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Metallization & Interconnection WORKSHOP

Plating as Metallization Method in Photovoltaics – Properties, Developments and Applications

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October 20th 2025, Berlin
Metallization and Interconnection Workshop

Introduction

Short history of plating in PV

Plating has been used in PV for a long time

- Very early cells, even at Bell Labs
- Motorola / JPL, NASA
- BP Solar
- …

Motivations for plating

- Technological Advantage
- **Cost reduction potential (even in the 80s)**
- Coming from evaporated contacts
- Process cost lower, similar advantages
- Silver cost, no mature screen printing…

TROCHEMICAL SOCIETY April 1962

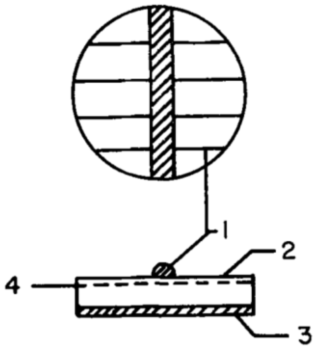


Fig. 2. Phosphorous solar-cell structure, active surface Krylon coated: 1, nickel plate, solder dip contact; 2, diffused layer-phosphorus; 3, contact-rhodium plate; 4, junction, 0.6μ deep.

„Ancient" solar cell with plated contacts[1]

Solar Energy Materials and Solar Cells 31 (1994) 499–507
North-Holland

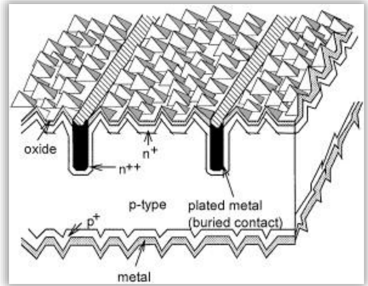
Solar Energy Materials and Solar Cells

A low cost metallization scheme for double sided buried contact silicon solar cells

A.U. Ebong, M. Taouk and S.R. Wenham *

Centre for Photovoltaic Devices and Systems, School of Electrical Engineering and Computer Science, University of New South Wales, P.O. Box 1, Kensington, N.S.W. 2033, Australia

Received 4 June 1993; in revised form 1 July 1993



BP buried contact solar cell[2]

Solar Cells, 11 (1984) 19 - 27 19

HIGH RELIABILITY NICKEL ELECTROLESS METALLIZATION OF SOLAR CELLS

G. COCORULLO, G. PREZIOSO and M. ZARCONE
Istituto Elettrotecnico dell'Università di Napoli, Naples (Italy)
(Received January 5, 1983; accepted June 24, 1983)

THE Pd_2Si - (Pd) - NI - SOLDER PLATED METALLIZATION SYSTEM FOR SILICON SOLAR CELLS*

M. G. Coleman, R. A. Pryor and T. G. Sparks

Motorola Inc., Semiconductor Group
Phoenix, Arizona

[1]Mandelkorn, J.; McAfee, C.; Kesperis, J.; Schwartz, L.; Pharo, W. (1962): Fabrication and Characteristics of Phosphorous-Diffused Silicon Solar Cells. In: Journal of The Electrochemical Society 109 (4), S. 313. DOI: 10.1149/1.2425407.
[2]Mason, N.B., Jordan, D., Summers, J.G. (1991). A High Efficiency Silicon Solar Cell Production Technology. In: Luque, A., Sala, G., Palz, W., Dos Santos, G., Helm, P. (eds) Tenth E.C. Photovoltaic Solar Energy Conference. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-3622-8_70

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Introduction

Short history of plating in PV

Few attempts to commercialize in mainstream PV

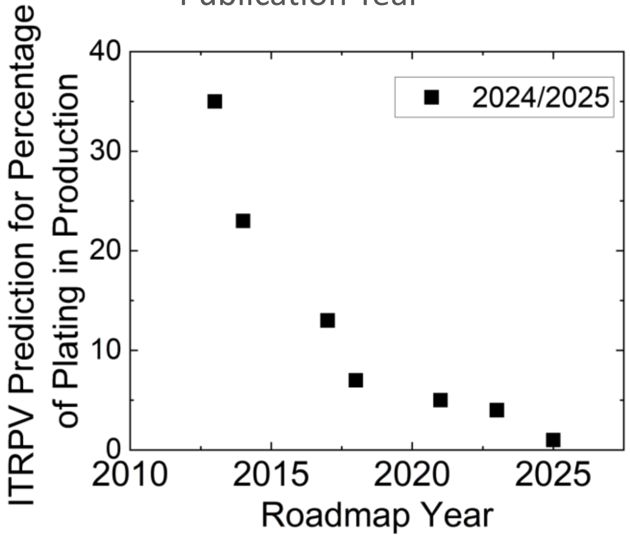
- E.g, „Pluto“ cell (Wuxi Suntech)
- R&D in Plating for PV is still strong
- Conincides with Silver price (?)

