Switzerland and some PV activities in Neuchâtel

Prof. Christophe Ballif[1,2]
Laboratoire de Photovoltaique et couche mince électronique, EPFL
Directeur Sustainable Energy Center, CSEM

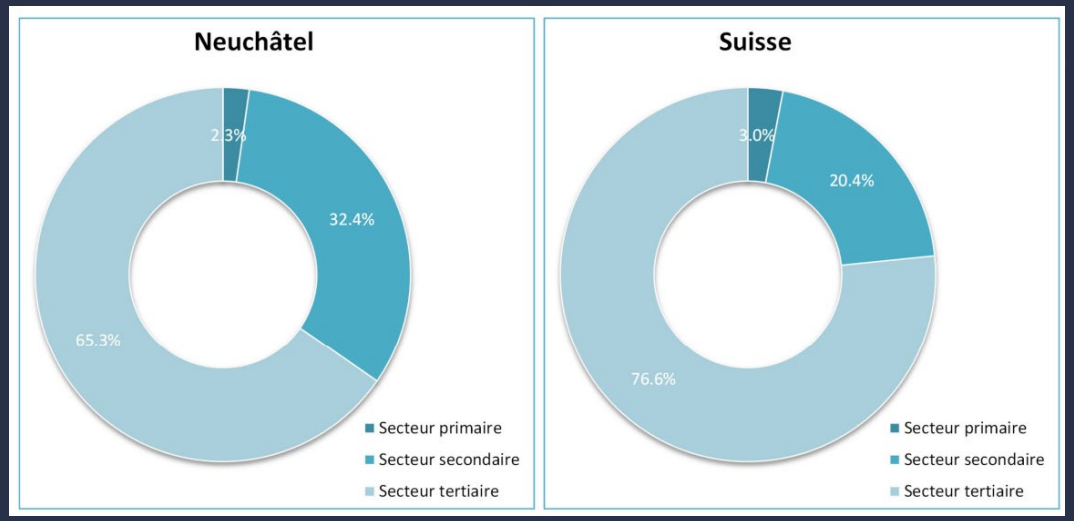
EPFL, 29.04.2023

Neuchâtel at the heart of microengineering !

The three robots of Jacquet-Droz

1766-1774: fully mechanically programmable

The painter, the poet, and the pianist….



127 kCHF product export per Neuchâtel Habitant in 2021

Switzerland and energy

(still 75% fossile fuel in final consmumption)

An upcoming vote
18. June 2023

Loi fédérale
sur les objectifs en matière de protection du climat, sur l'innovation et sur le renforcement de la sécurité énergétique

A lot of incitations to reach net zero emission By 2030

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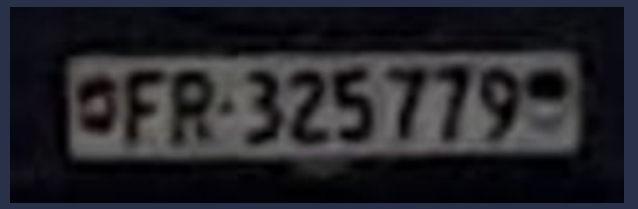
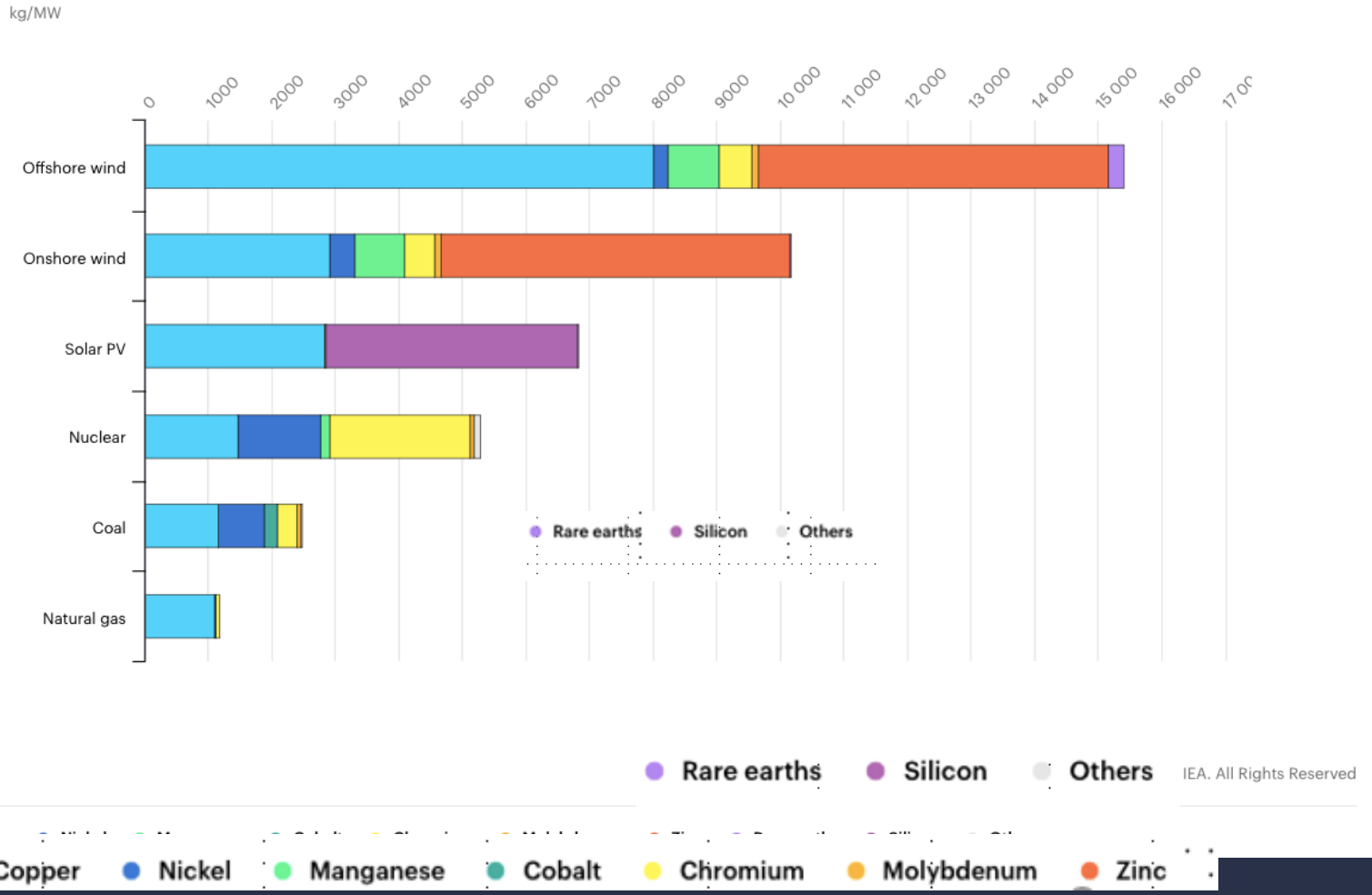
Fliegl
Fliegl
SAVARY TRANSPORT VESIN
avesco
MAKE DIESEL GREAT AGAIN


FR·325779

One major party against the law:

- Lets' refuse the uglisness of nature
- Higher energy price and lack of electricity
- More expensive appartements for all…..
- Destroy the energy security

Material extraction



Minerals for **renewable a small fraction of total mining**
Impact much less than current status (in particular fossile fuel and coal extraction brings huge issues and pollution)

ELSEVIER
Energy Research & Social Science
Volume 82, December 2021, 102311

Perspective

More transitions, less risk: How renewable energy reduces risks from mining, trade and political dependence

Jim Krane, Robert Idel

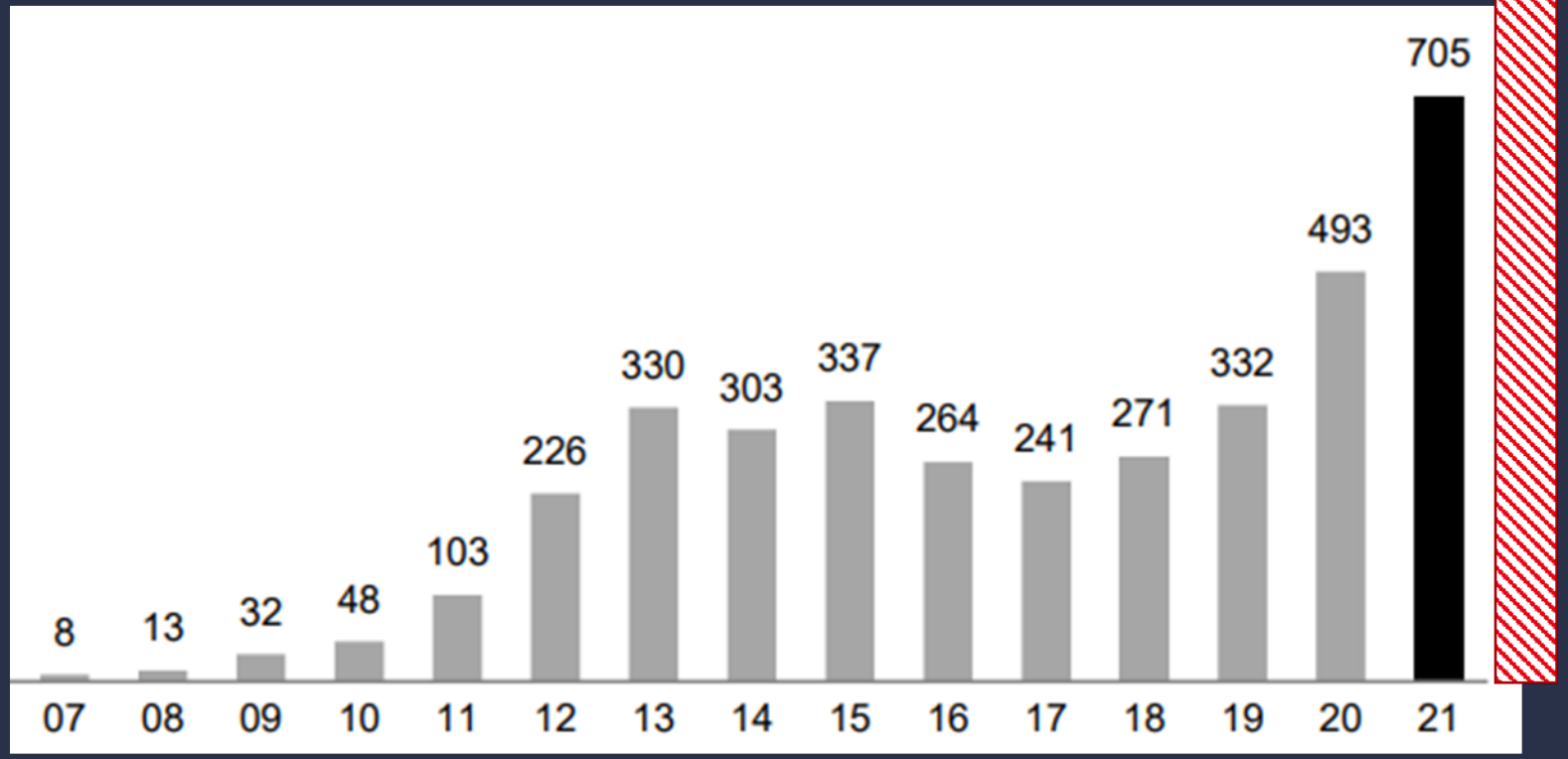
More transitions, less risk: How renewable energy reduces risks from mining, trade and political dependence - ScienceDirect

"an emerging perspective in the US public discourse makes the opposite case, arguing that a buildout of renewable electricity would exacerbate supply risks, mining intensity, and import dependence. This paper's findings challenge such assertions."

