, stencil printing pastes require a combination of silver powder and organic system optimization.

Split	LD (mg)	△Eff (%)	△Voc (mV)	△FF (%)	△Isc (mA)
High mesh screen+BL paste	-	-	-	-	-
Stencil(more finger) + paste A	-13.4	0.107	1.5	-0.07	79.2
Stencil(more finger) + paste B	-13.1	0.134	1.5	0.00	81.8

Solamet® TOPCon PV3NL- Laser Transfer Fine Line





+0.13

Efficiency (Eff) Increase

Fill Factor → -0.4%

Voltage → +3mV

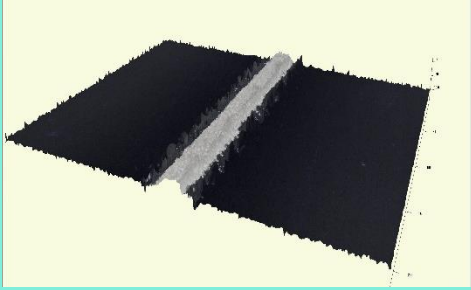
Short-Circuit Current Density → +0.28mA/cm²

- Laser transfer of 10µm films has resulted in excellent line shapes with high aspect ratio.
- Currently, there are still some issues:
  - The paste idle time on the transfer film affects the film release during transfer, resulting in broken fingers- This issue has been resolved.
  - Some fingers have tiny breaks less than 50µm in size, invisible by vision inspection- This is currently under optimization.
  - The higher finger may cause a problem: finger peeling by cell friction during process after firing- This is currently under optimization.
  - higher laser power needed for smaller trench film but high laser power can cause silver paste particle splatter and impact Isc- This is currently under optimization.

Fine Line Metallization Technology Opening Status

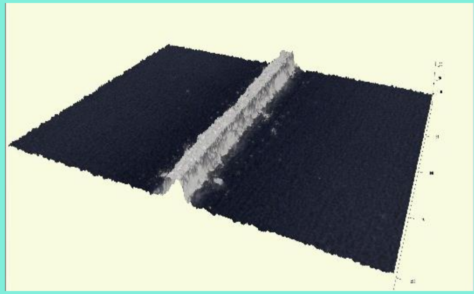
High temperature firing

Screen printing



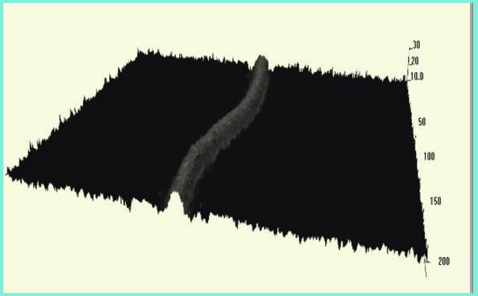
Current: 15~19um @ 8~11um opening
Next target: 13~17um @ 6~9um opening

Stencil



Current: 12~15um @ 6~11um opening
Next target: 9~11um @ 4~6um opening

Laser transfer



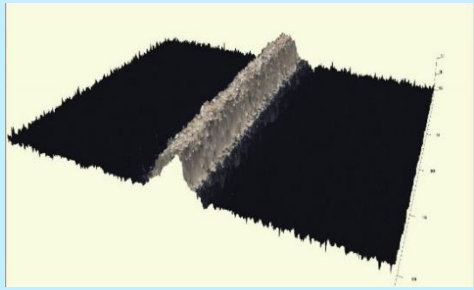
Current: 10~12um @ 8~10um opening
Next target: 7~10um @6~8um opening

Low temperature curing

Screen printing

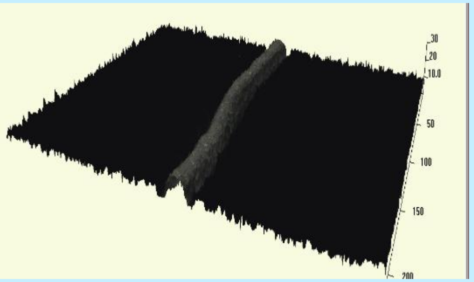
Current: 28~34um @ 16~17um opening
Next target: 24~30um @ 14~17um opening

Stencil



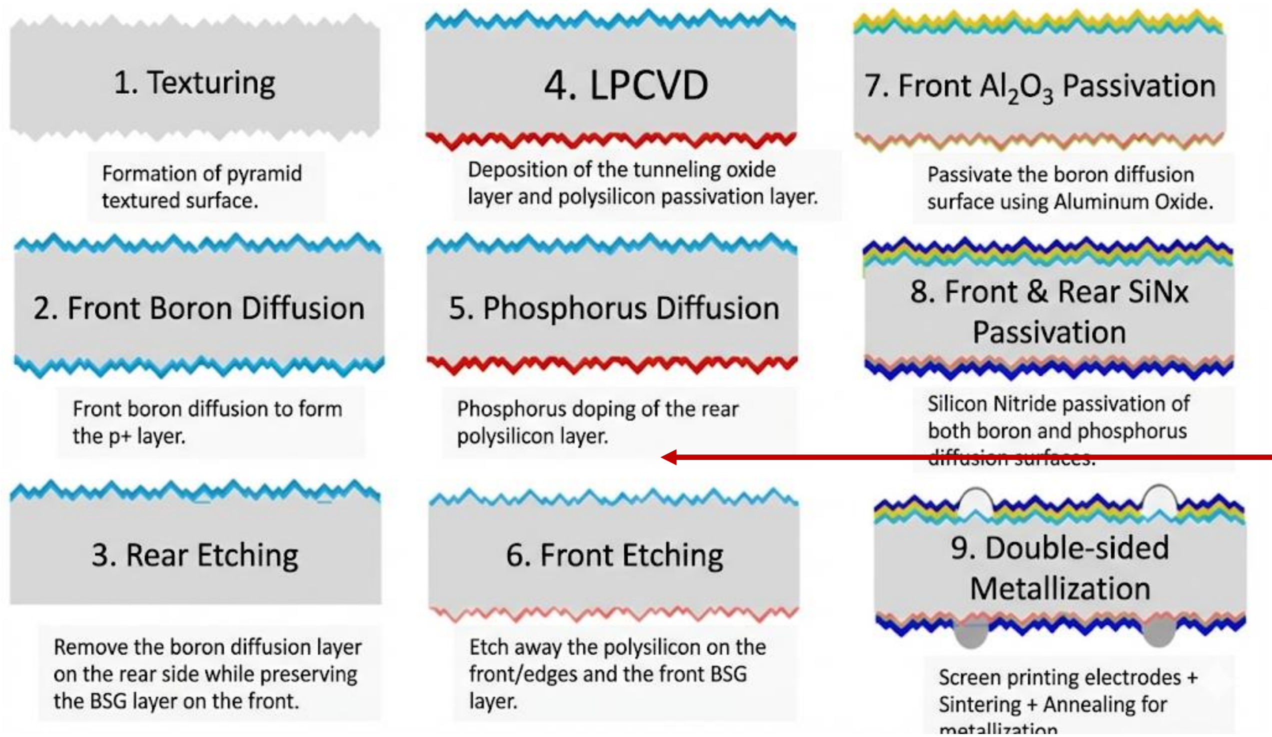
Current: 22~28um @ 12~14um opening
Next target : 18~24um @ 10~12um opening

Laser transfer



Current: 17~19um @ 15~17um opening
Next target : 13~17um @ 12~15um opening

Poly Finger Process



1. Texturing

Formation of pyramid textured surface.