Simple "Web of Science" publication analysis "Cu plating in Si-PV"

ITRPV expectations for plating

- Used to be strong
- Currently rather „honorable mention“

Analysis expectations for plating development of all ITRPV roadmaps so far



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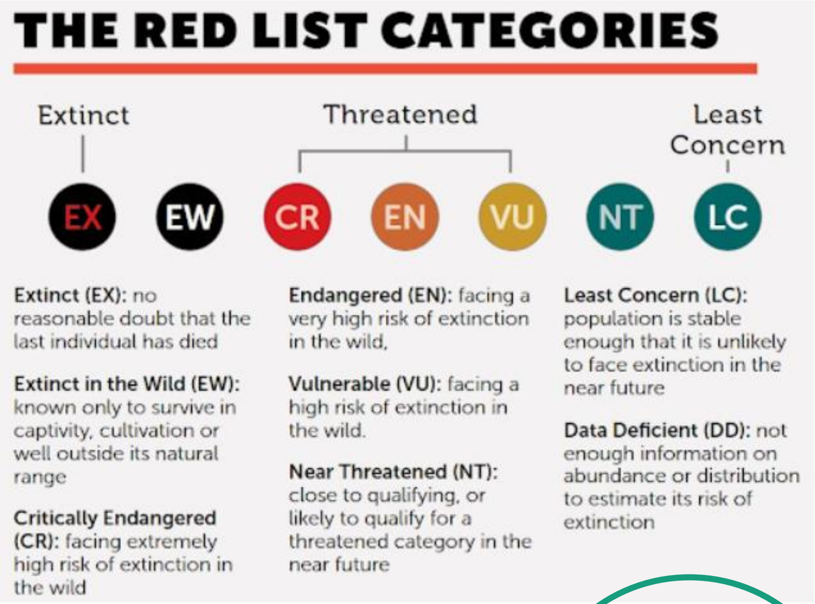
Introduction

Quo vadis plating in PV?

Plating is an endangered species in PV!

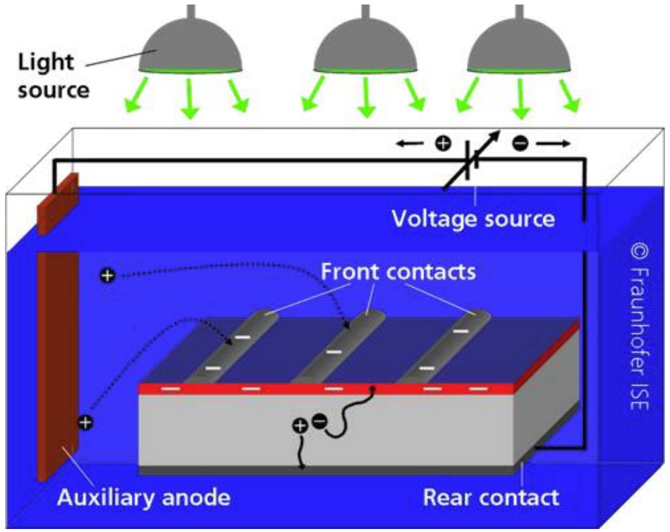
- **Which category to put plating into?**
- **Where are it's „ecological" niches?**