Annual Swiss PV market in MW: new installation

Currently support:
- On time payement (0.3 chf/W)
- Right for self-consumption
- Invest tax deductible

Est. 1 GW 2022



Source: Swissolar/internal data

A factor 1.7 to 2 two slow.
But 20x better than 12 years ago

End 2022: 4.2 GW installed
~6. % of annual CH electricity consumption of 2022

Min > 1.7 GW year

For scenarios with 50 GW solar (current ~~government~~ scenario more at 35 GW)

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Alpine PV: boost critical witnter production

Demo floating Dam PV lac des toules

First infrastructure system on

Damm (Axpo)

New law: up to 60% CAPEX covered for Alpine PV (if more than 500 kWh/Wp in 6 months of winter… achievable thanks through bifacial modules)

Simulation of Alpine PV by opponents
(Greniols park)

Photovoltaics and energy systems in Neuchâtel

EPFL PV-lab IMT NEUCHATEL

- EPFL
  IMT/PV-Lab (1984)
  - Fundamental research
  - Advanced devices

:: csem PV-Center

- CSEM, RTO
  Sustainable Energy center
  (since 2013)
  - Focus on tech. transfer
  - Dev. for industry, innovation

Production and commercialization

Industrial partners
Spin-off, Start-ups

In contracts with over 45 companies
Along the value chain

Technology infra-structure Platforms

Coatings and thin film devices fabrication	Cells Pilot lines	Modules R&D lines	Polymers coumpounding/ extrusion	Batteries fabrication and storage tesing	Data /AI energy management

Reliability and accelerated aging tests

Metrology and characterization

~ 115 people

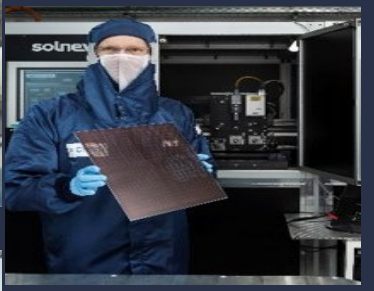
2800 m2

In collaboration with 40 companies

2000 m²

RESEARCH

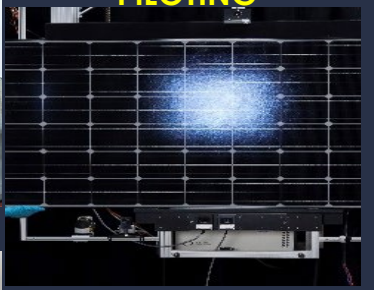
&



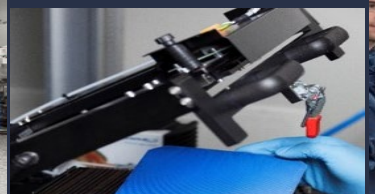
CONTRACTS WITH OVER

40 COMPANIES

ALONG



PILOTING



THE CHAIN

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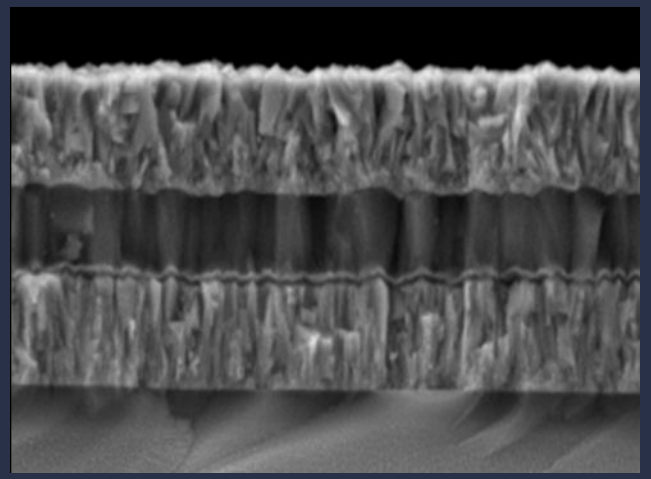
An history starting with IMT-UniNe, then EPFL



- Development of a culture of process
  and know-how development,
- Coatings and interfaces
  up to 20 layers, with 6 critical Interfaces
- Patenting strategy

- Flexcell: first roll-to-roll panels on PET foil

oerlikon solar

- Oerlikon: equipment for thin film Silicon modules on glass

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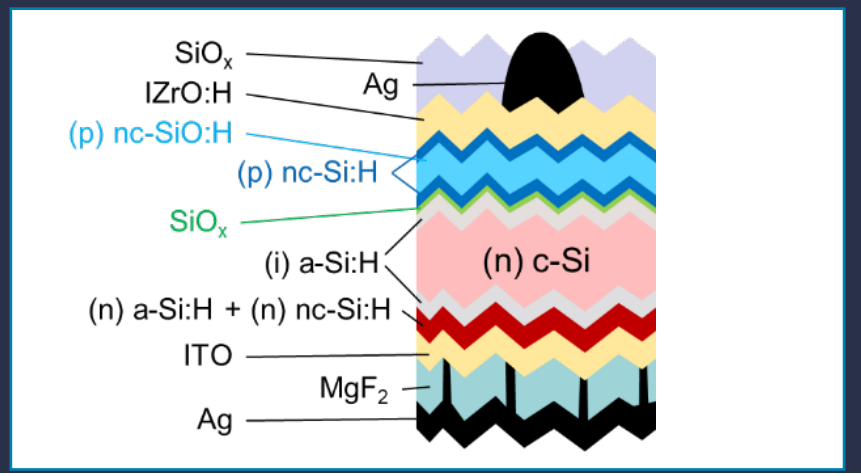
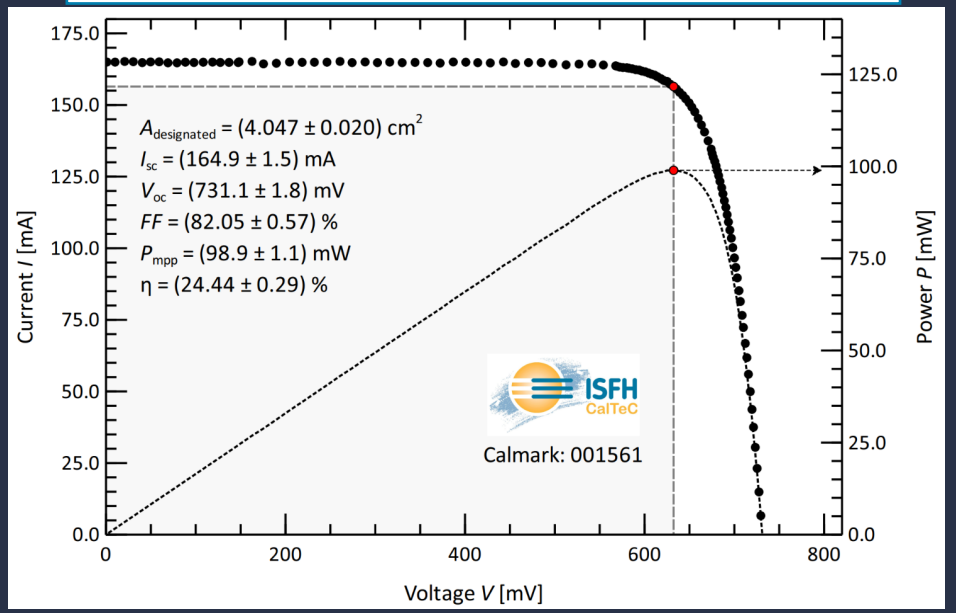
…. the T-Touch Solar Connect

- **Solar dials developped by CSEM,**
  production fully ramped-up by CSEM

From lab device, to 24.4% certified





Mathieu Boccard, Luca Antognini, Jean Cattin, Julie Dréon, Wenjie Lin, Vincent Paratte, Deniz Türkay, Christophe Balli, 2022

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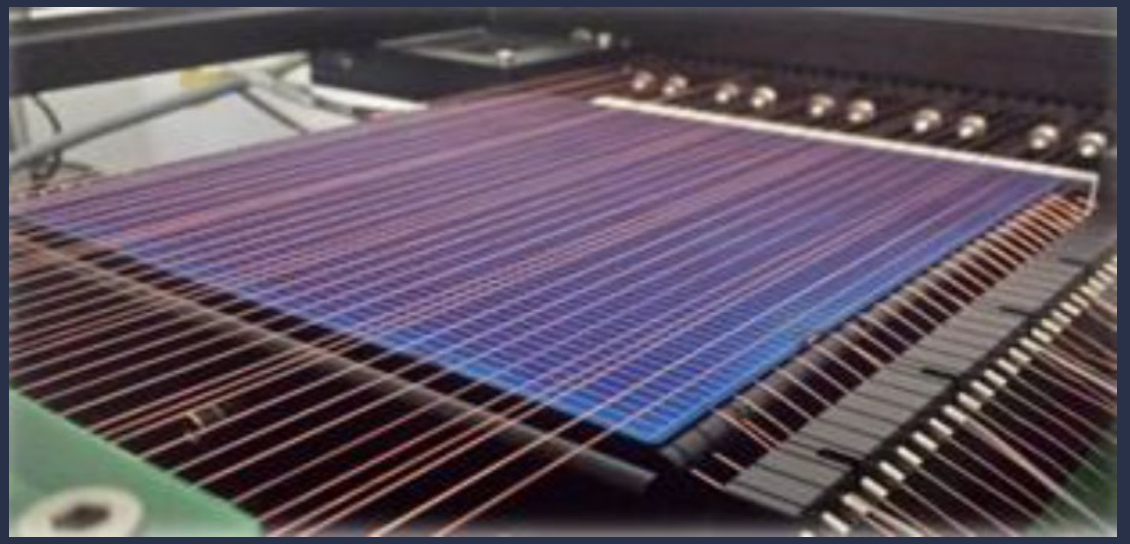
Silicon Heterojonction (monocrystalline) on large area

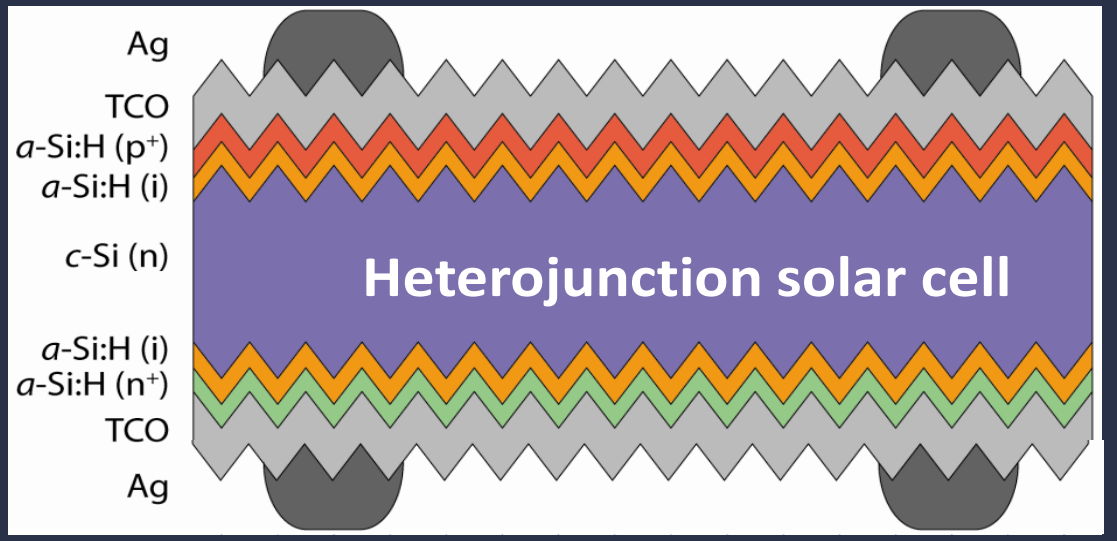
- **24.2** % in-house
- All screen-printed contacts

