


N-TOPCon Paste Selection Guide and its Impact to Performance

Solamet Electronic Materials

2025. Apr.



Agenda

- Solamet® company introduction
 - ✓ Technical center & manufacturing site
 - ✓ Solamet intellectual property
- N-TOPCon FS paste selection guide
 - ✓ Metal recombination vs. contact
 - ✓ Efficiency vs. reliability
 - ✓ Module BOM impact to reliability

Introduction - Solamet Global Presence

DuPont™ Solamet®  **SOLAMET® 索特**

- Headquarters:
 - Huzhou-Zhejiang (CN)
 - Shanghai (CN)
- R&D and Technology Centers:
 - Shanghai (CN)
 - Taoyuan (TW)
- Manufacturing Sites:
 - Dongguan (CN), 1000 t/yr
 - Taoyuan (TW), 300 t/yr → support customers with Taiwan made certification for US end market since 2023

Dual technology centers to strategically serve the China and oversea markets



Shanghai R&D Center



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

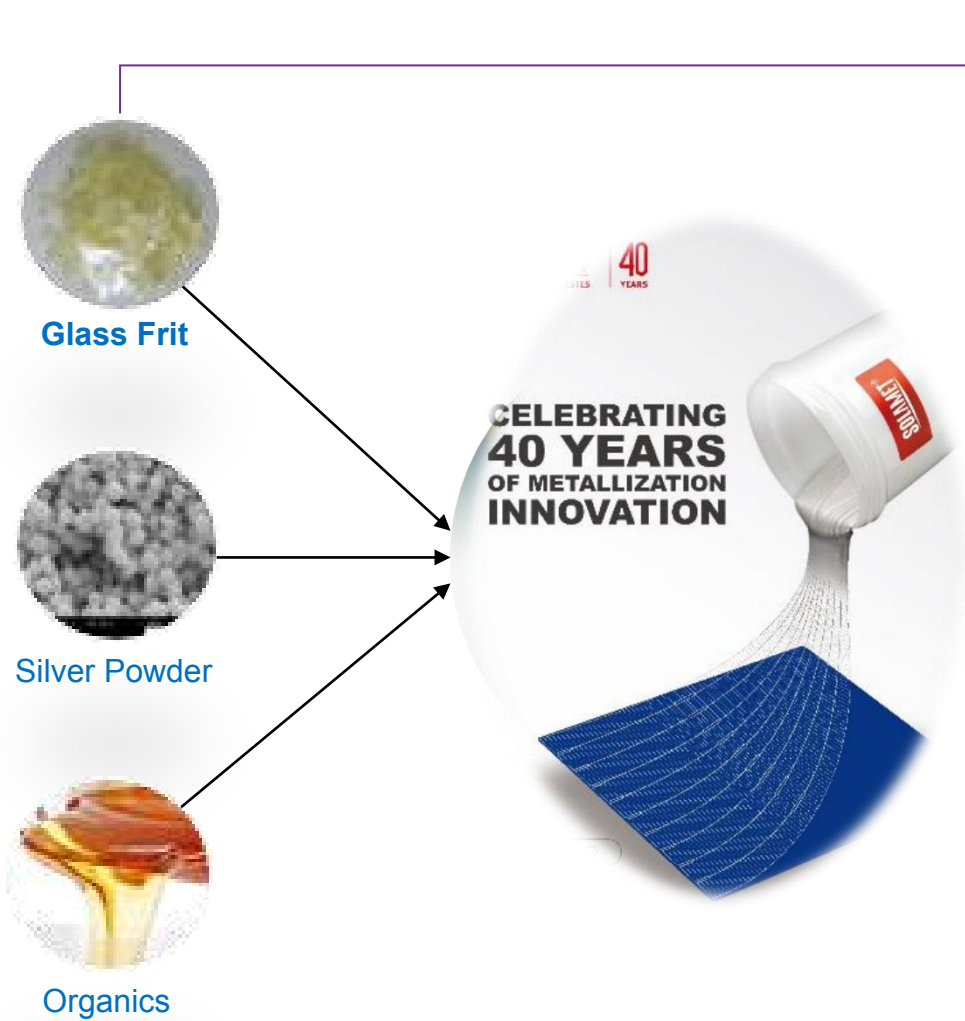
Dual Technology Centers both equipped with updated facilities and tools to support fast-paced new product and application development

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

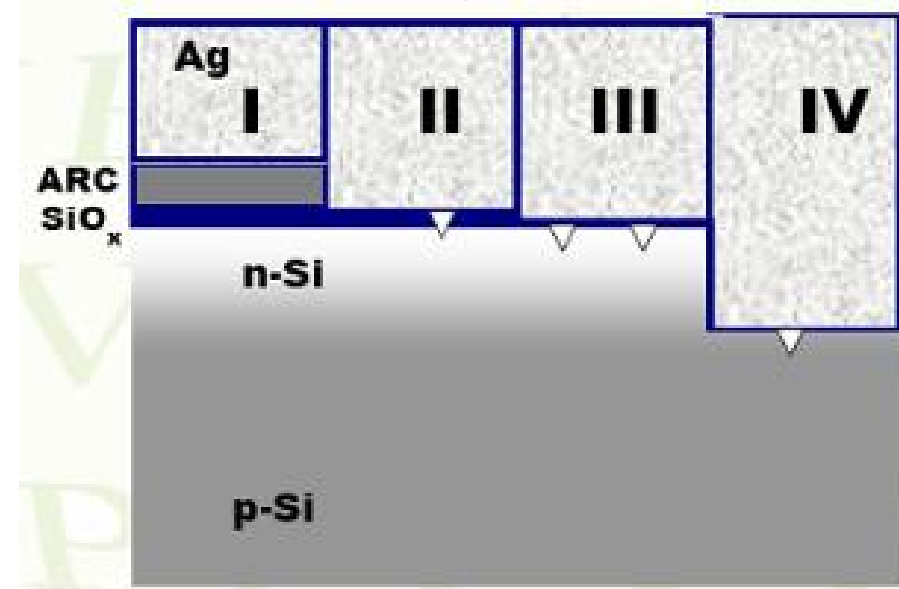
Agenda

- Solamet® company introduction
 - ✓ Technical center & manufacturing site
 - ✓ Solamet intellectual property
- N-TOPCon FS paste selection guide
 - ✓ Metal recombination vs. contact
 - ✓ Efficiency vs. reliability
 - ✓ Module BOM impact to reliability

Frit is the Key for Firing Metallization Process

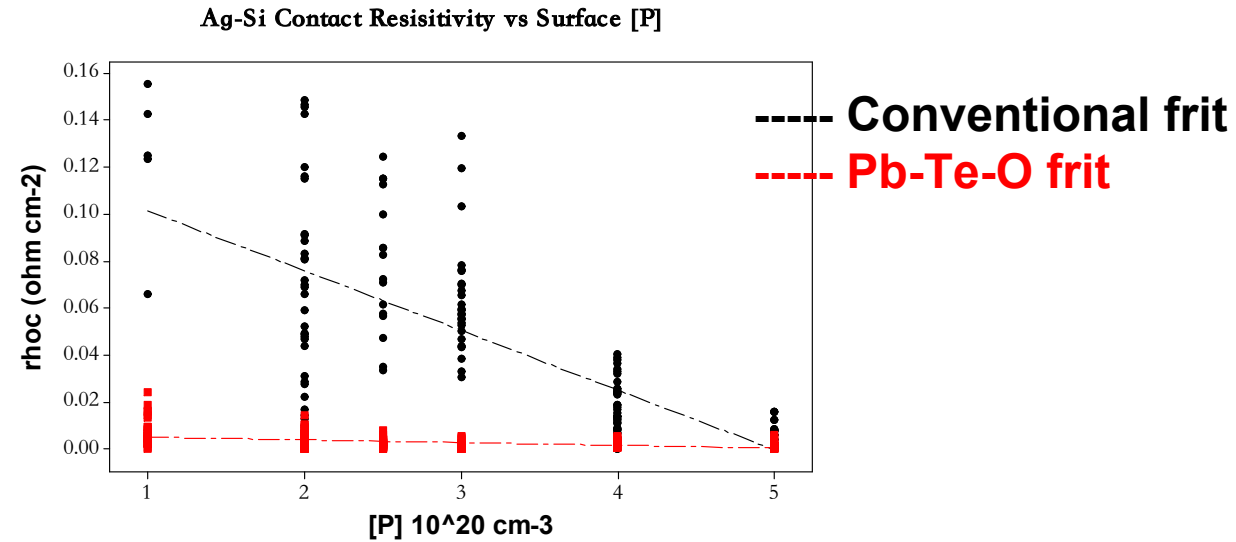
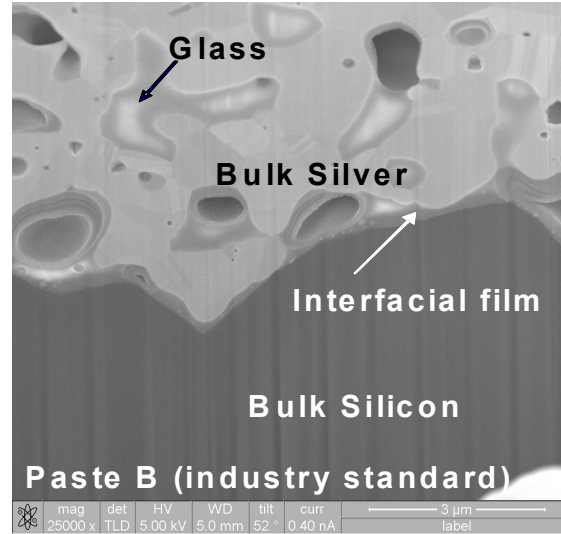
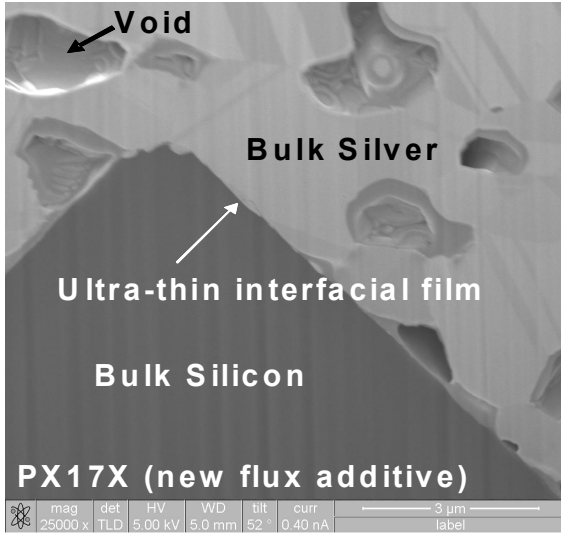