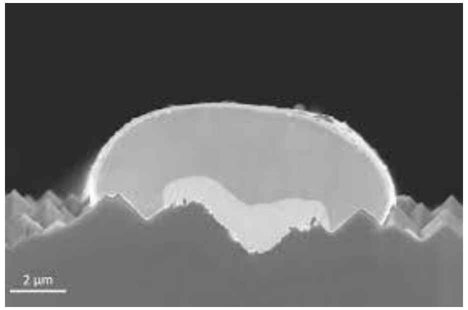


International Union for Conservation of Nature – www.iucn.org

Introduction

Properties of plated contacts

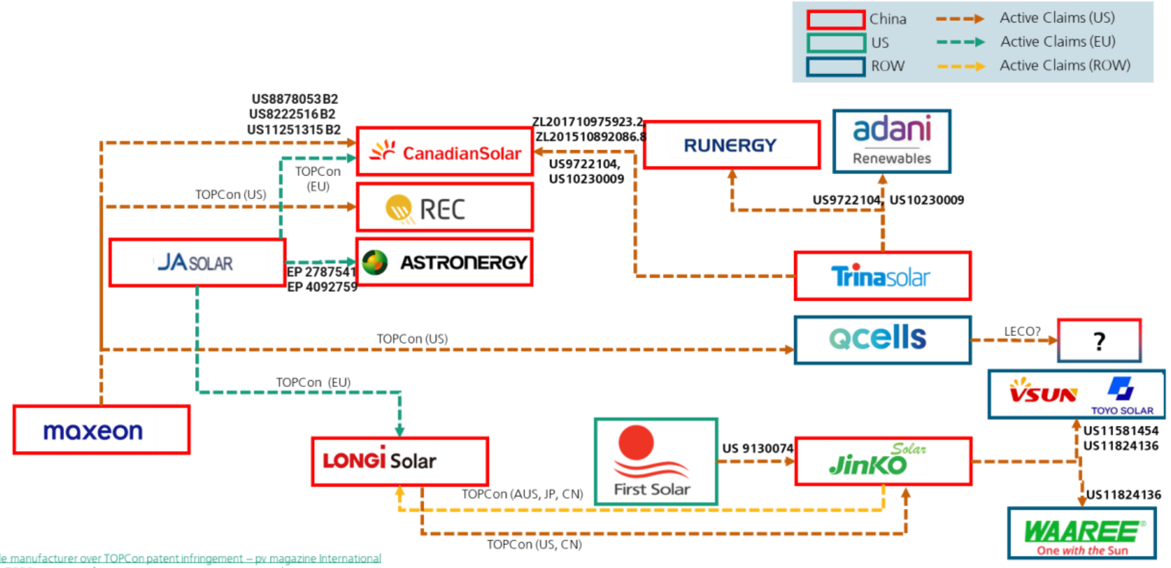




Plating from aqueous solutions

- Simple, cheap
- Dense, highly conductive layers (close to bulk conductivity)
- Low-Temperature (<60°C)
- Not affected by critical IP

- Limited to certain metals (from aqueous media)
  - Nickel, Copper, Silver, Tin, Zinc, …
- Requires „prepared" surfaces (see Jonas Eckert's presentation last session)
- Higher process complexity, less workforce



JA Solar sues rival module manufacturer over TOPCon patent infringement – pv magazine International
JinkoSolar sues Longi for TOPCon patent infringement – pv magazine International
Longi sues JinkoSolar for alleged patent infringement in China, United States – pv magazine International
Trina Solar sues Canadian Solar over patents in $147 million lawsuit – pv magazine International
Maxeon sues REC, Hanwha Qcells for alleged TOPCon patent infringement – pv magazine International
Maxeon sues Canadian Solar for alleged TOPCon patent infringement – pv magazine International
Maxeon alleges Canadian Solar is infringing on patented TOPCon technology - Energy News

IP restrictions in printed contacts[1]

[1] S. Kluska et al, EU-PVSEC 2025, Bilbao

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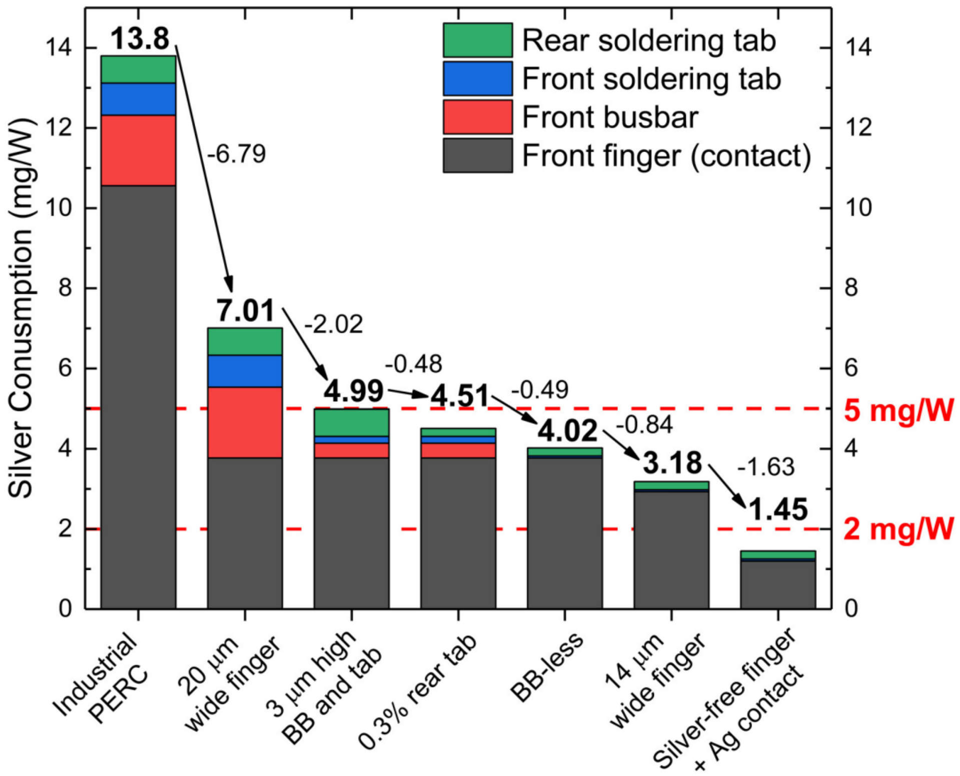
Applications & Developments

Mainstream – PERC

PERC: Bad Timing

- Process ready for industrial implementation since ~2015
- Would have been needed in 2011
- Meanwhile, much paste reduction
- Limited driving force

→ Plating unlikely to enter (decreasing) PERC production



Silver consumption roadmap for printed contacts in PERC cells[1]