Area [cm²]	V_{OC} [mV]	J_{SC} [mA/cm²]	FF [%]	Eff. [%]
220	740	39.7	82.5	24.2

4 cm2 Certified:
N-type mono : 24.2%
P-type mono: 23.8%

1-2% absolute higher than industry standard





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A LEAN PROCESS TO MAKE HIGH EFFICIENCY CRYSTALLINE SILICON SOLAR CELLS

2005 2008 2009 2011 2013 2017 2022

First high efficiency solar cells

Hosting and transfer of technology to Roth&Rau Switzerland

Industri-alisation phase

Large scale demonstrator

First production lines and tools sold

Becoming the Leading EU cell and module manufacturer

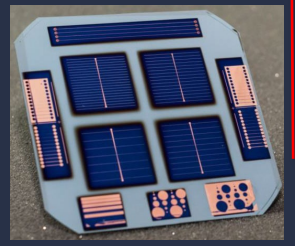
Swiss Electric Research award 2007

Creation Roth and Rau Switzerland

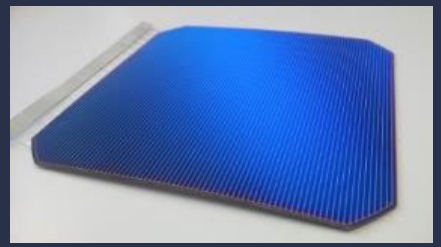
Meyer Burgers Acquires Roth&Rau

19.2%

22-23 %



22-23 %

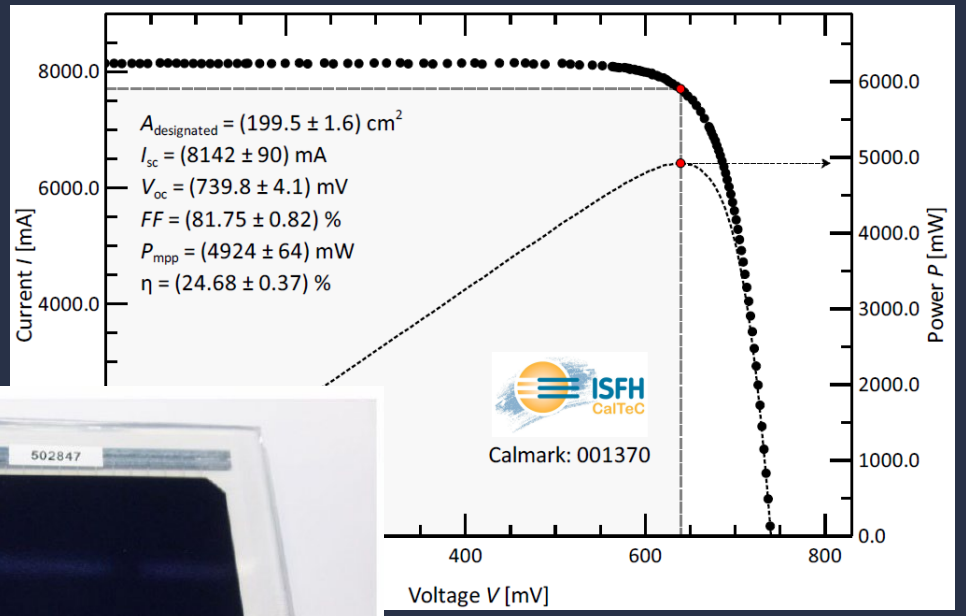


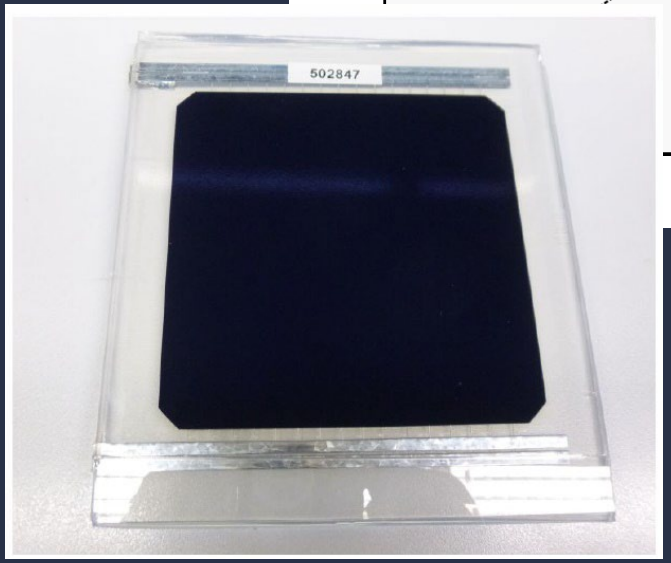
Beyond standard cells: The tunnel back-contact cell

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

- World record single-cell **laminate** with tunnel-IBC + SmartWires® :





✓ 24.7 % efficiency: world record for a laminate !

- First 60-cell tunnel-IBC module in glass/backsheet configuration:

These activities are supported by SFOE in the frame of the project "SIRIUS" (2021-2024E)and by EU under the Pilatus Project

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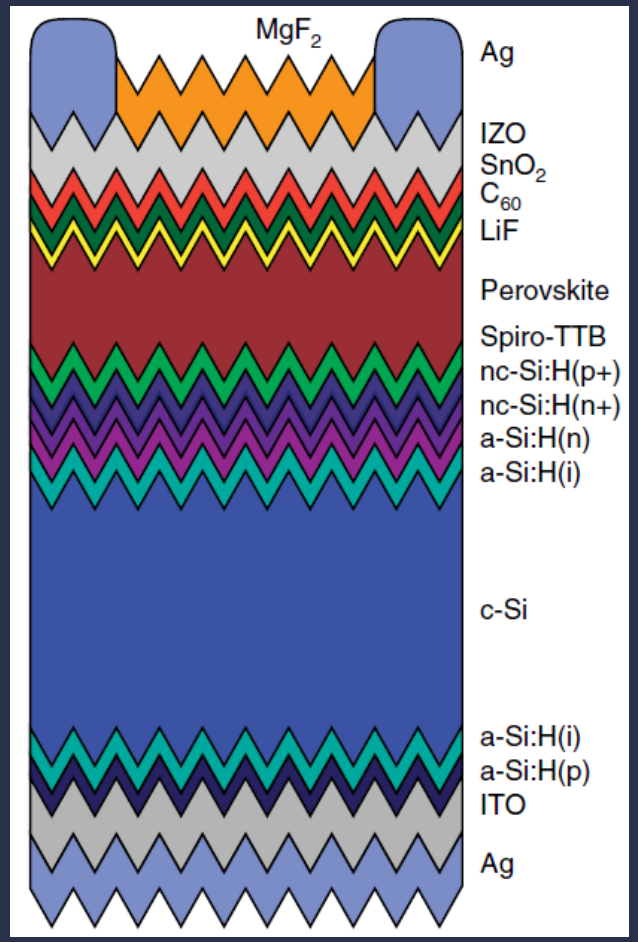
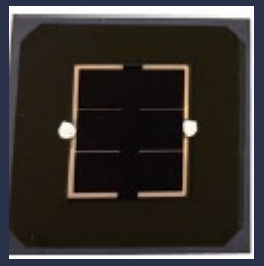
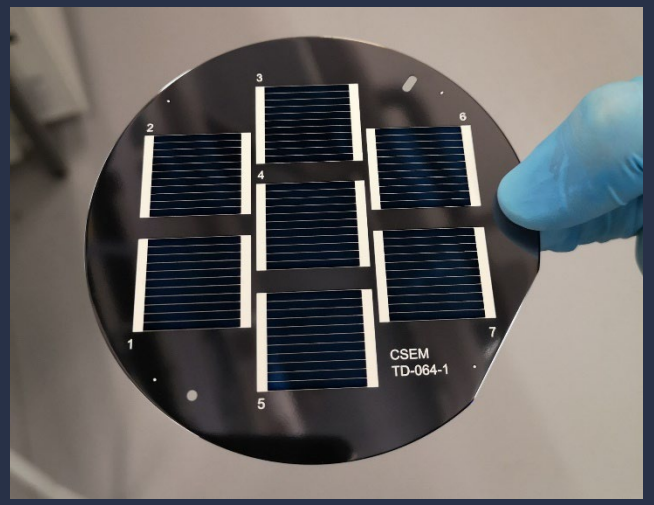
Cells above 30% ? Perovskite/silicon tandem solar cell





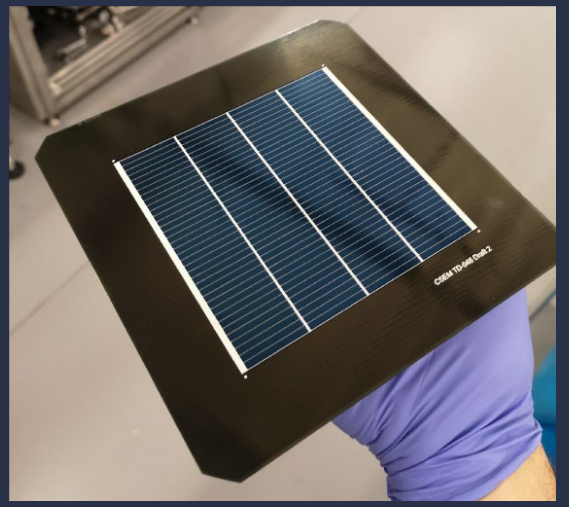
EPFL PV-lab and CSEM :

Certified > **31.3%***



Upscaling ongoing

(special 3 T at 29.6% on 25 cm2)



