



2D Periodic Photonic Nanostructures Integrated Into 40 um Thin Crystalline Si Solar Cells

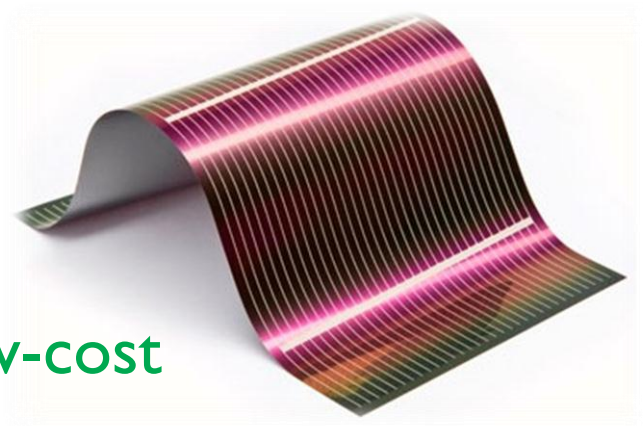
CHRISTOS TROMPOUKIS, OUNSI EL DAIF, VALERIE DEPAUW, JEROME MULLER,
JONATHAN GOVAERTS, TWAN BEARDA KRIS VAN NIEUWENHYUSEN,
HARIHARSUDAN SIVARAMAKRISHNAN RADHAKRISHNAN, STEFANO GRANATA,
ROBERTO MARTINI, IVAN GORDON, JEF POORTMANS



OUTLINE

- Introduction/Motivation
- 2D Periodic Photonic Nanostructures Integrated Into 40 um Thin Crystalline Si Solar Cells
 - Fabrication
 - Characterisation
 - Integration
- Outlook

Thin-film



😊 Low-cost

😊 Simple

😊 Scarce

☹ Toxic

Crystalline Si



😊 Abundant

😊 Well-known

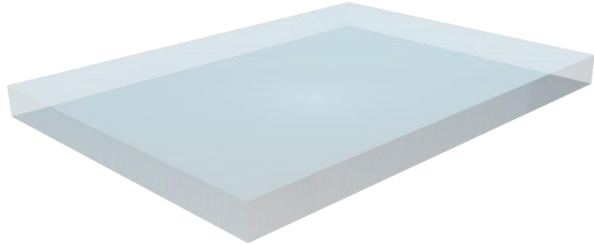
☹ \$ module

☹ \$ material

😊 Stable

😊 Efficient

HOW THIN-FILM C-Si PANELS ARE MADE

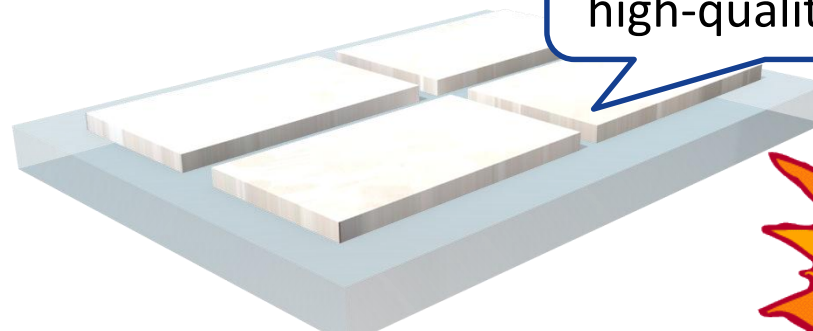


Starting material is a piece of glass

We need high-quality thin c-Si

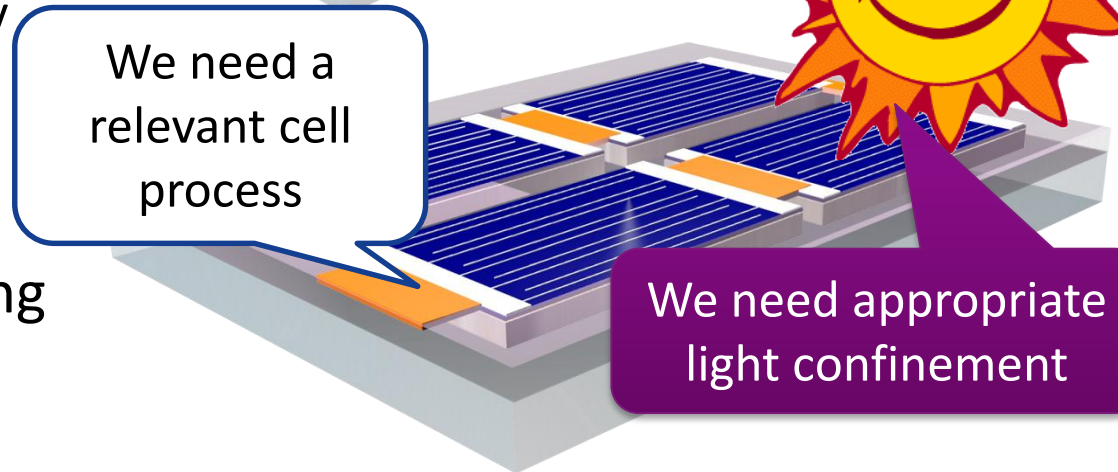
Fabrication of a thin layer of Si

- Thickness < 50 μm
- High material quality



We need a relevant cell process

Parallel processing on module level



We need appropriate light confinement

Dross et al. PIP 20 (2012)

ADVANCED LIGHT TRAPPING IS POSSIBLE

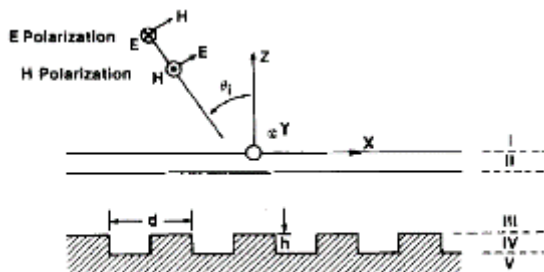
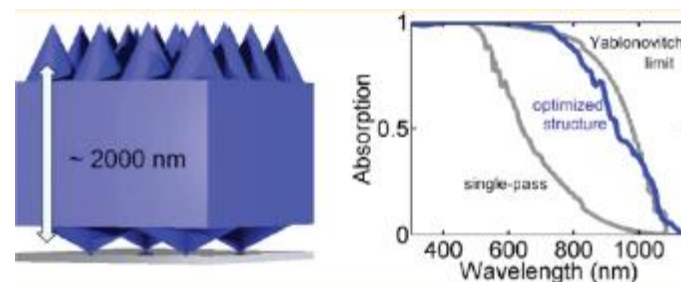


FIG. 1. Geometry of the cell used in optical calculations.