[1] Y. Zhang, "Novel Metallization Designs to Overcome Challenges of Screen-Printed Contacts in Silicon Solar Cells", PhD-Thesis, UNSW, 2023

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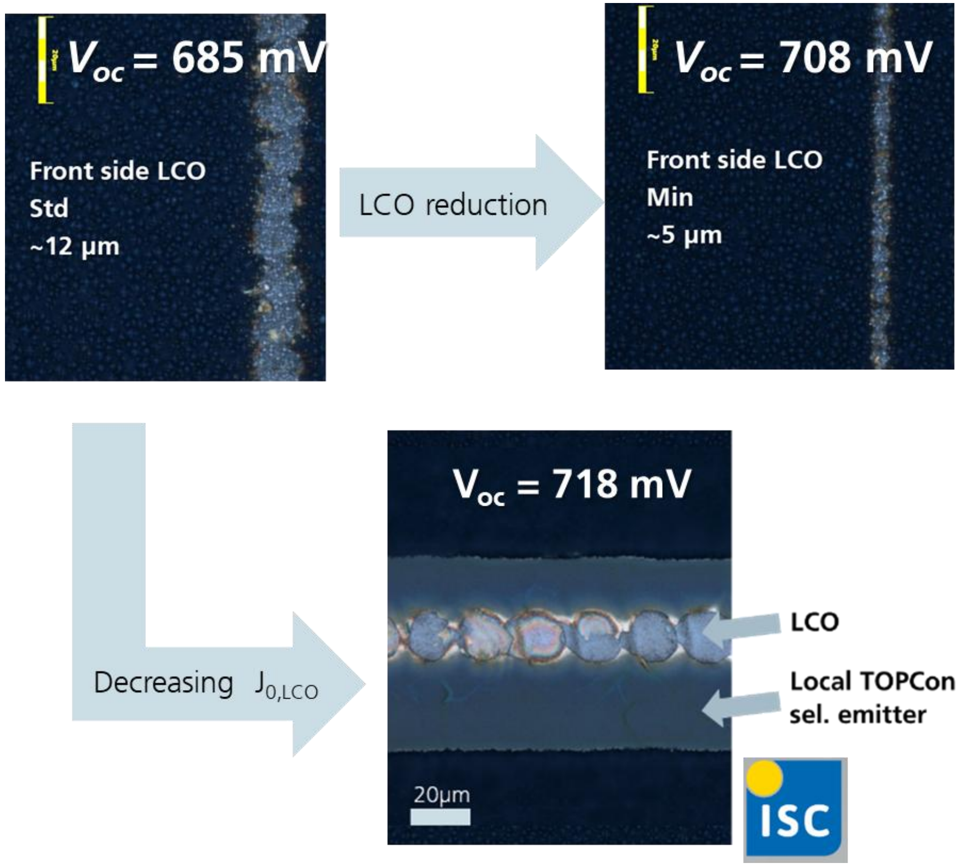
Applications & Developments
Mainstream – TOPCon

- TOPCon: LECO + paste process too powerful
- Local TOPCon / selective emitter as perspective
- Hybrid process possible – Pros and Cons in CoO (50% Ag savings, two techniques, …)
- Printed copper on the horizon

→ Best chance for plating is local TOPCon front



Challenges with V_{OC} in plated contacts on TOPCon[1,2]

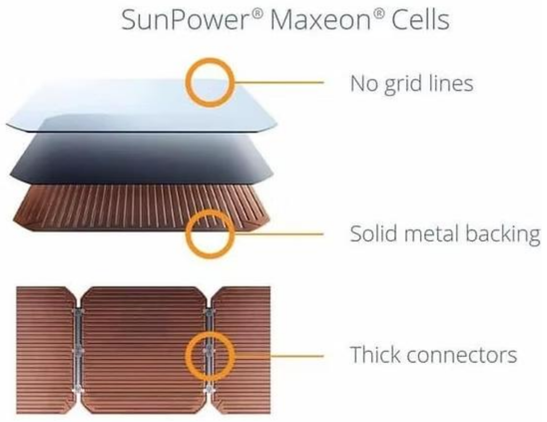
[1] S. Kluska et al, EU-PVSEC 2025, Bilbao
[2] Jonas Eckert, this Workshop

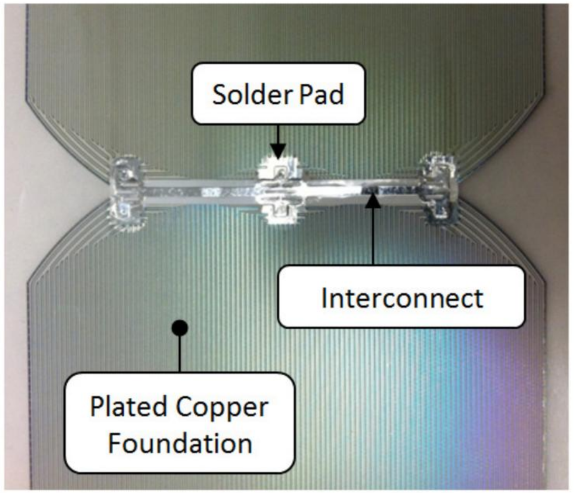
Applications & Developments

High conductivity / high reliability

Back-Contact Solar Cells

- Only Technology where plating has been used continuously in production (SunPower / Aiko)
- Advantages due to cell design (high conductivity)
- High-end product
- Superior longevity → Plating can be a solution for applications where long lifetime matters
- But: More and more challenged by paste