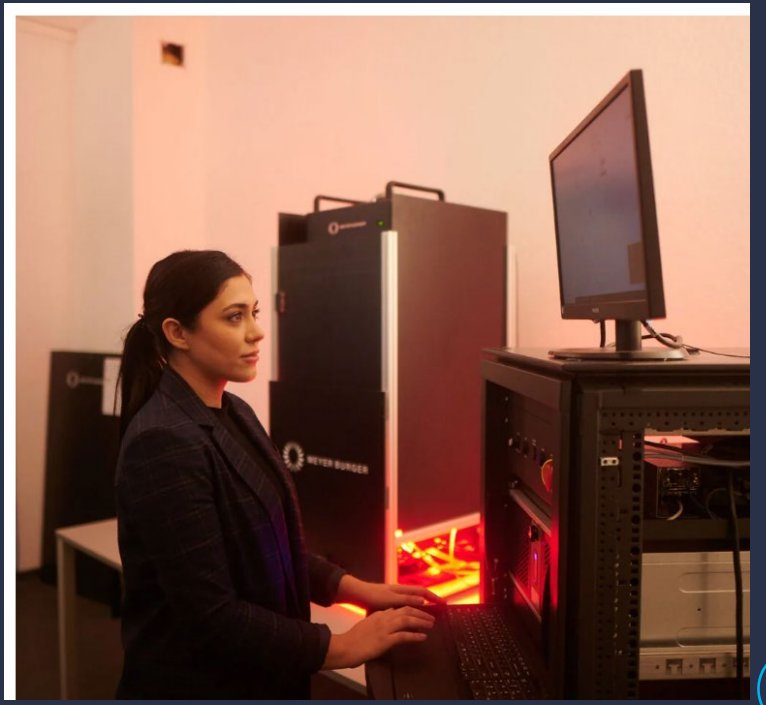
Sahli et al. Nature materials 2018, Xin Yu et al. To be published

csem EPFL

Christian Wolff/ Christian.wolff@epfl.ch

PASAN SA, Neuenburg

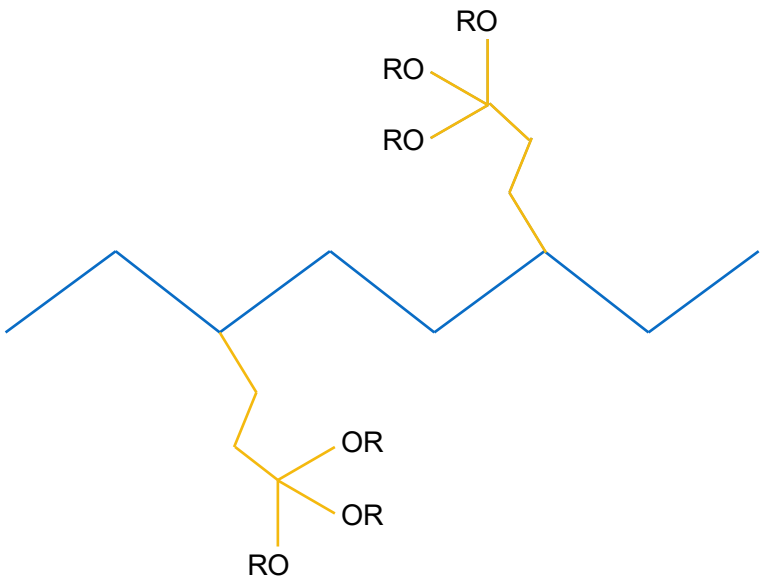
Metrology for cell and modules



A key tool from an IMT start-up for high efficiency c-Si cells

EPFL

Exemple of dveloppement by Padanaplast and CSEM
Encapsulant film formulation and production



Polidiemme® Solar

SPO compound

\+ (antioxidants, UV filter,…)

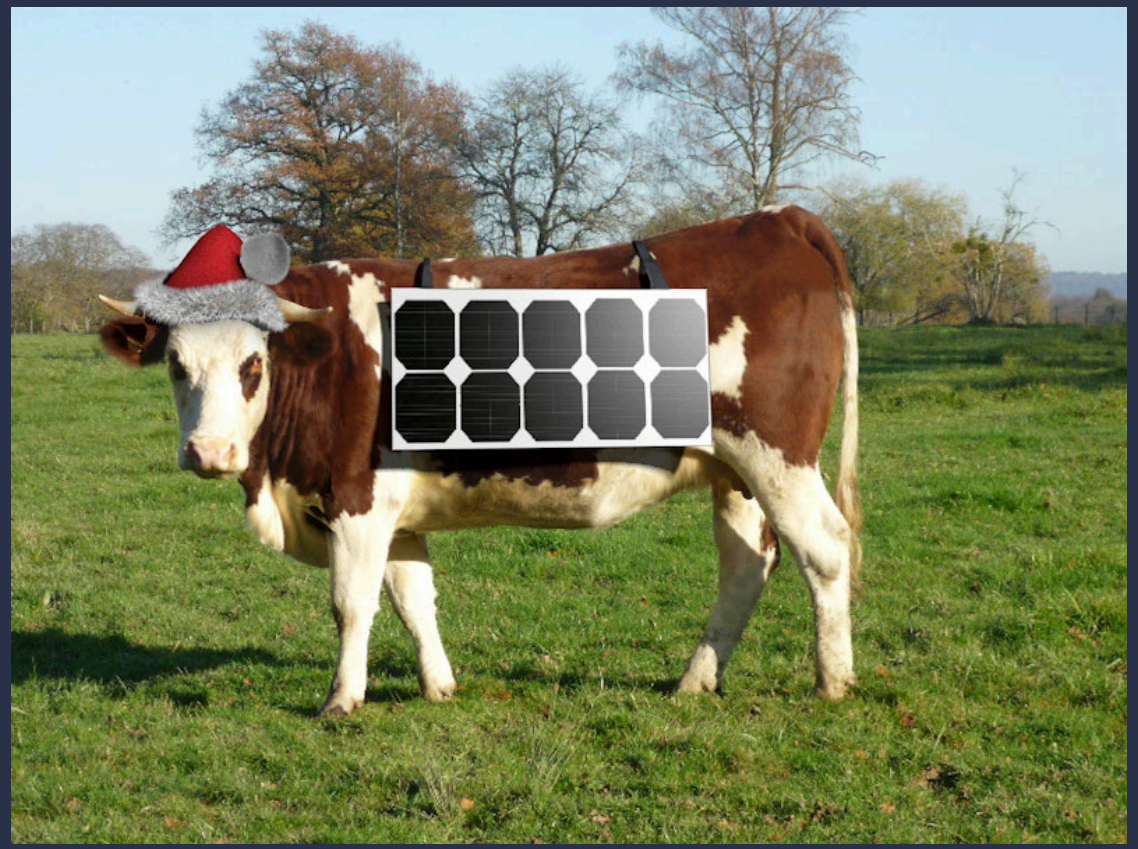
Masterbatch PV

Polidiemme® Solar Film

- processability as easy as a thermoplastic film
- facile customization through Masterbatch PV formulation
- low density (-8% vs EVA 28% VA)
- very low Water Vapor Transmission Rate (WVTR)
- very low water intake
- high volume resistivity

Switzerland, sensitive to acceptance in Rural and Urban Environment

Sensitive to aesthetics



- **Neuchâtel, maison des associations, Swiss Solar Award 2015 «renovation category»**
- **Over 20’000 “Megaslates” systems installed (3S solar plus)**

Prix solaire

Suisse 2015

Elegance and architecture

Transforming building and cities

- CSEM as pioneer of transformative technologies for PV panes

Based on low cost c-Si modules, ….

White PV panels, together with Solaxess

SOLAXESS
white solar technology

SOLAXESS
WHITE & COLOR SOLAR TECHNOLOGY

Concluding the EU Be-smart project, in Marin, Neuchâtel

And many more products upcoming

Laure-Emanuelle, Alessandro, Olatz, Luca, Xavier, Antonin et al., with Solaxess and CSEM

Prix solaire

Suisse 2018

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Ecuvillens

- One of the Terra-cotta tones
- With ISSOL, Solstis, Userhuus, SFOE
- Soutien des Service de l'énergie et des biens culturels de Fribourg

ETAT DE FRIBOURG
STAAT FREIBURG


Prix solaire
Suisse 2019
With support of
ne.ch
RÉPUBLIQUE ET CANTON DE NEUCHÂTEL

SOLAXESS
WHITE & COLOR SOLAR TECHNOLOGY

3S Solar Plus

csem

EPFL


SOLAXESS
white solar technology
3S Solar Plus
Schutz & Rettung
STOP


SOLAXESS
white solar technology
3S Solar Plus


FREE SUNS
SOLAR ENERGY


FREE SUNS
SOLAR ENERGY


FREESUNS
SOLAR ENERGY

Private house Neuchâtel

Courtesy L.E. Perret-Aebi

compáz

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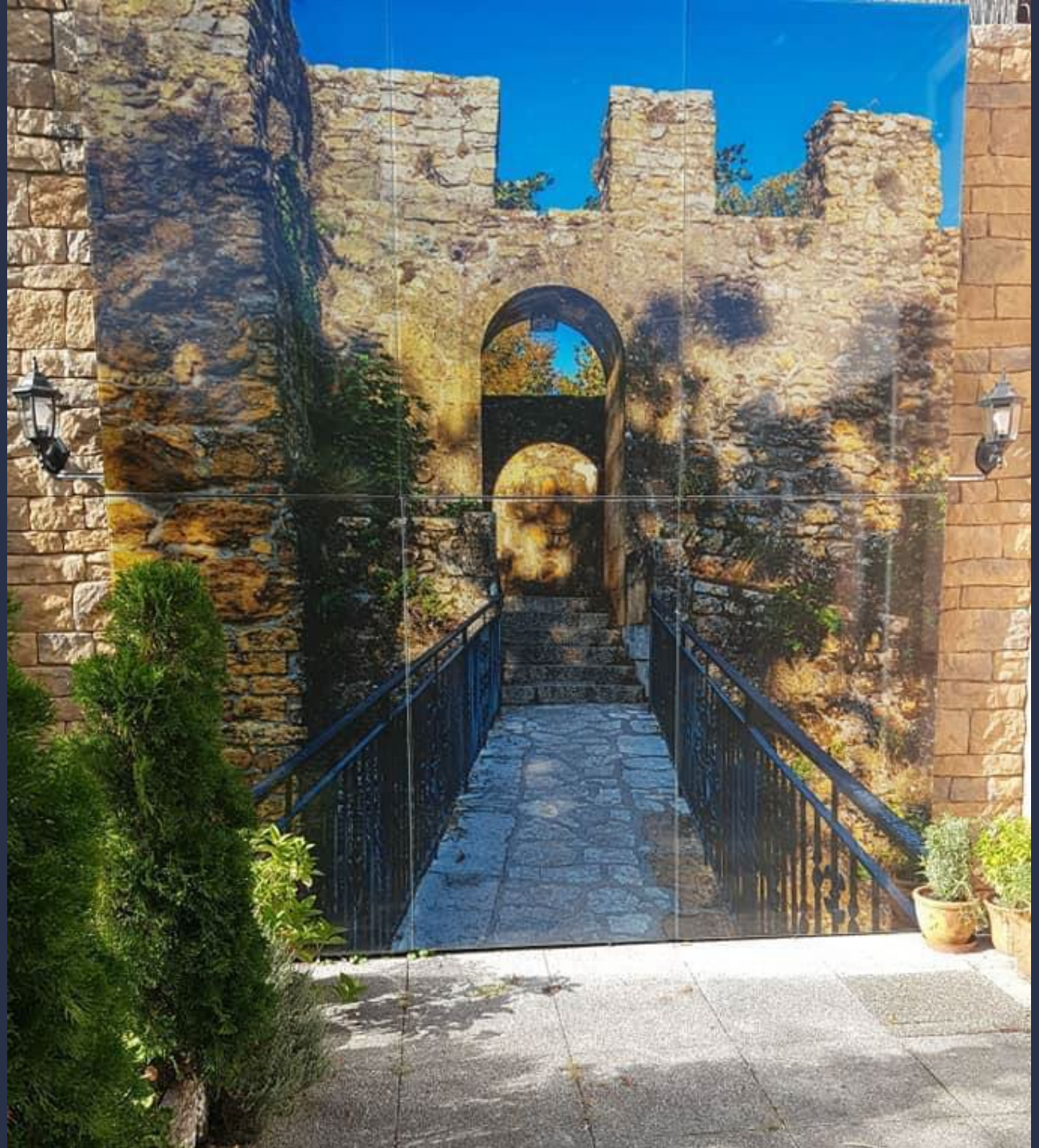
Private garden Neuchâtel