Wavelength-selective absorption enhancement in thin-film solar cells

Ping Sheng, A. N. Bloch, and R. S. Stepleman
Exxon Research and Engineering Company, Linden, New Jersey 07036
 (Received 4 May 1983; accepted for publication 1 July 1983)



NANO LETTERS

pubs.acs.org/NanoLett

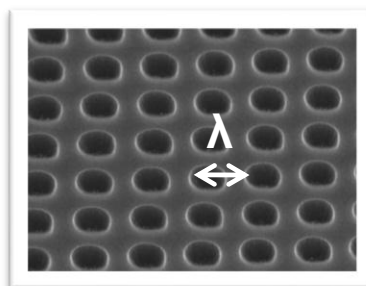
Absorption Enhancement in Ultrathin Crystalline Silicon Solar Cells with Antireflection and Light-Trapping Nanocone Gratings

Ken Xingze Wang,¹ Zongfu Yu,² Victor Liu,³ Yi Cui,^{3,4} and Shanhui Fan^{1,2}

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⁴Stanford Institute for Materials and Energy Sciences, SLAC National Accelerator Laboratory, Menlo Park, California 94025, United States

Go towards wavelength-scale patterning



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DEVICE PROCESSING

Epitaxial foils on parent substrates

Front side processing:

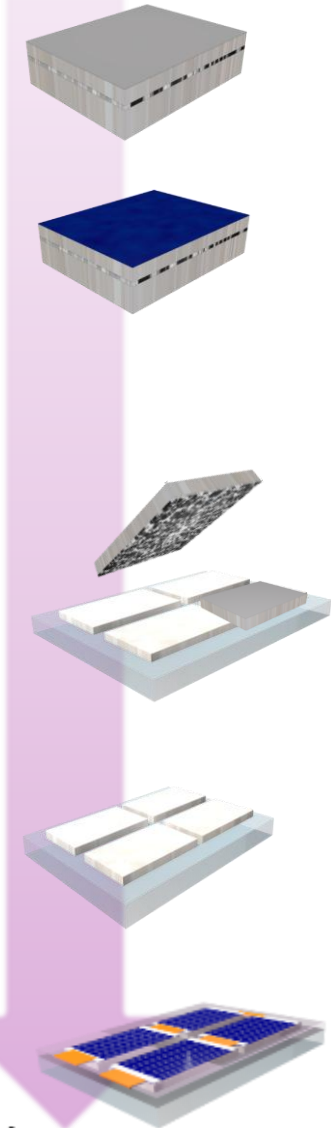
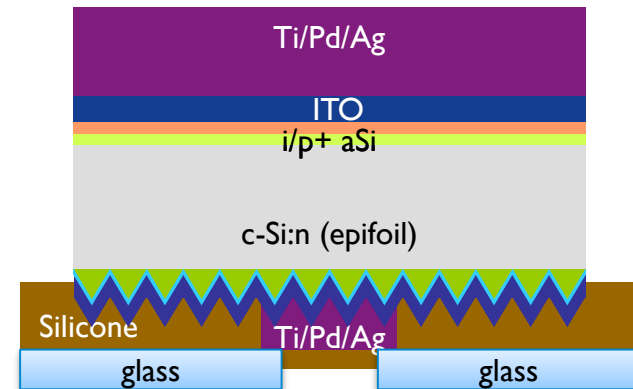
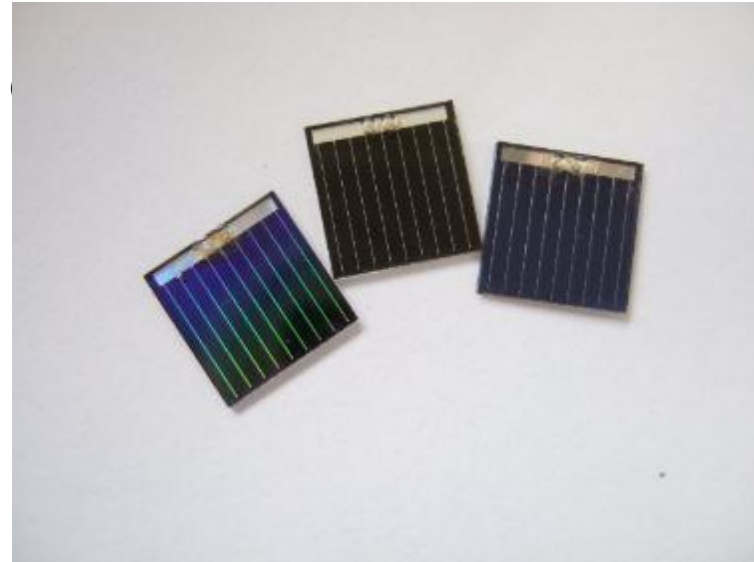
1. Texturing
2. Passivation/FSF
3. ARC
4. Metallization

Bonding and detachment

Back side processing:

1. Emitter
2. Dielectric metal stack

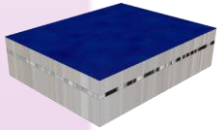
Dicing



DEVICE PROCESSING

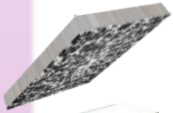


Epitaxial foils on parent substrates

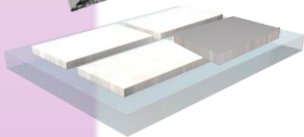


Front side processing:

1. Texturing
2. Passivation/FSF
3. ARC
4. Metallization

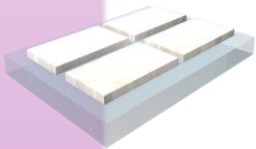


Bonding and detachment

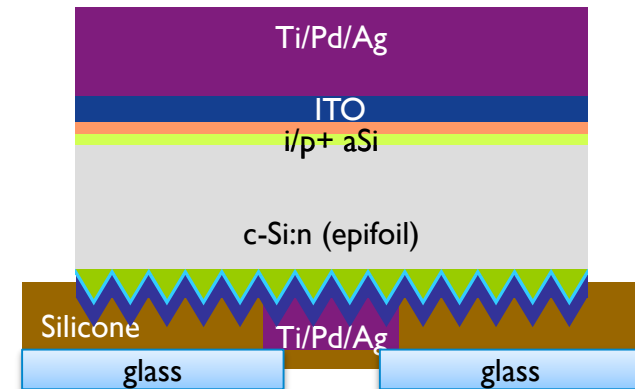
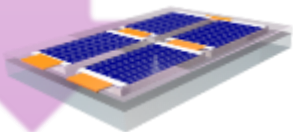


Back side processing:

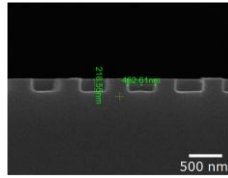
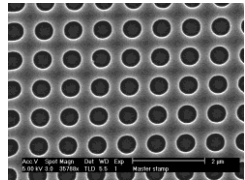
1. Emitter
2. Dielectric metal stack



