Printing Technologies for PV
Beyond Metal Pastes and Stainless Steel Screens

Dr. Ning CHEN

Wuxi Autowell Technology Co., Ltd.

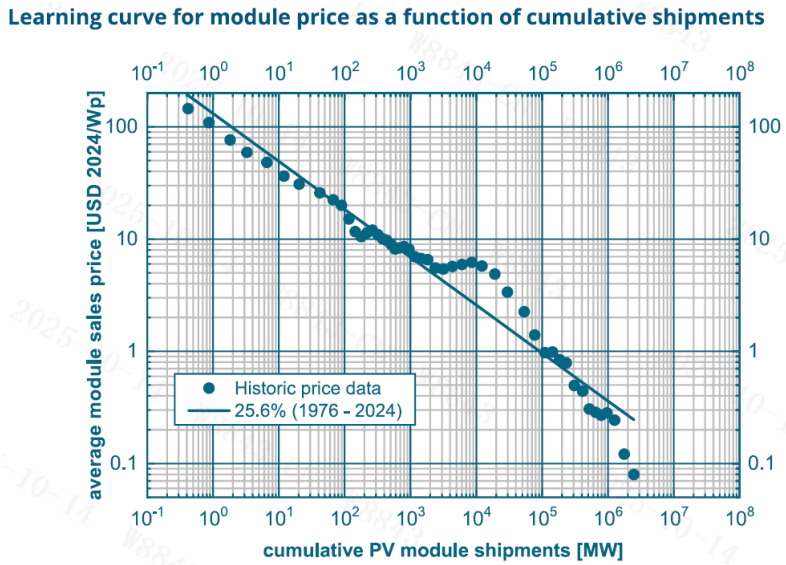
奥特维
股票代码：688516

MIW 2025, Berlin

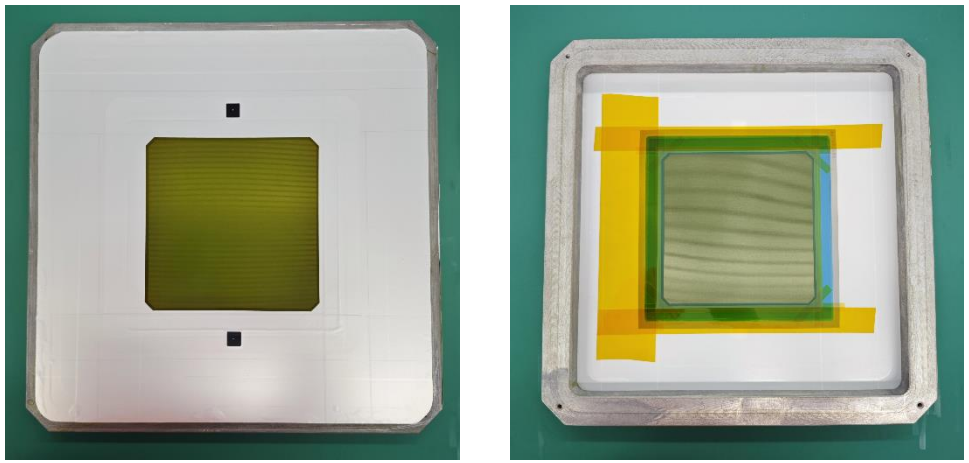
Introduction

- PV module price is record low
- But NOT the Ag paste
- But NOT the stainless steel screen

- Typical stainless steel screen for front fingers of TOPCon cells
  - Cost as high as € 1,000 per screen
  - If stainless steel mesh sale by weight the price is higher than Gold
  - Cost has to be compromised by increase screen lifetime



Source: ITRPV 2025



Screen, wafer side (left), squeegee side (right)

Outline

- Screen printing with non-Ag, even non-metal pastes
- Printing using non-SS screen

Pastes

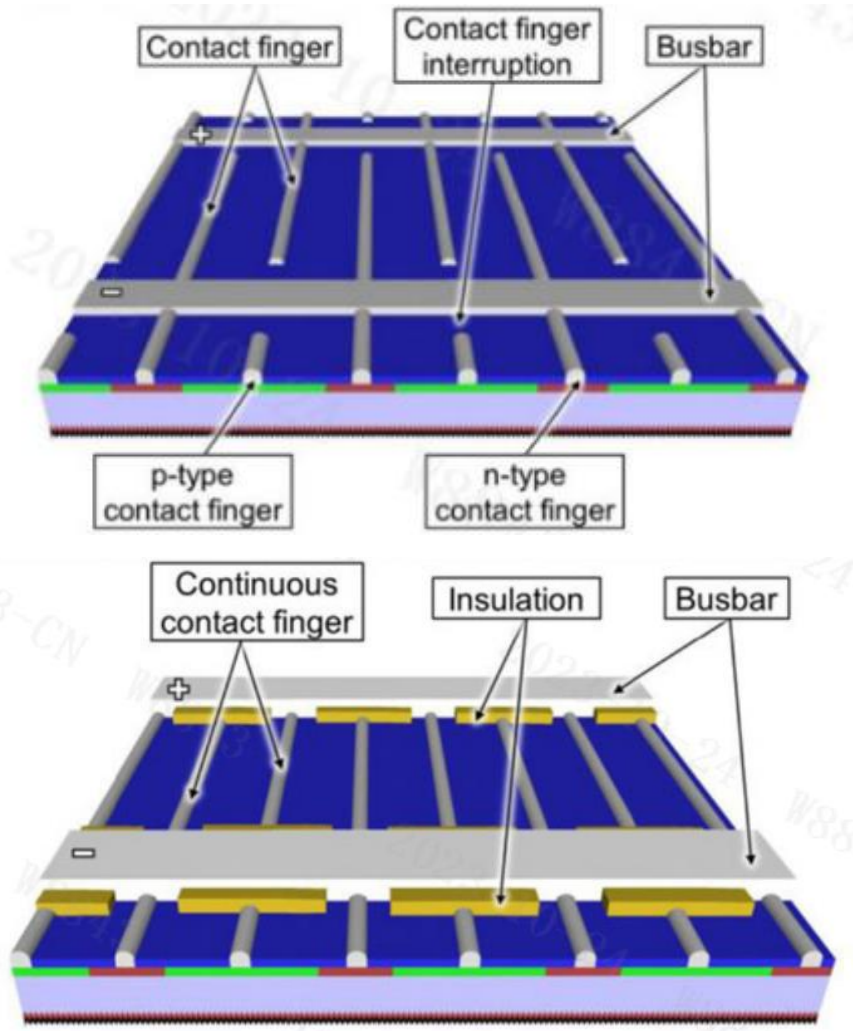
- TOPCon: Ag pastes
- SHJ: Ag coated Cu pastes
- IBC cells:
  - Ag/Al pastes
  - Paste for replacement of separation papers
  - Isolation pastes
  - Solder paste