SunPower Maxeon Cell - Rear

for 20 years in a humid environment). The Conventional Module shows a 28% power loss. This degradation is evidence of water vapor diffusion through the backsheet and around the edges of the cells. This weakens the bonds and corrodes the silver grid lines, resulting in a substantial loss in the ability to carry current. In contrast, the SunPower module (Figure 11, right) appears virtually unchanged. The current carrying copper layer is much more substantial than required to carry the current, proving a large design safety factor. Also it is coated with tin plating, providing a high level of corrosion resistance. The reader will note that the image at far right is not after DH3000, but after DH7750, where it experienced a power loss of 2.7%.

SunPower Module Test Report[1]

[1] SunPower Module Degradation rate and SunPower Module 40-year Useful Life, Whitepapers, 2013 and 2014

Applications & Developments

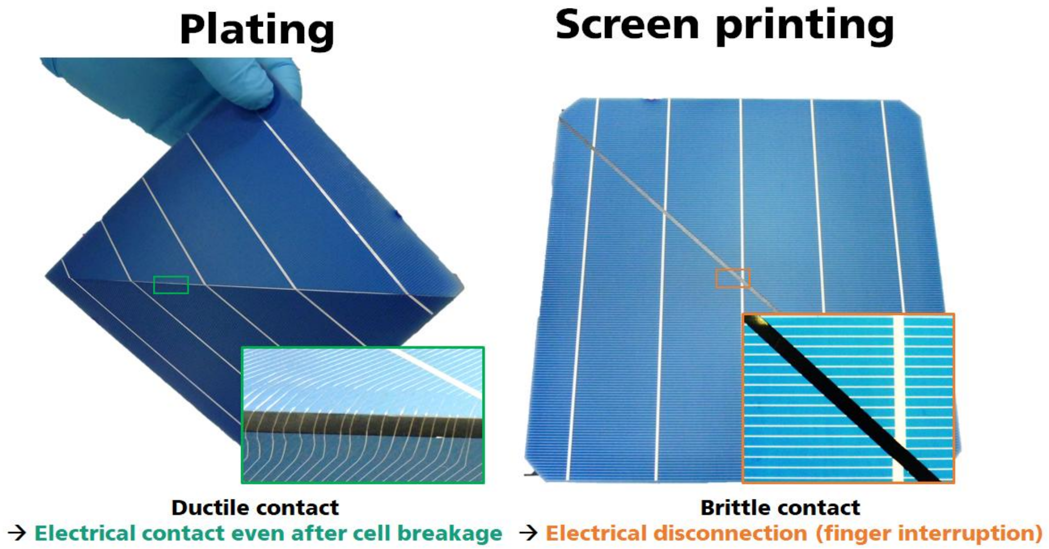
High conductivity / high reliability

Standard Solar Cells

- In principle, similar reliability advantages
- Also shown for BP solar cells (Toledo study)

Shingle Solar Cells

- Longer gridlines can be tolerated
  → Fewer cuts, less handling etc.



Behaviour of plated vs. printed solar cell upon breaking[1]

> PV modules power degradation has been estimated as 0.2% yearly for BP modules and 1% for Nukem modules in the first 10 years. Degradation increases in last three years to around 1% in BP modules and 2% en NK modules. An extensive campaign of power measurements

Key result of „Toledo Study“[2]

[1]S. Kluska et al., EU-PVSEC 2021, Lisbon
[2] Alonso-Abella, M., et al. "Toledo PV plant 1 MWp—20 years of operation." 29th European Photovoltaic Solar Energy Conference and Exhibition. 2014.

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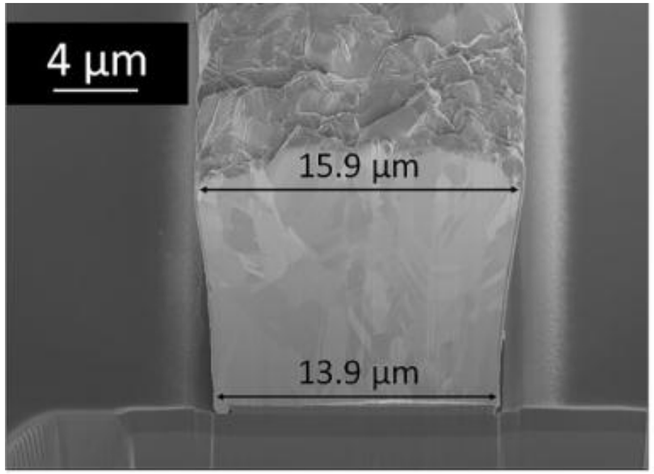
Applications & Developments