Dicing



NANOTEXTURING: NANOIMPRINT LITHOGRAPHY

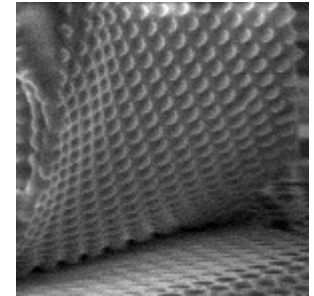


Soft stamp fabrication

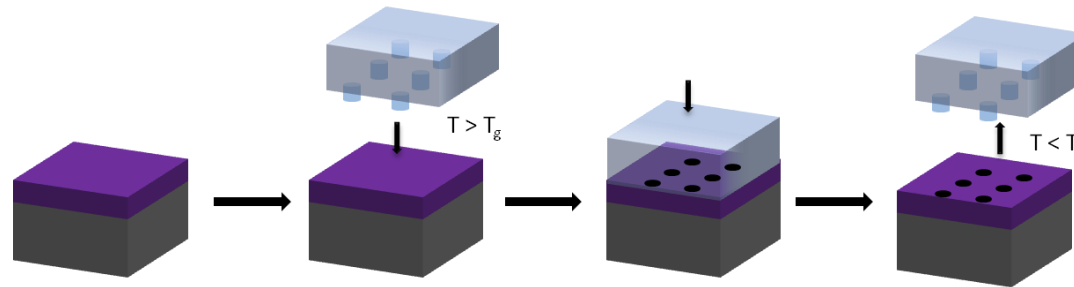
Master stamp

Silicone

Soft stamp



Nanoimprint

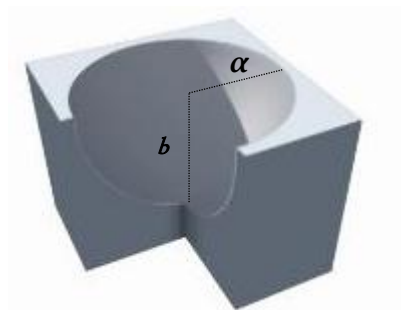
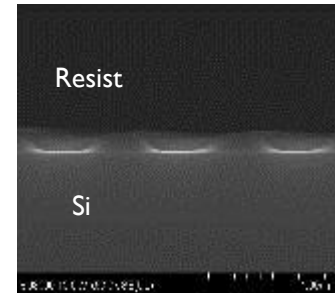


Spin coat resist

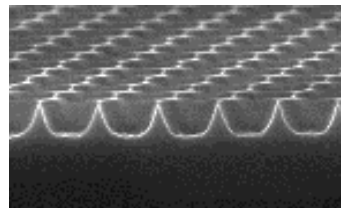
Heat up

Press

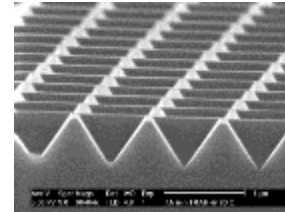
Cool down and detach



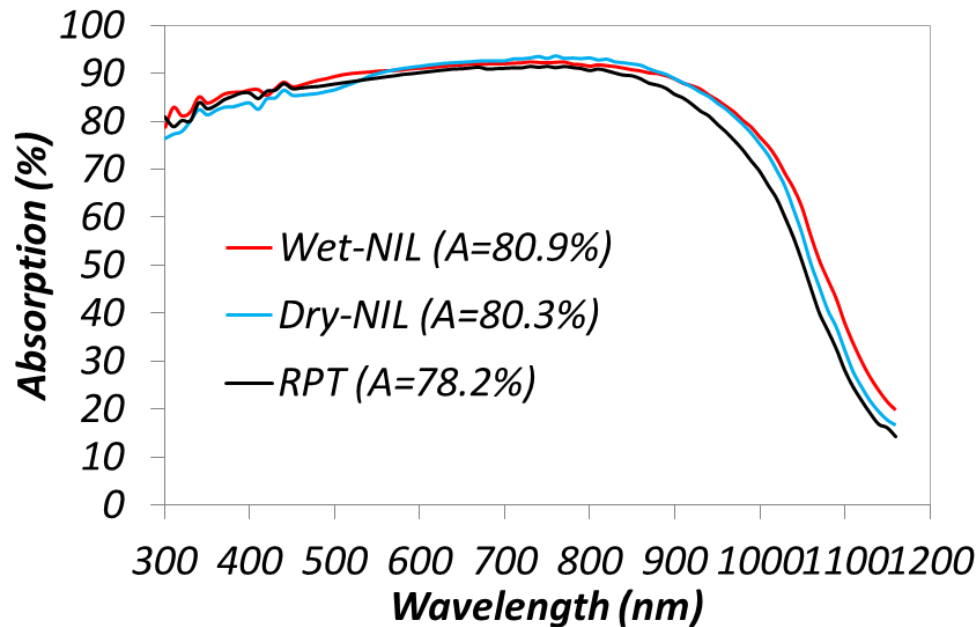
DRY - NIL
Reactive ion etching



WET - NIL
TMAH etching



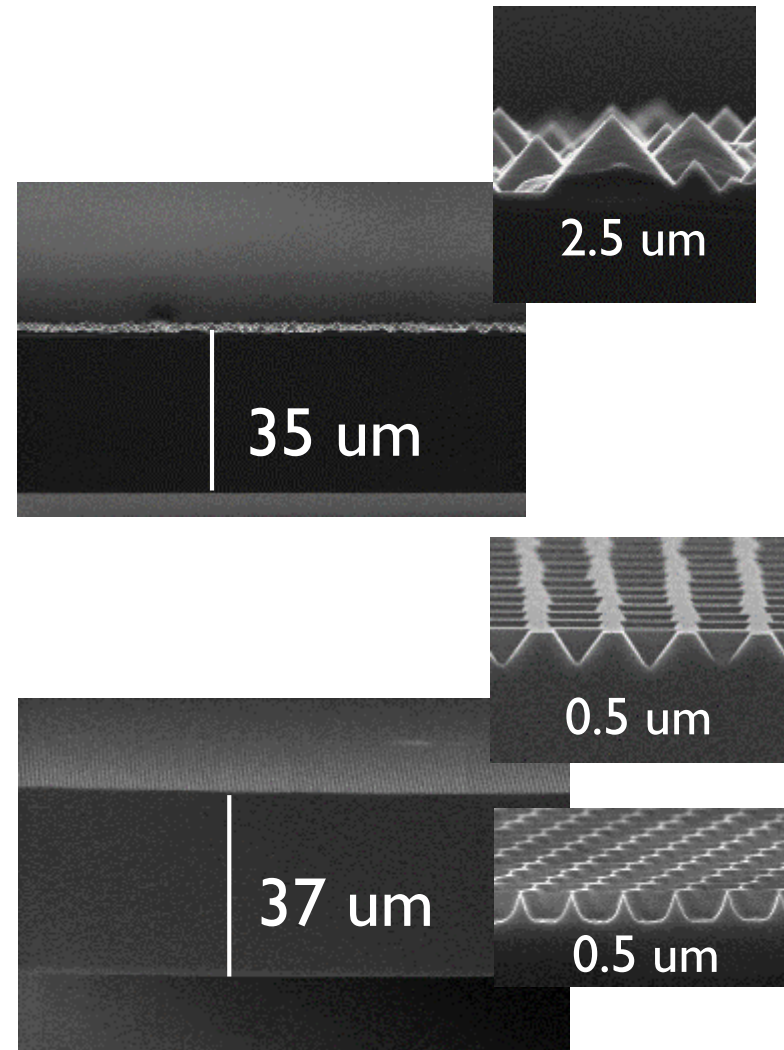
FRONT SIDE TEXTURING



Better light-trapping than state-of-the-art texturing (37 μm Epifoils)

C. Trompoukis et al. PIP (2014)

DOI: 10.1002/pip.2489



DEVICE PROCESSING

Epitaxial foils on parent substrates

Front side processing:

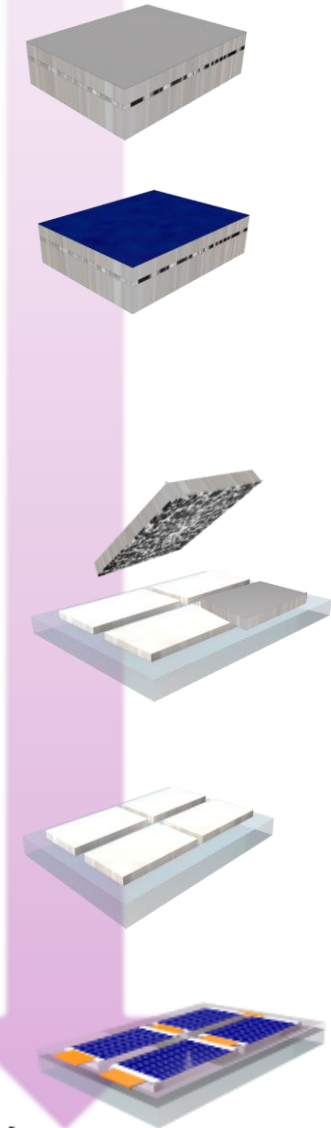
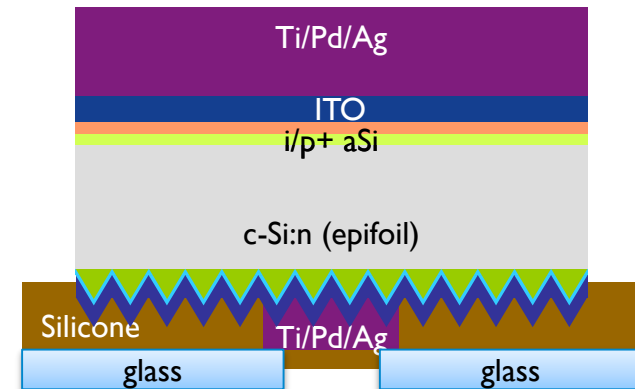
1. Texturing
2. Passivation/FSF
3. ARC
4. Metallization

Bonding and detachment

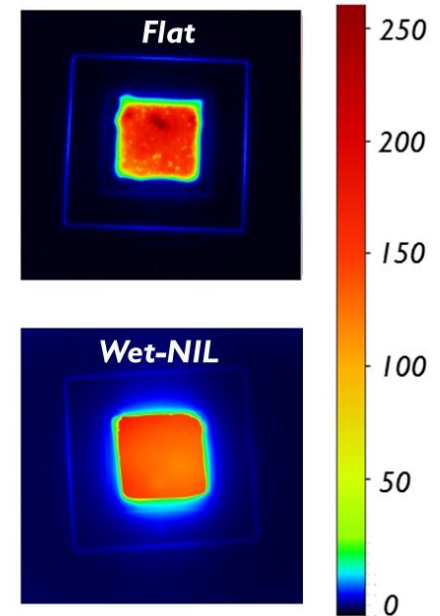
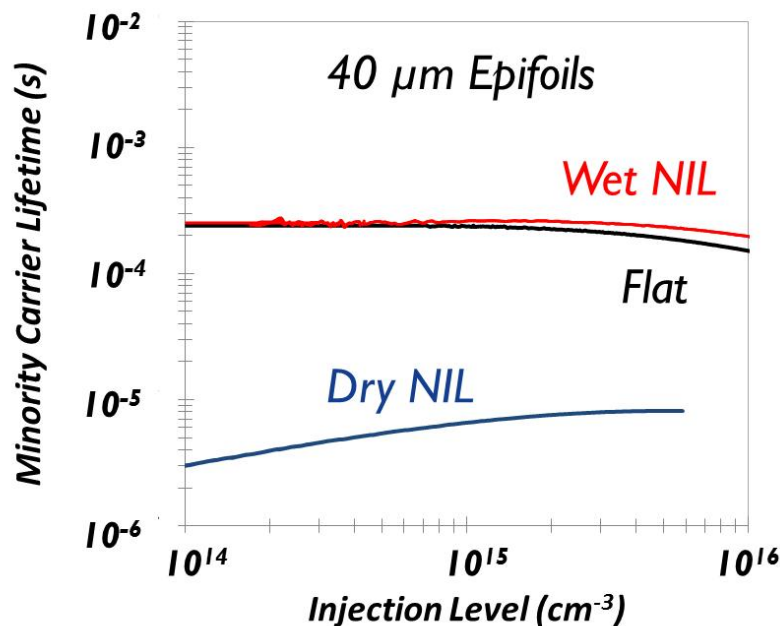
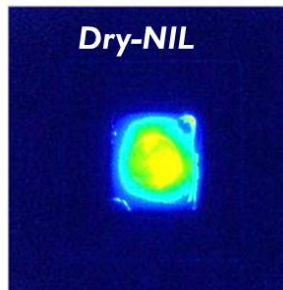
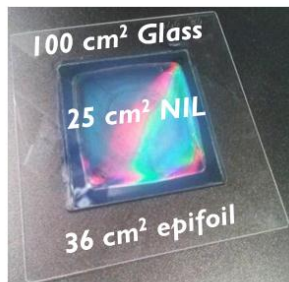
Back side processing:

1. Emitter
2. Dielectric metal stack

Dicing



ELECTRICAL PROPERTIES: MATERIAL QUALITY

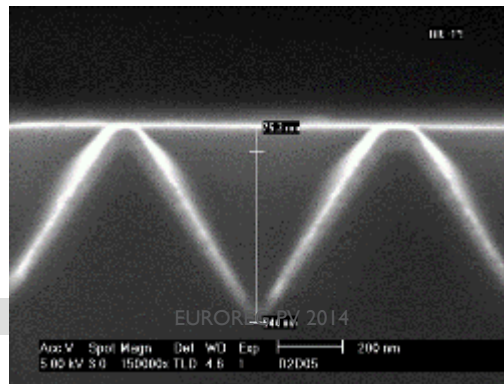
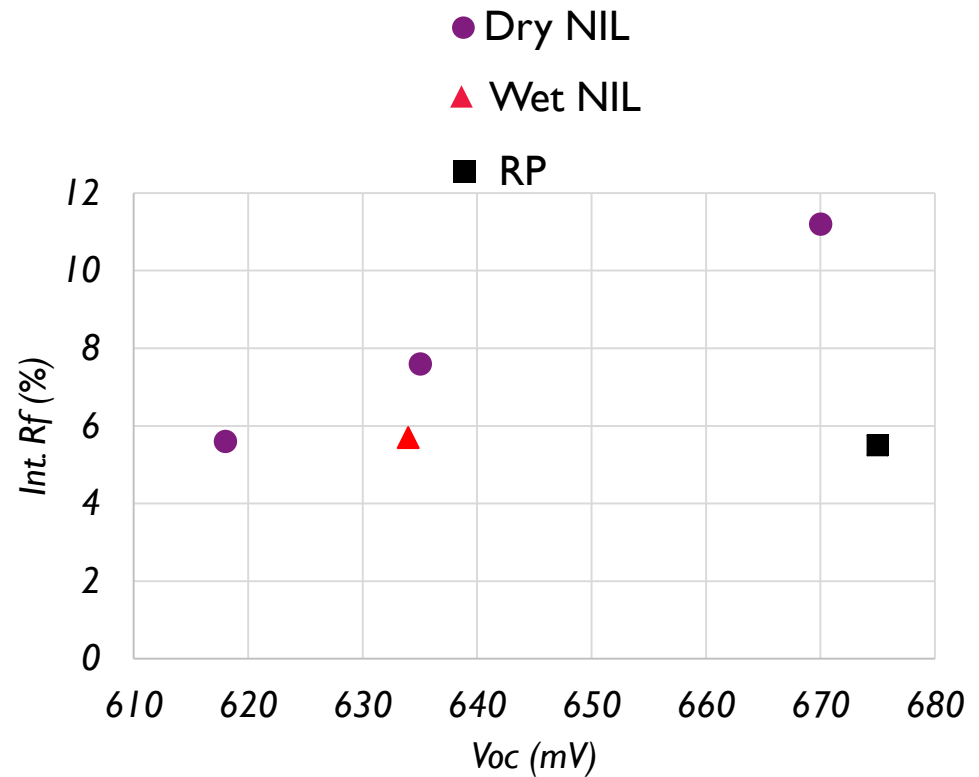
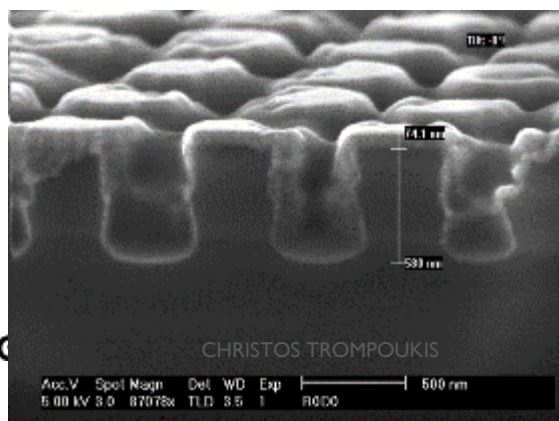
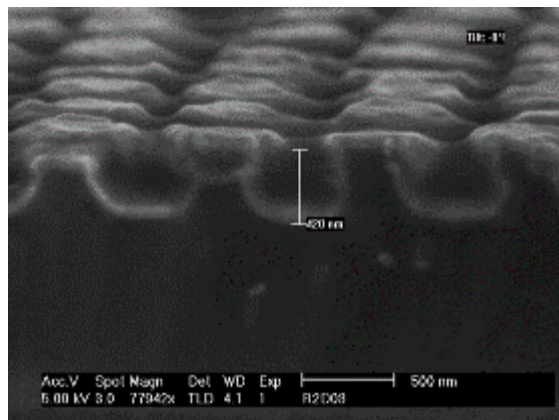
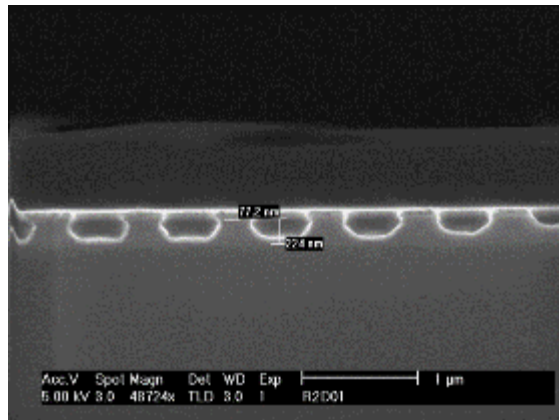


Better passivation for Wet NIL compared to Dry NIL

C. Trompoukis et al. PIP (2014)

DOI: 10.1002/pip.2489

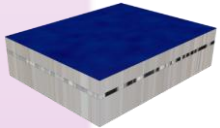
OPTOELECTRICAL TRADE-OFF



DEVICE PROCESSING

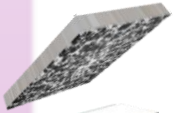


Epitaxial foils on parent substrates

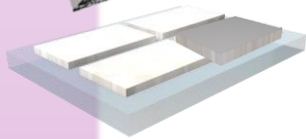


Front side processing:

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4. Metallization

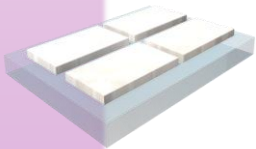


Bonding and detachment

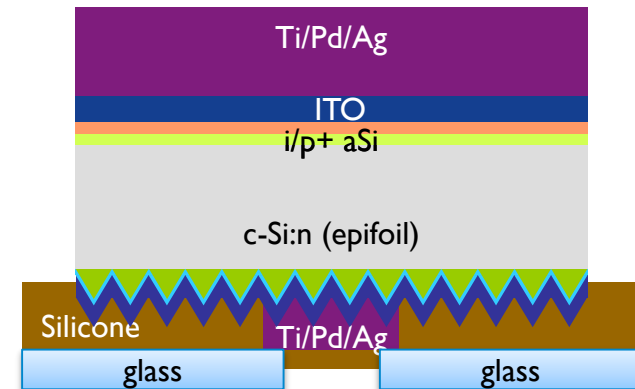
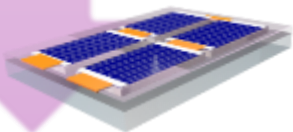


Back side processing:

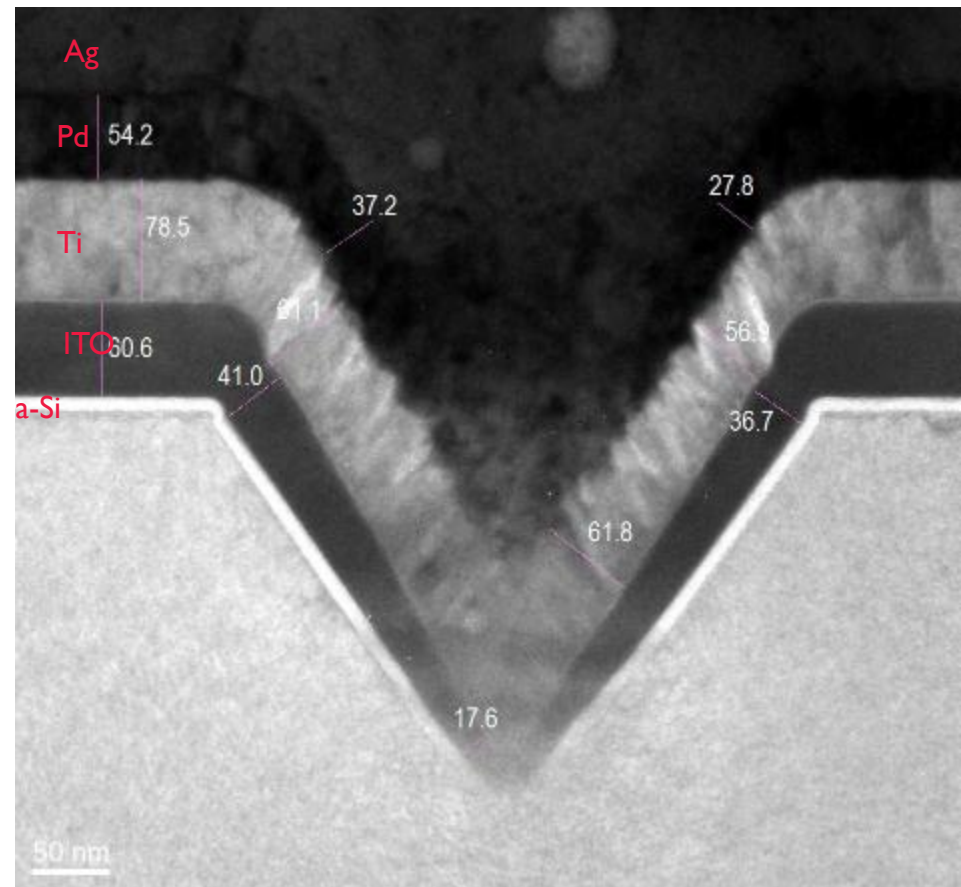
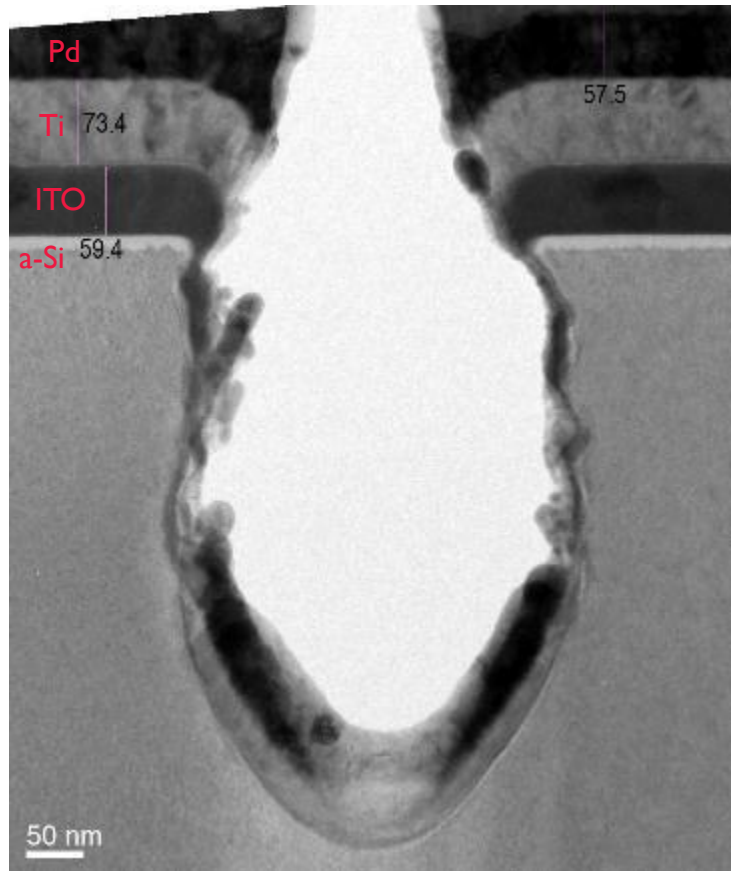
1. Emitter
2. Dielectric metal stack