Screen printing for IBC solar cells - Isolation paste

- 2D design, isolation paste printing is needed before interconnection
- 3D design, isolation paste printing during cell metallization

- 2D designed is widely used in mass production
- Special dryer for isolation paste
  - In-line dry furnace (IR, UV)
  - cassette dryer

Slide from MIW 2024



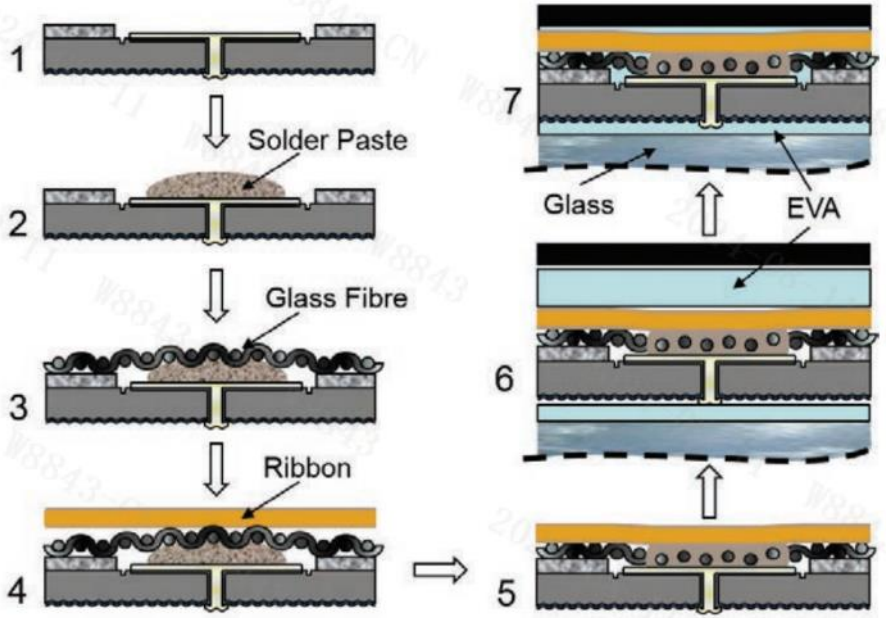
IBC cells with 2D (upper) and 3D design [1]

[1] M. Hendrichs et. al., IEEE JPV, 2016

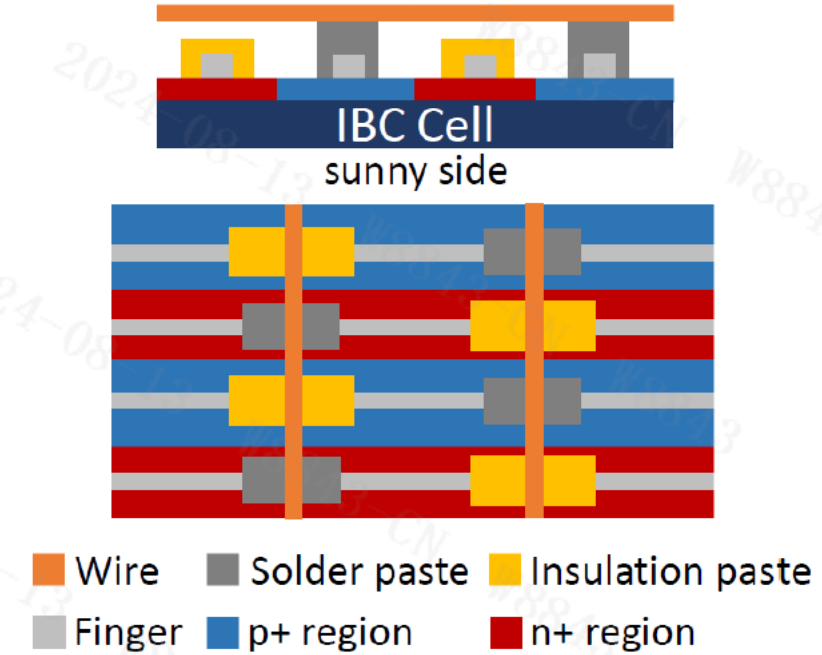
Screen printing for IBC solar cells - Solder paste

Slide from MIW 2024

- Reports on MWT [1] and IBC solar cells [2]
- Solder paste has been used in the manufacturing of IBC solar cells



Solder paste application on MWT cells [1]



Solder paste application on IBC cells [2]

[1]Borgers T, Govaerts J, Van der Heide A, Dewallef S, Gordon I, Szlufci k J, Poortmans J. Adapting conventional tabbing-stringing technology for back-contact solar cells and modules. Photovoltaics International 2015; 26(7)

[2] Meßmer T, Chu H, Mihailetchi V.D. Roescu R, Libal J, Halm A, Interconnection Approach for Busbar-Less IBC Cells Based on Printed Solder Paste, EU PVSEC, 2022

Isolation paste and solder paste printing

- Linear printing, fast speed and high capacity（CT≤0.8s）
- Strong compatibility, simple switchover from full cell to half-cut cell, wafer size from 182mm to 210mm, maximum wafer size to 230mm
- Highly adaptive drying process, supporting a variety of materials