compáz

Courtesy L.E. Perret-Aebi

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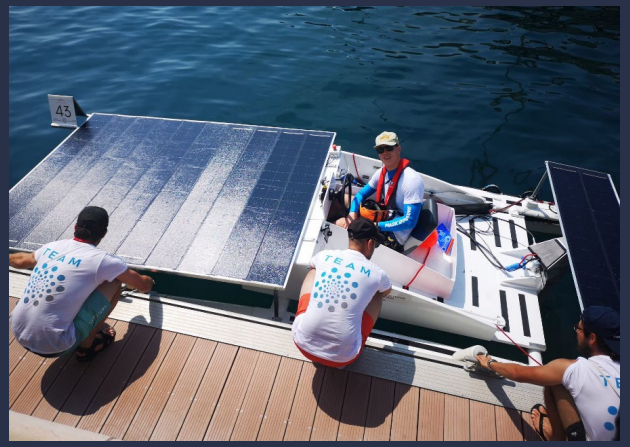
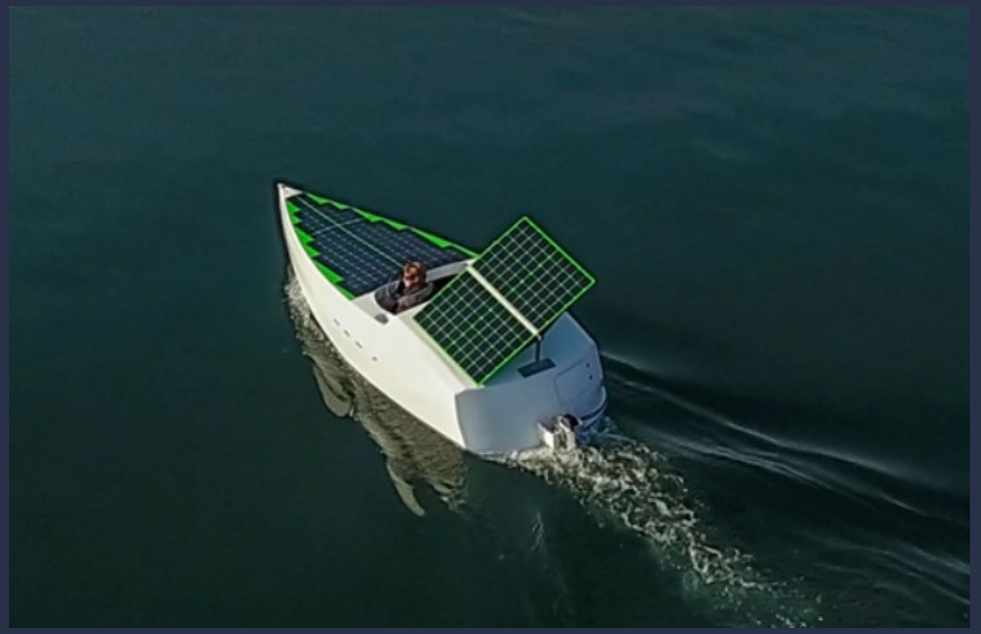
Light weight ultra-reliable modules: direct to the applications





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Integrated PV to reach the Stratosphere

SOLARSTRATOS
TO THE EDGE OF SPACE

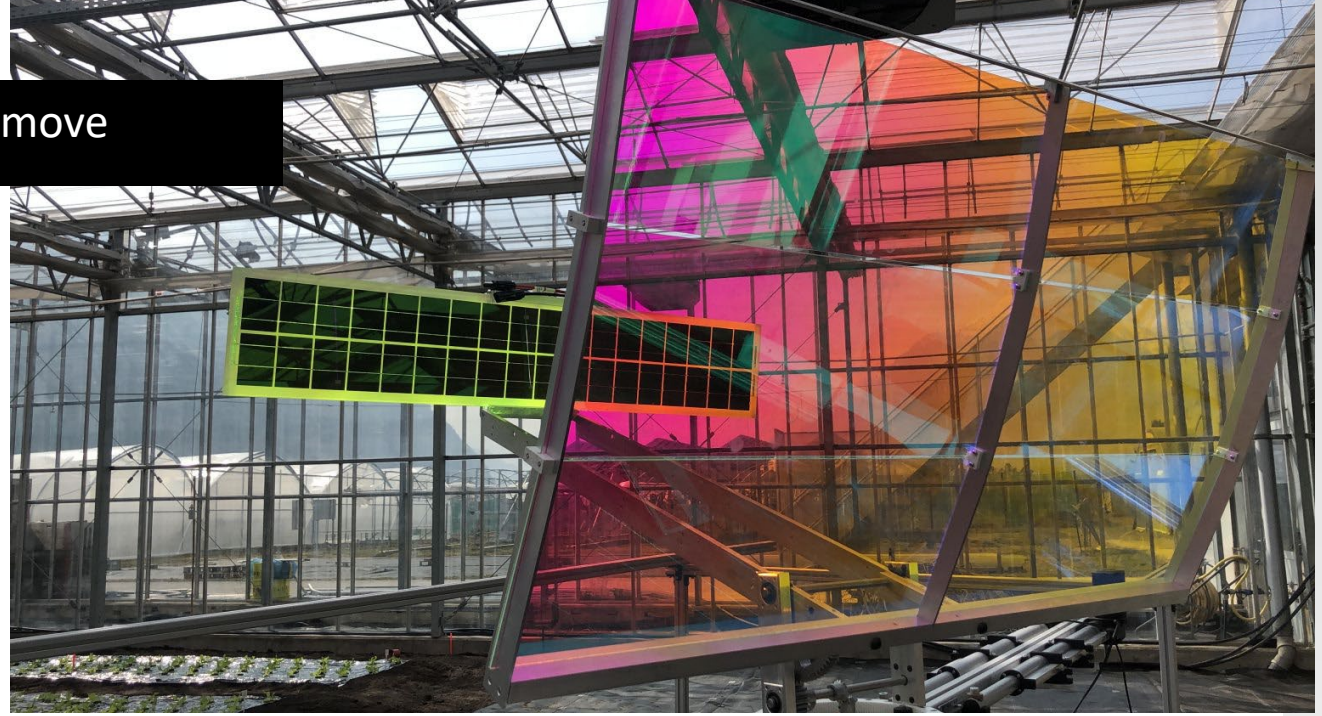
Deployable lightweight structures and PV modules qualified in stratosphere !

Innovation in Switzerland: of course DHP (GR)

dhp
ENERGY FOR MANKIND

Deployable PV systems

Agrivoltaics on the move



Voltiris

Insolight: Special greenhouse modules

insolight

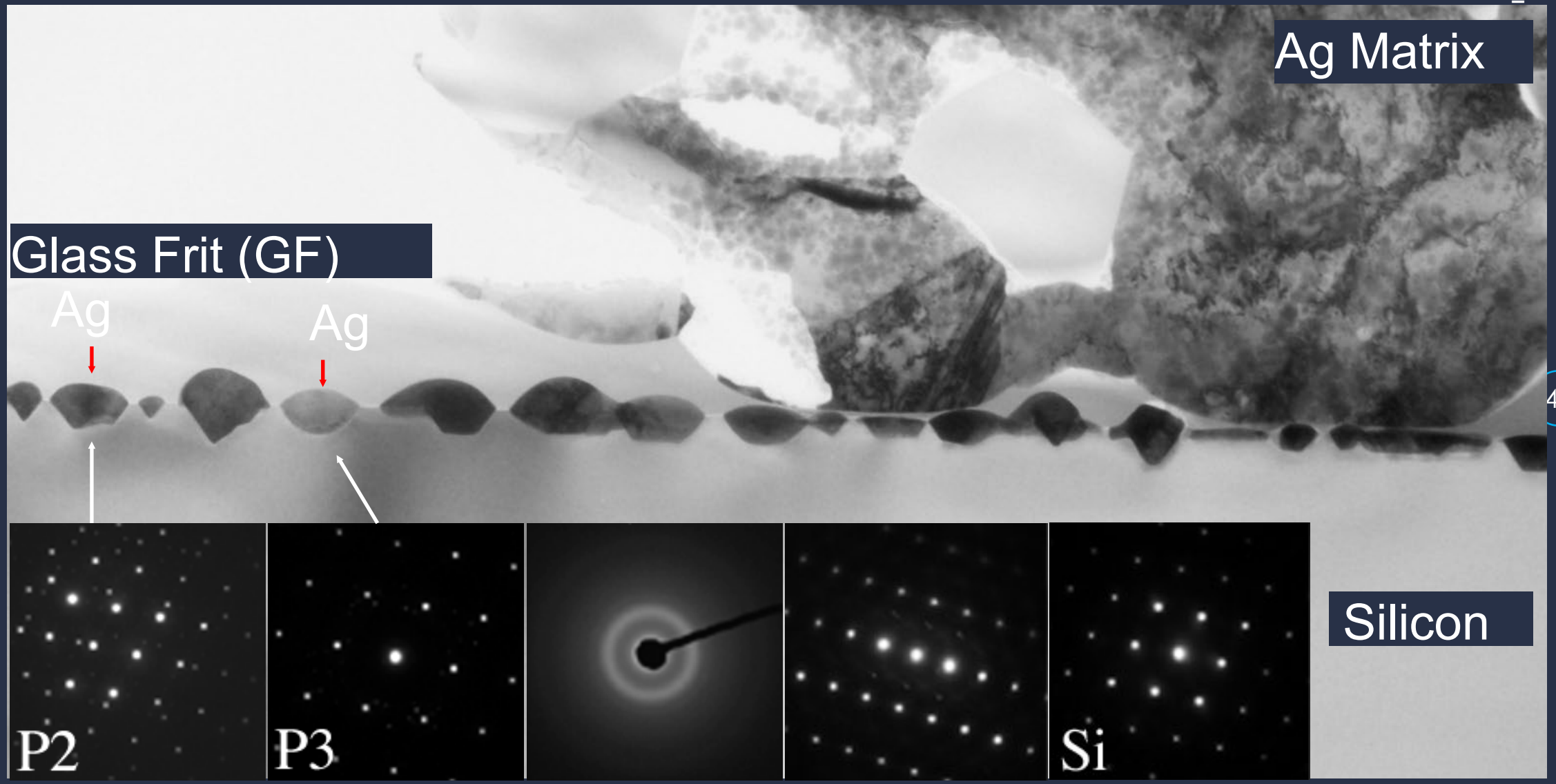
ROMANDE ENERGIE

csem

hiperion
MAX SOLAR POWER

And what about metalisation ??