2. Front Boron Diffusion

Front boron diffusion to form the p+ layer.

3. Rear Etching

Remove the boron diffusion layer on the rear side while preserving the BSG layer on the front.

4. LPCVD

Deposition of the tunneling oxide layer and polysilicon passivation layer.

5. Phosphorus Diffusion

Phosphorus doping of the rear polysilicon layer.

6. Front Etching

Etch away the polysilicon on the front/edges and the front BSG layer.

7. Front Al_2O_3 Passivation

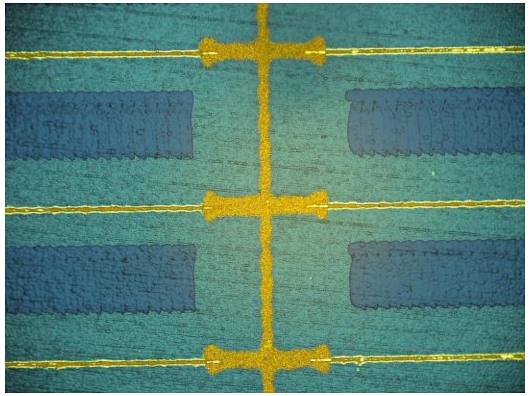
Passivate the boron diffusion surface using Aluminum Oxide.

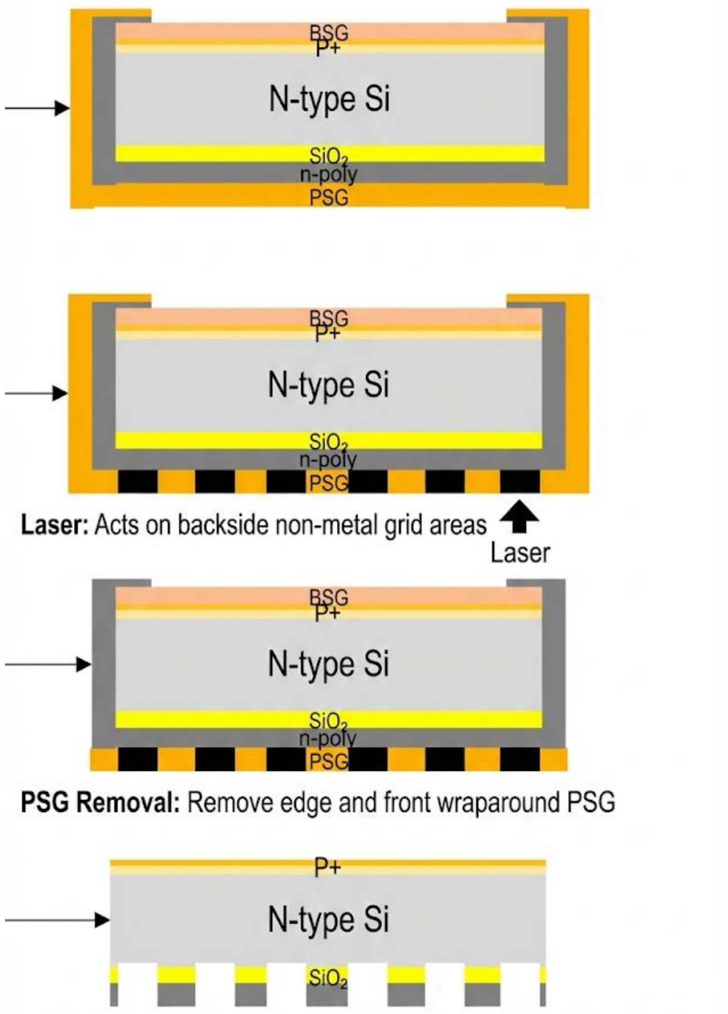
8. Front & Rear SiNx Passivation

Silicon Nitride passivation of both boron and phosphorus diffusion surfaces.

9. Double-sided Metallization

Screen printing electrodes + Sintering + Annealing for metallization





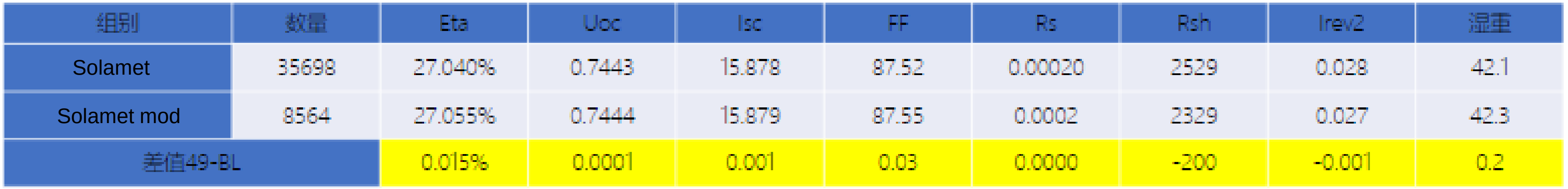
Laser: Acts on backside non-metal grid areas

PSG Removal: Remove edge and front wraparound PSG

RCA Cleaning: 1. Alkaline bath removes front wraparound poly
2. Alkaline bath etches backside laser-doped PSG and poly layers, etching down to Si substrate

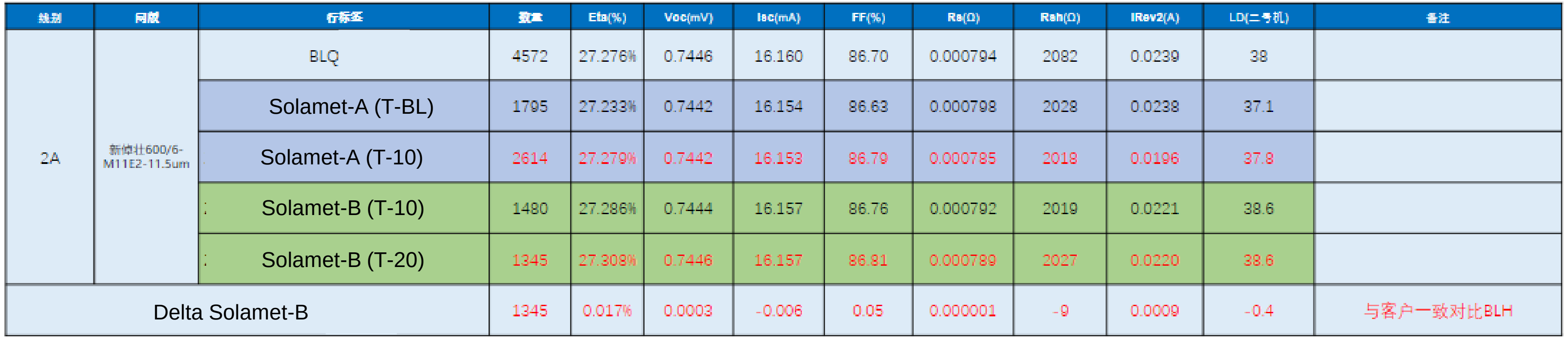
Solamet® Poly Finger Testing

Customer A



组别	数量	Eta	Uoc	Isc	FF	Rs	Rsh	Irev2	湿重
Solamet	35698	27.040%	0.7443	15.878	87.52	0.00020	2529	0.028	42.1
Solamet mod	8564	27.055%	0.7444	15.879	87.55	0.0002	2329	0.027	42.3
差值49-BL		0.015%	0.0001	0.001	0.03	0.0000	-200	-0.001	0.2

