BURST

Breaking Limits Using Record Enabling Silicon Technology With Photonic Management

SMARTIES cluster workshop
03/06/2026

Front side texturing strategies for BC solar cells in the BURST project

Laurent CLOCHARD

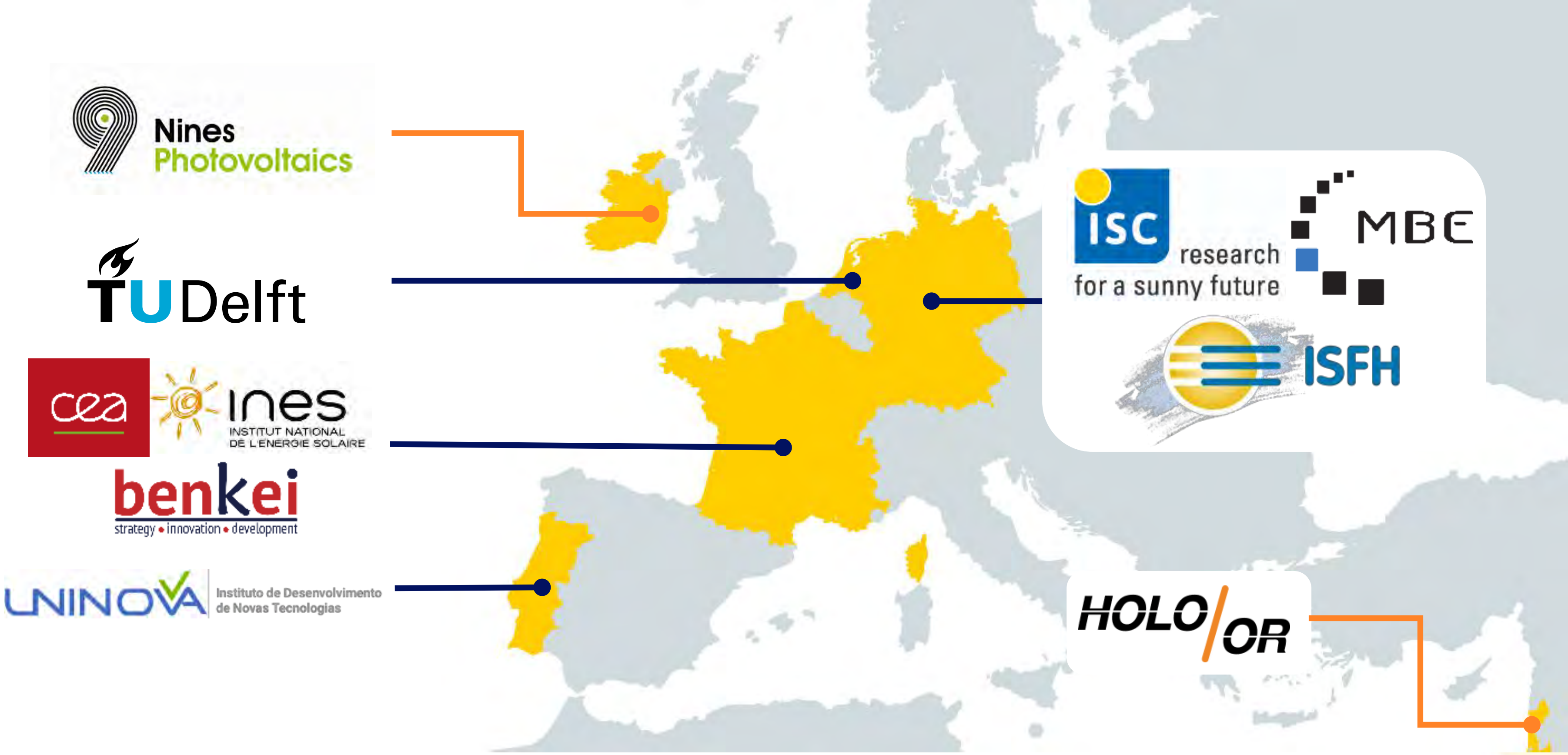
NINES PHOTOVOLTAICS

BURST: Breaking Limits Using Record Enabling Silicon Technology With Photonic Management