Progressive
Ag-Si Interaction
Ideal State = III

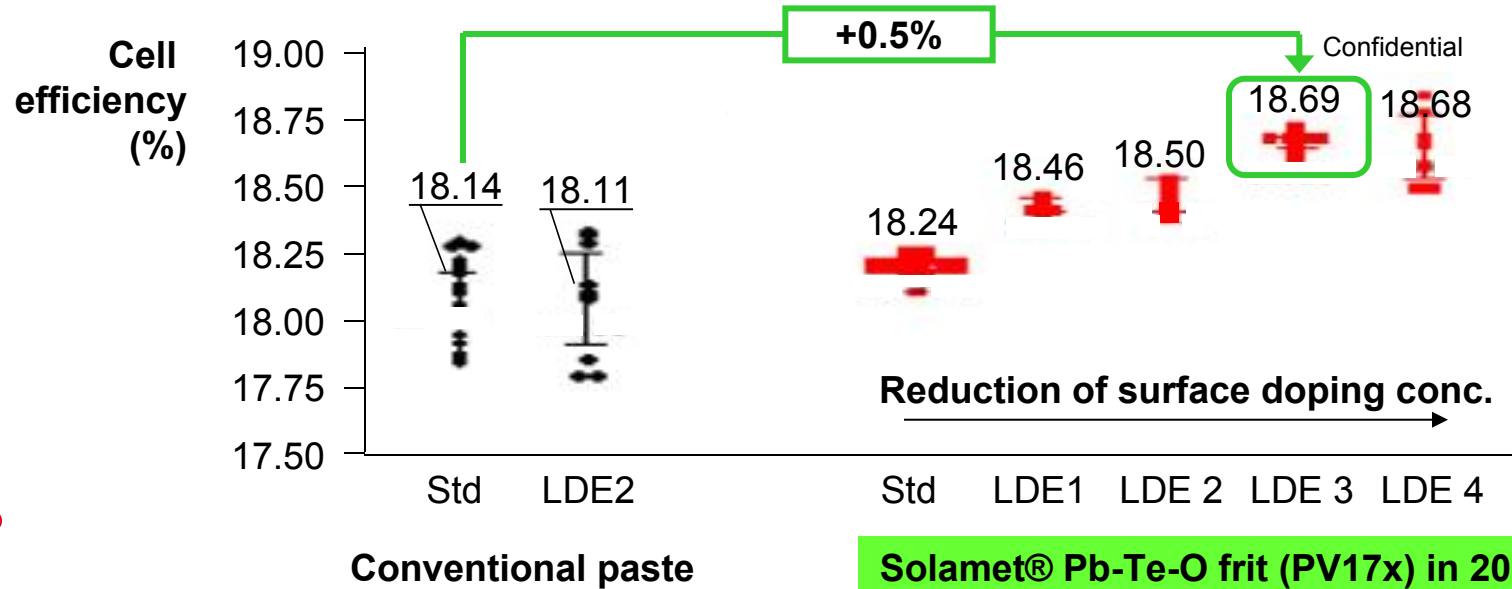


- Etch through ARC in a controlled manner → Uniformly remove SiN_x:H at high temperature
- Contact emitter with thin interfacial films → Reduce R_{contact} , reduce R_{series} ;

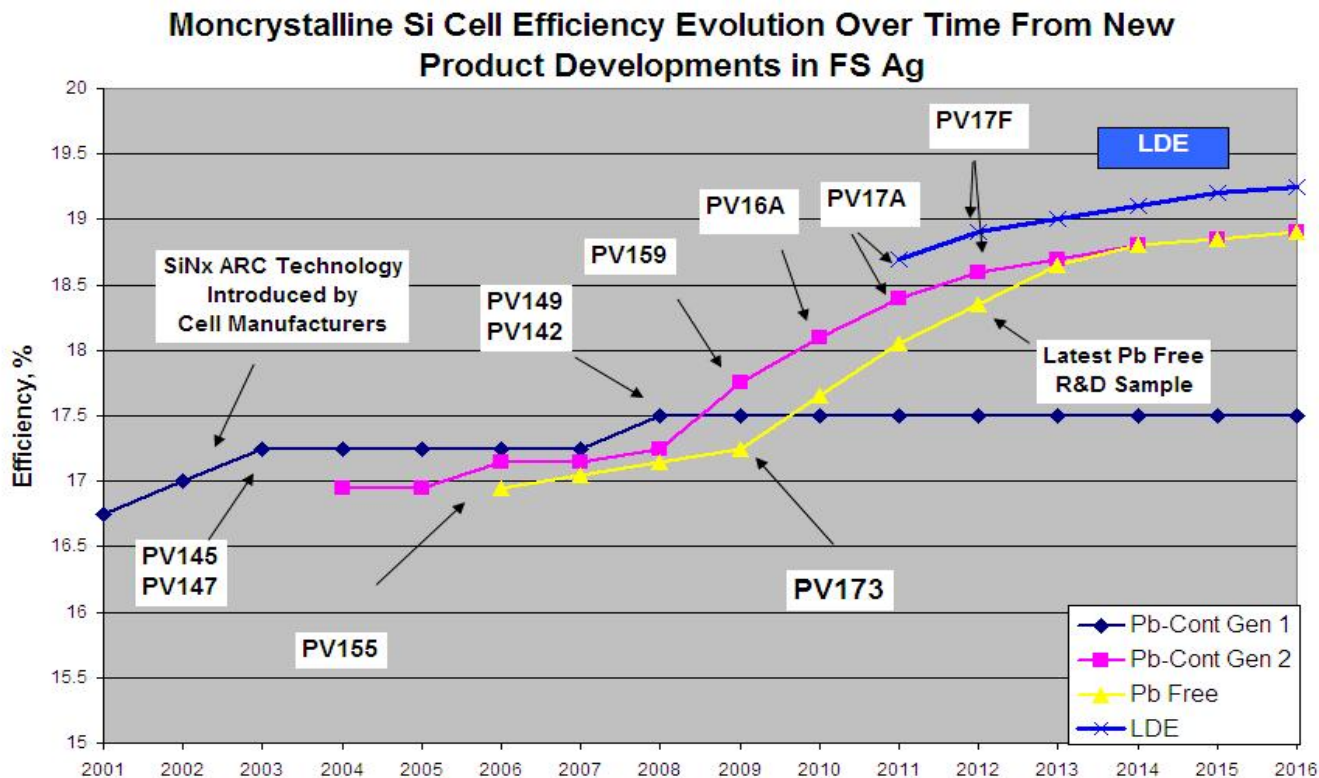
Pb-Te-O Frit Enable LDE with Significant Eff. Improvement



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



Solamet®'s Pb-Te-O Frit Chemistry Helped a Step Change in PV Cell Efficiency



Pb-Te-O frit was introduced from PV17x

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

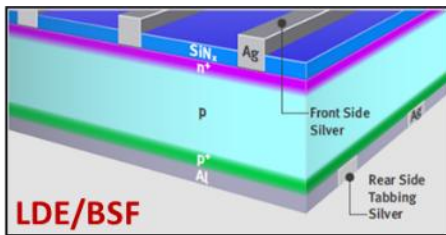
Supported by Solamet patented Pb-Te-O frit chemistry for all high temperature firing metallization process

2018

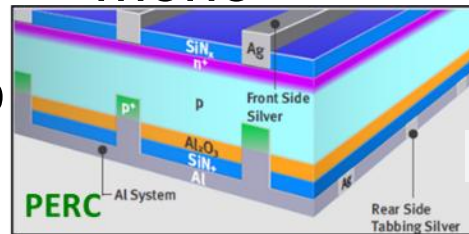


ACS Awards
Heroes of Chemistry

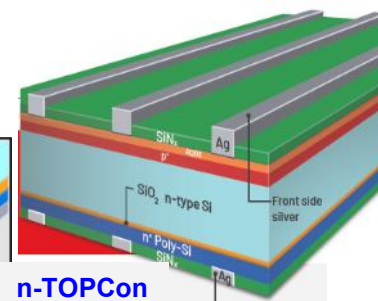
Pb-Te-O frit chemistry



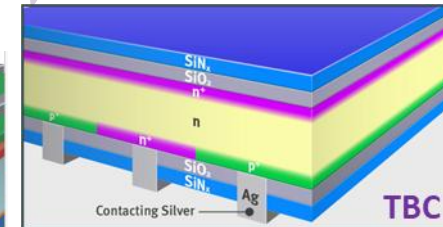
Mono
LDE



PERC
mono



N-
TOPCon



TBC

PbTeO frit chemistry enabled mono LDE, and continue to be the chosen frit system in current PERC mono/n-TOPCon and future BC platform

Selected Solamet® Patents on Te Frit Technology

US Patents

US8497420
US8889980
US8895843
US9722100
US10069020
US10468542
US10559703
US10658528

South Korea Patents

KR10-1569567
KR10-1569568
KR10-2031570
KR10-2048388

European Patents

EP2566823
EP2566824
EP2566826

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

>115
patent families

▶ Key granted patents have >10 years of remaining life

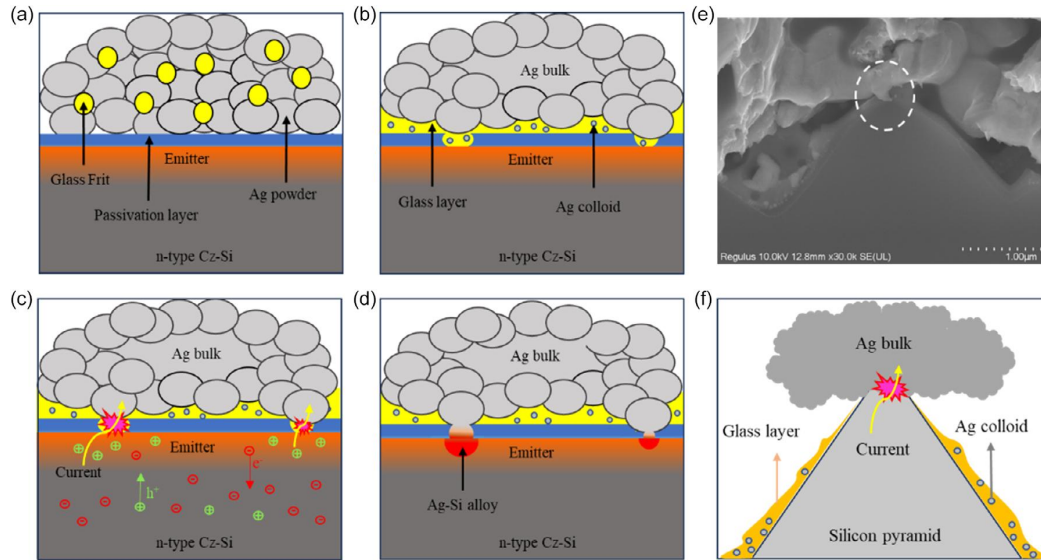
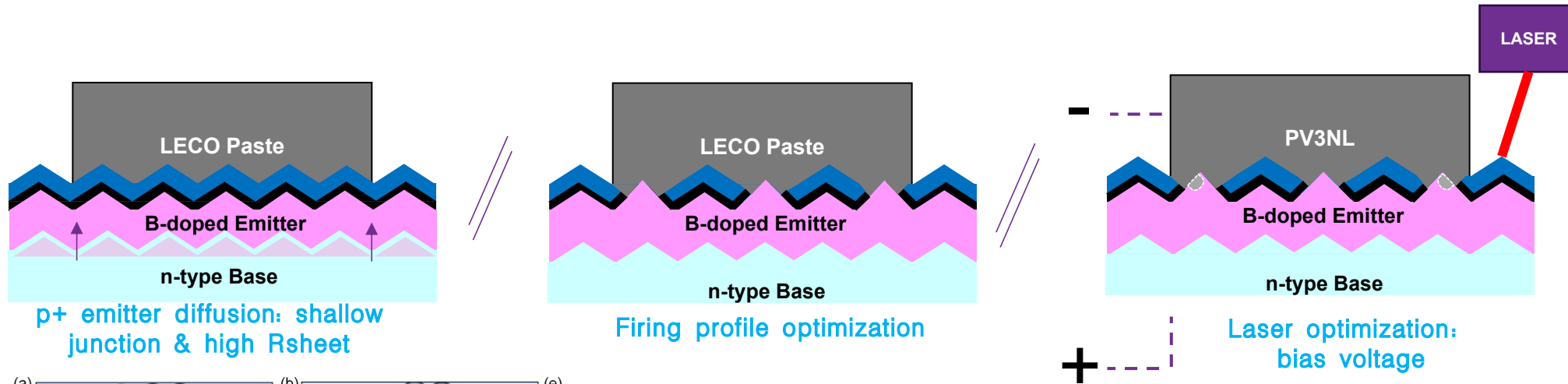
▶ Solamet® IP based on the Pb-Te-O frit technology is the keystone to the PV paste industry