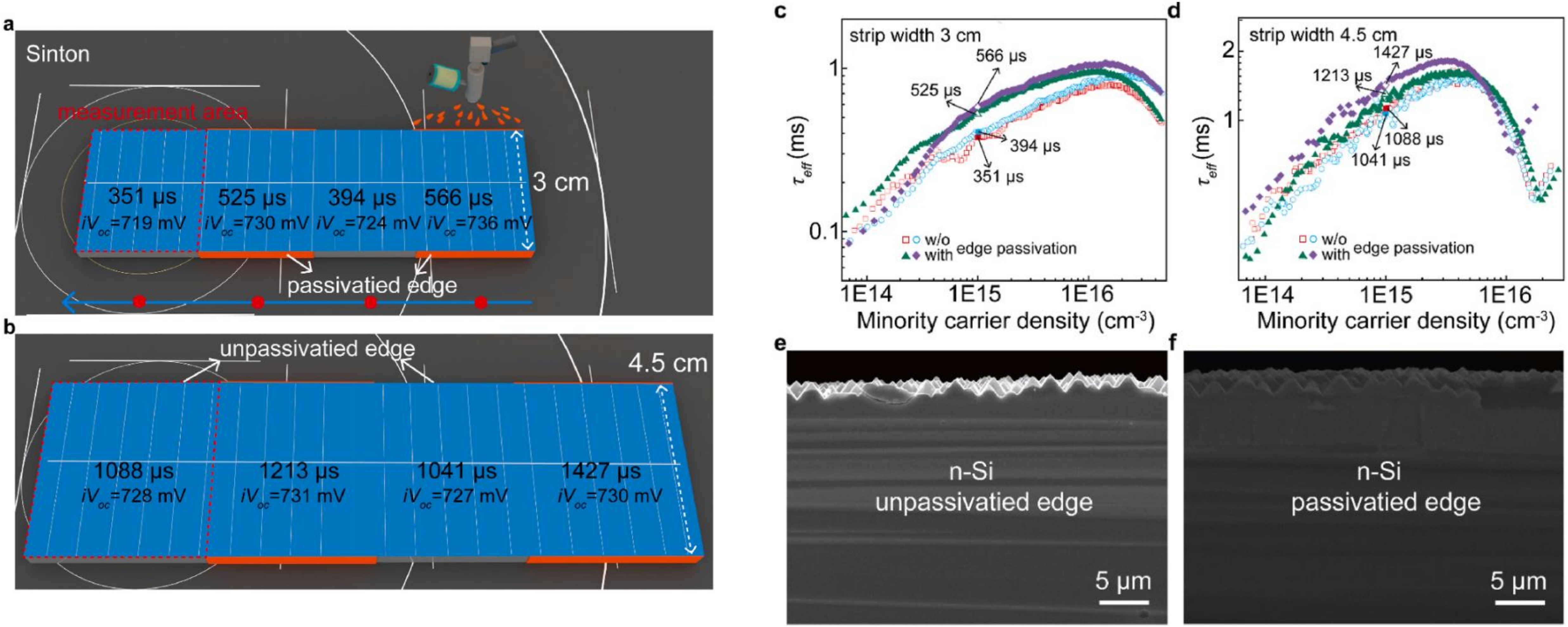
Customer B



线别	网版	行标签	数量	Eta(%)	Voc(mV)	Isc(mA)	FF(%)	Rs(Ω)	Rsh(Ω)	IRev2(A)	LD(二号机)	备注
2A	新帅壮600/6-M11E2-11.5um	BLQ	4572	27.276%	0.7446	16.160	86.70	0.000794	2082	0.0239	38	
		Solamet-A (T-BL)	1795	27.233%	0.7442	16.154	86.63	0.000798	2028	0.0238	37.1	
		Solamet-A (T-10)	2614	27.279%	0.7442	16.153	86.79	0.000785	2018	0.0196	37.8	
		Solamet-B (T-10)	1480	27.286%	0.7444	16.157	86.76	0.000792	2019	0.0221	38.6	
		Solamet-B (T-20)	1345	27.308%	0.7446	16.157	86.81	0.000789	2027	0.0220	38.6	
Delta Solamet-B			1345	0.017%	0.0003	-0.006	0.05	0.000001	-9	0.0009	-0.4	与客户一致对比BLH

- In general, poly finger (RS only) improve eff. by **<u>0.1-0.2%</u>**
- Based on external data from multiple customers, for poly finger applications, the paste fire-through capability needs to be adjusted to reduce shunting while maintaining Voc & FF.