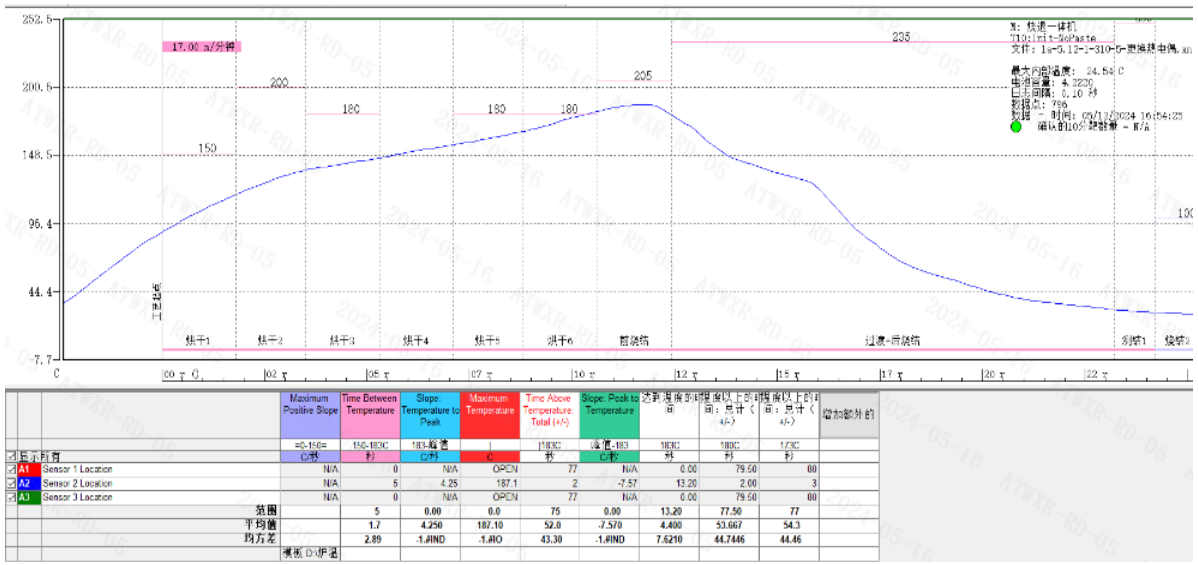
Wafer loading → Isolation paste → Dryer → Solder paste → Dryer → Unloading

Key equipment, cassette dryer

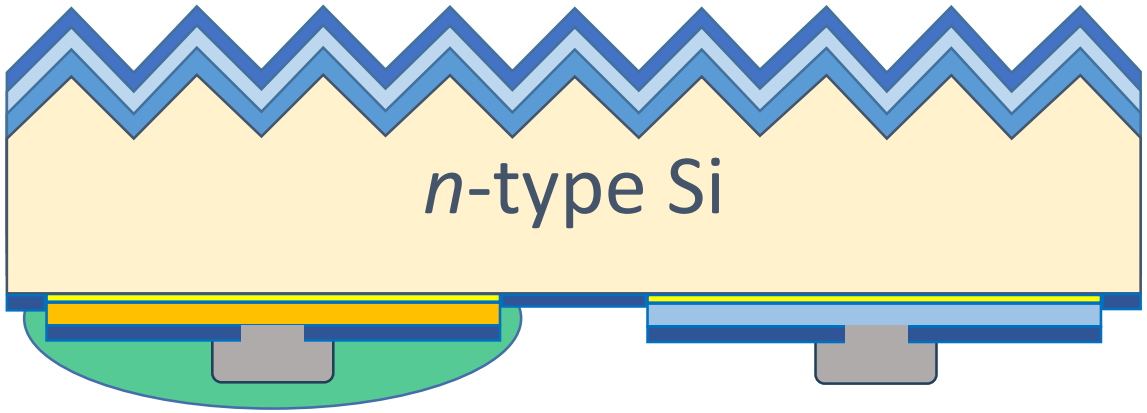
- High productivity: Capacity ≥ 9,000 pcs/h
- Compatible with full and half cells without modification, and also compatible with N_2 atmosphere modification
- High temperature uniformity: Temperature uniformity within ±5℃
- Customization: Supports customized development

Key equipment, inline dryer

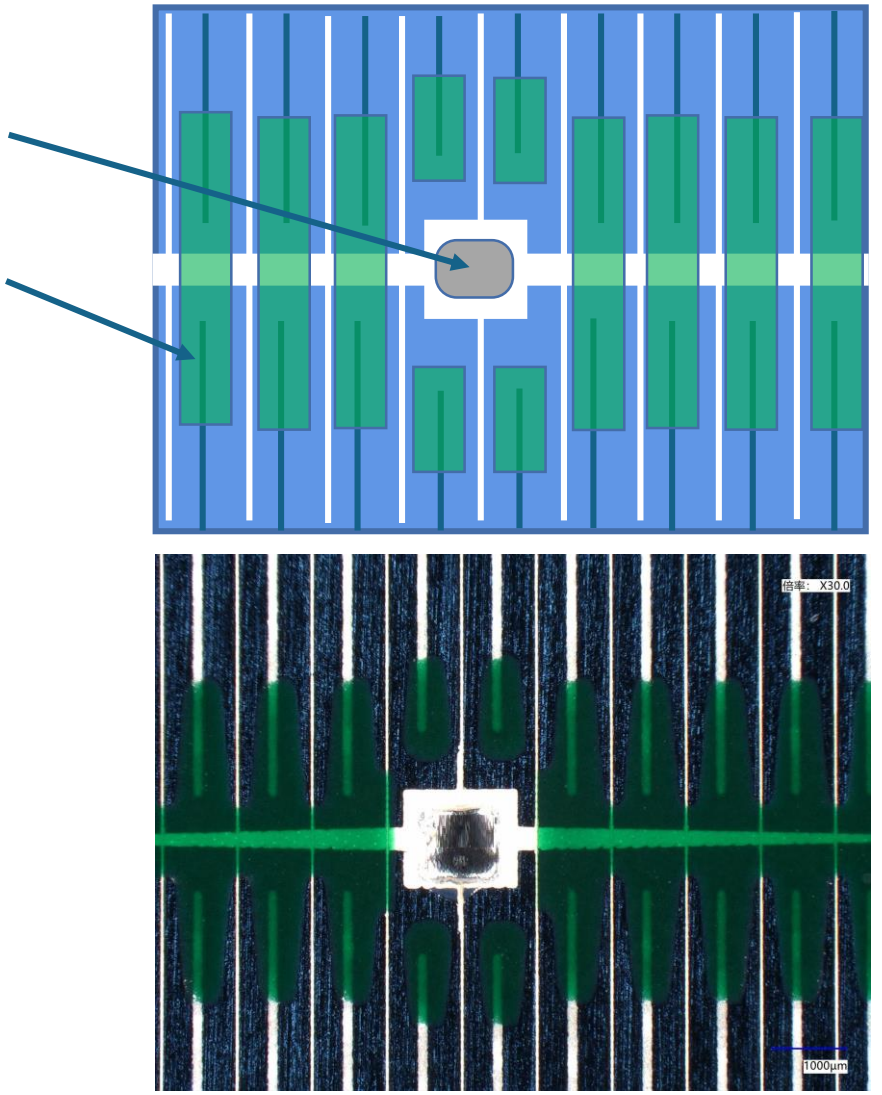
- High productivity: Capacity ≥ 9,000 pcs/h
- High yield: No over-drying of solder paste, and under-drying rate ≤ 0.05%;
- High temperature uniformity: Temperature uniformity within ±3℃
- Supports customized development