Dicing



ELECTRICAL PROPERTIES: CONTACTING



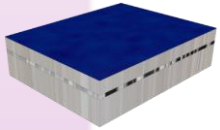
More conformal depositions for Wet NIL

*C. Trompoukis et al. PSSA (2014)
DOI: 10.1002/pssa.201431180*

DEVICE PROCESSING

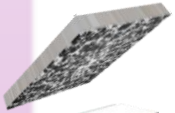


Epitaxial foils on parent substrates

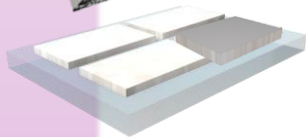


Front side processing:

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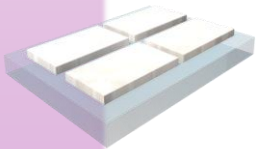


Bonding and detachment

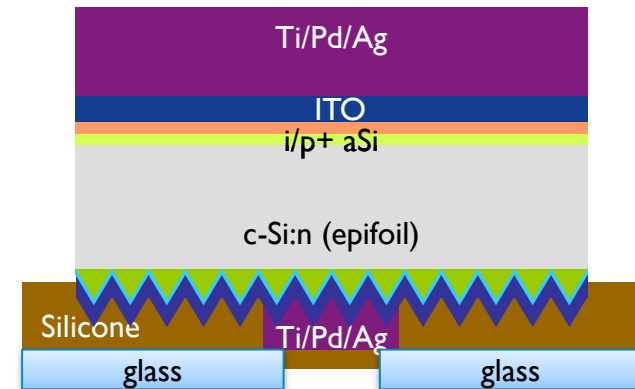
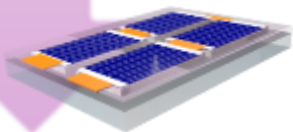


Back side processing:

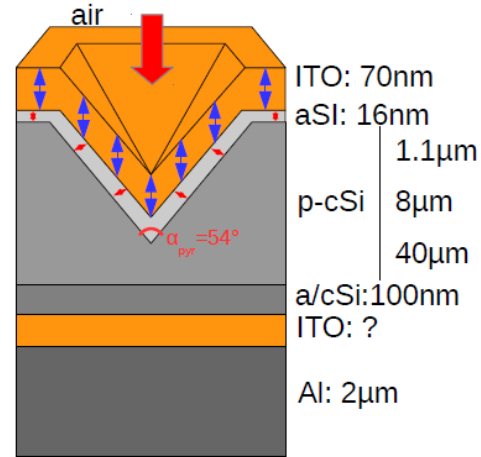
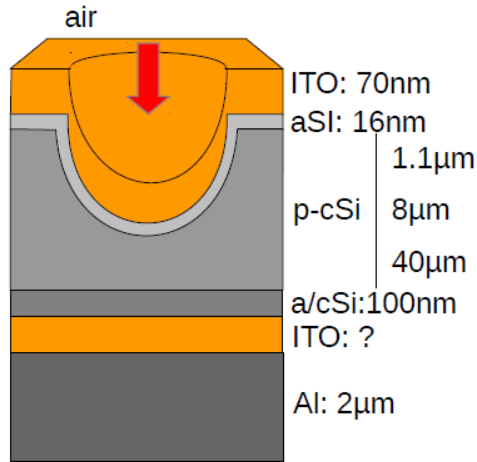
1. Emitter
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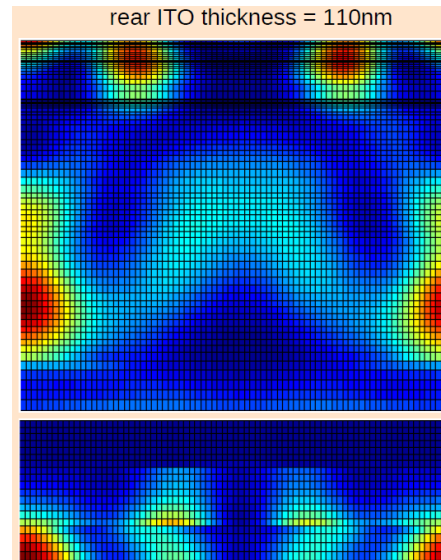
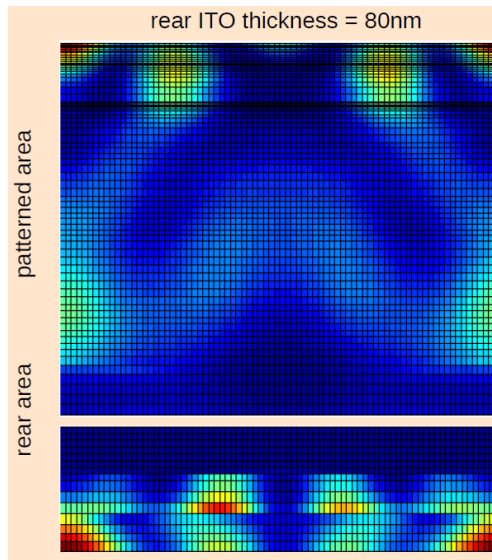
Dicing