New Technology for n-TOPCon- Edge Passivation



SOLAMET®

New Technology for n-TOPCon- Edge Passivation

Cell after edge passivation- SunsVoc

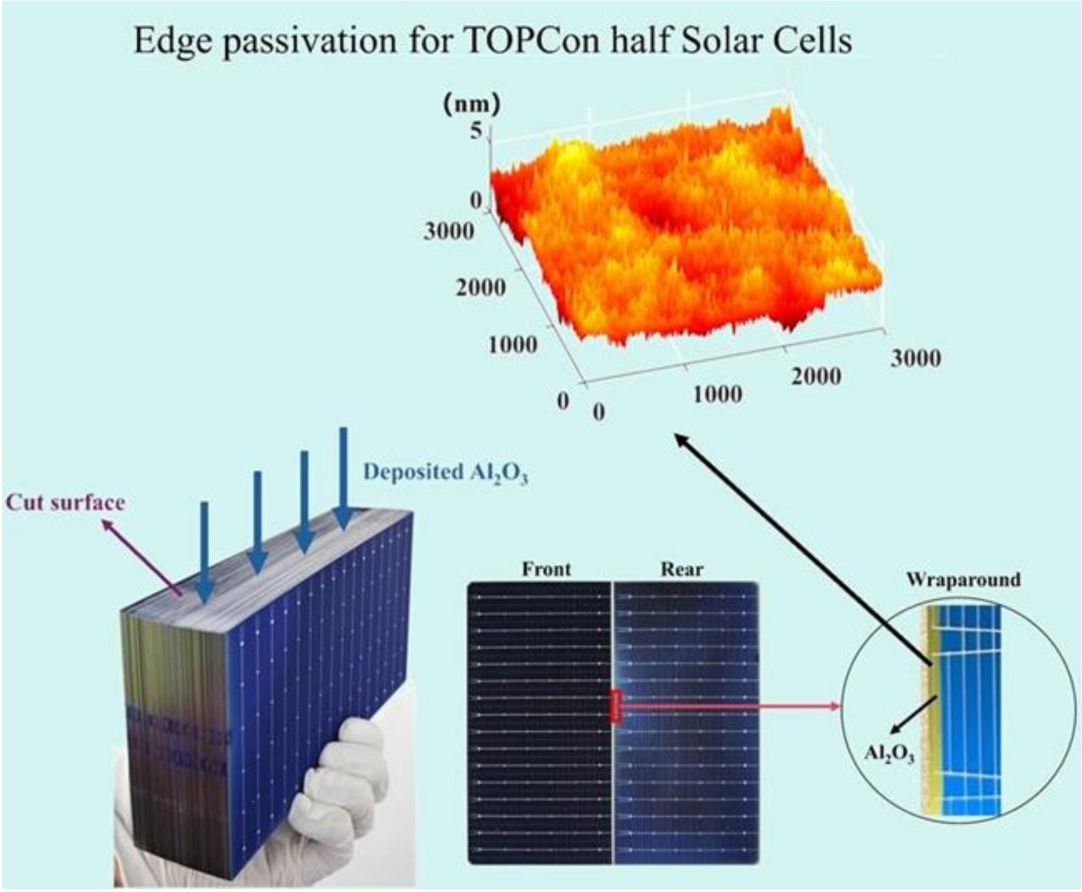
Comment			Voc(mV)	pFF(%)	PEff(%)
JSG	中间条	Δ（后-前）	+2.3	+0.27	+0.16
	两边条		+3	+0.08	+0.12
Competior I	中间条	Δ（后-前）	+0.8	+0.14	+0.071
	两边条		+0.6	+0.15	+0.06

Module power

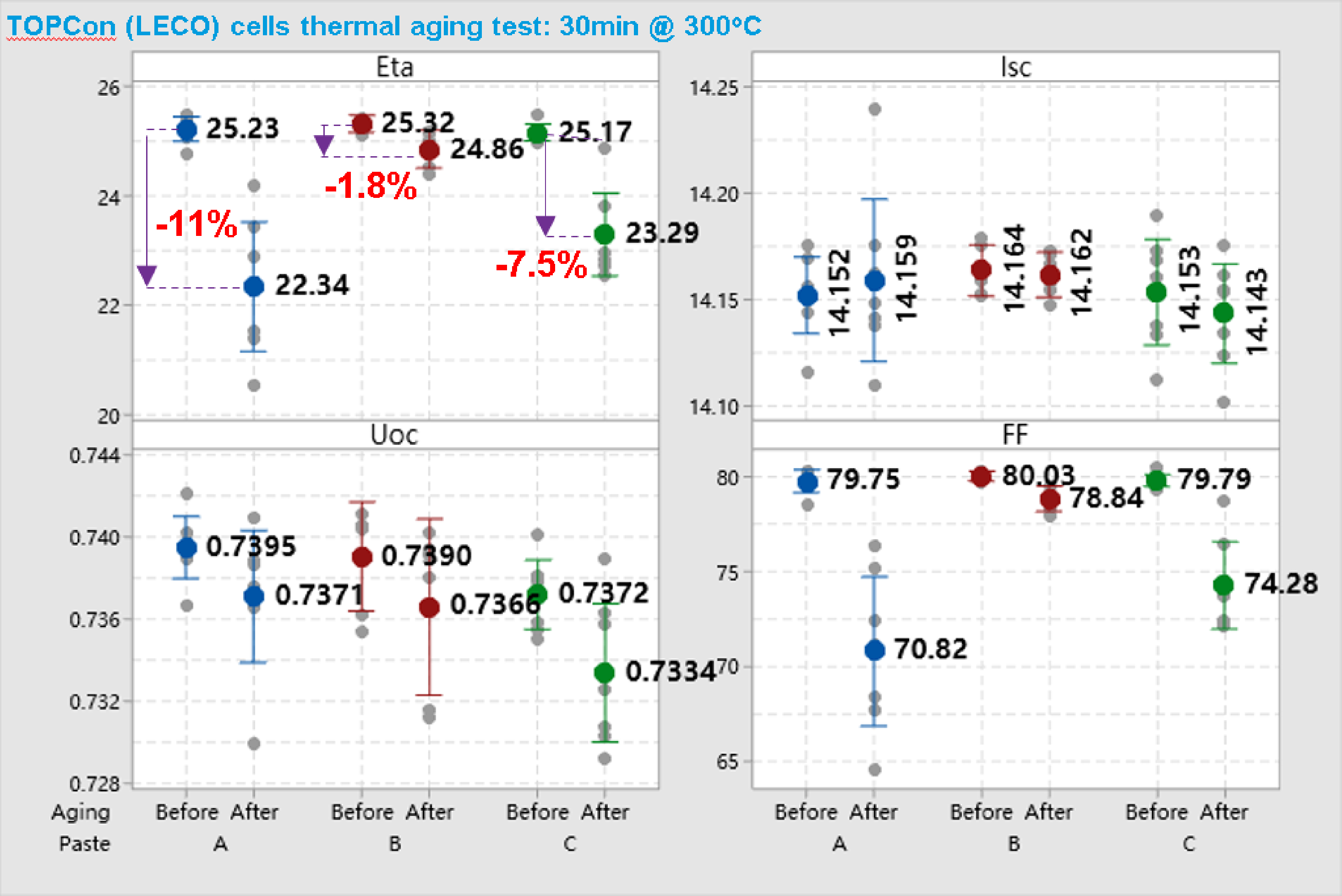
Comment		Pmax(W)	Voc(V)	Isc(A)	FF(%)
JSG	Delta(Exp-BSL)	+5.50	+0.034	-0.042	+0.75
Competior I	Delta(Exp-BSL)	+3.69	+0.025	+0.057	+0.14

Performance of edge passivation on TOPCon

■ Cell efficiency	■ Module power	■ Wrap-up
+0.12-0.16%	+5.5W（ + 0.77%）	No edge wrap-up