Funded by the European Union

Partners

Gathering expertise from across Europe

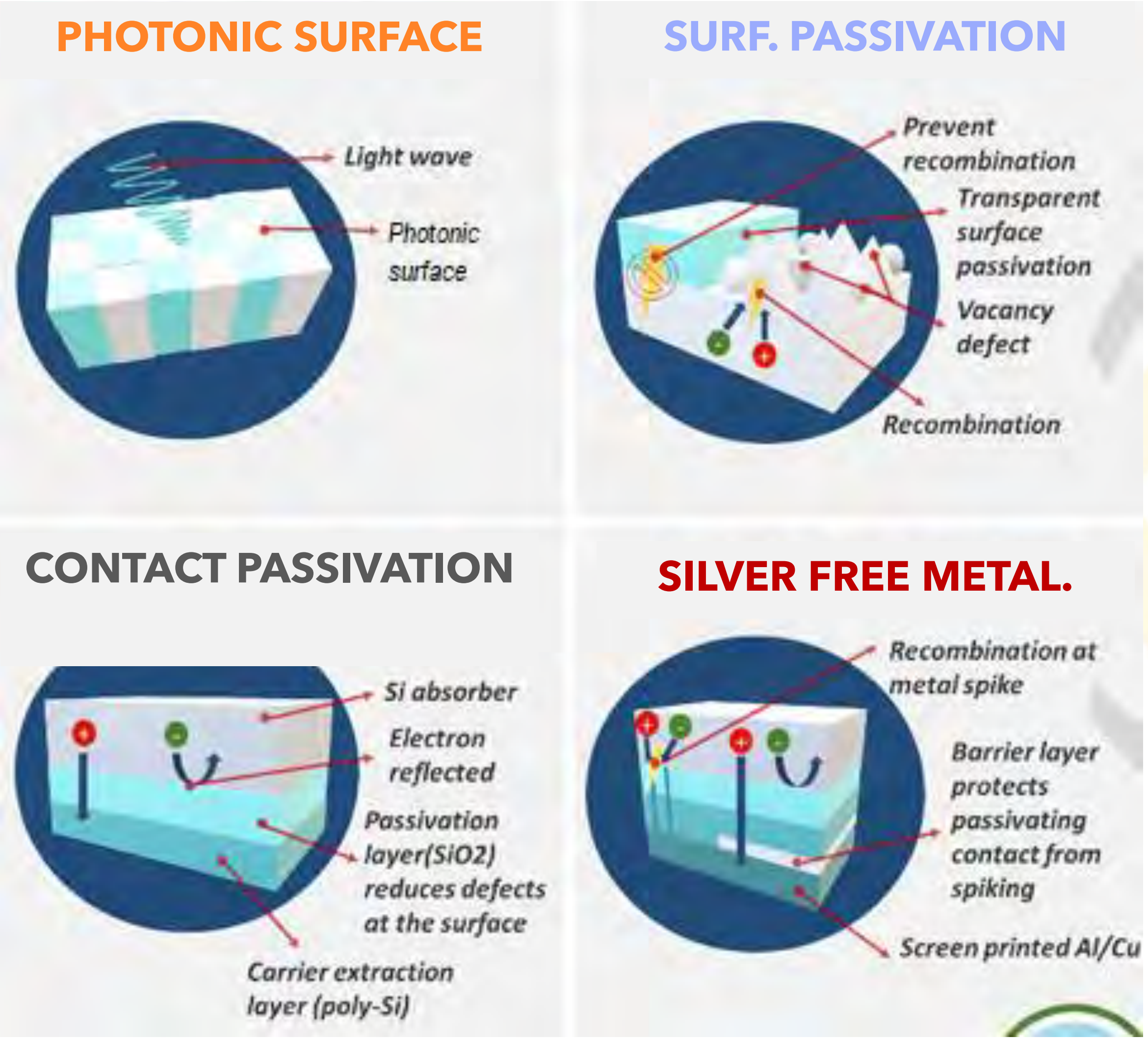


Timeline: 2 out of 3 years

Funded by the European Union

The BURST project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101146684

TECHNOLOGICAL BUILDING BLOCKS



- 4 main areas
- TRL 4/5

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BURST ambition

Efficiency targets of

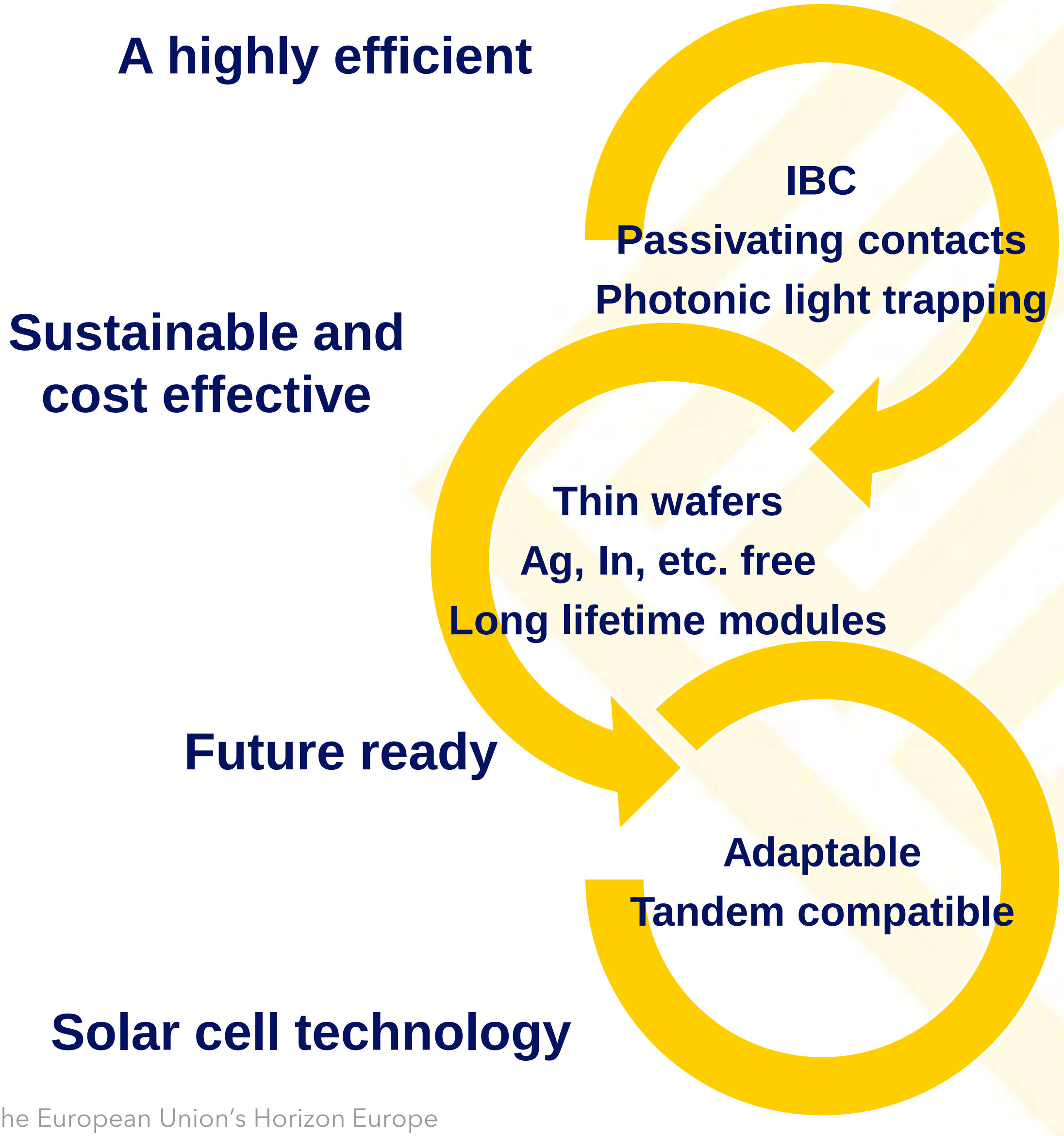
- 27% on 300 µm thick solar cells
- 26% on 80 µm thin solar cells

Industrial viability

- All processes compatible with high throughput tools

Flexible applicability

- Most developments suitable for Si bottom cell
- Most developments compatible with TOPCon



A highly efficient

IBC
Passivating contacts
Photonic light trapping

Sustainable and cost effective

Thin wafers
Ag, In, etc. free
Long lifetime modules

Future ready

Adaptable
Tandem compatible

Solar cell technology

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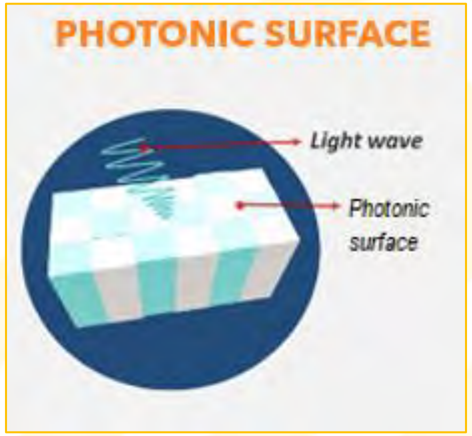
Overview of investigated light trapping schemes