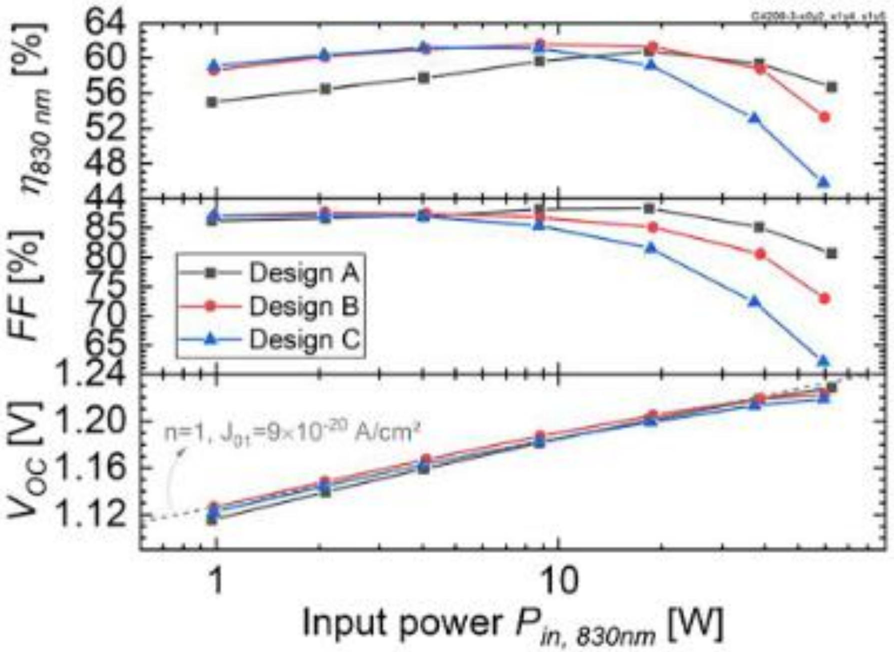
High conductivity / high reliability

Photonic Power Converters (PPCs)

- Very high conductivity needed
- Irradiation as high as possible
- Our best cell: Eta 61.3% @ 18.8W (1cm² !) for 830nm monochromatic irradiation[1]



Plated silver contact on PPC[1]



IV-data of 1cm² solar cells at different irradiation intensities[1]

[1]Helmers, Henning, et al. "Overcoming optical-electrical grid design trade-offs for cm2-sized high-power GaAs photonic power converters by plating technology." Progress in Photovoltaics: Research and Applications 32.9 (2024): 636-642.

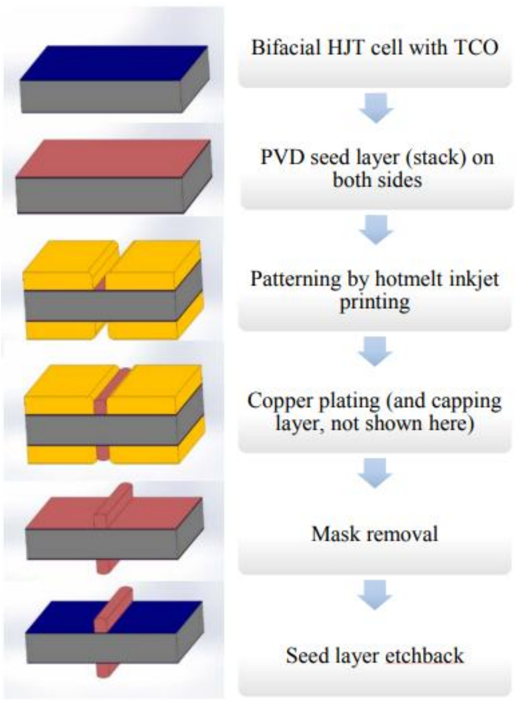
Applications & Developments

Low thermal budget

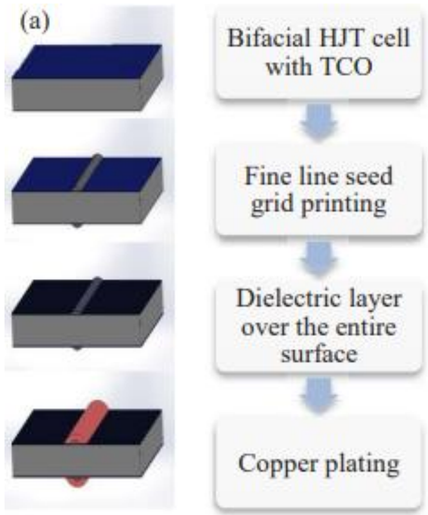
Silicon Heterojunction Solar Cells

- Currently most in discussions – see this session!
- Thermal budget below 240°C
- China moving, lots of plating activities
- Masking of TCO / edge is challenging
- Copper-Containing Low-T Pastes are improving