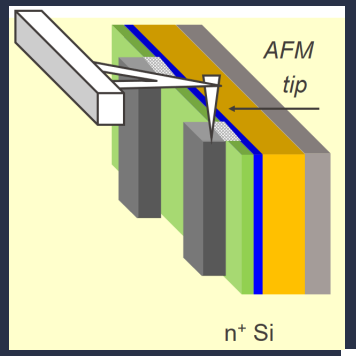
My personnal starts (with Fraunhofer ISE jointly with EPFL, 2022-2023)



Ballif, Hessler-Wyser, Huljic, Willeke, APL 2003

Old first investigations

Model for current flow



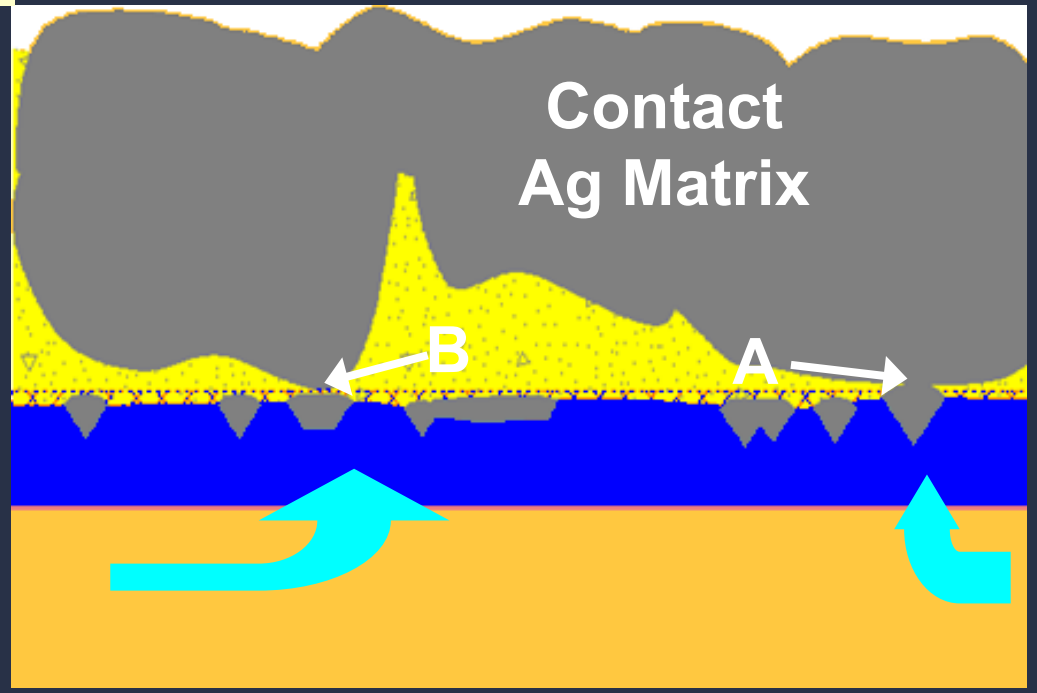
Glass frit

- No Ag or Pb precipitates
  → isolating

- Only a few crystallites contribute to current flow

A: direct connections

B: tunnel effect through ultra-thin glass frit



→ High doping necessary ↔ low « active » surface for contact

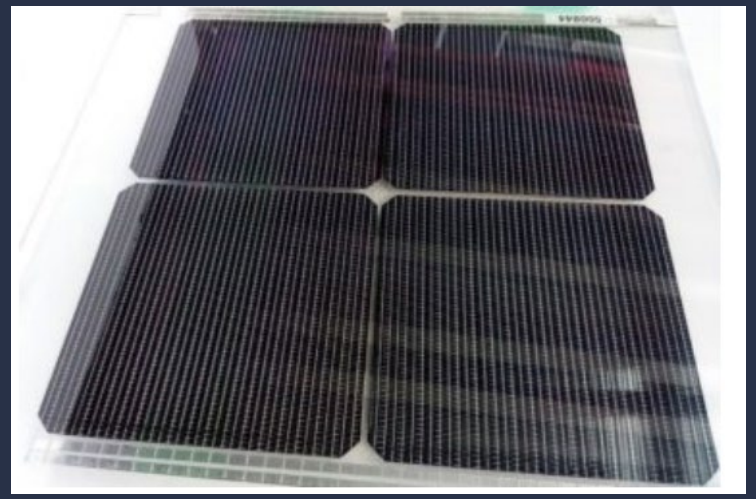
→ Deep junction ↔ Ag crystallites and impurity diffusion

Ballif, Hessler-Wyser, Huljic, Willeke, APL 2003

Further work ongoing

Own design for interconnectors for specific applications

Smartwire for HJT and IBC



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NEXTBASE

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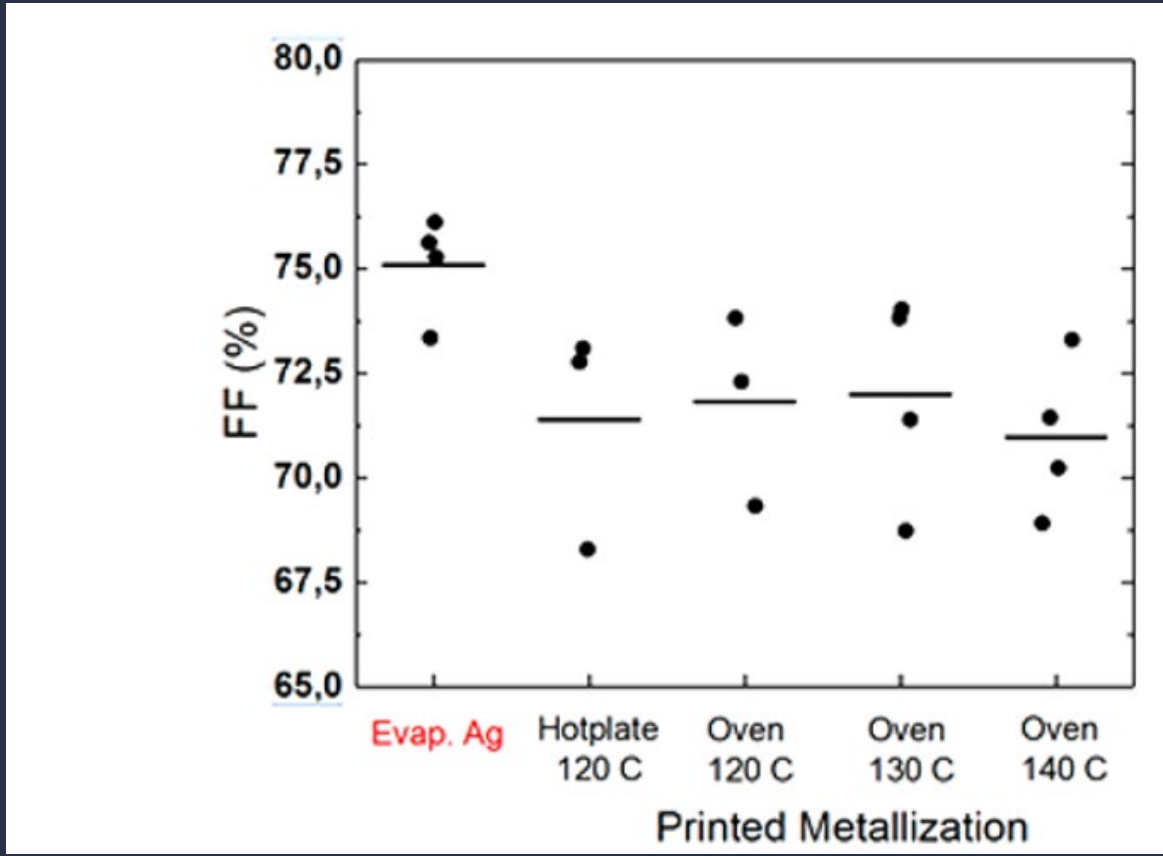
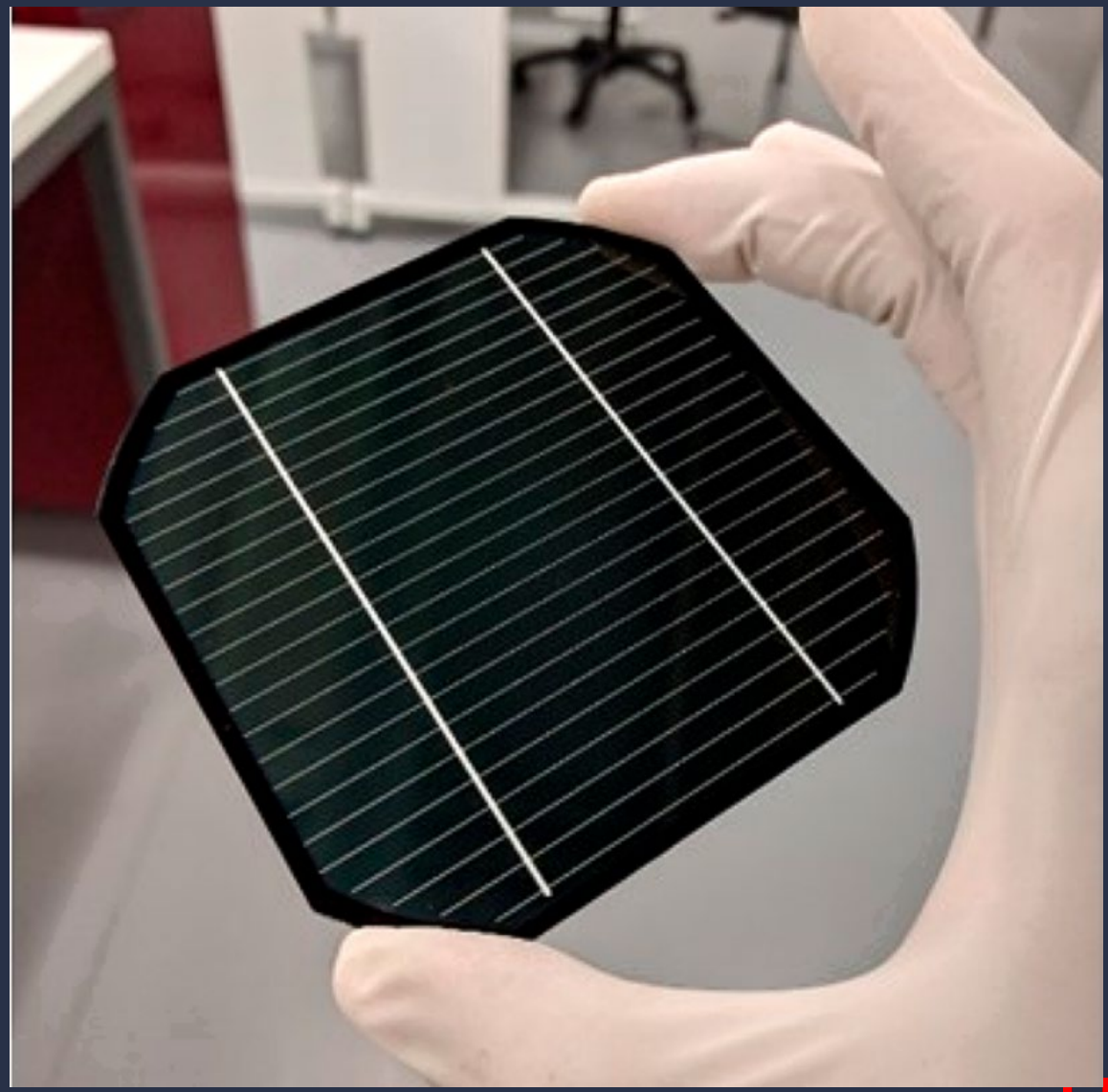
Perovskite's metalisation



ACS APPLIED ENERGY MATERIALS
Article
Cite This: ACS Appl. Energy Mater. 2019, 2, 3815−3821
www.acsaem.org

Low-Temperature Screen-Printed Metallization for the Scale-Up of Two-Terminal Perovskite−Silicon Tandems

Brett A. Kamino,*[,†] Bertrand Paviet-Salomon,[†] Soo-Jin Moon,[†] Nicolas Badel,[†] Jacques Levrat,[†]



[Low-Temperature Screen-Printed Metallization for the Scale-Up of Two-Terminal Perovskite–Silicon Tandems | ACS Applied Energy Materials] 2019, Kamino et al.