▶ Nearly all p-type, n-TOPCon and TBC Si solar cells today uses Solamet® innovations

Agenda

- Solamet® company introduction
 - ✓ Technical center & manufacturing site
 - ✓ Solamet intellectual property
- N-TOPCon FS paste selection guide
 - ✓ Metal recombination vs. contact
 - ✓ Efficiency vs. reliability
 - ✓ Module BOM impact to reliability

n-TOPCon Efficiency Improvement: Contact & Metal Recombination Balance (p+)



Fan et al., Solar RRL, 2024, 2024, 8, 2400268

Paste	Firing Pk T	Laser Bias V	Δ Eff (%)	Δ Voc (mV)	Δ FF (%)	Δ Isc (mA)
BSL(Ag-Al) w/o LECO	-	-	-	-	-	-
LECO Paste A -BSL	-20°C	-	0.30	5.8	0.19	-13
LECO Paste A -BSL	-40°C	-	0.37	6.1	0.32	-15
LECO Paste A -BSL	-60°C	-	0.36	6.3	0.25	-12
LECO Paste A -BSL	-60°C	+5%	0.39	6.0	0.41	-5

p+ Emitter Diffusion Optimization

Efficiency improvement by high Rsheet

TOPCon P+ Emitter High Rsheet x LECO Pastes Test						
Paste	Rsheet (Ω/\square)	Δ Eff (%)	Δ Voc (mV)	Δ FF (%)	Δ Isc (mA)	
A	350	0	0	0	0	
A	380	0.01	1.4	-0.13	2	
B	380	0.07	0.8	0.14	-2	

- LECO + specialty LECO pastes make metallization on TOPCon high Rsheet p+ emitter possible.
- Paste B showed better balance between metal recombination and contact than baseline A and boosted eff on higher Rsheet wafer.

FS Rsheet(Ω/\square):150 \rightarrow ~400 now \rightarrow What is high Rsheet limitation? SE may come back?

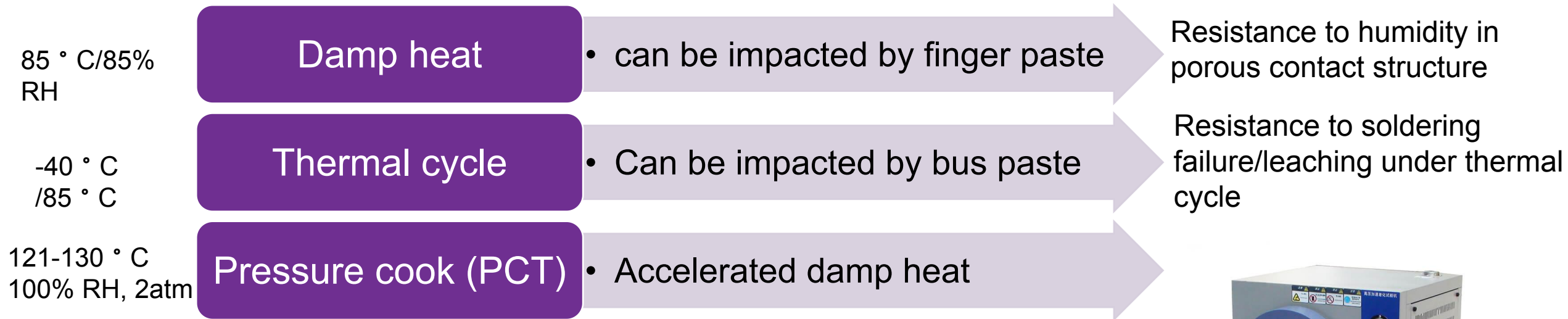
With LECO process, customized frit is still critical while moving to high Rsheet to optimize efficiency

Agenda

- Solamet® company introduction
 - ✓ Technical center & manufacturing site
 - ✓ Solamet intellectual property
- N-TOPCon FS paste selection guide
 - ✓ Metal recombination vs. contact
 - ✓ Efficiency vs. reliability
 - ✓ Module BOM impact to reliability

Reliability Issue from Metallization Front-side Finger Paste

The most relevant reliability issue from paste



In order to achieve better reliability (most likely damp heat/PCT from finger), frit optimization is needed and may have up to 0.05-0.1% eff. compromise based on different p+ emitter or LECO process parameter

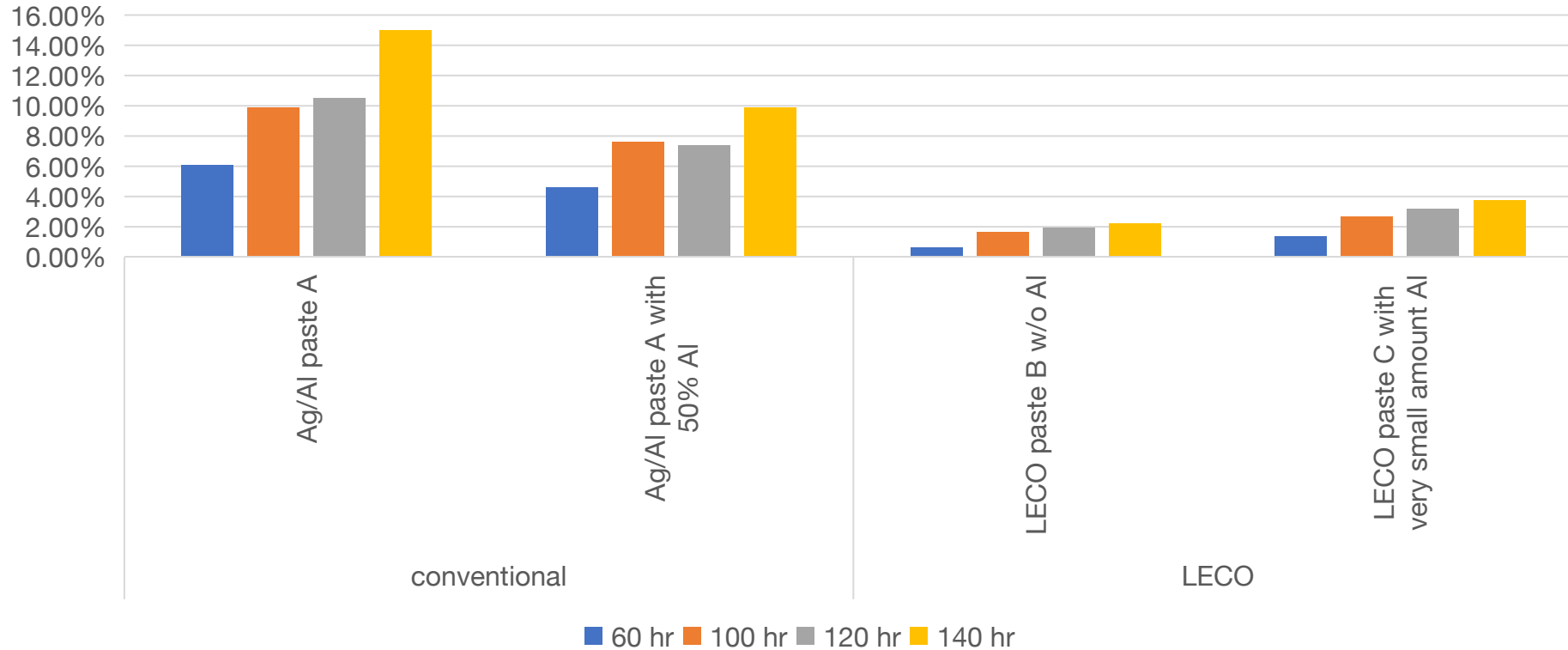


Reliability Issue from Metallization Front-side Finger Paste

Example :

Test by TOPCon double glass/POE mini module

IV degradation (PCT)



LECO paste without Al demonstrate significantly better PCT performance → but is there any other factor to impact reliability?

Agenda

- Solamet® company introduction
 - ✓ Technical center & manufacturing site
 - ✓ Solamet intellectual property
- N-TOPCon FS paste selection guide
 - ✓ Metal recombination vs. contact
 - ✓ Efficiency vs. reliability
 - ✓ Module BOM impact to reliability

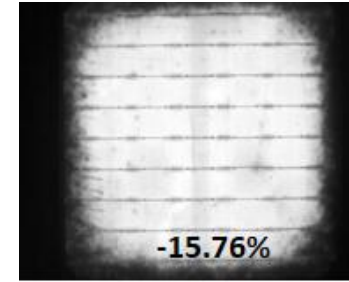
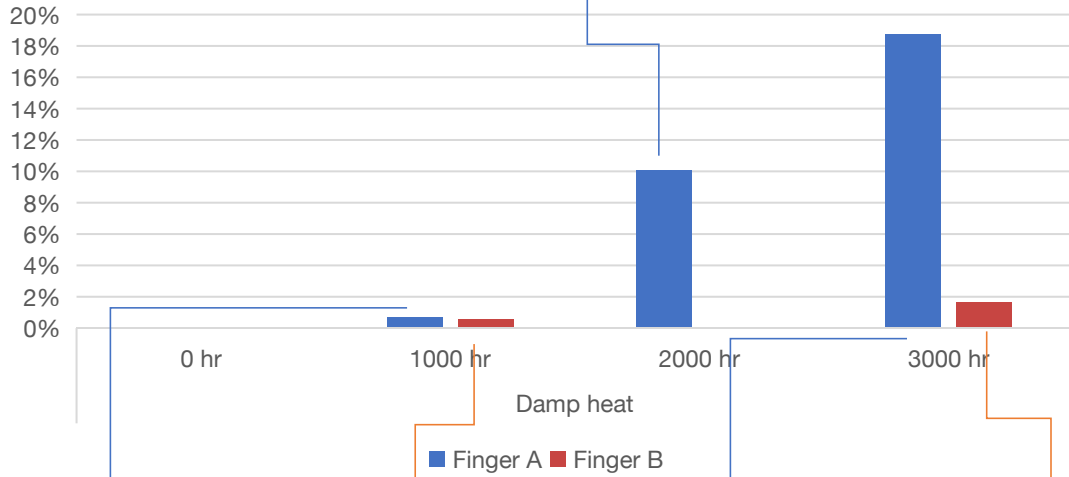
Module BOM Impact to Reliability- Case Sharing in 2023