Type of Structure	Masking method	Pattern transfer	Structure obtained
PERIODIC	Std. lithography	Wet-chemical etching	Inverted pyramids
		RIE + wet-chemical etching	
		ADE gas-phase etching	Inverted domes
	Colloidal lithography	TiO2 infiltration	
		ADE gas-phase etching	exploratory
	Split beam Laser opening	Wet-chemical	Inverted pyramids
		ADE gas-phase etching	Inverted domes
RANDOM	-	RIE Plasma etching	Nano-texture
		SiO2 etched	
		ADE gas-phase etching	
	-	KOH pyramids + ADE	Micro + Nano
MIXED	-	Inverted pyramids + ADE	
	-	Inverted pyramids + SiO2 etch	



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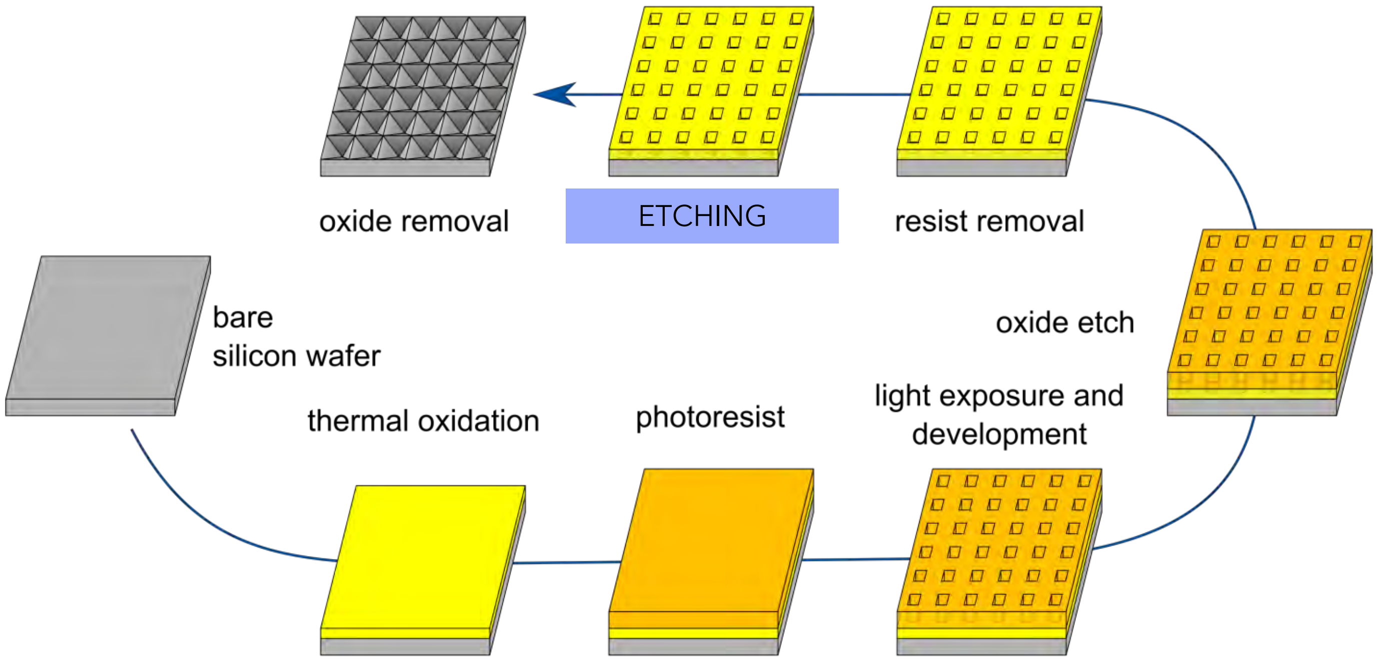
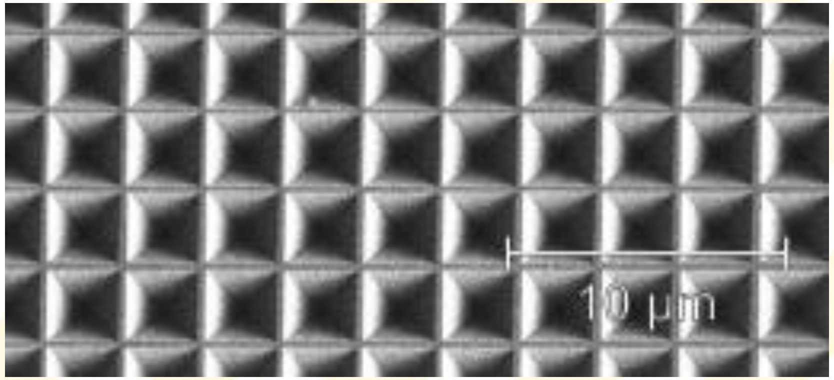
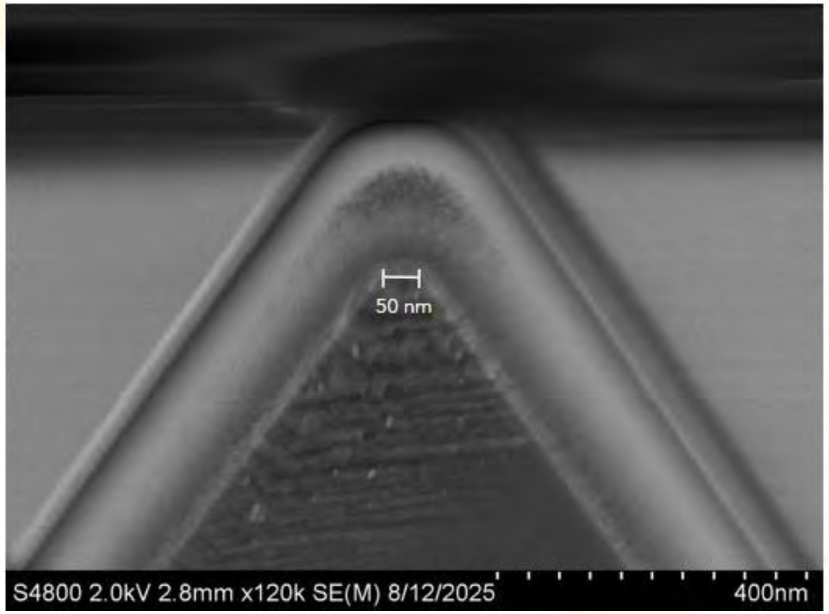