Solamet® FS Finger Optimization for Edge Passivation

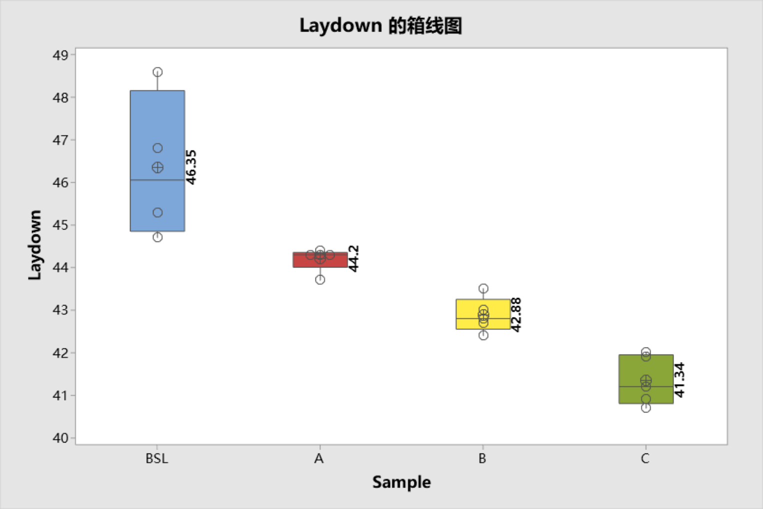

TOPCon (LECO) cells thermal aging test: 30min @ 300°C

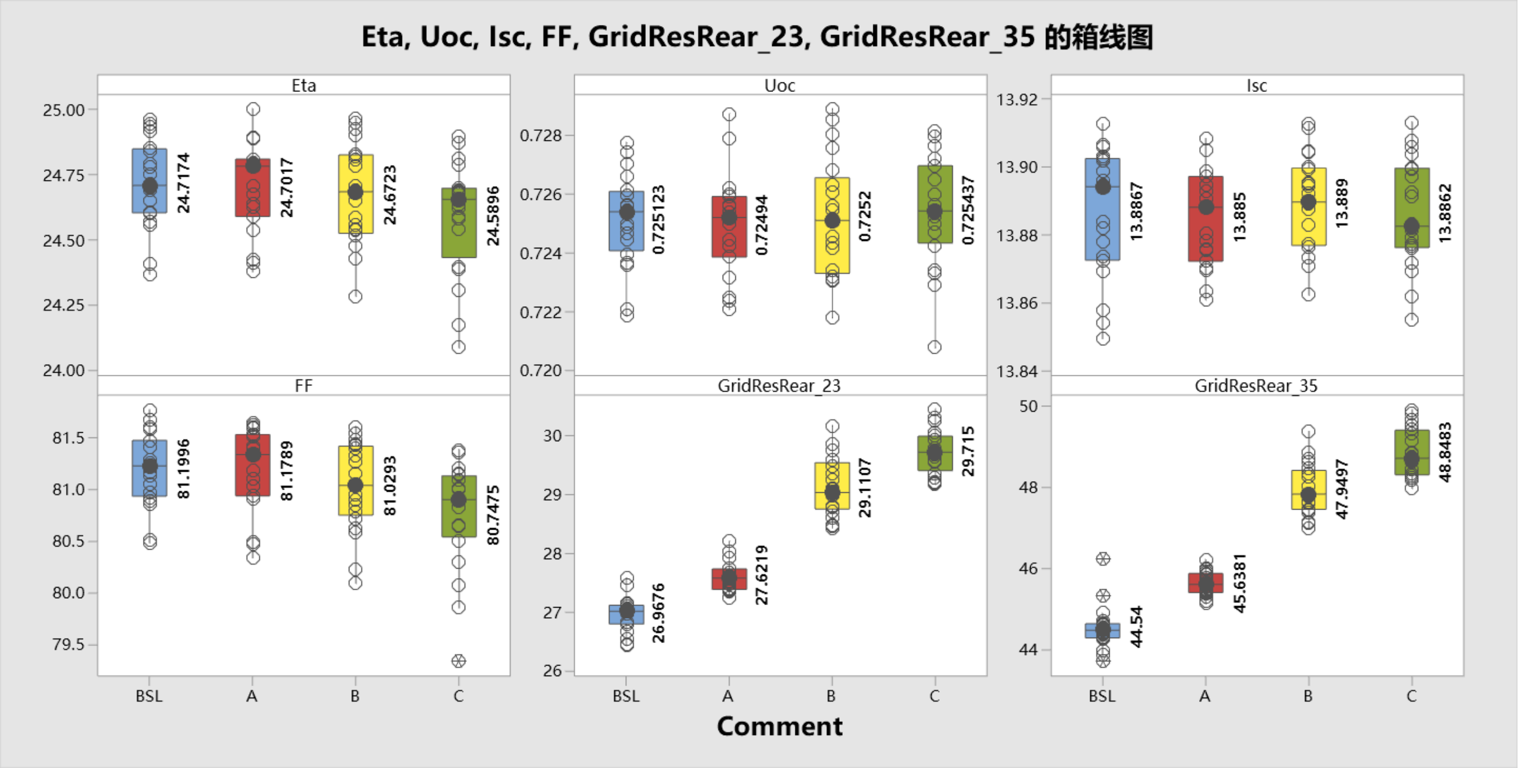
By adjusting the paste frit, the influence of edge passivation process conditions on the contact performance of LECO paste can be reduced.

Agenda

- Solamet® company introduction
  - ✓ Technical center & Manufacturing site
  - ✓ Solamet intellectual property
- New technology for n-TOPCon
  - ✓ Stencil printing
  - ✓ Laser transfer
  - ✓ Poly finger
  - ✓ Edge passivation
  - ✓ Rear side low cost approaches
    - ✓ Nickel blending
    - ✓ Silver seed layer + Ag/Cu or Cu paste

Previous RS Finger Paste Approach to Reduce Cost





BSL is 89% solids
rear-side finger
A： 88.5% solids
B： 88.0% solids
C： 87.5% solids

Three 89% solid content rear-side finger A, B, and C

① The laydown of the three lower solid content samples further decreases with decreasing solid content

② The efficiency of the three samples decreases with decreasing laydown, primarily due to FF degradation. Sample A, with an 88.5% solid content, show similar efficiency to BSL.

Ongoing Cost Saving for RS finger paste- Nickel blending

Metal Powder	Resistivity (Ω·m)	Sintered Grid Line Resistivity (Ω·m)	Room Temperature Stability	High Temperature Stability	Powder Particle Size Distribution
Ag	1.59E-08	2.5~3.5 E-08	Good	Good	1~3um narrow distribution, can be printed with fine lines
Al	2.65E-08	2~5 E-07	Easy to oxidize, the oxide layer is thin and has good stability	Easy to oxidize, the oxide layer is thin and has good stability	1~15um wider distribution, cannot be printed with fine lines
Cu	1.68E-08	/	Easy to oxidize	Easy to oxidize	1~3um narrow distribution, can be printed with fine lines
Ni	6.84E-08	/	Easy to oxidize, the oxide layer is thin and has good stability;	Easy to oxidize, the oxide layer is thin, and the stability is normal	1~3um narrow distribution, can be printed with fine lines

The metal powders currently available for photovoltaic conductive pastes mainly include Ag, Al, Cu, Ni, etc. There are different issues with each metal in conductive pastes :

Al: ①Cannot achieve fine lines ②The resistivity is high ③The Al-Si alloying reaction is too fast and it is easy to form excessive metal compounds;

Cu: ①Oxidation from low to high temperature firing ②The cured/sintered grid lines on cells may continue to oxidize, and the reliability is questionable;

Ni: ①The resistivity itself is very high ②Oxidation during high temperature firing;

Due to the above issues with 100% base metal pastes, a solution of using silver as the main powder + replacing silver powder partly with base metal is adopted; and because front-side finger is more sensitive to line resistance, which may lead more efficiency impact, this approach is developed first for the rear-side finger & bus.