Solar cell after isolation and solder paste



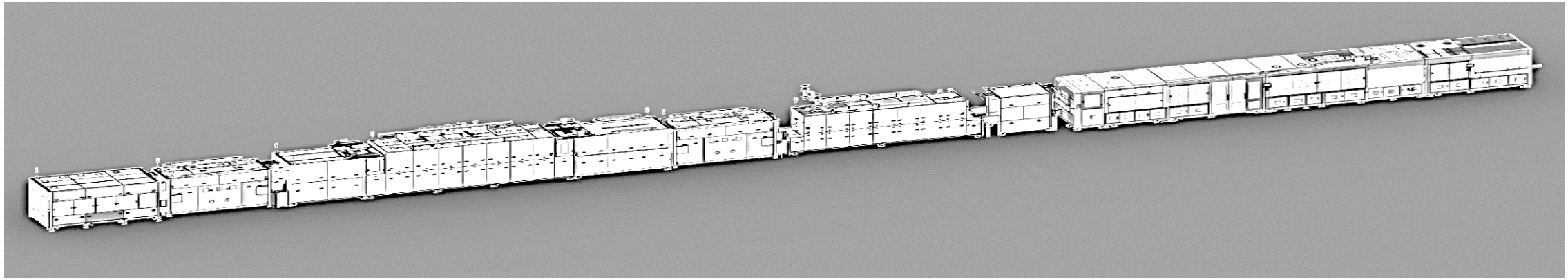
Cross section of an IBC solar cells



Top view, schematic diagram and microscopic image

Printing line for IBC solar cells

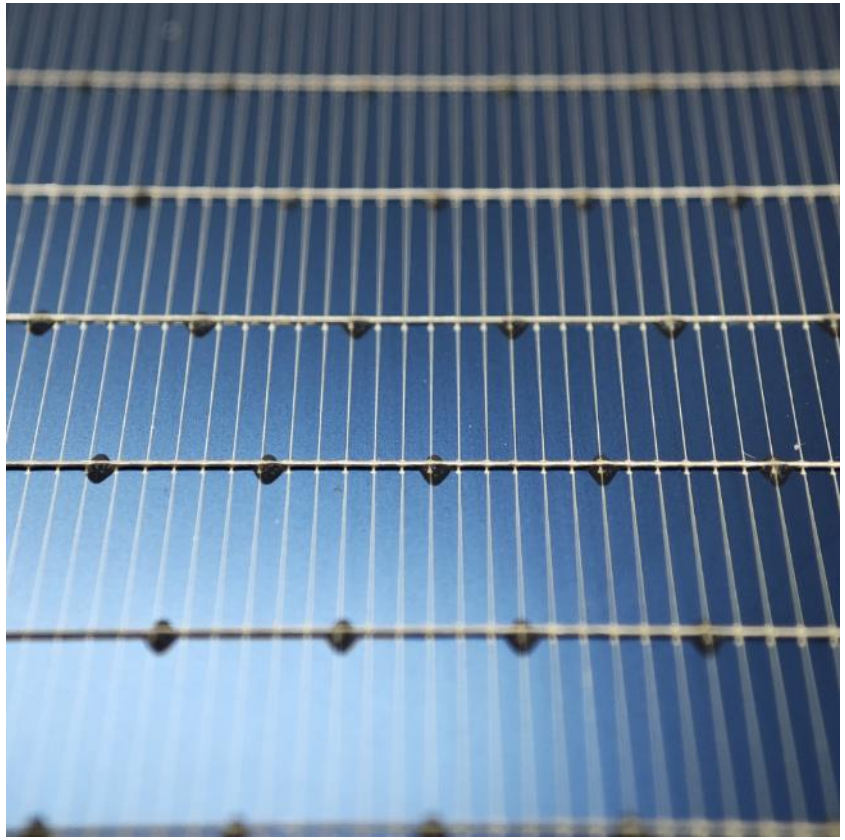
- Integrated design: printing line integrated with stringer
  - Space-saving: The total length is reduced by 1/3, suitable for renovation of old factory;
  - Low breakage: Reduces handling operations;
  - Low investment: Eliminates the logistics line between the stringer and the printing line.



Printing for 0BB solar cells - Glue

- Improvement of ribbon peel force and module reliability with glue
- Can be applied by dispensing or screen printing
- Screen printing has the advantages of high throughput and alignment accuracy
- Screen printing of glue paste on 0BB cells, as shown in the image on the right