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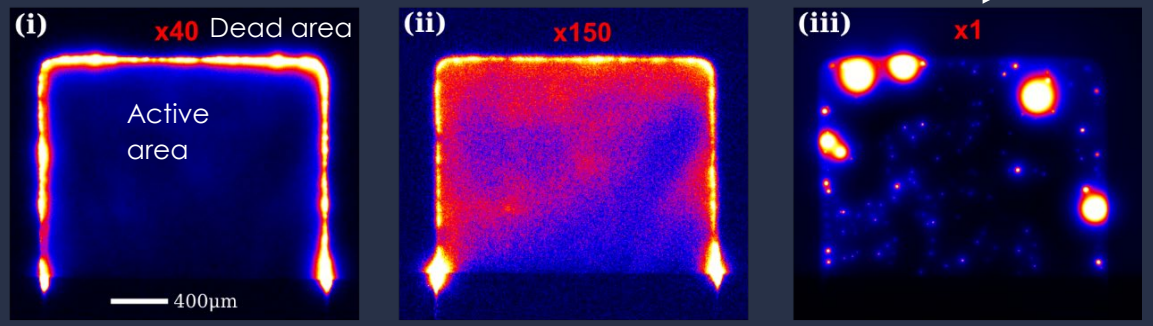
Lateral ion migration may result in shunting

[Lateral ion migration accelerates degradation in halide perovskite devices - Energy & Environmental Science (RSC Publishing)](#)
2022, Daniel Jacobs et al.

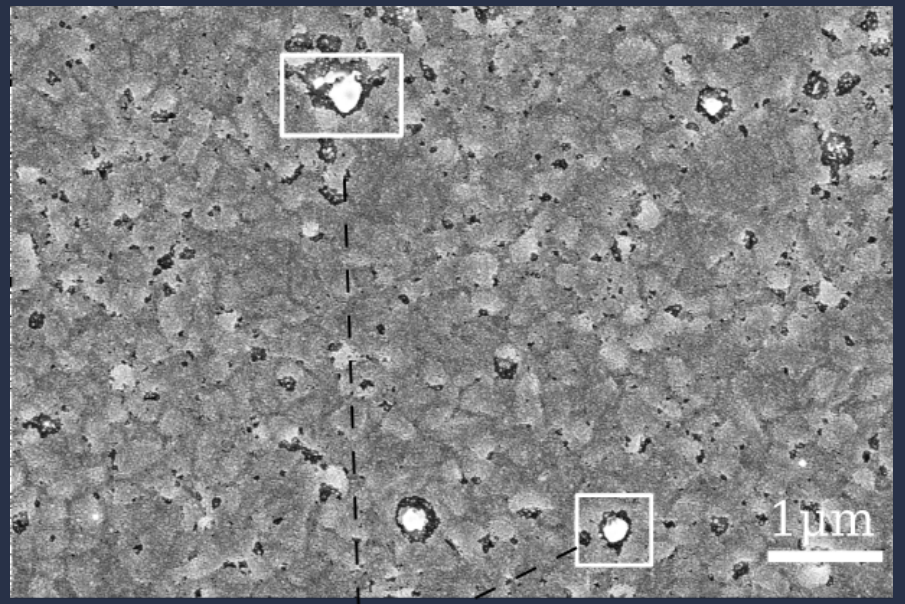
Edges degrade first in the absence of harmful impurities

Accumulation of ions due to potential difference

Sequence of thermographs at -4V

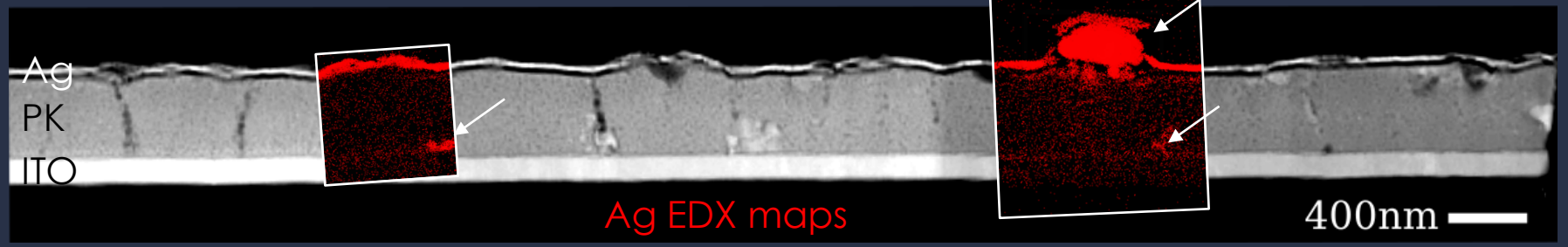


SEM top view



Ingress of metal leads to shunts

STEM x-section



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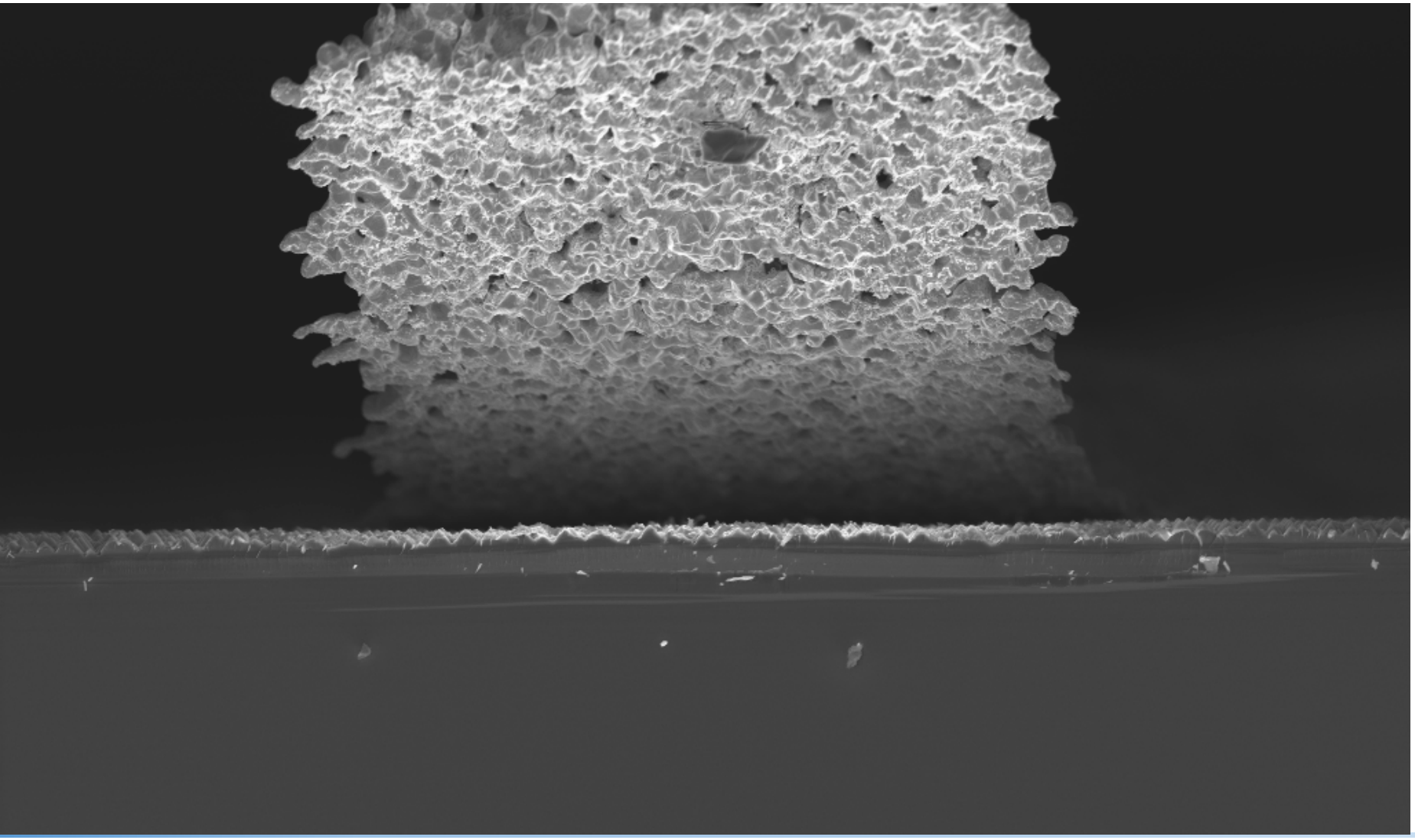
- Contacting Passivating contacts



Large Ag finger on top of small pyramids

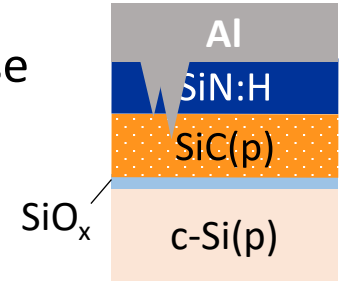
J. Hurni, A. Morisset, F.J. Haug.