Tested by PERC mono mini module
(single glass/EVA)

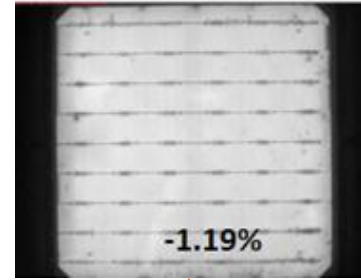
-10.05%

IV degradation (damp heat)

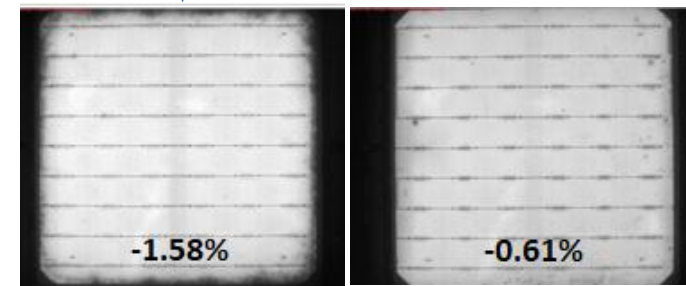
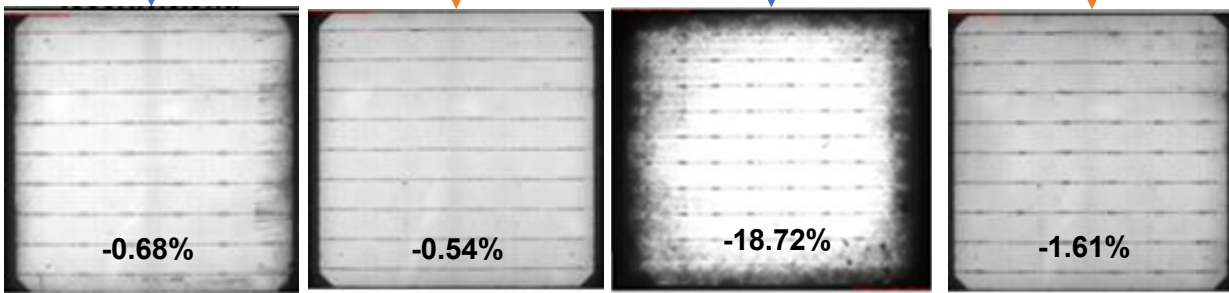
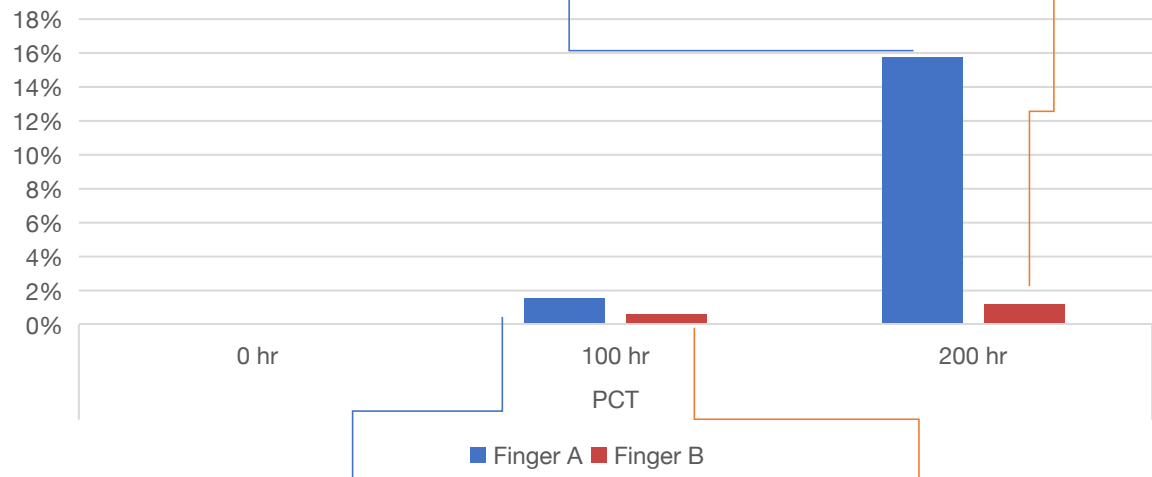


IV degradation (PCT)

-15.76%



-1.19%

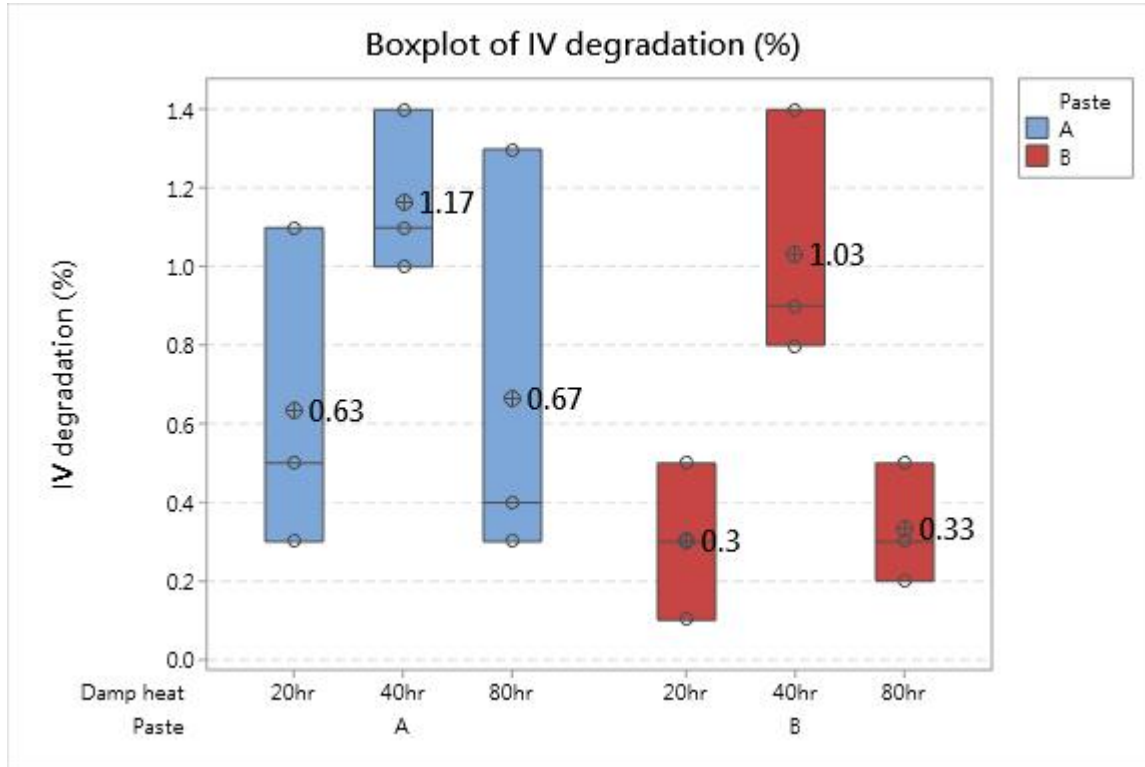


Very good correlation between damp heat and PCT

Module BOM Impact to Reliability- Case Sharing in 2023

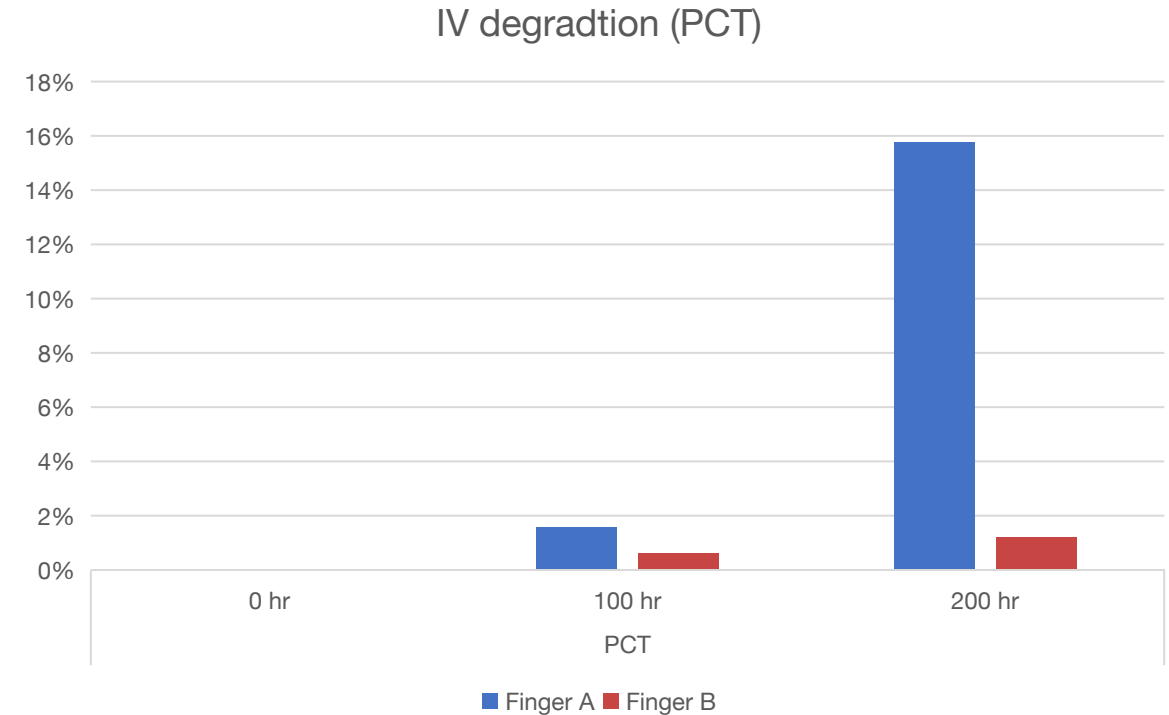
[Tsted by PERC mono bare cell](#)

Damp heat test
85degC / 85% RH



[Tested by PERC mono mini module \(single glass/EVA\)](#)