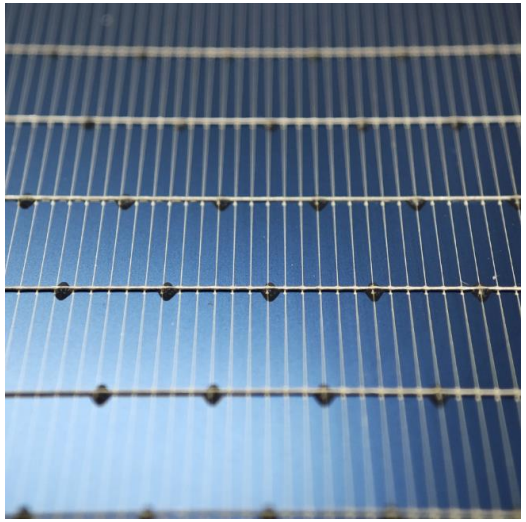
Slide from MIW 2024

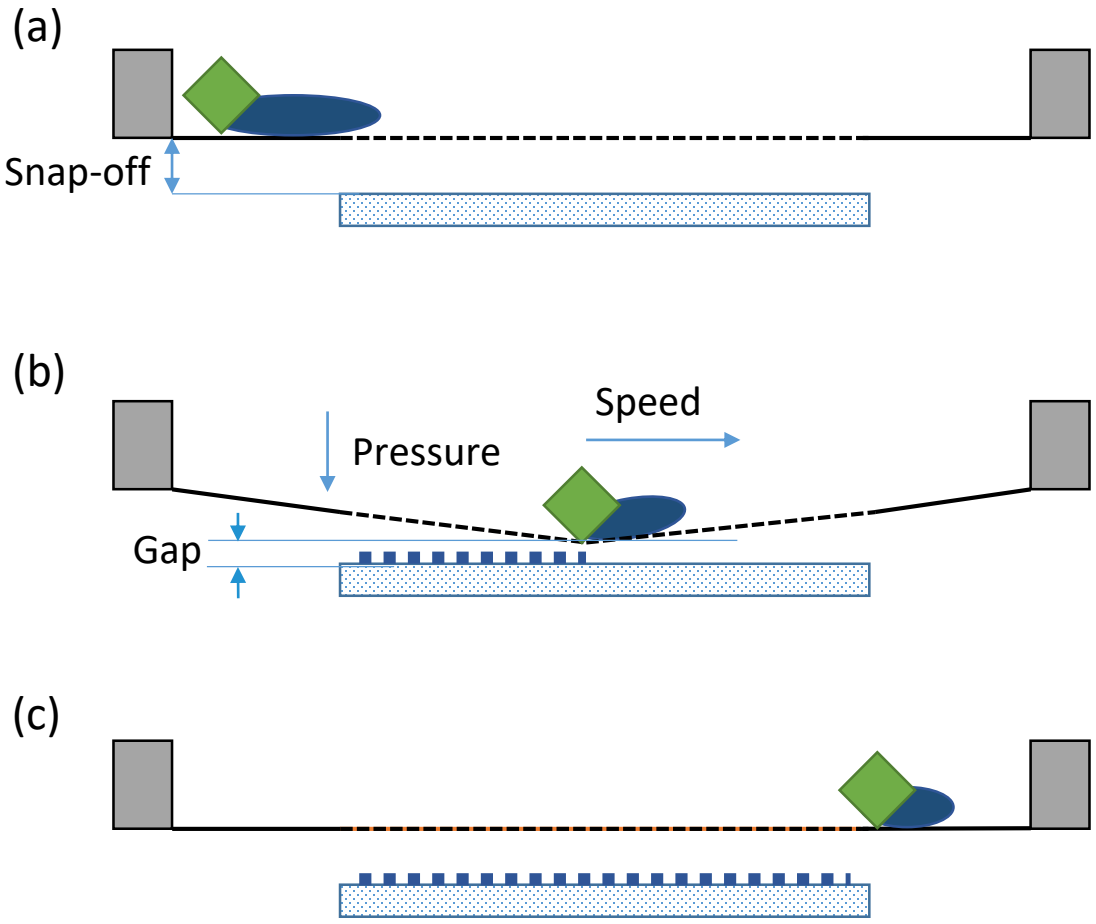


Cell with printed glue and interconnection

No contact printing for glue

- No contact printing!
- Less breakage and more possibilities
- Printing can be done before or after ribbon placement

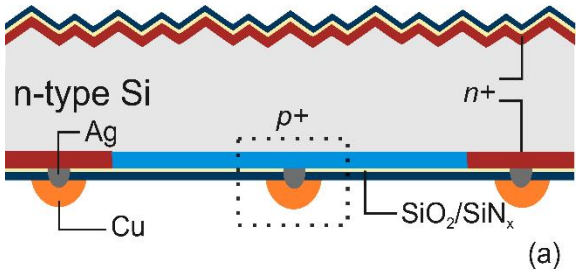




No contact printing for glue

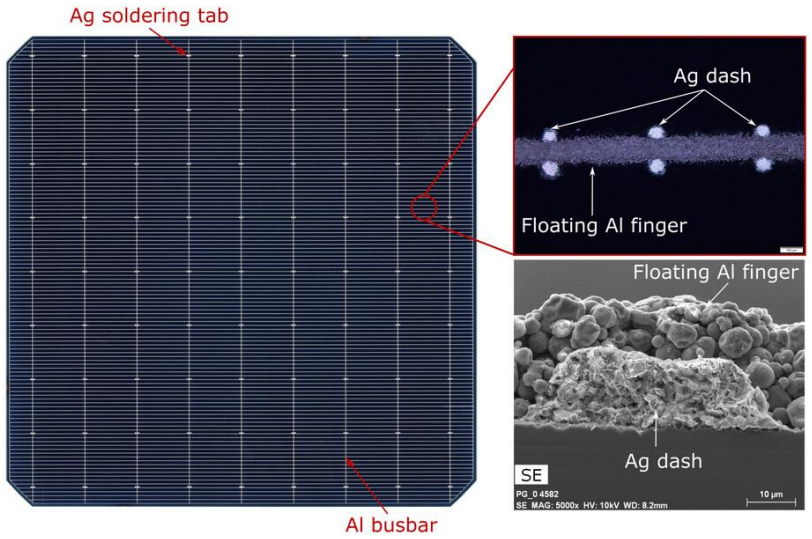
Printing Ag-less/Ag-free metal paste

◘ Reduction of Ag usage on various of cells



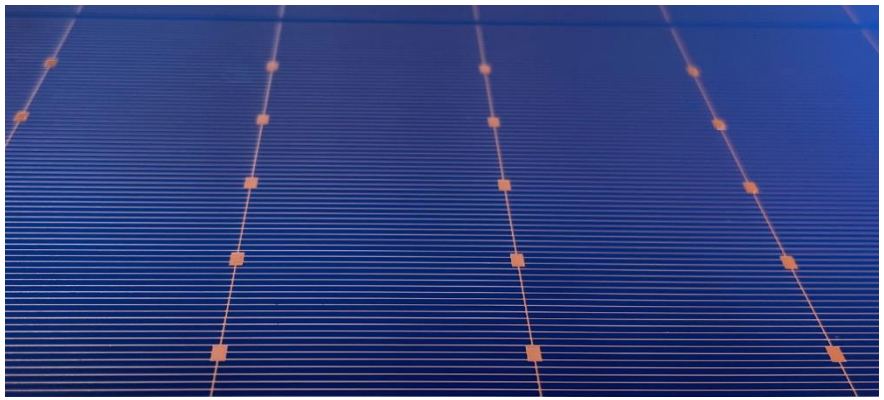
IBC cells, ISC Konstanz, 4mg/W Ag

N. Chen et al., Solar RRL, 2022



TOPCon cells, UNSW, 1.4mg/W Ag

Y. Zhang, Solar RRL, 2024



SHJ cells, Fraunhofer ISE, 1.4mg/W

https://www.ise.fraunhofer.de/en/press-media/news/2025/silicon-heterojunction-solar-cells-realized-with-record-savings-in-silver.html