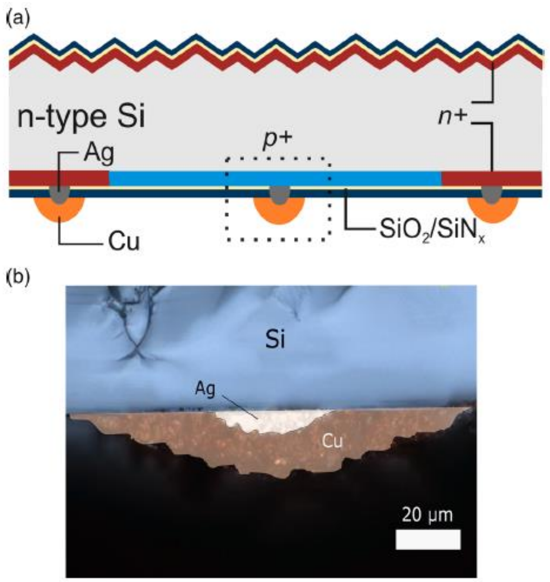
Internal Testing for RS Finger Containing Base Metal

Internal Test Data of RS Finger Containing Base Metal								
TOPCON-LECO, RS Finger (430-8-M12-E3.5-12um)								
Sample	Nickel wt%	Eff	Uoc	FF	Isc	Rs	Rsh	LD
silver paste	\	25.182	0.7307	83.06	13.888	0.003	1651	0.048
SY-1	3%	25.183	0.7311	83.11	13.872	0.003	1720	0.049
SY-2	5%	25.179	0.7308	83.06	13.884	0.003	1627	0.049
SY-3	7%	25.200	0.7315	83.07	13.881	0.003	1698	0.05
SY-4	10%	25.179	0.7306	83.10	13.882	0.003	1667	0.049
SY-5	12%	25.147	0.7286	83.17	13.891	0.003	1618	0.048

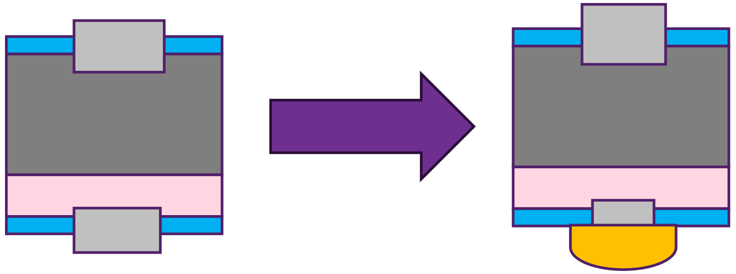
- For 4 samples with 3%~10% base metal content, the efficiency is not significantly degraded with similar laydown compared to silver samples
- For the 12% base metal content sample, Eff. loss is 0.03% vs. silver sample

New Technology for n-TOPCon- Ag Seed layer + Ag/Cu paste

- Ag seed layer + base metal conductor



Chen et al, Sol. RRL 2023 7, 2200874



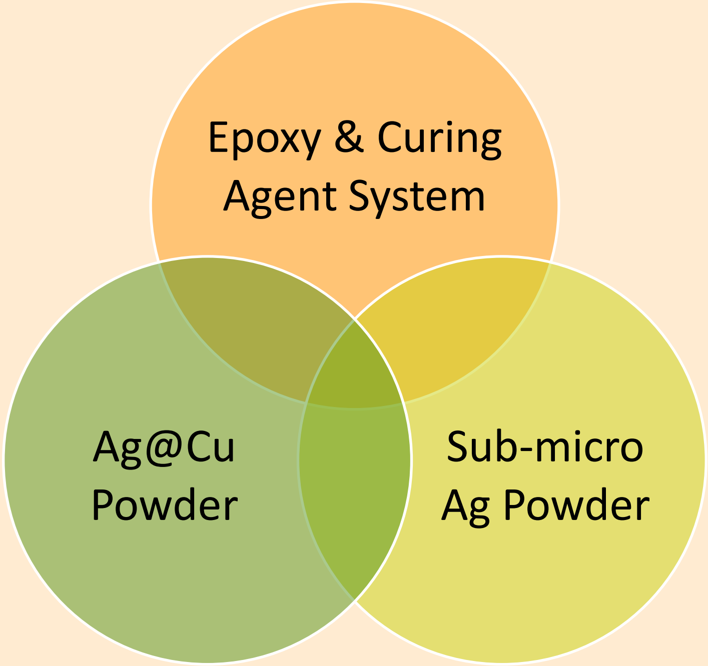
High temperature firing paste

High temperature seed layer
+
Low temperature Ag/Cu
Or Cu paste

	Ag content	Resistivity μΩ·cm
PV42A-X9030	100% Ag	4.0-4.5
PV43A-T6	4×% Ag	5.0-6.0
PV43A-T7	3×% Ag	6.0-7.0
PV43A-T8	2×% Ag	7.0-8.5
PV43A-T9	1×% Ag	8.0-9.9