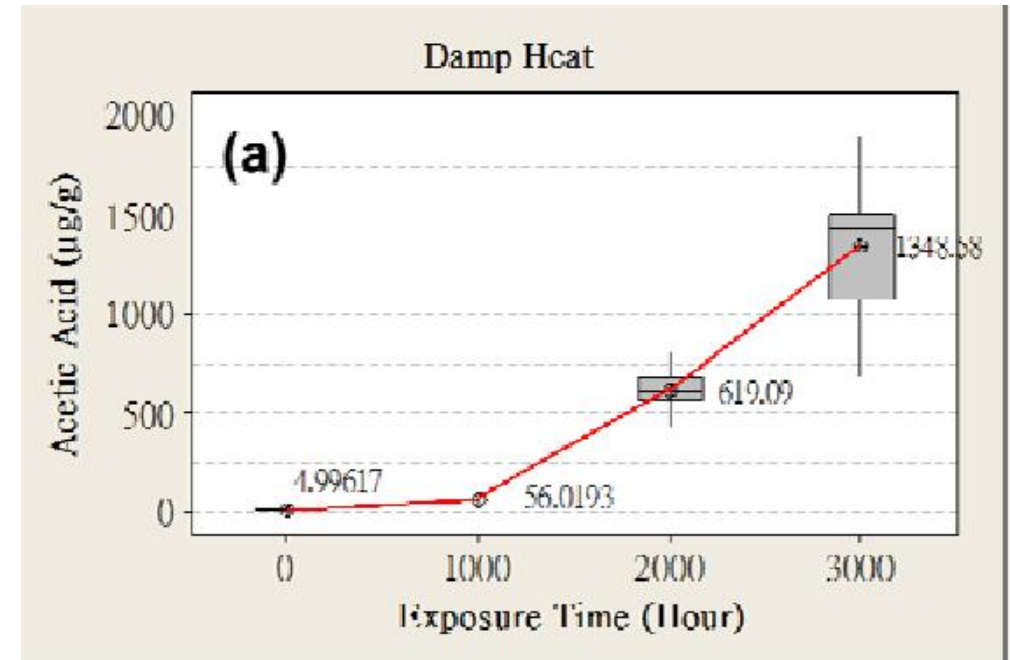
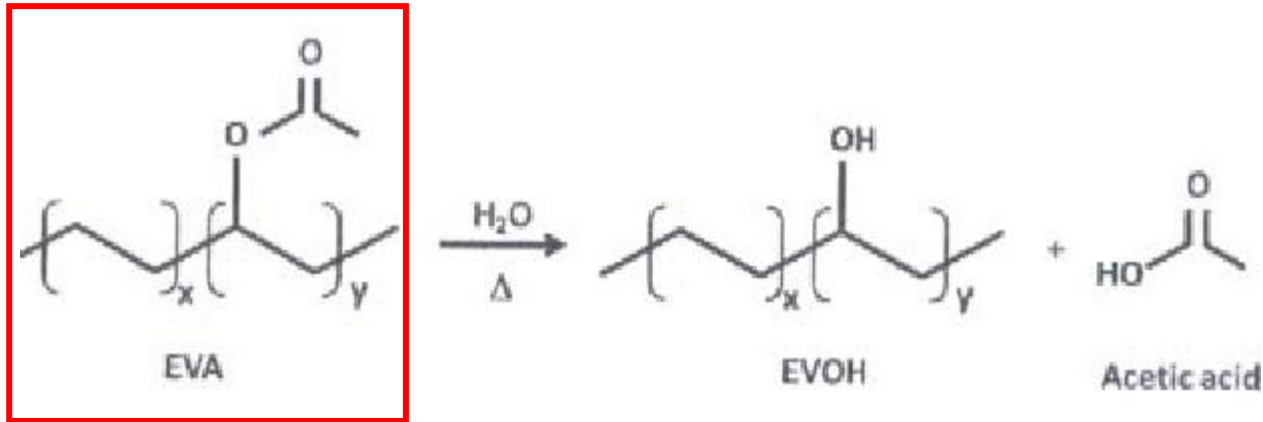
PCT
121degC / 100% RH (2atm)



Why damp heat test by bare cell was **NOT** aligned to module damp heat/PCT performance?

Module BOM Impact to Reliability- Case Sharing in 2023

Theoretically bare cell test is even harsher, the difference between bare cell and module test is **encapsulant material**



Courtesy of a paper from :
Determination of Acetic Acid Content in Ethylene-Vinyl Acetate (EVA) Based PV Modules
Ethan Wang, H. Yang, Sunny Chi, Carl K. Wang, C. Peng, Chih-Chun, Tsai, Ivan Chou
Published 2013
Engineering, Environmental Science, Materials Science, Chemistry

Encapsulant EVA is the major source of acetic acid generation accelerated by humidity & temperature
→ with encapsulant EVA, more concern for backsheet vs. double glass module

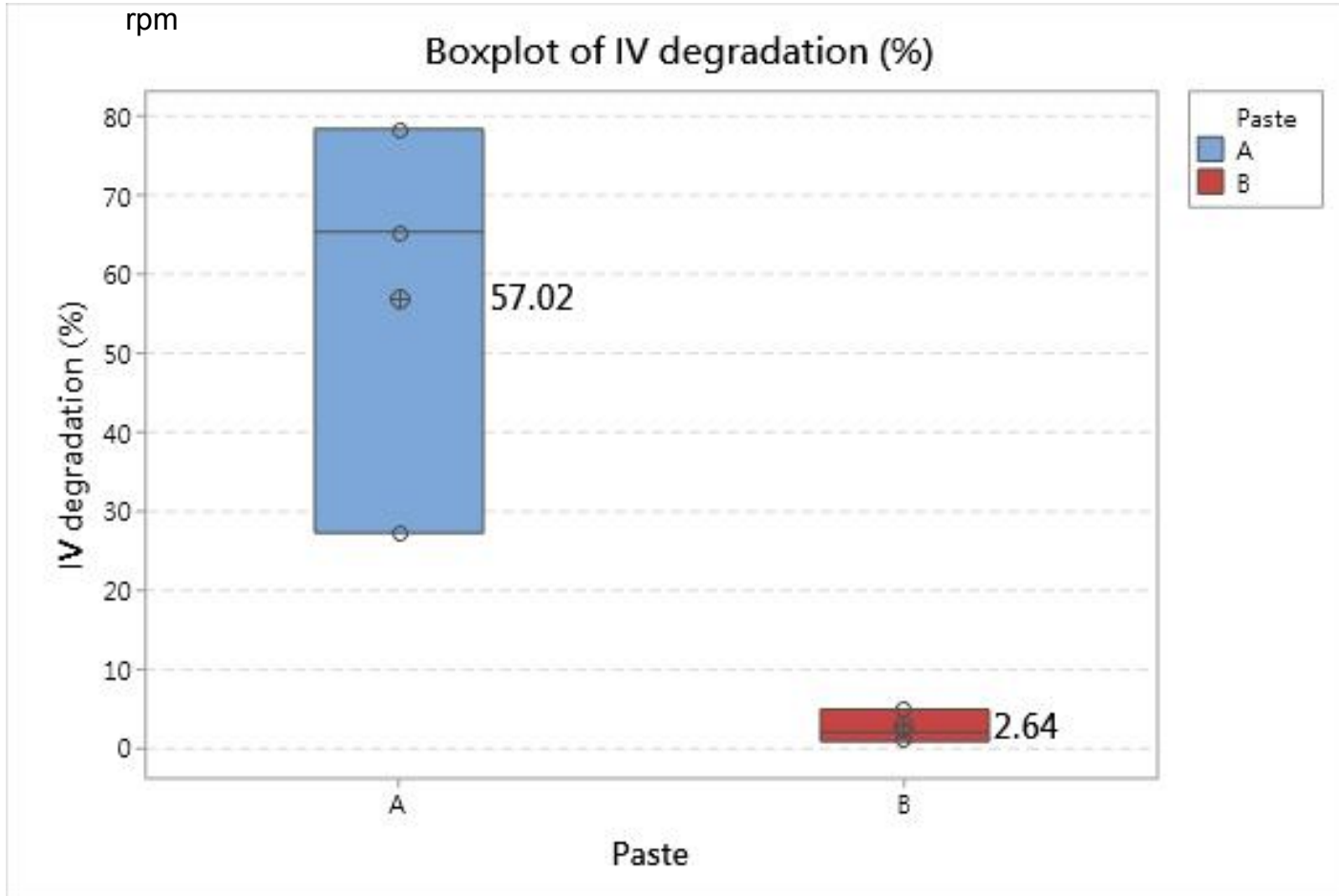
Module BOM Impact to Reliability- Case Sharing in 2023

[Tsted by PERC mono bare cell](#)

Acetic acid test

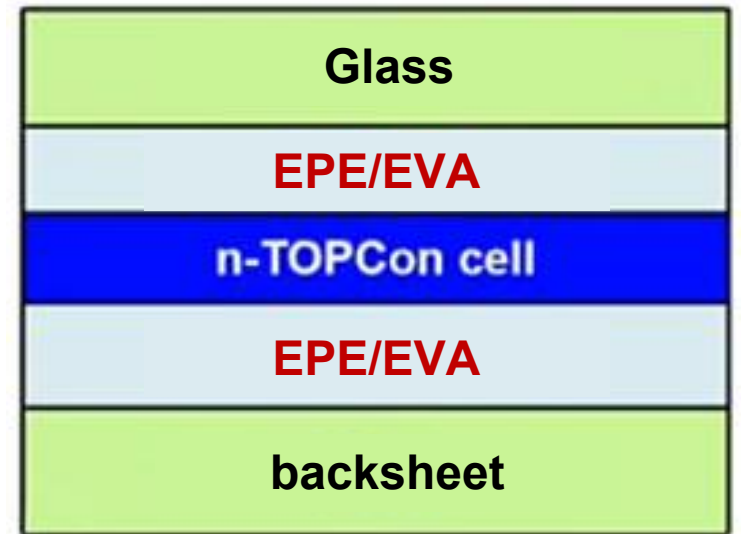
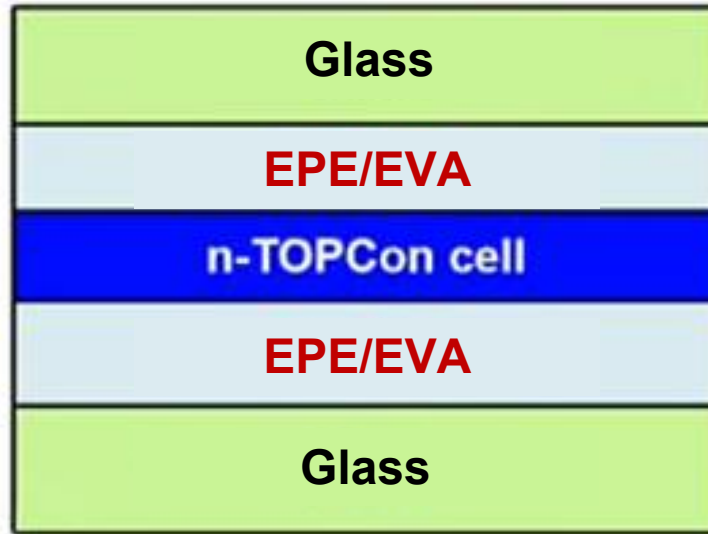
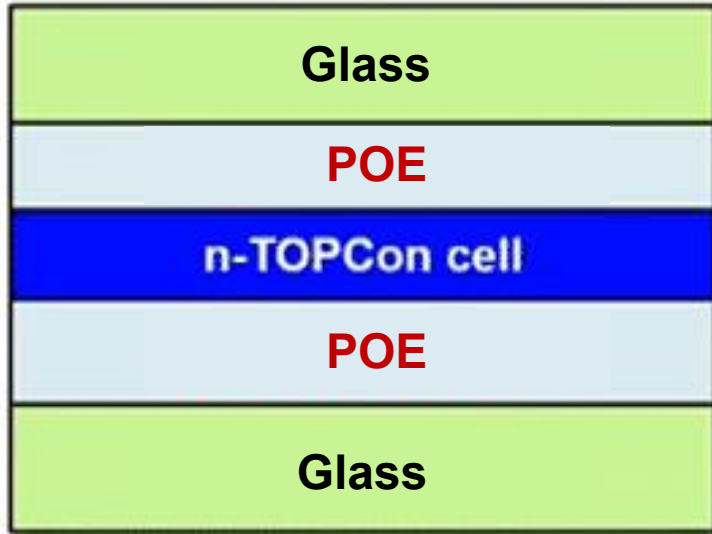
AcOH conc. 1%; KCl conc. 37%; Time: 4hr; Temp:85degC; Fan: 3000