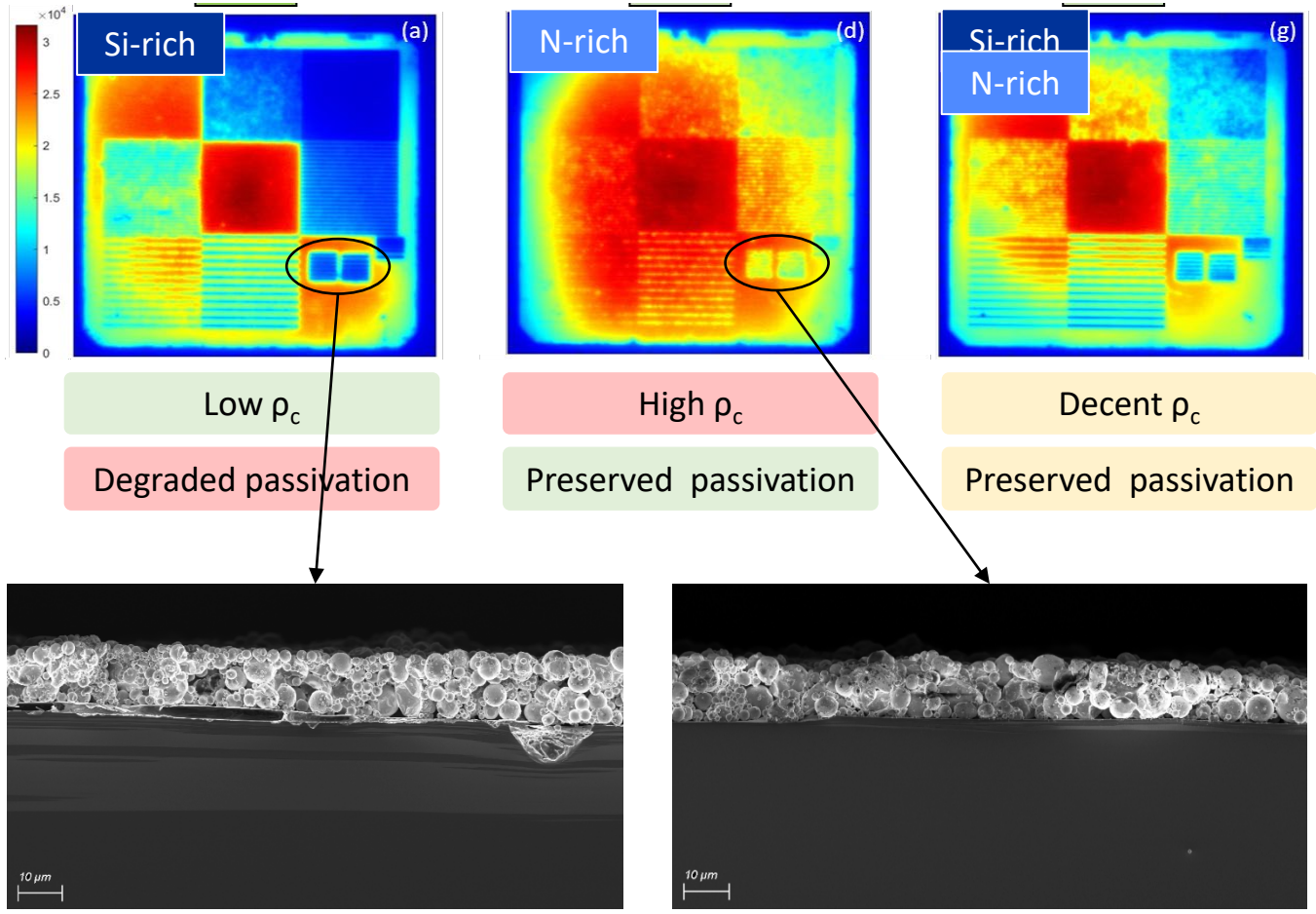
Advanced characterization of metal/poly-Si contact formation

Al firing-through SiN:

Optimization of SiN_x layer for better compromise between passivation and contact:

- Si-rich → spikes go into the wafer
- N-rich → passivation preserved but no contact
- Si-rich/N-rich → best compromise





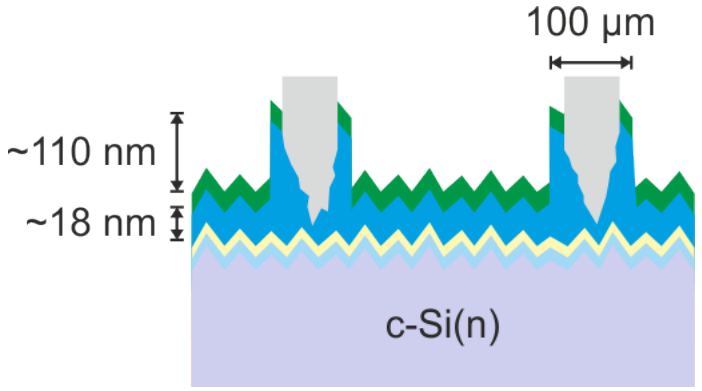
Full study just published → S. Libraro et al., Sol. Energy Mater. Sol. Cells.

https://doi.org/10.1016/j.solmat.2022.112051

Metalisation for Topcon cells: front localized contacts

hard mask during layer deposition

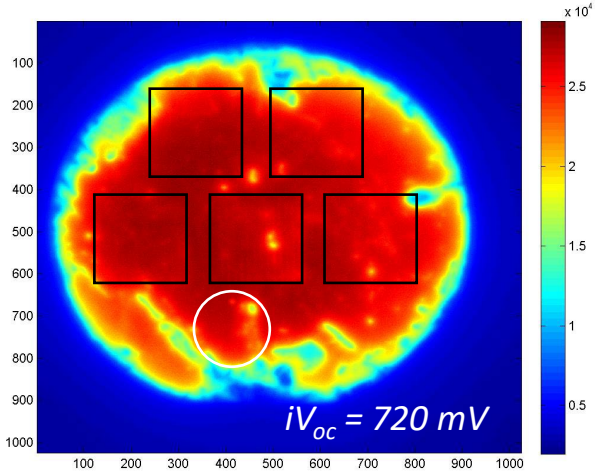
- PECVD:
  - Deposition rate reduced by a factor 3 through mask opening
  - Opening down to 100um for layer >80nm
  - Homogeneous passivation after PECVD
  - Low spreading
  - Alignment of metal fingers possible



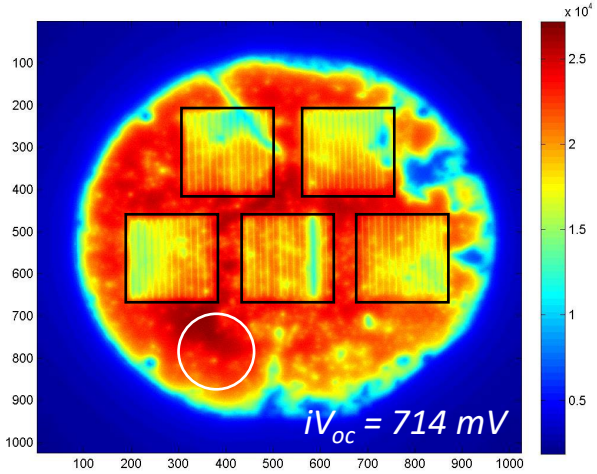
F. Meyer et al., Sol. Energy Mater. Sol. Cells. 235 (2022) 111455

J. Hurni et al.

After PECVD + hydrogenation:

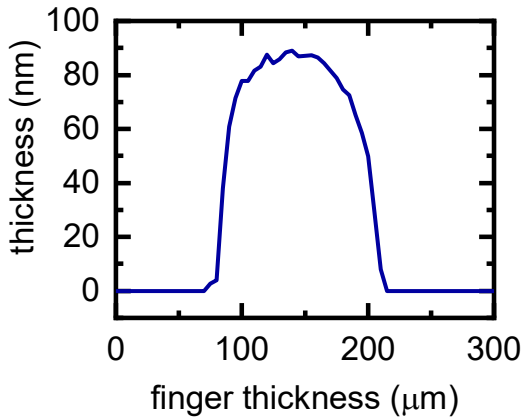


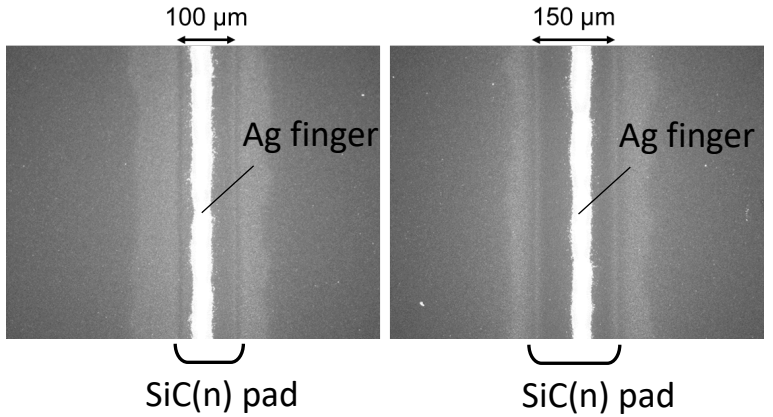
After metallization:



Raman profilometry

Mask opening of 100 µm





Subsituting Ag in HJT

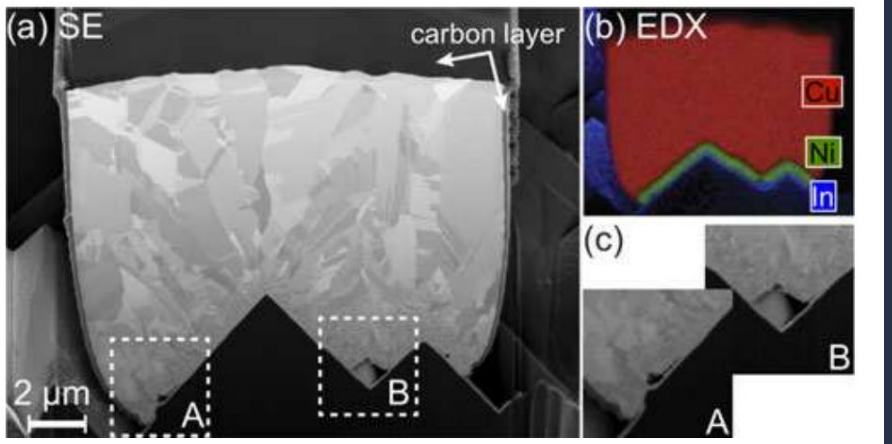


Fig. 6. (a) Secondary-electron SEM image of a Ni/Cu finger FIB cross section (in lens detector). (b) EDX maps of copper (using the K_α X-ray energy), nickel (K_α), and indium (L_α). (c) Magnified view of two different kinds of defects observed at the ITO/Ni interface.

J. Geissbuhler et al IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 4, NO. 4, JULY 2014

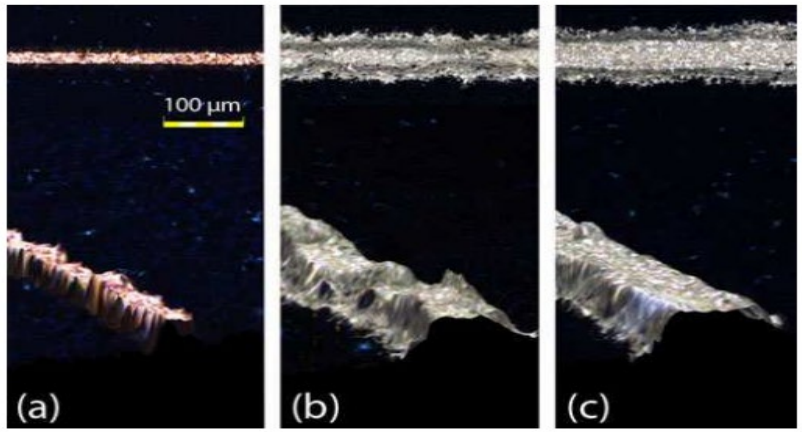


Fig. 3. Optical microscopy top views and confocal microscopy 3-D reconstructions of metallic fingers made by (a) copper electroplating, (b) silver paste screen-printing, and (c) silver paste stencil-printing.

Various processes for cupper plating since 2012

Several innovative processes with Cu pastes, self-masking

See talk by Agata Lachowicz et al. today !

Project ameliz: Patterning techniques for copper electroplated metallization on heterojunction solar cells | AIP Conference Proceedings | AIP Publishing

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Thanks for your attention !

"We need many more E. Becquerel's Children"
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