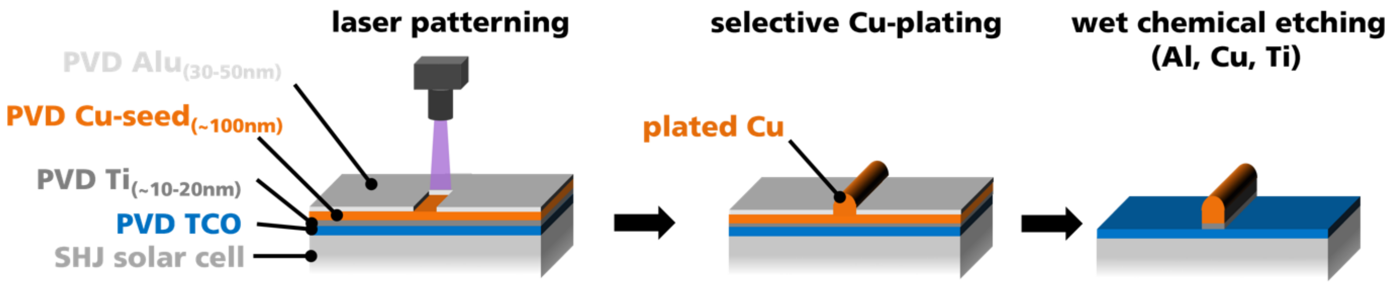
→ Presently, window of opportunity for plating



Baseline Plating on SHJ[1]



Plating on SHJ using printed seed[2]



NOBLE Process (developed at ISE, now proprietary to PV2+)[3]

[1]Lachowicz, Agata, et al. "Copper electroplated metallization for heterojunction cells with AZO." *2020 47th IEEE Photovoltaic Specialists Conference (PVSC)*. IEEE, 2020.
[2]Lachowicz, Agata, et al. "Project ameliz: Patterning techniques for copper electroplated metallization on heterojunction solar cells." AIP Conference Proceedings. Vol. 2367. No. 1. AIP Publishing LLC, 2021.
[3]Hatt, Thibaud, et al. "Native oxide barrier layer for selective electroplated metallization of silicon heterojunction solar cells." Solar RRL 3.6 (2019): 1900006.

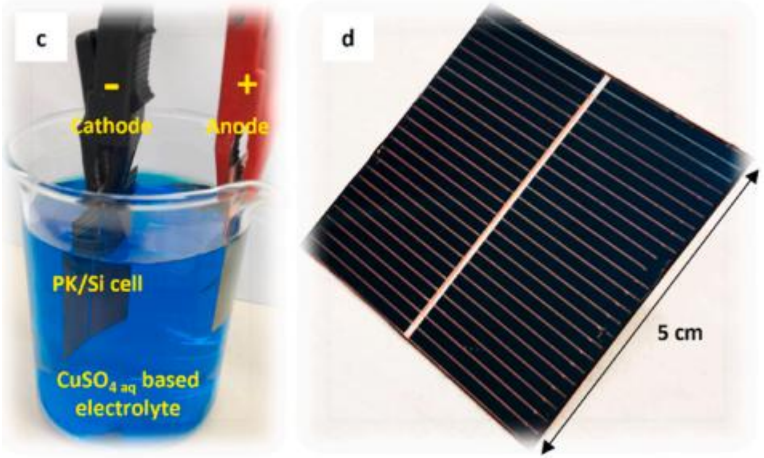
Applications & Developments

Low thermal budget

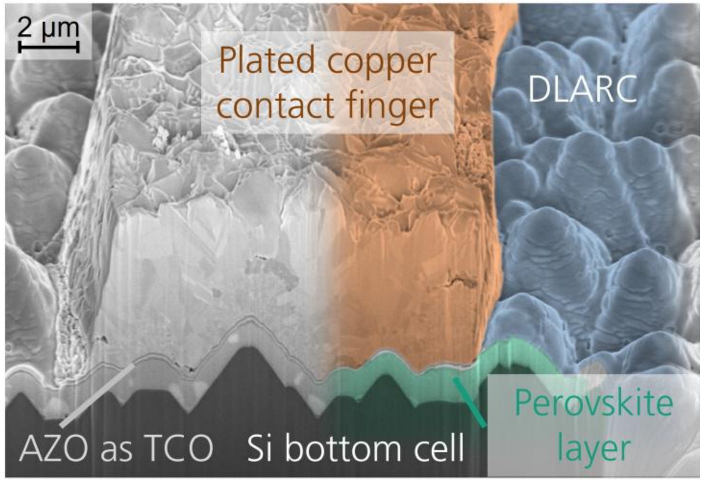
Perovskite

- Even higher constraint in thermal budget (ideally <100°C)
- Paste particles can be problematic (rear side, especially TOPCon bottom solar cell)
- Dissolution of sensitive layers is a challenge
  - Already addressed in several publications[1,2,3]

- But:
  - Conductivity requirements lower
  - ULTP are already catching up



Plating on 5x5cm² Si-Perovskite Tandem solar cell[2]