rpm

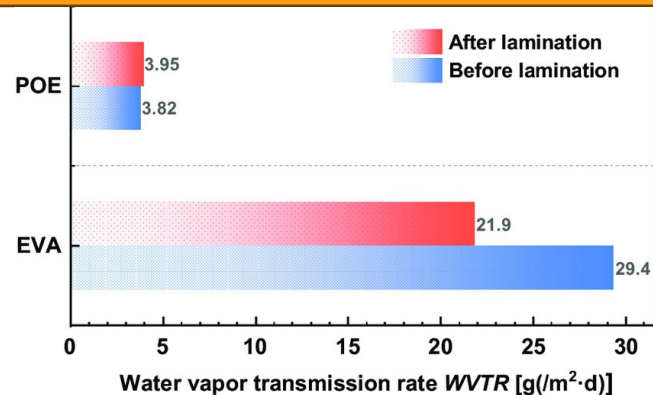


From acetic acid test, clear performance difference was seen between finger A & B, which explained that the damp heat failure of finger A with EVA encapsulated module but ok with bare cell

Module BOM Impact to Reliability



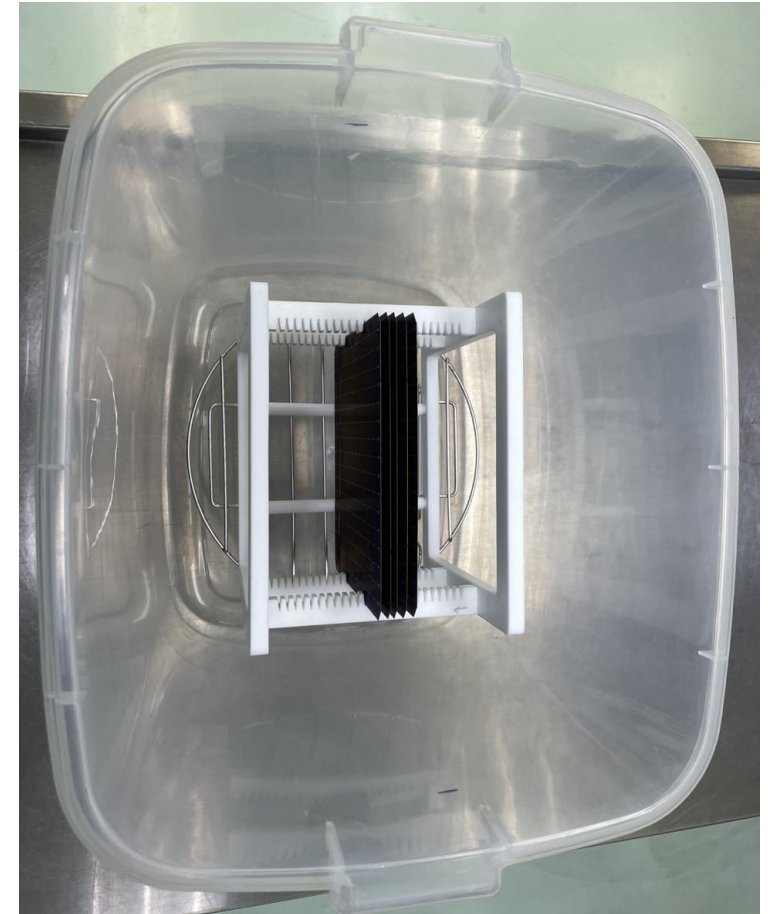
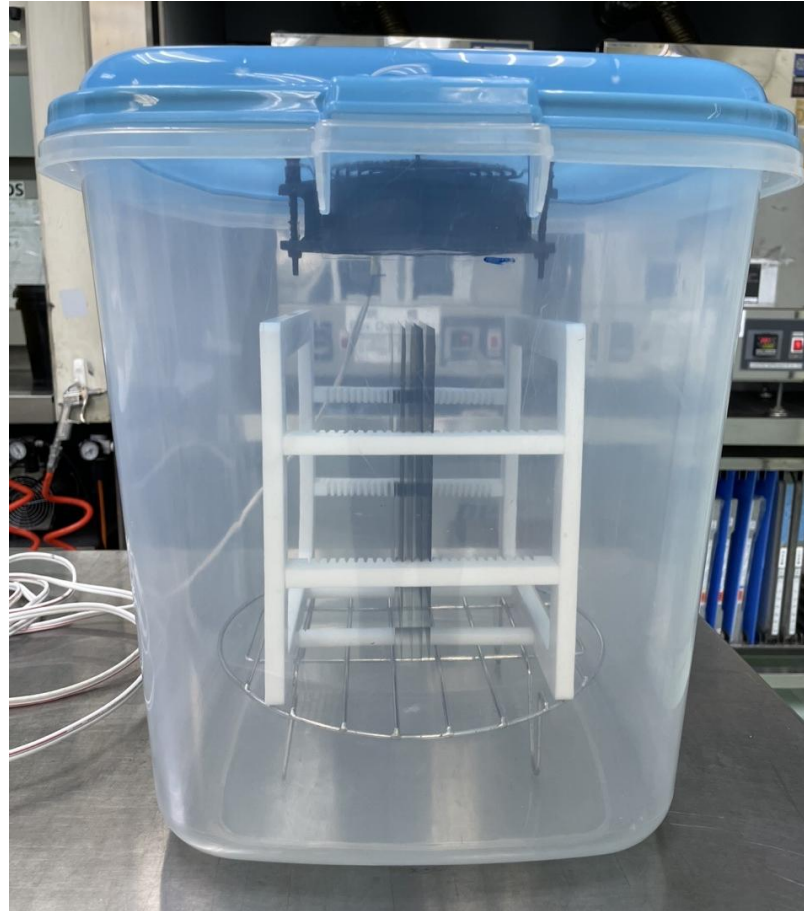
May not need to consider acetic acid impact to reliability



Need seriously considering acetic acid impact to reliability

Module BOM Impact to Reliability- acetic acid test optimization

Solamet internal acetic acid test setup



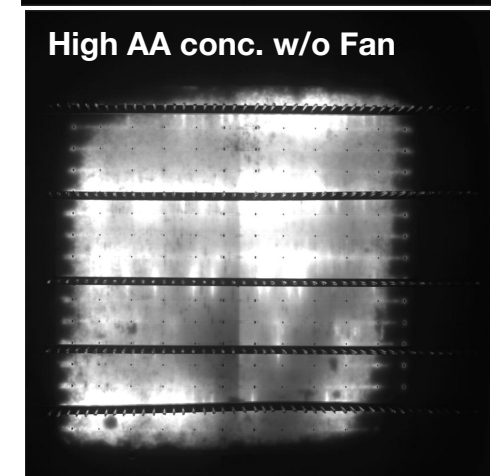
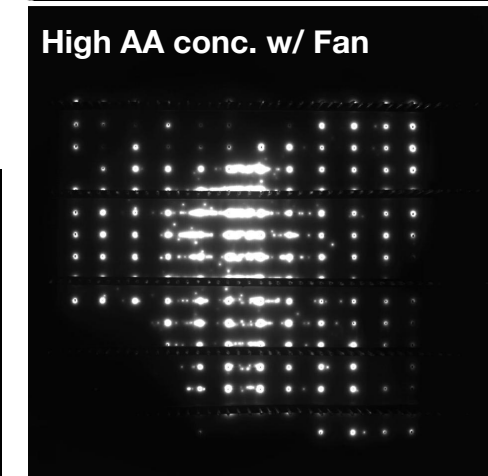
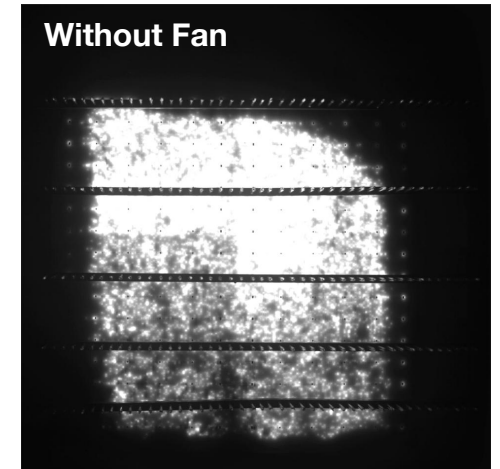
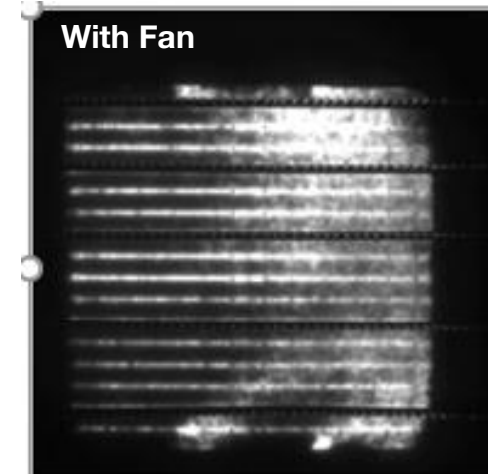
Module BOM Impact to Reliability- acetic acid test optimization

Acetic Acid test in the market

Company	C company	T company	S company	S company-2	Solamet
AcOH conc.	0.30%	4.8%	10%	5%	1.0%
KCl conc.	39%	19%	38%	29%	37%
Time	8hr	6hr	4hr	6hr	4hr
Temperature	85C	85C	85	85	85C
Fan	0.25~0.35 m/s	N/A	N/A	N/A	3000 rpm
Spec.	<20%	<40%	<30%	<40%	ok control

Group	temp.(C)	AcOH conc.	time(hr)	Fan	衰减 (eff)	Difference between good & bad	Repeatability
1	85	3	4	v	>98%	No (all EL dark)	
2	85	0.3	4	v	<15%	OK	
3	85	3	4	x	<15%	Degradation between good & bad is small	Not good
4	85	10	4	x	~60%	Large variation between cells	Not good