Challenges in the "new" pastes printing

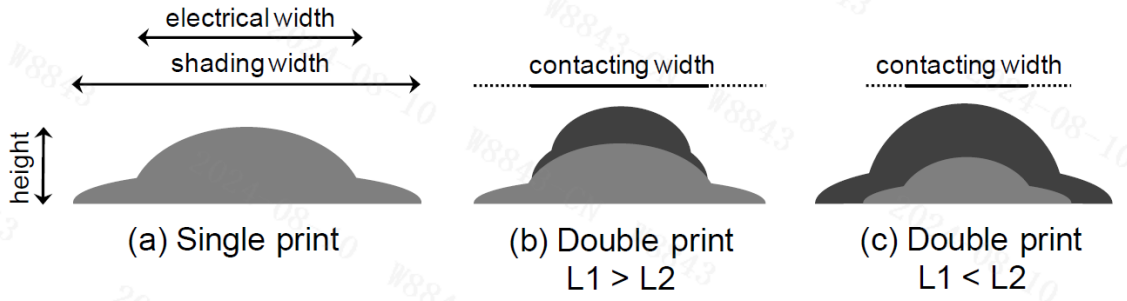
- Different materials printing
  - Viscosity
  - Choose of screen/stencil
  - Choose of squeegee

Table 1. Viscosity of different pastes

Paste	Viscosity	
	Shear rate = 1 s^{-1} (Pa•s)	Shear rate = 10 s^{-1} (Pa•s)
A: Ag paste	116.3	40.2
B: Glue	1.6	0.5
C: Isolation paste	39.8	20.1
D: Solar paste	409.5	98.1

- New process may need accurate alignment
  - Alignment of different pastes
  - Improvement alignment of printers

Improvement of screens[1]



[1] M. Comak et al. Distortion of knotless printing screens in solar cell mass-production, solmat, 2026

[2] J. Lossen et al. Double printing nPERT cells with narrow contact layers, Energy Procedia, 2016

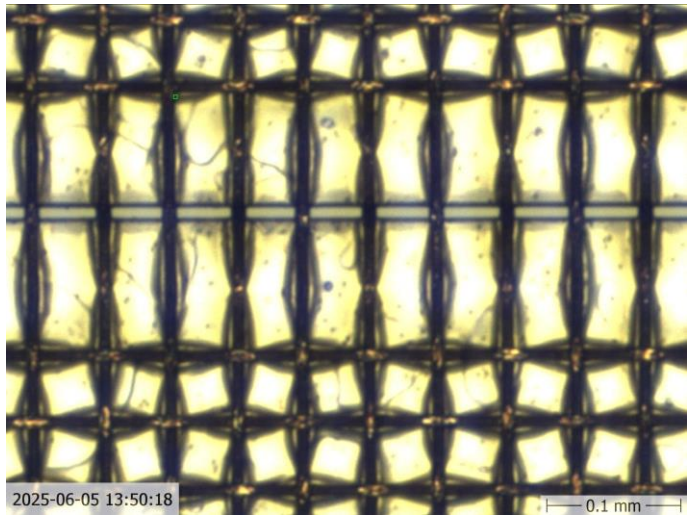
Stencil printing

- Stencil printing is not a new technologies
- Latest achievements from micro-nano fabrication technologies, including laser

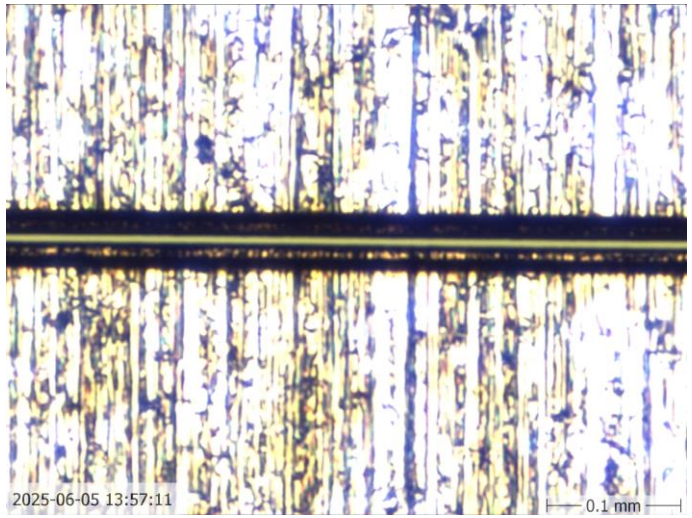
Table 2. Selected publications on stencil printing

Year	Author	Affiliations	Title
1997	Jaap Hoornstra, et al.	ECN	The importance of paste rheology in improving fine line, thick film screen printing of front side metallization
1997	HHC de Moor, et al.	ECN	Printing high and fine metal lines using stencils
1998	J. Hoornstra, et al.	ECN, BP Solar	First experiences with double layer stencil printing for low cost production solar cells
2000	Jaap Hoornstra, et al.	ECN	Improved front side metallization on silicon solar cells with stencil printing
2004	A. Hauser, et al.	University of Konstanz	Thick-film buried contact solar cells as a future trend for industrial crystalline silicon solar cells
2005	Guoxiao Yao, et al.	UNSW	Comparison of stencil and screen printed solar cells
2008	MB Edwards	UNSW	Screen and stencil print technologies for industrial n-type silicon solar cells
2011	A. Bettinelli, et al.	INES	Advanced Printing Based on Specific Stencils Developed by INES
2016	H Hannebauer, et al.	ISFH, ASM	Single print metal stencils for high-efficiency PERC solar cells
2016	Andrew Zhou, et al.	ASM, ISFH	Stencil printing and metal squeegees for improved solar cell printing results