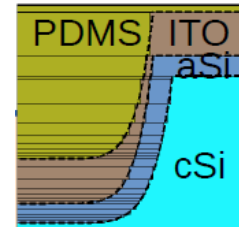
REAR SIDE: ITO THICKNESS OPTIMISATION



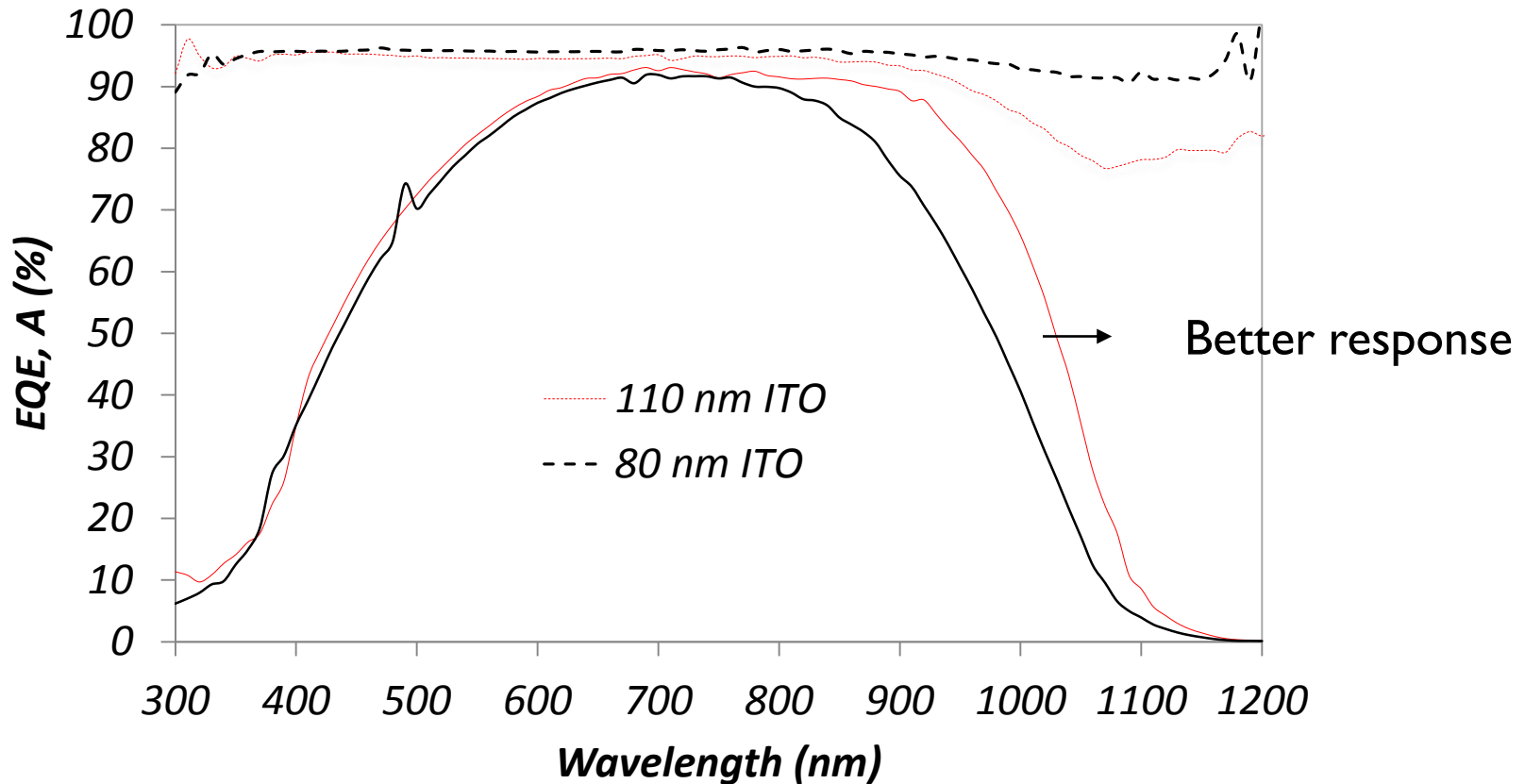
RCWA simulations $\rightarrow$
ITO optimal thickness of 110 nm



More
absorption in
cSi



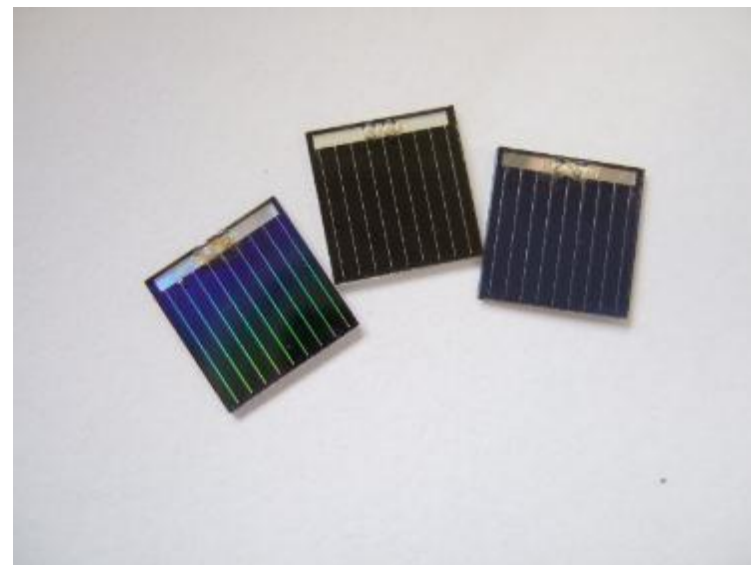
REAR SIDE: EFFECT OF PARASITIC ABSORPTION



DEVICE RESULTS

Sample	Jsc* [mA/cm ²]	Voc [mV]	FF [%]	Eta [%]
Dry NIL	25.2 (30.8*)	635	73	11.8
Wet NIL	25.2 (32.6*)	635	72	11.5
RP	26.1 (32.6*)	675	75	13.2