➔ STRUCTURED scheme aims to investigate potential effects from photonic crystals





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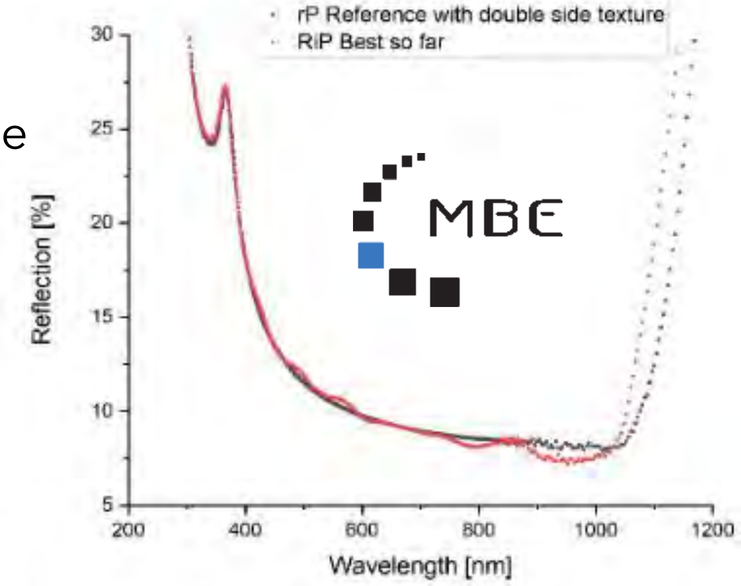
	Laser opening	Wet-chemical	Inverted pyramids
		ADE gas-phase etching	Inverted domes

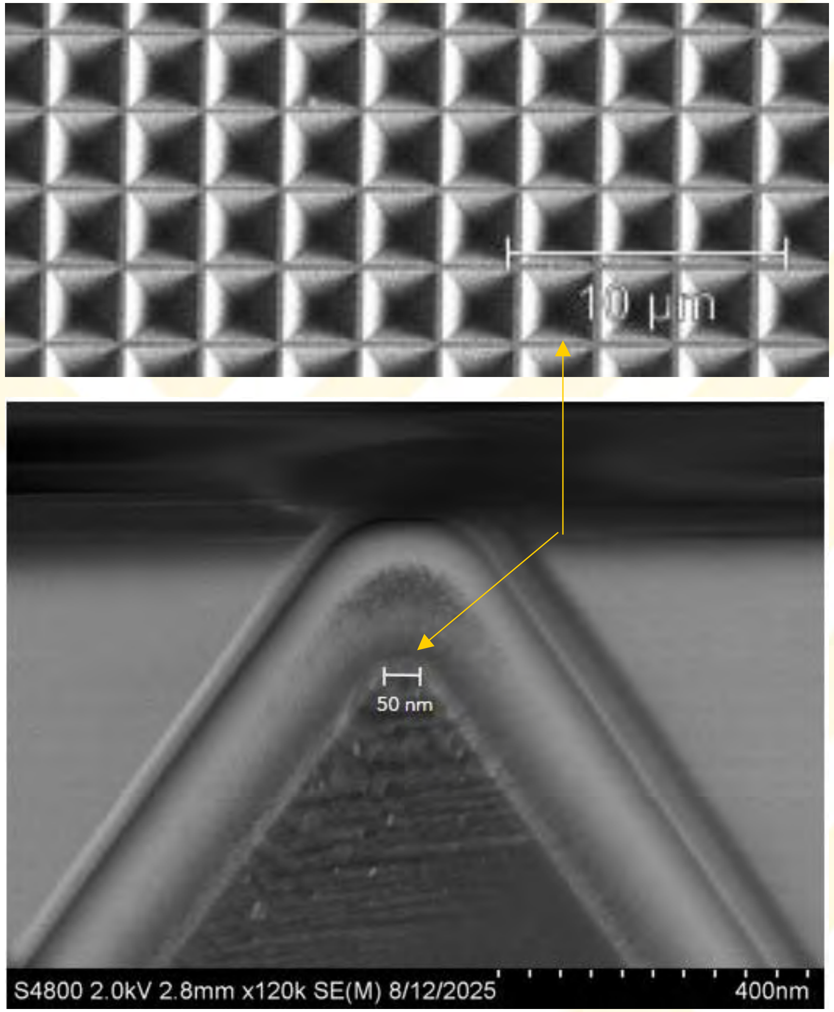
Main challenge:

➔ Minimizing the flat edges between inverted pyramids (highly reflective)

Best reflectivity so far:

➔ Close match to alkaline reference





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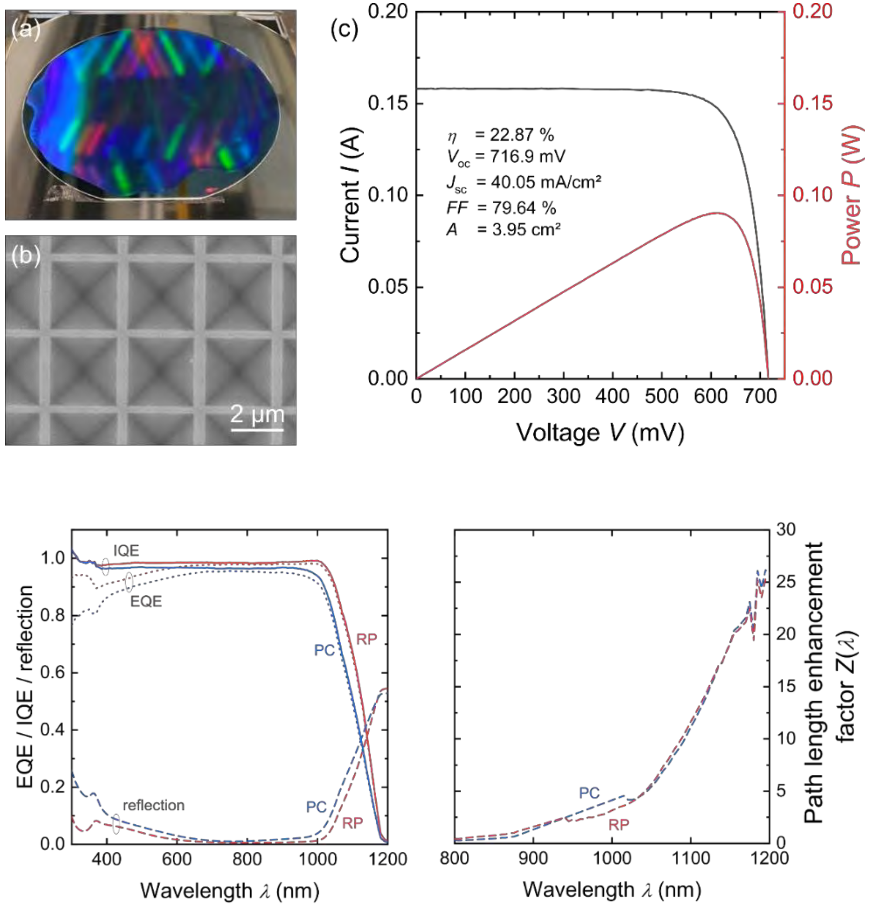
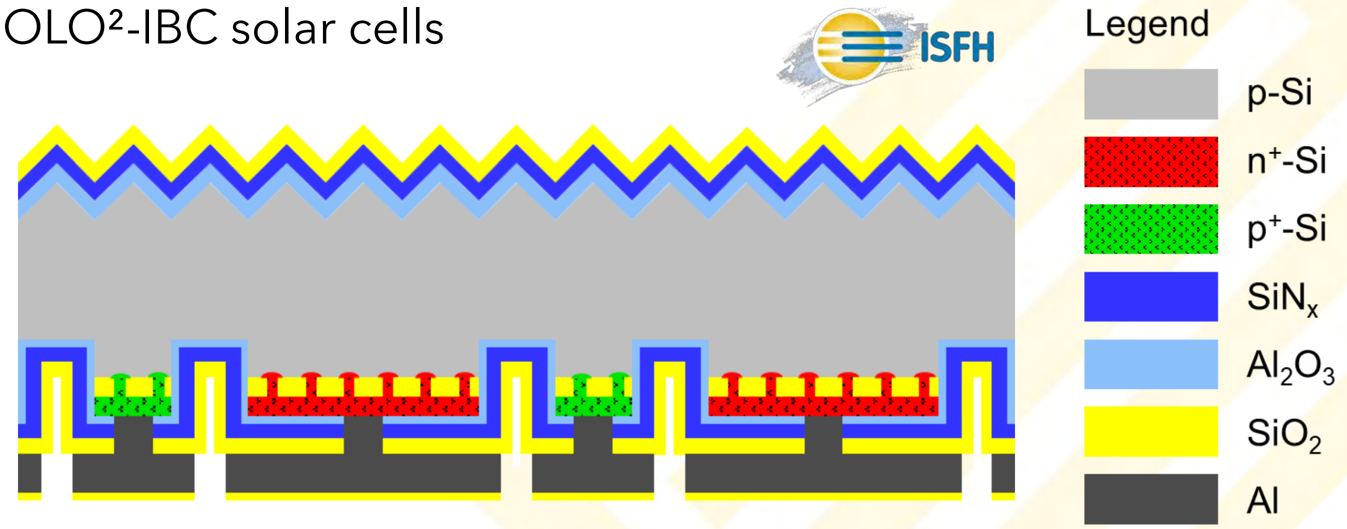
IMPLEMENTATION INTO SOLAR CELLS

Inverted pyramids with a pitch of 3.1 µm in POLO²-IBC solar cells

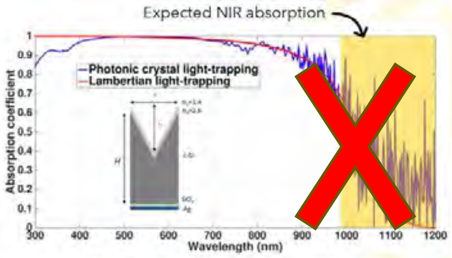




Main conclusion:

No evidence of increased absorption in the IR

- ➔ Correlates with advanced simulations carried out within this project
- ➔ No "photonic crystal" effect at long wavelength range



S. Bhattacharya, S. John, Scientific Reports, 2019

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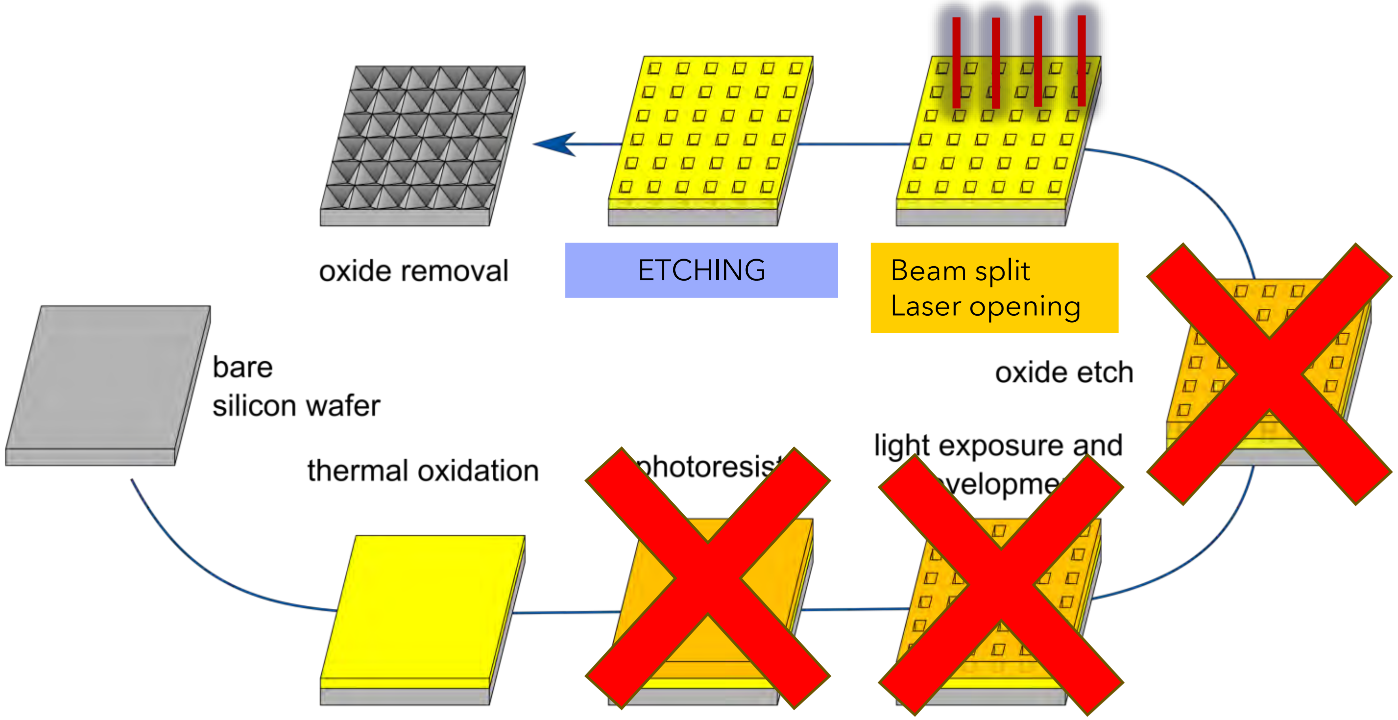
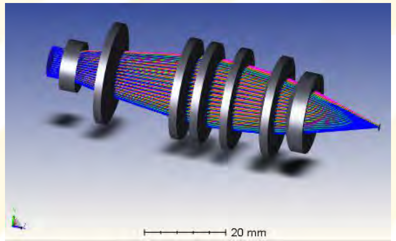