Curing : 180-200degC/10min

PV43A: thermoset, Ag-coated Cu products for lower cost



Epoxy & Curing Agent System

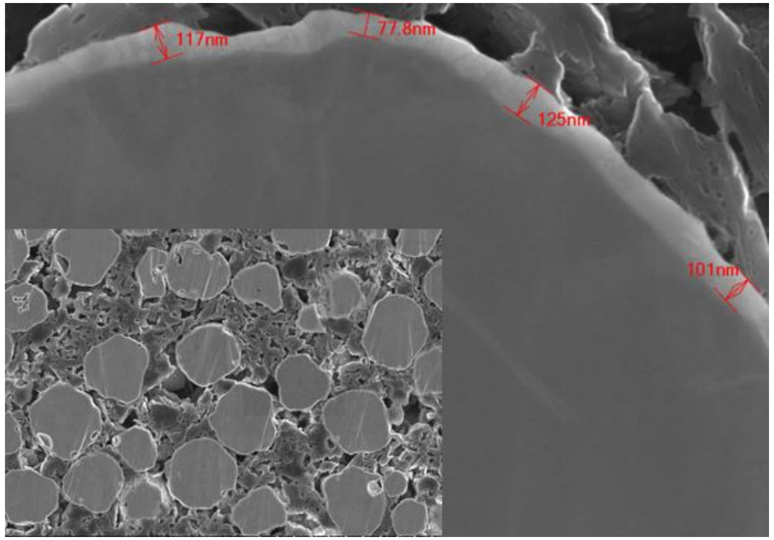
Ag@Cu Powder

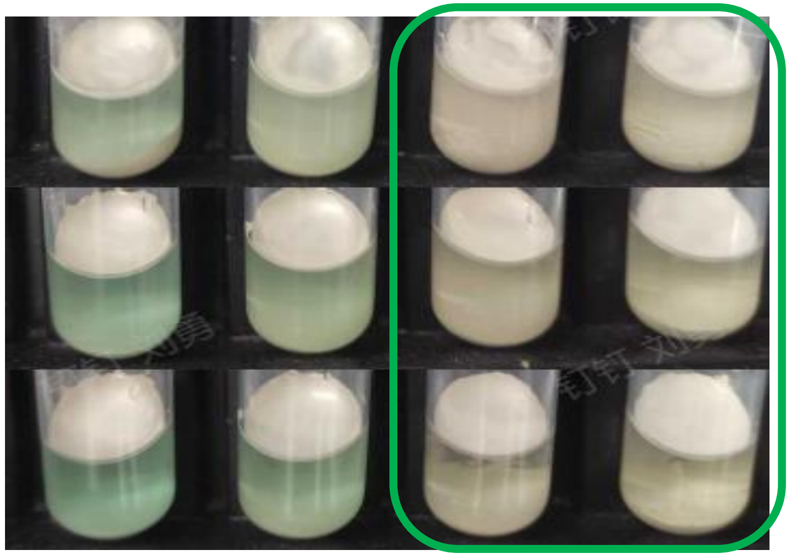
Sub-micro Ag Powder

Organic: Good adhesion, Lower volume resistivity & Better contact.

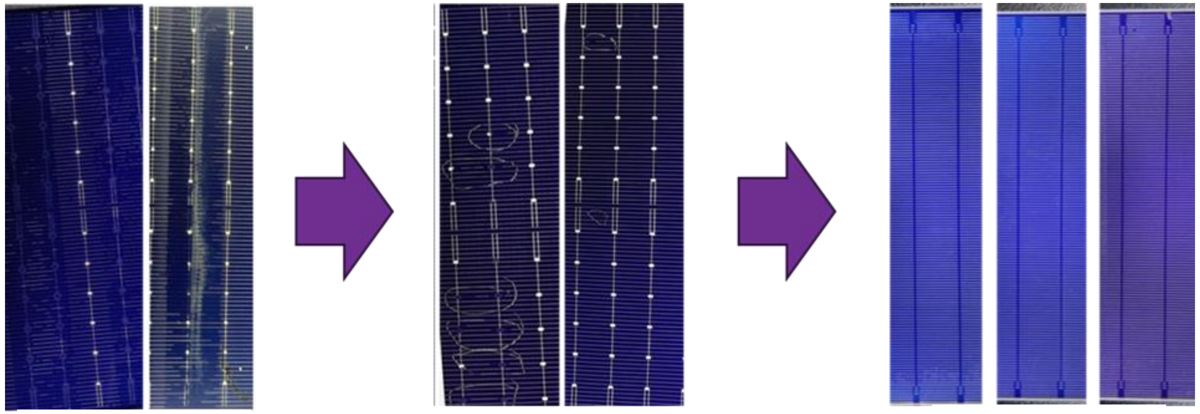
Ag coated Copper Powders: Perfect interface bonding - Better stability under thermal & acid.

Sub-micro Ag Powders: Proper PSD reconstruction – balance volume resistivity & contact resistivity.





PV43A Ag/Cu Paste : High Reliability

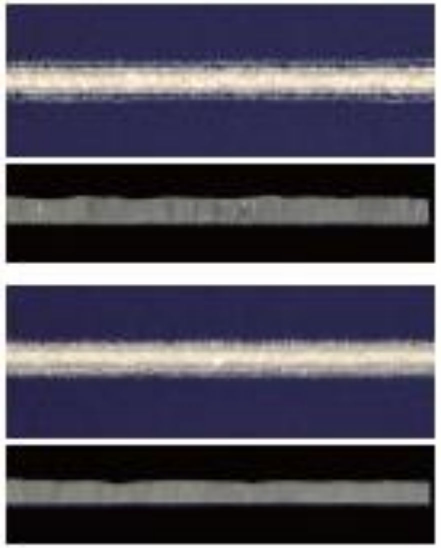

RD stage

RD improved stage

Current stage

The cells were immersed in water at 85℃ for 30min, then 3M tape was used to check finger adhesion with substrate

- Compatible with conventional knotless and 100% open stencil screens
- Excellent storage shelf life time (refer to below table)
- Excellent printability & aspect ratio
- Low cost, high efficiency and reliability



PV43A (22%Ag) Stability Check at Room Temperature

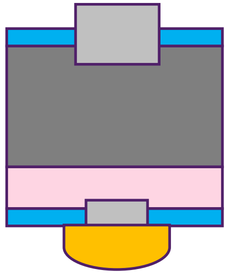
Duration	BF viscosity	Resistivity μΩ·cm
Fresh	158	7.26
3 days	151	7.45
1 week	165	7.68
2 weeks	169	7.16
1 Month	175	7.66

Solamet® External Testing by Ag Seed Layer + PV43A

	Ag seed layer	PV43A	Eta %	Voc mV	Isc mA	FF %	Rs	Rsh	IRev2
Baseline	52mg		/	/	/	/	/	/	/
Ag seed+PV43A	15mg	68mg（30% Ag）	0.02	0.6	1	-0.03	0.00001	-111	0.022
	11.0mg	70mg（50% Ag）	0.01	1.4	16	-0.22	0.00068	1664	0.019

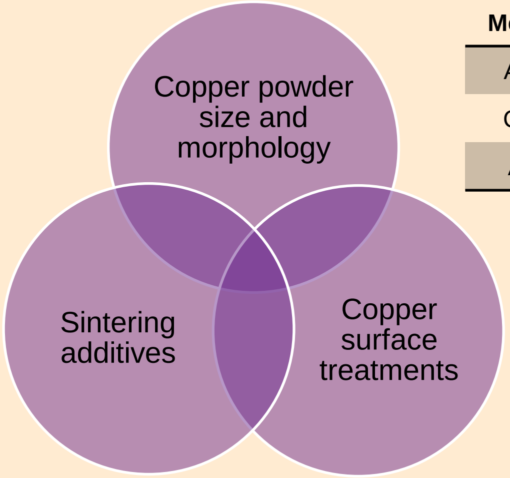
- Low laydown of Ag seed layer help less etching during firing, which leads to less recombination & better Voc.