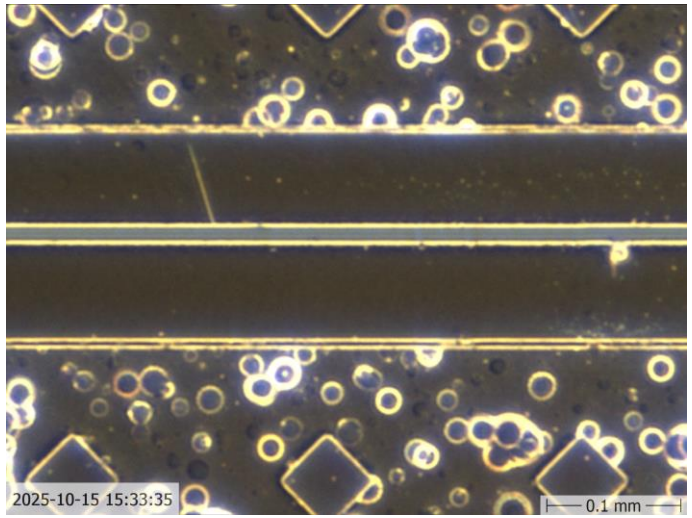
Stainless Steel screens and Stencils 2025



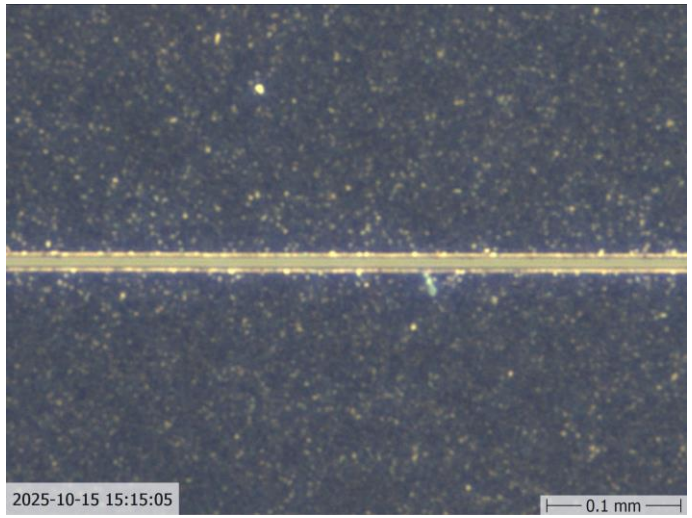
7µm finger opening, squeegee side



6µm finger opening, squeegee side



9um finger opening, squeegee side



9um finger opening, wafer side

Micro-Vu Vertex 341

Printing results in 2025

- Fine line opening, less than 10μm
- Printed finger width less than 15 μm, or even less

Solar cells results

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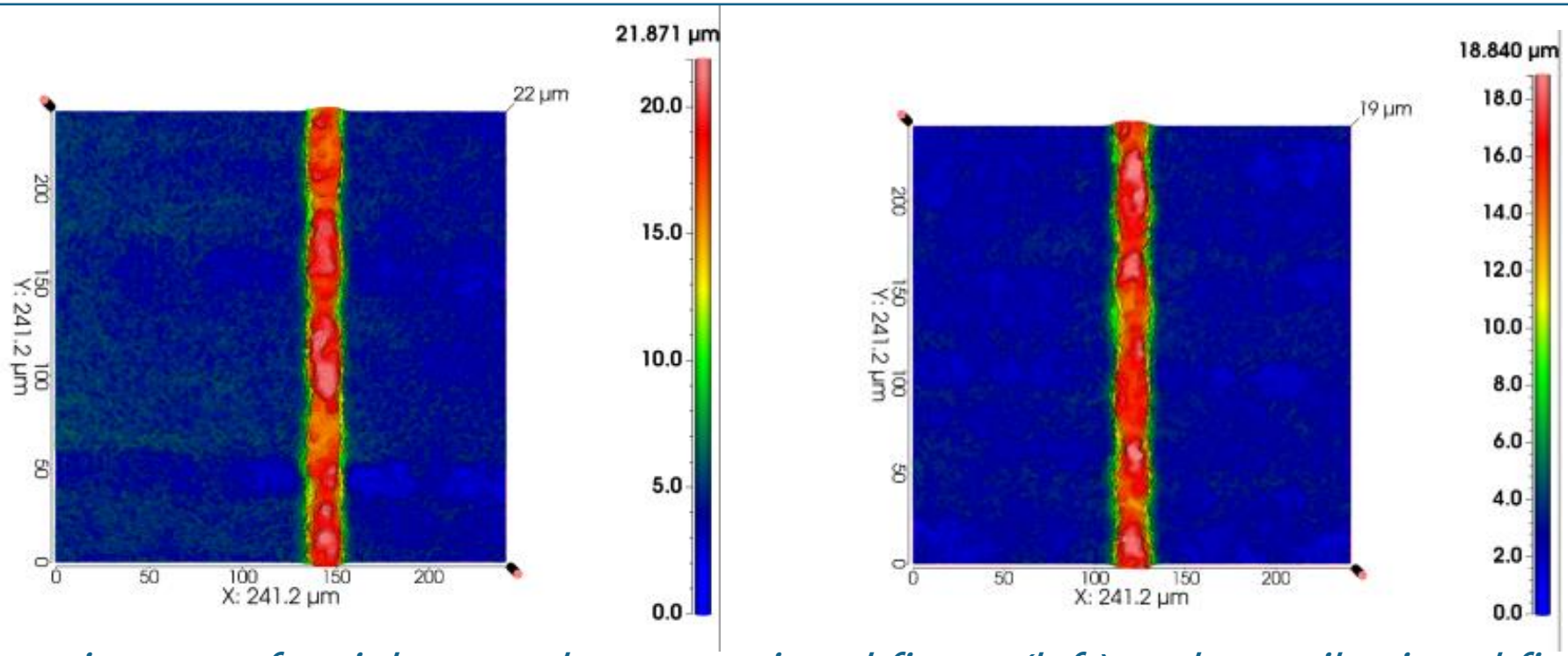
SHJ cells

Screen	Paste laydown (mg)	finger width (μm)	finger height (μm)	Aspect ratio (%)	*η* (%)	*Voc* (mV)	*Isc* (A)	*FF* (%)
SS	32.5	31.5	14.9	0.47	Baseline	Baseline	Baseline	Baseline
Stencil	21.9	31.8	10.5	**0.33**	0.16	0.1	0.011	0.40



Microscope images of stainless steel screen printed finger (left) and stencil printed finger (right).