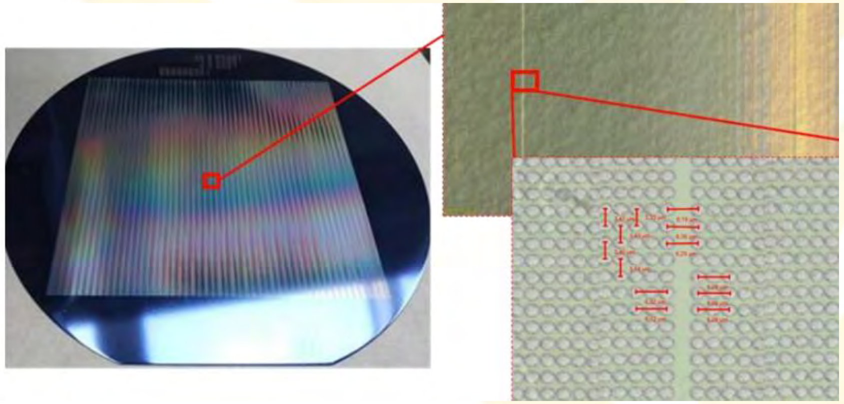
➔ Removes Steps from standard litho. process

Development of a beam splitter

HOLO/OR



Single module: 2mm lines, made of 667 x 3um spots



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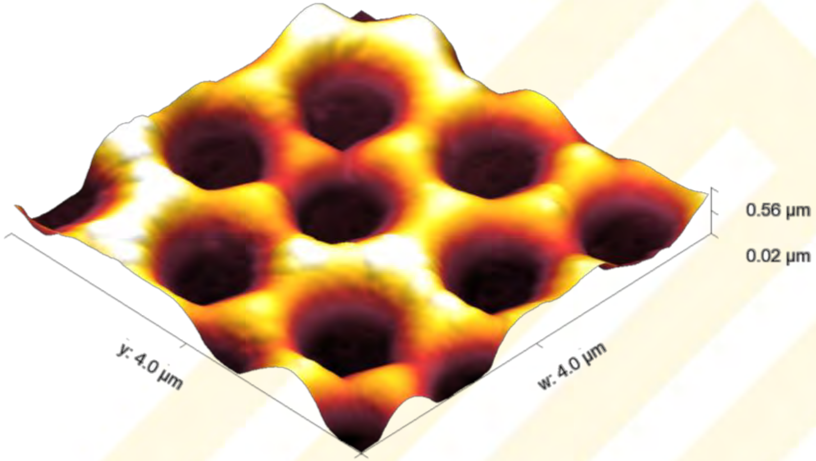

TiO$_2$ voids

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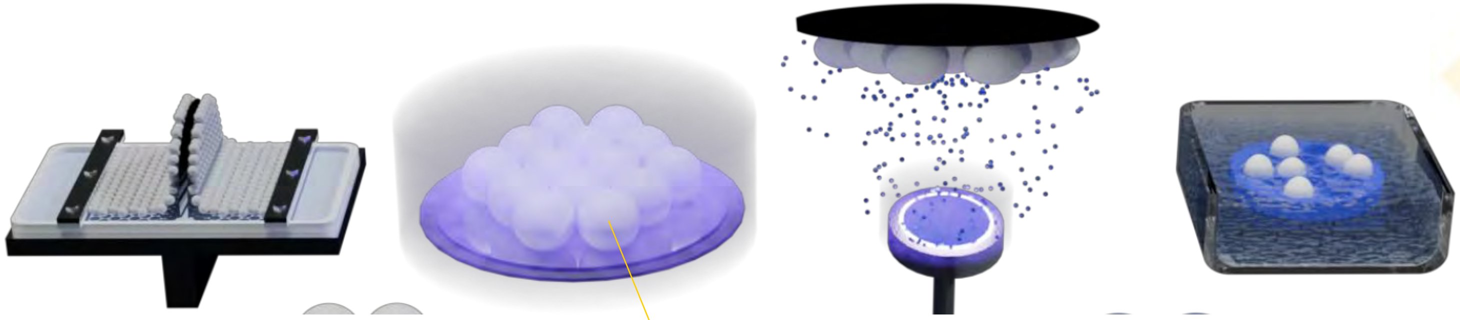
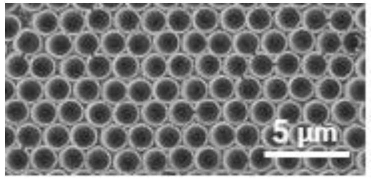
1. Langmuir-Blodgett **2.** O$_2$ RIE **3.** TiO$_2$ Infiltration **4.** Lift-off