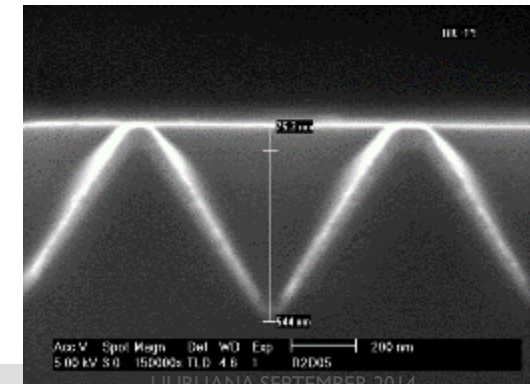
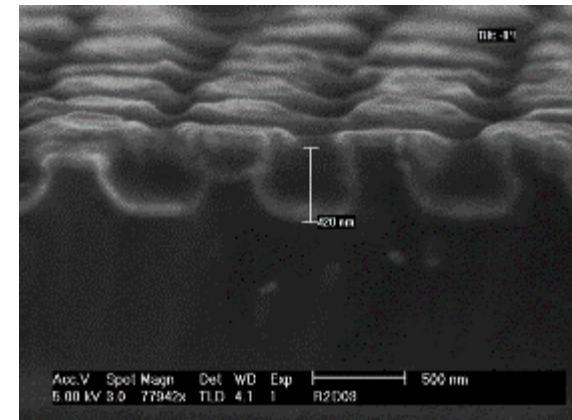
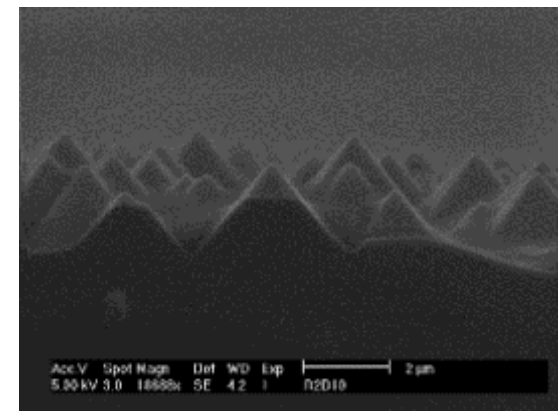
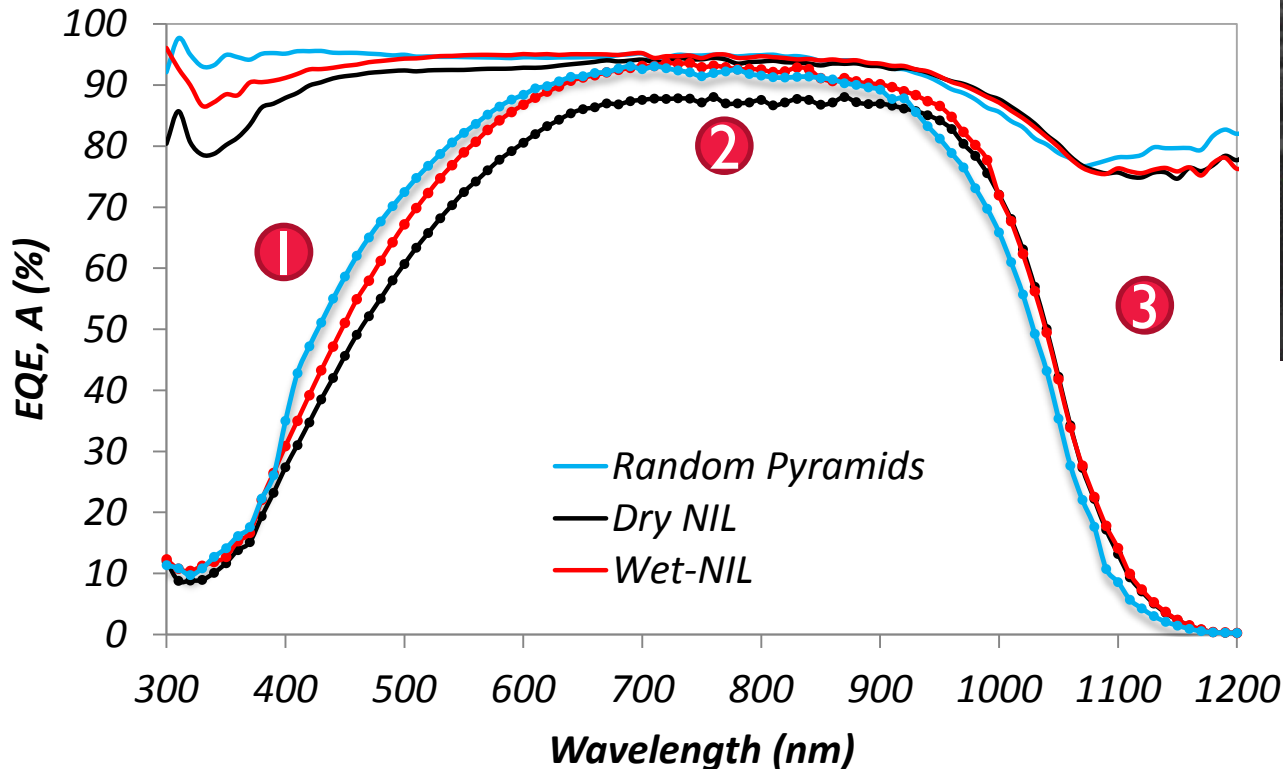
**Current in the parenthesis calculated by integrating the measured EQE*



- Wet nil and RP have comparable currents
- Nanopatterning showed lower Voc and ff than RP

LIGHT TRAPPING

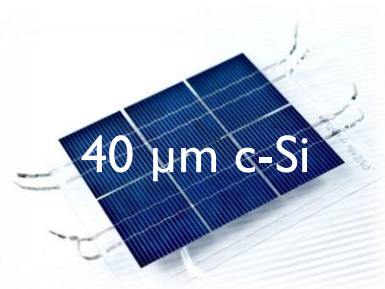
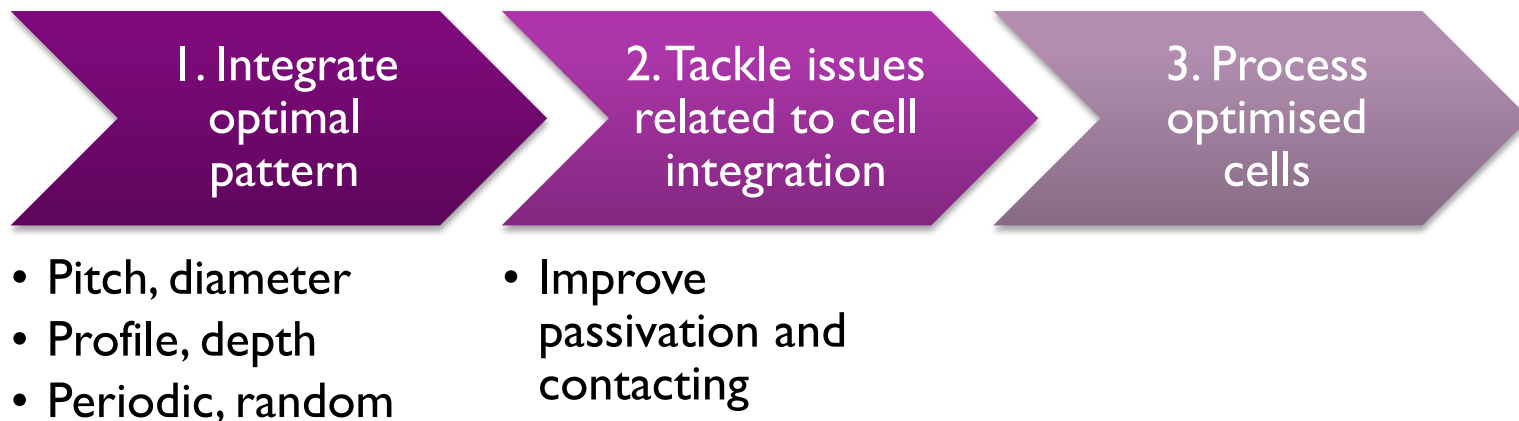
- 1) Better UV response for RP
- 2) Better performance for Wet NIL because of a better optical vs electrical trade off
- 3) Better light trapping for nanopatterning



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OUTLOOK: FROM NANOSCALE TO GIGAWATT...



Jsc (mA/cm ²)	Voc (mV)	FF (%)	Efficiency (%)
40	650	78	~21

A large, abstract splash of purple ink or paint, originating from the top left and flowing downwards, creating a dynamic, swirling pattern.

THANK YOU

Christos.Trompoukis@imec.be