Plating on Si-Perovskite tandem solar cell using Ti-Anodization[3]

[1]Hatt, Thibaud, et al. "Electroplated copper metal contacts on perovskite solar cells." Solar RRL 5.9 (2021): 2100381.
[2]Hatt, Thibaud, et al. "Plated copper electrodes for two-terminal perovskite/silicon tandem solar cells." Solar Energy Materials and Solar Cells 246 (2022).
[3]Jakob, Leonie, et al. "Multifunctional Ti (Al) Ox layers for silver and indium-free perovskite/silicon tandem solar cells." Solar Energy Materials and Solar Cells 294 (2026)

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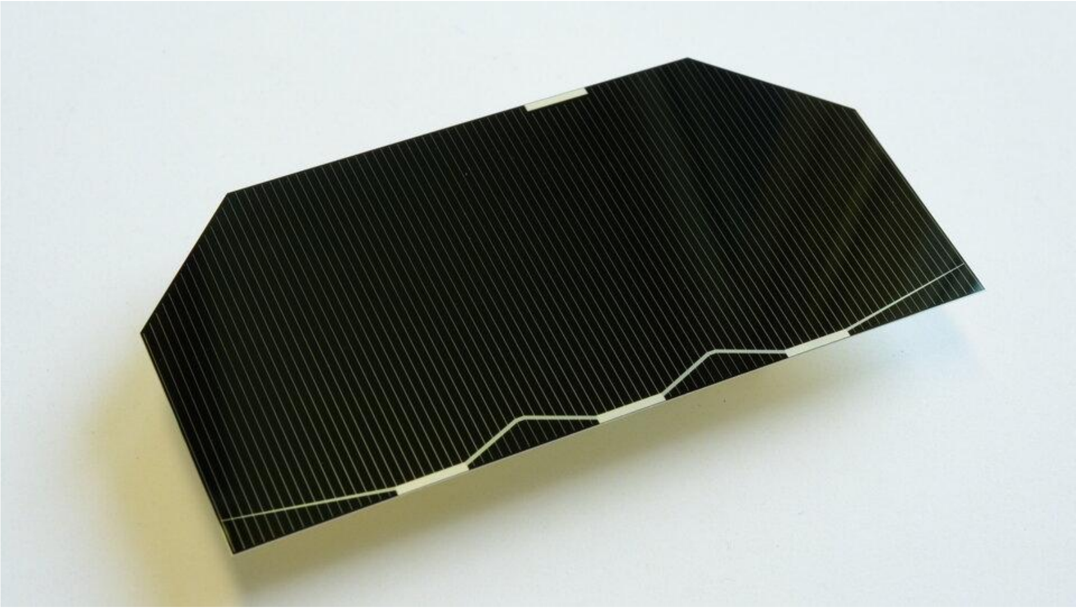
Applications & Developments

Material incompatibilities

Space Solar Cells

- So far: evaporated contacts
- Volume increases (constellation programmes, LEO satellites), cost reduction desired
- No outgassing tolerable (Space)
- Only qualified materials tolerated
- Application of plating discussed, successful demonstrations (PV2+, Solestial)



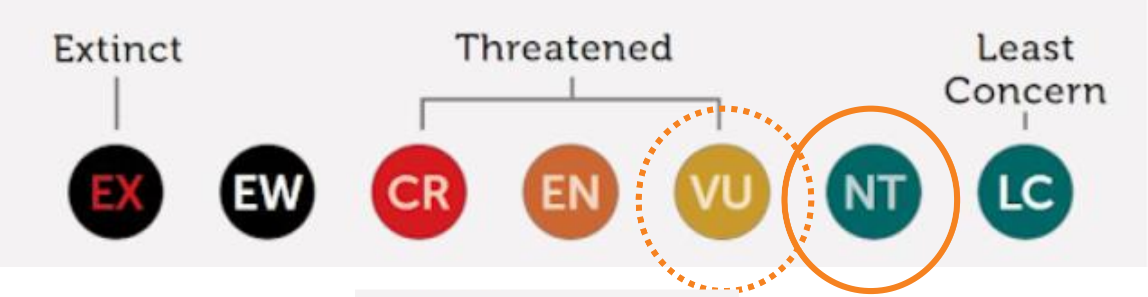
Space Solar Cell[1]

[1]https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Using_solar_cells_across_Earth_and_space (accessed October 14th 2025)

Summary & Conclusion

Why should we still consider plating?

- Plating adds unique features to the „gene pool" of PV metallization
- Paste is stronger in current mainstream ecosystems
- Ecological niches for plating for cells with:
  - Limited thermal budget
  - Required superior reliability
  - Very high conductivity needs
  - Difficulties with outgassing / particles
- More and creative approaches are still developed
- **Further plating development keeps the PV metallization gene pool diverse and flexible**



Vulnerable (VU): facing a high risk of extinction in the wild.

Near Threatened (NT): close to qualifying, or likely to qualify for a threatened category in the near future

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Thank you for your attention!

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