  At the same time, conductivity was provided by double printed PV43A Ag/Cu paste
- Demonstrate comparable eff. by 20-30% Ag content PV43A vs. standard TOPCon metallization



High temperature seed layer
\+
Low temperature Ag/Cu
Or Cu paste

New Technology for n-TOPCon- Ag Seed layer + Cu paste

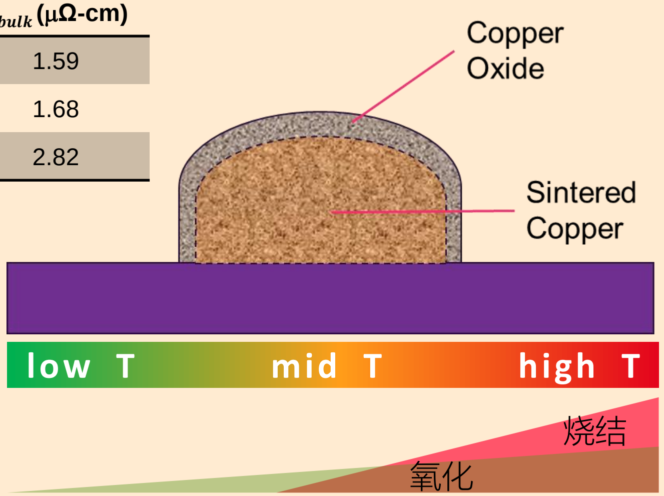


Copper powder size and morphology

Sintering additives

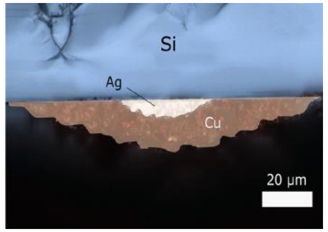
Copper surface treatments

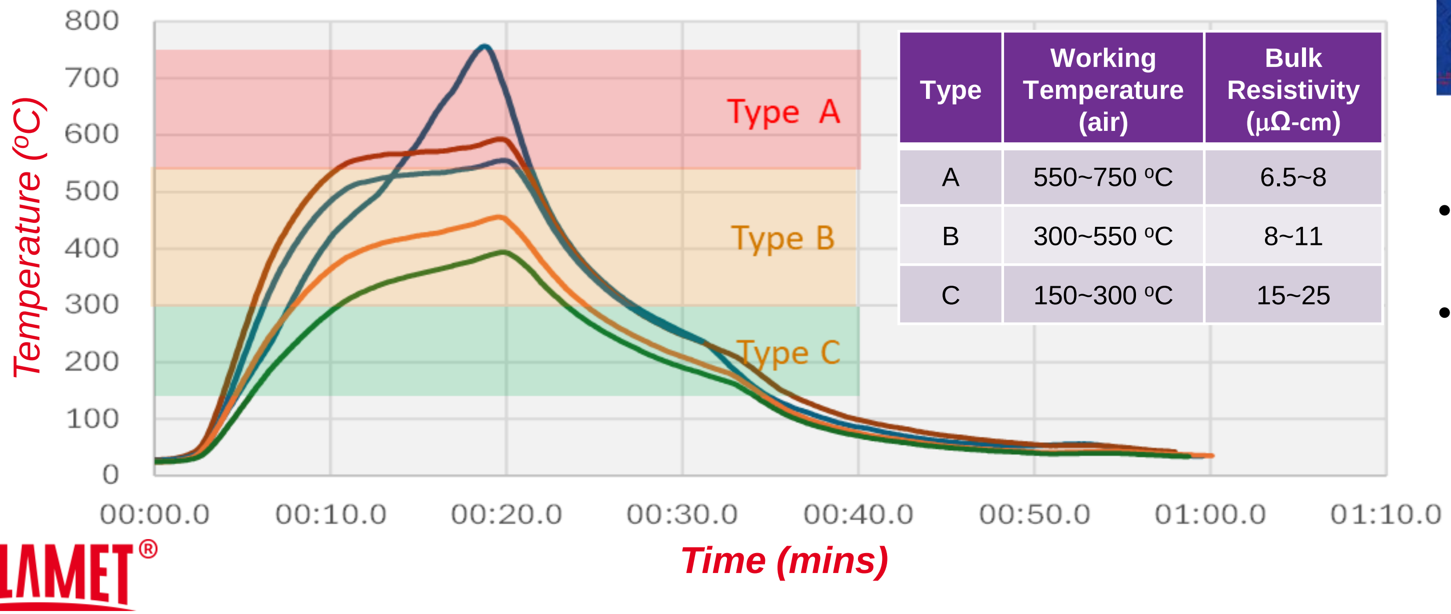
Metal	ρ_{bulk} (µΩ-cm)
Ag	1.59
Cu	1.68
Al	2.82



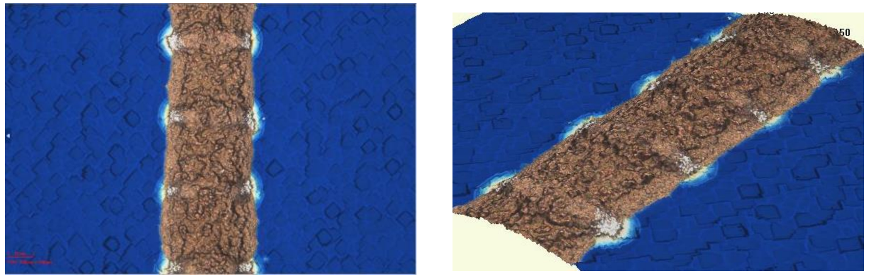
Two step using seed layer + low T copper paste for n-TOPCon and n-TBC

Chen et al, Sol. RRL 2023





Type	Working Temperature (air)	Bulk Resistivity (µΩ-cm)
A	550~750 ºC	6.5~8
B	300~550 ºC	8~11
C	150~300 ºC	15~25



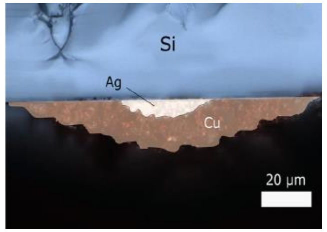
- Feasibility had been tested internally with similar eff. to standard process
- New advanced curing/sintering technology/equipment may be needed

Metallization Cost Saving Evolution for TOPCon

Cost saving

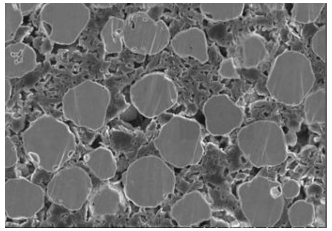
4. Two step using seed layer + low T copper paste for n-TOPCon and n-TBC

Chen et al, Sol. RRL 2023

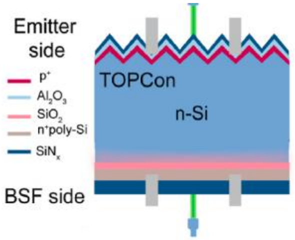


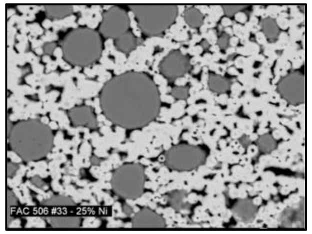
3. Two step using seed layer + low T Ag/Cu paste for n-TOPCon and n-TBC

Chen et al, Sol. RRL 2023

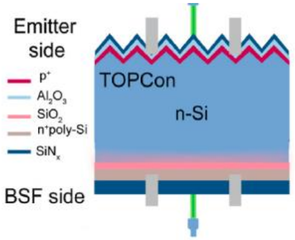


2. TOPCon RS finger with base metal Ni





1. Current standard TOPCon metallization process



Process complexity