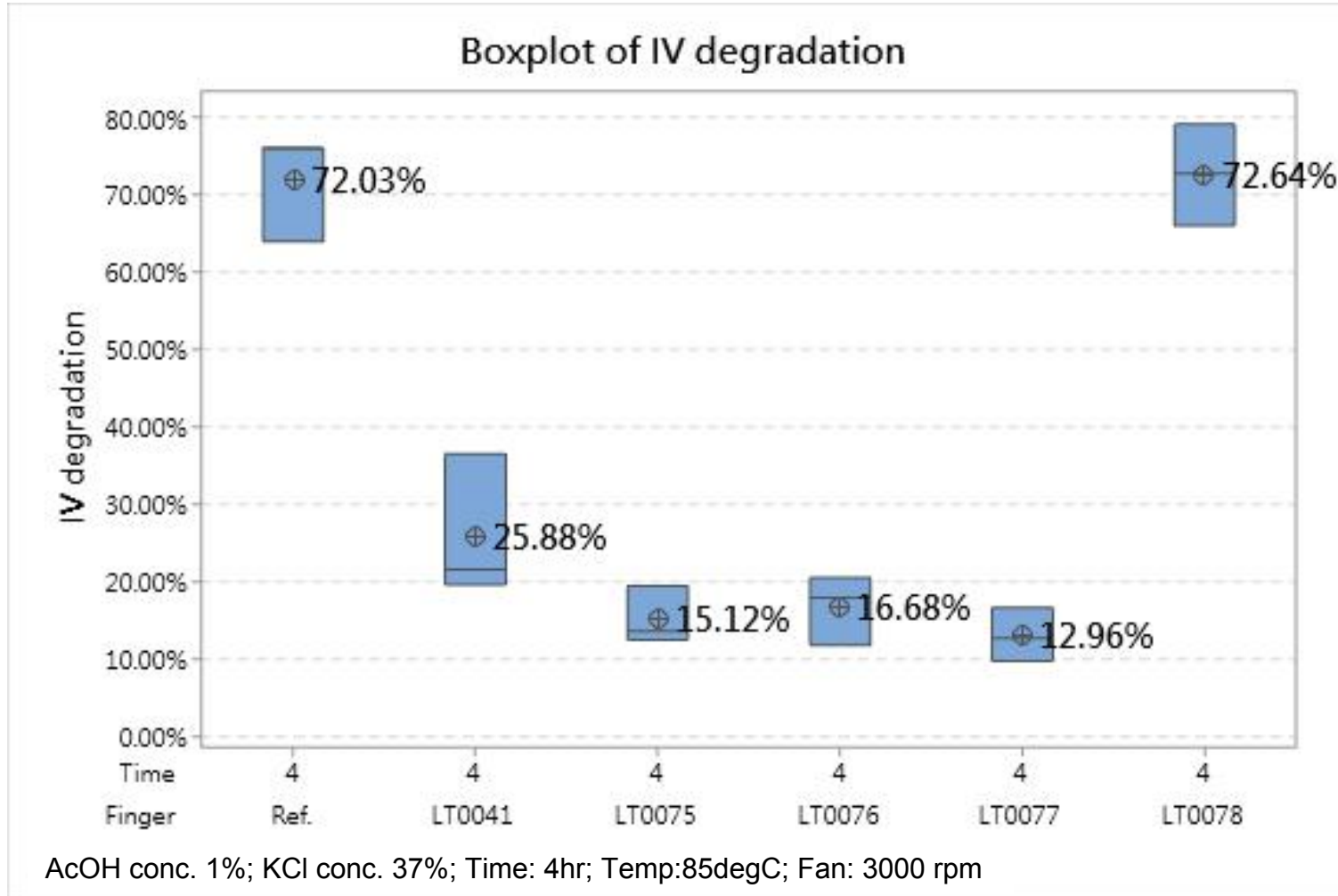
5	85	1	4	v	60~70%	OK	Good
---	----	---	---	---	--------	----	------



➔ This recipe was selected for Solamet internal test

Module BOM Impact to Reliability

Example of LECO front-side finger impact to acetic acid performance



Summary of TOPCon FS Finger Selection

- Understand reliability requirement like damp heat 1000hr, 2000hr, 3000hr, etc. and encapsulant BOMs → select suitable inorganic system to meet reliability requirement
 - ❑ Double glass with POE → less reliability concern
 - ❑ Double glass with EPE/EVA → acetic acid resistance need to be considered
 - ❑ Glass-backsheet with EVA → need strong acetic acid resistance and some degree of efficiency compromise may exist
- Specify sheet resistivity and screen spec. including opening → pick up optimized inorganic to balance contact and metal recombination and vehicle for designed screen spec.

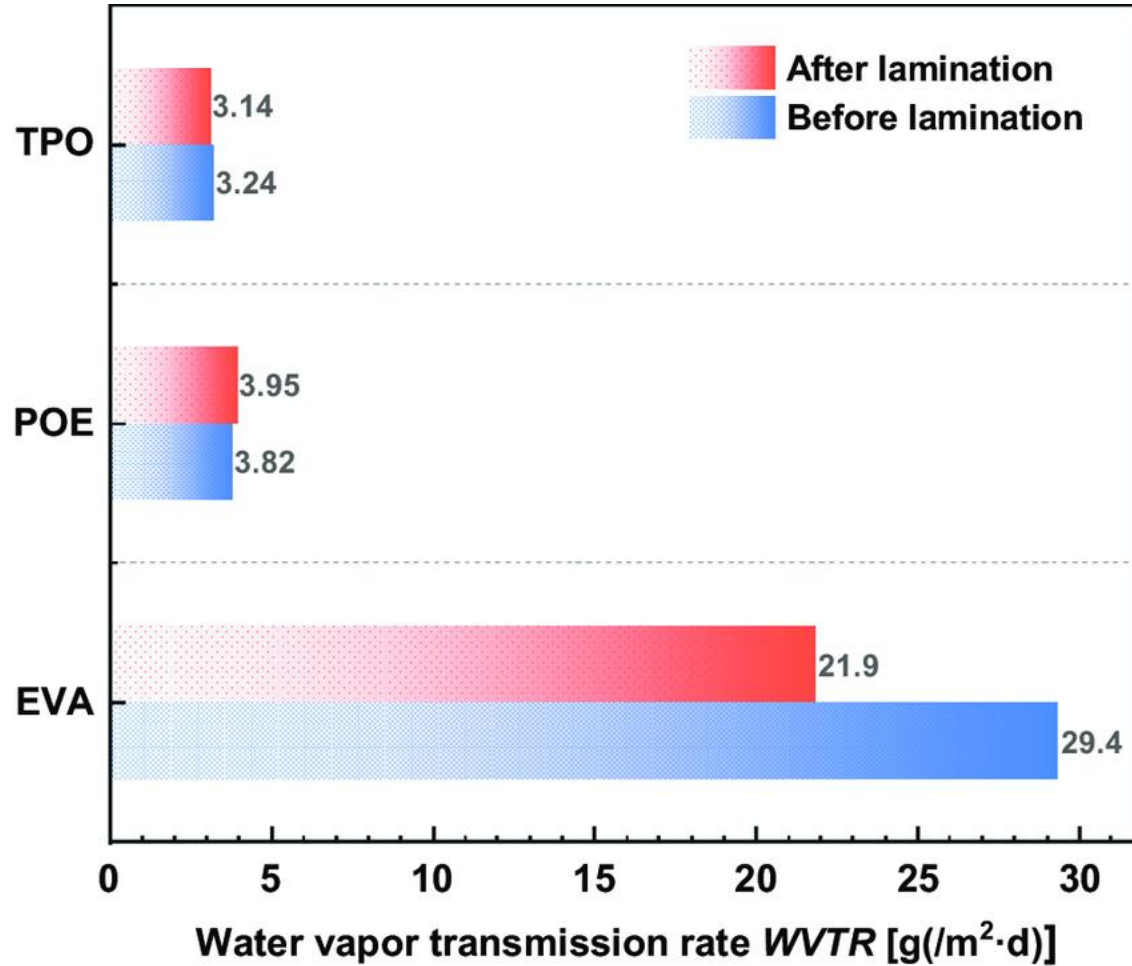


Copyright © 2025 Solamet. All rights reserved. Solamet® and the Solamet Logo are trademarks or registered trademarks of Solamet Electronic Materials Co., Ltd.

Nothing contained herein shall be construed as a representation that any recommendations, use or resale of the product or process described herein is permitted and complies with the rules or regulations of any countries, regions, localities, etc., or does not infringe upon patents or other intellectual property rights of third parties.

The information provided herein is based on data Solamet believes to be reliable, to the best of its knowledge and is provided at the request of and without charge to our customers. Accordingly, Solamet does not guarantee or warrant such information and assumes no liability for its use. If this product literature is translated, the original English version will control and Solamet hereby disclaims responsibility for any errors caused by translation. This document is subject to change without further notice.

Different Encapsulant Water Resistance Performance



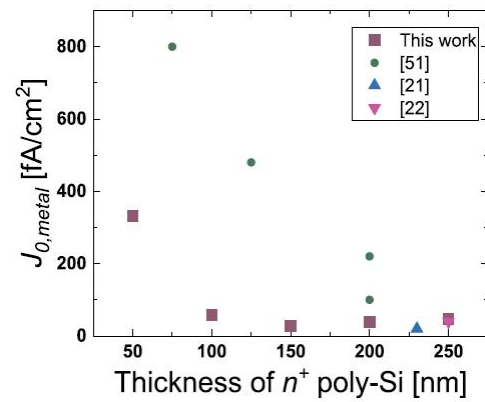
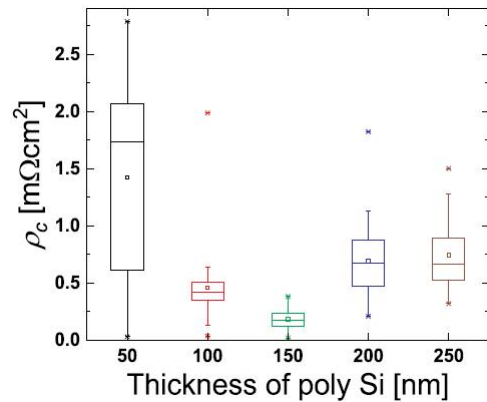
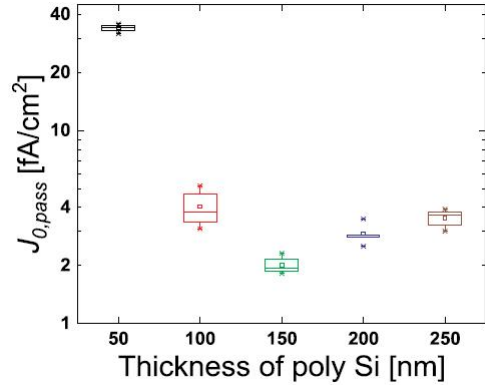
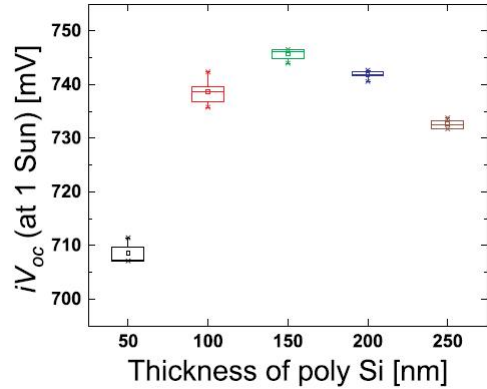
Lower LCOE achievement of silicon heterojunction solar modules with low water vapor transmission rate encapsulants
March 2023 Energy Technology 11