Solar cells results

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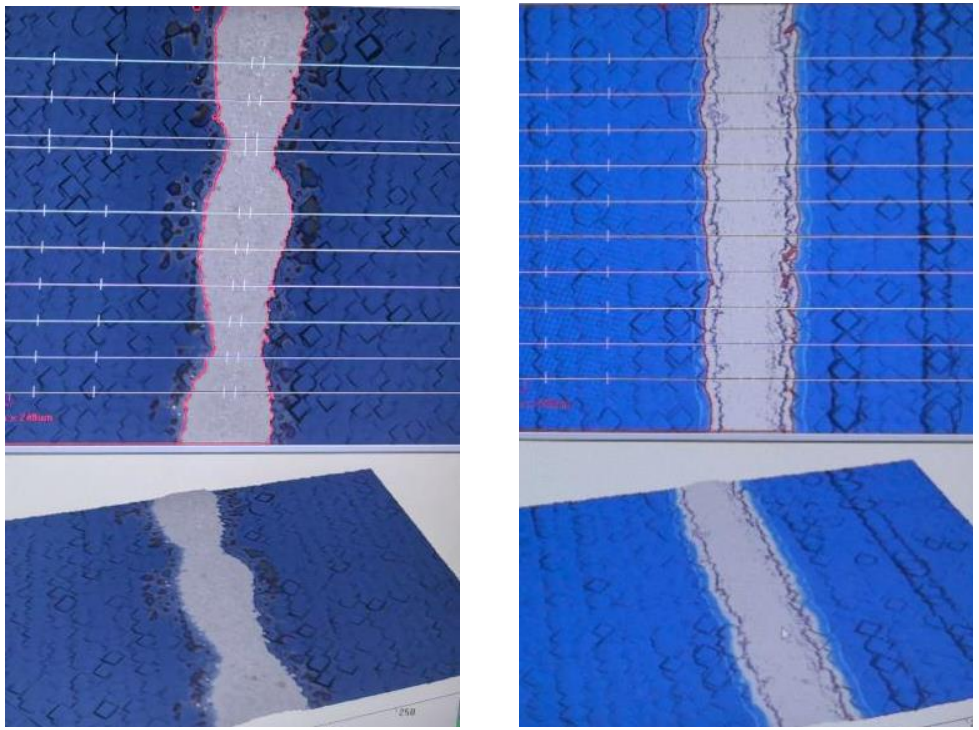
TOPCon cells (rear)

Screen	Paste laydown (mg)	finger width (μm)	finger height (μm)	Aspect ratio (%)
SS	48.0	39.2	6.2	0.16
Stencil	43.0	44.3	5.1	0.12

Screen	η (%)	V_{oc} (mV)	I_{sc} (A)	FF (%)
SS	Baseline	Baseline	Baseline	Baseline
Stencil	+0.08	+0.6	+0.006	+0.16



Microscope images of rear fingers of TOPCon cells, stainless steel screen printed finger (left) and stencil printed finger (right).

The application of AI technology

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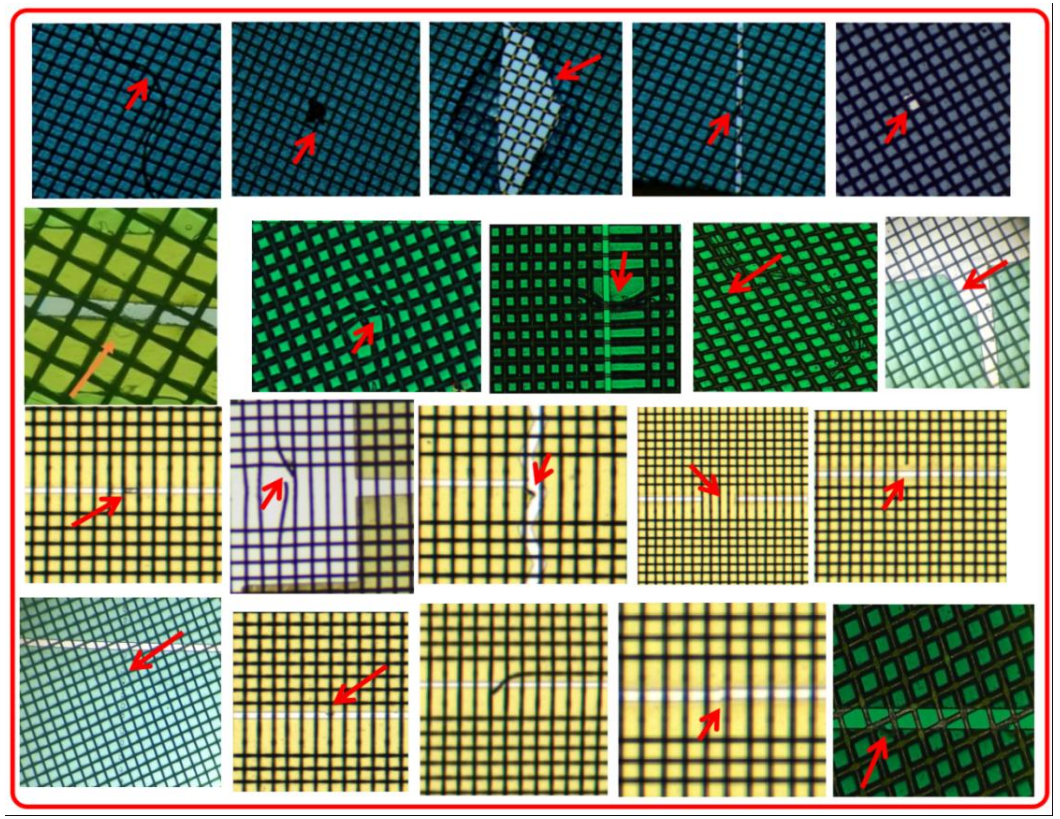
◘ AOI (Automated Optical Inspection) for screen checking



Source: Jiangsu Rich Optoelectronics Technology Group Co., Ltd.

Summary and outlook

- Printing expending its application on different pastes, especially on IBC solar cells
- Stencil printing application in mass-production
- Last year we talked about 20 μm finger width, this year we are talking about 15~10 μm, and what about next year?

chenning@wxautowell.com

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THANKS

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