2-3um Polystyrene spheres



➔ Added layer (TiO2) is structured to lower the flat surface reflection

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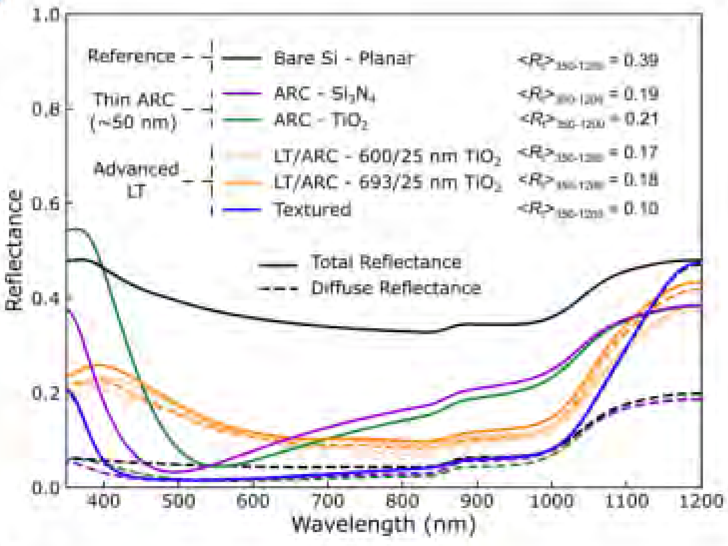
a)



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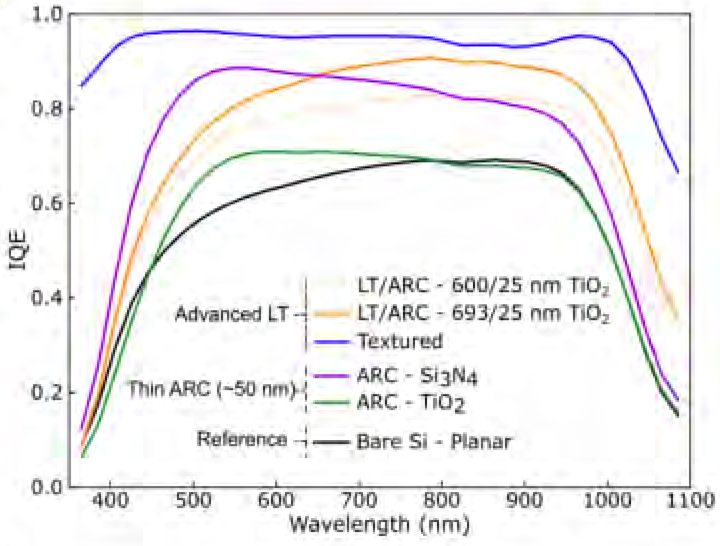

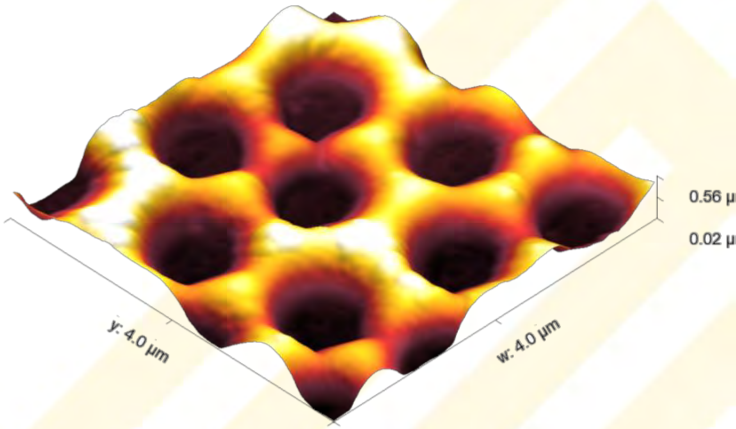

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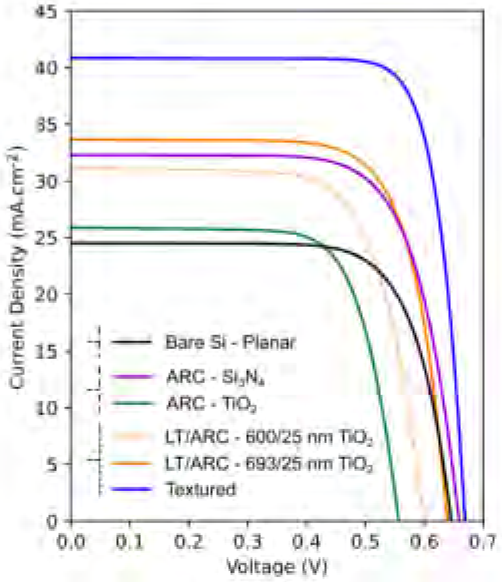
c)



d)

Sample	V_{oc} (mV)	J_{sc} (mA.cm-2)	FF (%)	PCE (%)
Bare Si – Planar	646	24.5	72.9	11.5
ARC – SiN	659	32.3	71.5	15.2
ARC – TiO_2	556	25.9	72.4	10.4
LT/ARC 600/25 nm	599	31.1	69.9	13.0
LT/ARC 693/25 nm	638	33.7	73.3	15.8
Textured	669	40.8	79.4	21.7

➔ Reflectivity reduction compared to flat Surface
➔ Useful for ultra thin wafers
Next: wok on index matching & passivation

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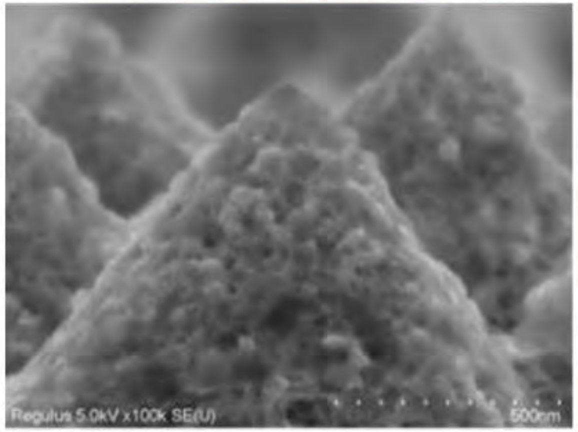
	-	KOH pyramids + ADE	Micro + Nano
MIXED	-	Inverted pyramids + ADE	
	-	Inverted pyramids + SiO2 etch	



Random nano-micro texturing for light in-coupling:

KOH random pyramid texture → RIE plasma etch

micro

nano

- room temperature plasma process employing fluorine/oxygen/argon chemistry.