Agenda

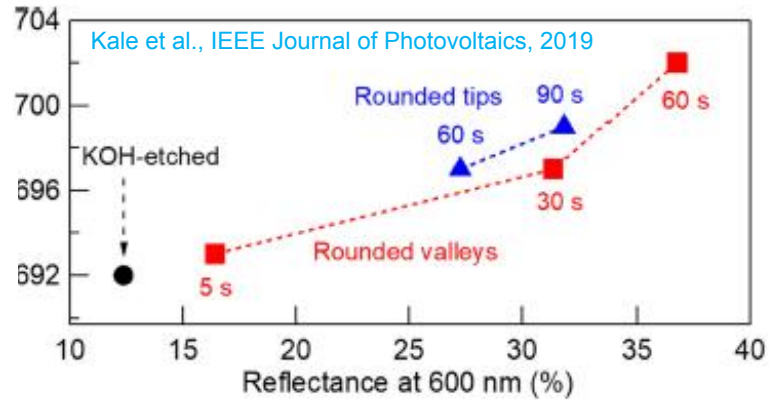
- Solamet® company introduction
 - ✓ Technical center & manufacturing site
 - ✓ Solamet intellectual property
 - N-TOPCon FS paste selection guide
 - ✓ Metal recombination vs. contact
 - ✓ Efficiency vs. reliability
 - ✓ Module BOM impact to reliability
 - N-TOPCon RS paste selection guide
 - ✓ Surface polish and poly thickness impact
-

n-TOPCon Efficiency Optimization for RS finger: Contact & Metal Recombination Balance (n+ Poly)

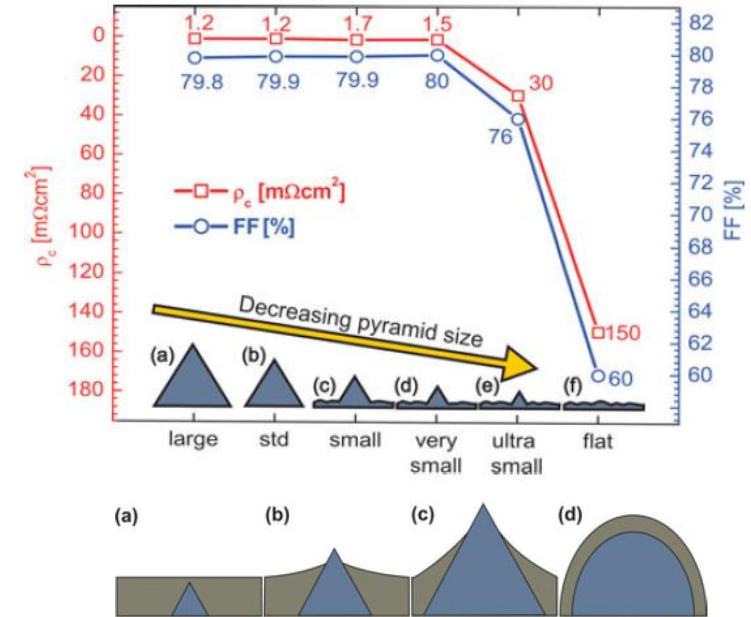
Thinner polysilicon (<75 nm) can reduce parasitic absorption losses. However, it also leads to poor passivation and higher recombination, resulting in significant Voc loss



Padhamnath et al., Solar Energy Materials & Solar Cells 207, 110358 (2020)

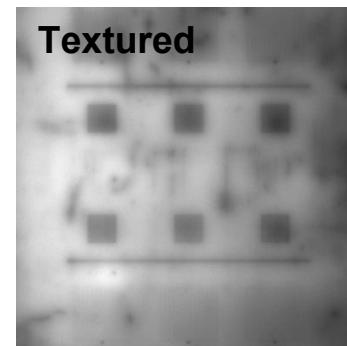
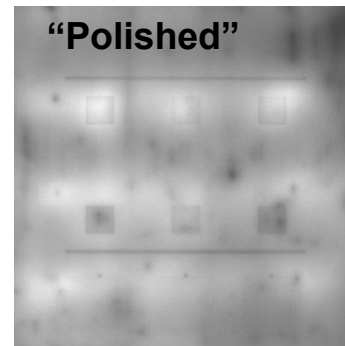


A smoother texturing on the back side improves the Poly-Si passivation but at the same time increases the need for contact



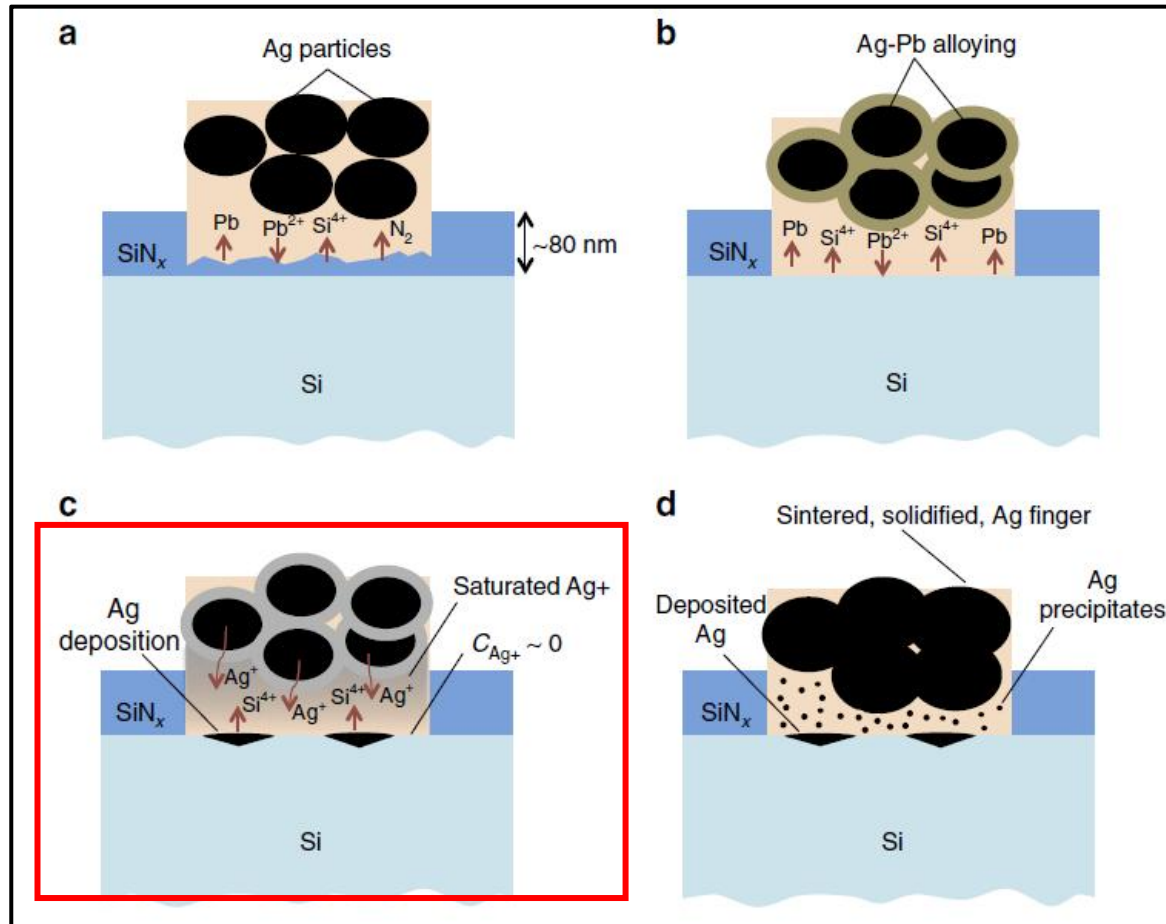
Cabrera et al, IEEE Journal of Photovoltaics, Vol 3, No. 1, 2013

Substantial improvement opportunity by optimizing RS texture with paste design



	ρ_c (mΩ-cm ²)	ΔV_{oc} (mV)
Polished	1.3	-0.23
Textured	1.1	-4.08

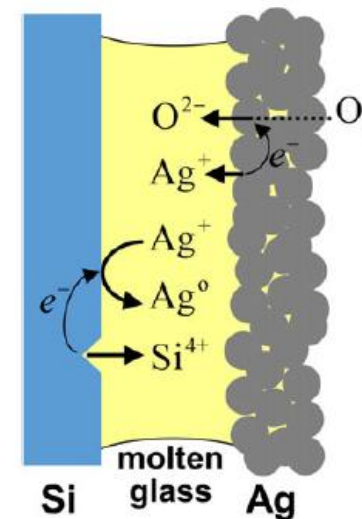
n-TOPCon Efficiency Optimization for RS finger: Contact & Metal Recombination Balance (n+ Poly)



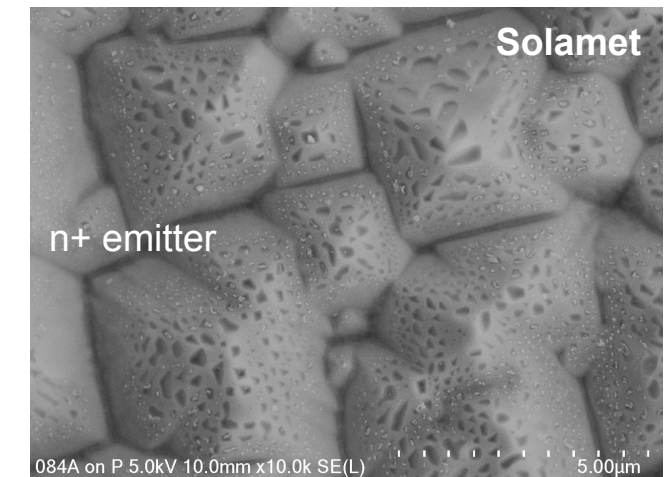
Fields et al, Nature Communications, 2016, 3, 11143

Fire through contact formation process:

- Low melting glass starts wetting and opening the SiN_x/AlO_x
- Ag⁺ is dissolved into the molten glass
- Transport of Ag⁺ to the n⁺ Poly-Si surface and deposit as Ag crystallites via an electrochemical redox reaction
- **The control of the above process is crucial for rear-side metallization. This process is governed by glass/Ag in the paste and is also influenced by factors such as the uniformity, thickness, and density of the passivation layer, the sensitivity of the poly layer in the metallization region, and the firing profile.**



Kim et al, Progress in Photovoltaics, 2016, 24, 1237-1250



The SEM morphology of the n⁺ emitter after selective etching to remove the silver grid lines, glass layer, and silver microcrystals