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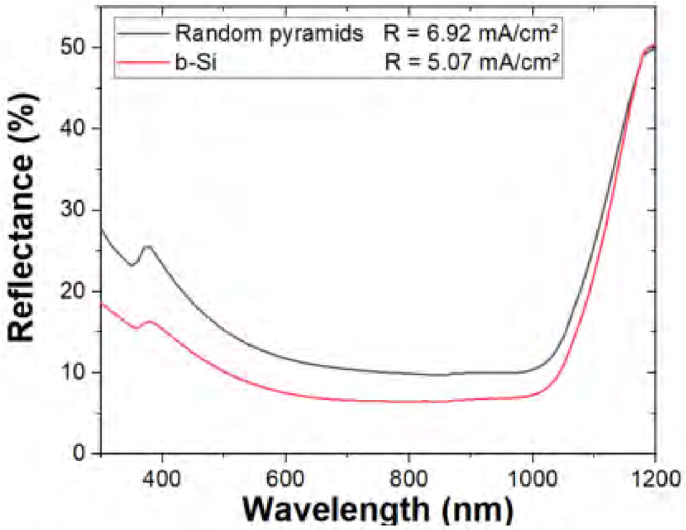
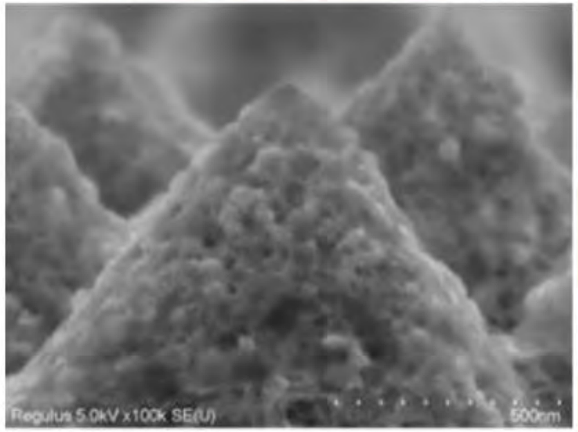


Reflection curves of M2 wafers with random pyramid texture and b-Si after a-Si:H deposition by PECVD.



- Preliminary tests executed on symmetric M2-sized c-Si wafers passivated with 20-nm thick ALD AlO_x
- τ_{eff} ~5 ms ($\Delta n = 1 \times 10^{15}$ cm^{-3}) and i-$V_{OC} > 735$ mV

➔ Can be passivated with ALD AlOX

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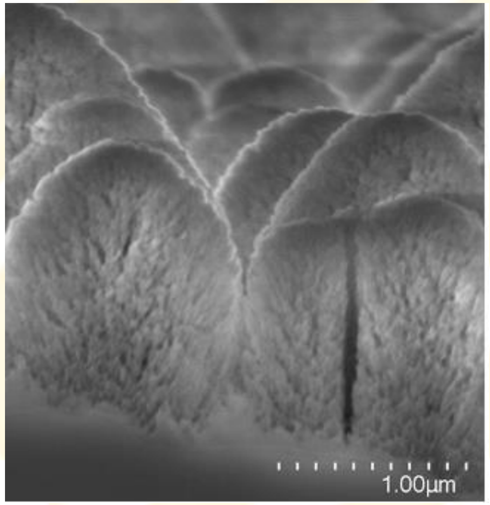

Random nano-micro texturing for light in-coupling:

KOH random pyramid texture → .. Full cell stack … → SiOx layer → Dilute Oxide etch

micro

nano

- Additional optical layer
- does not affect existing passivation

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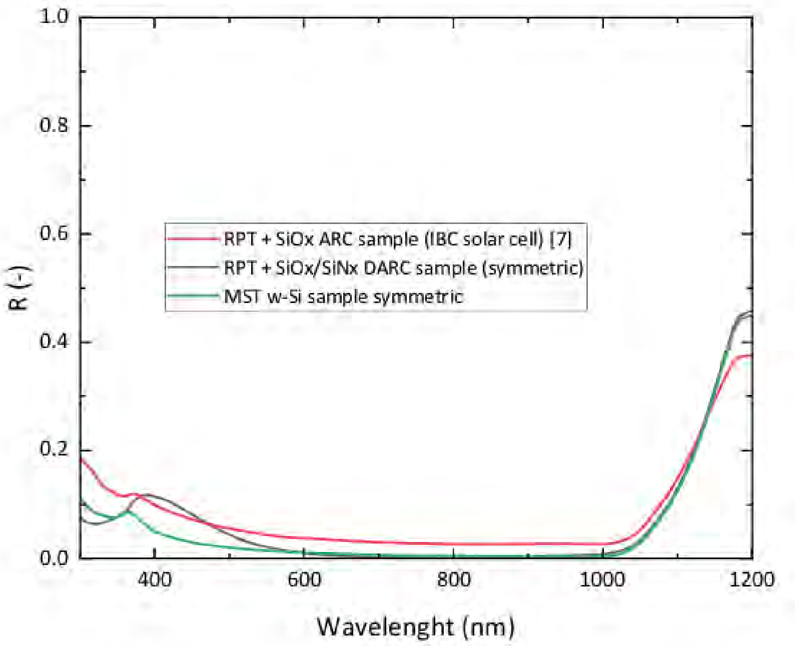

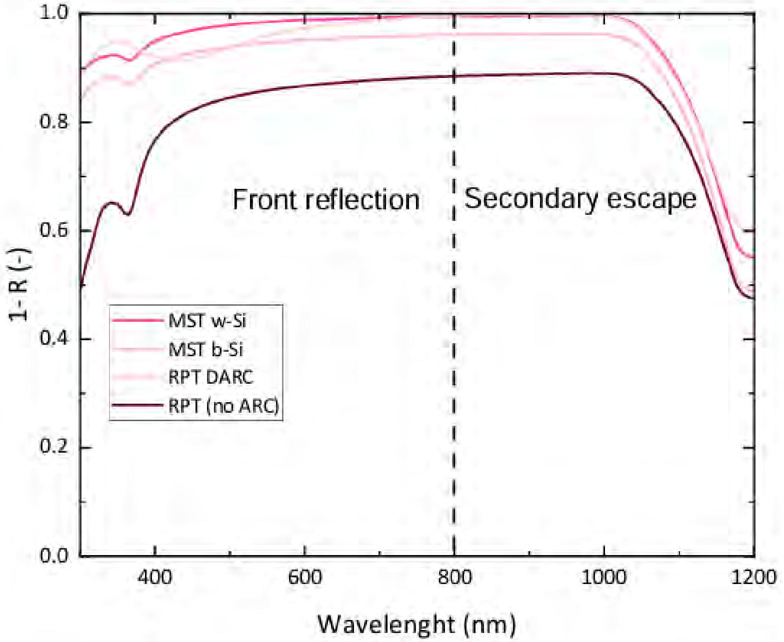

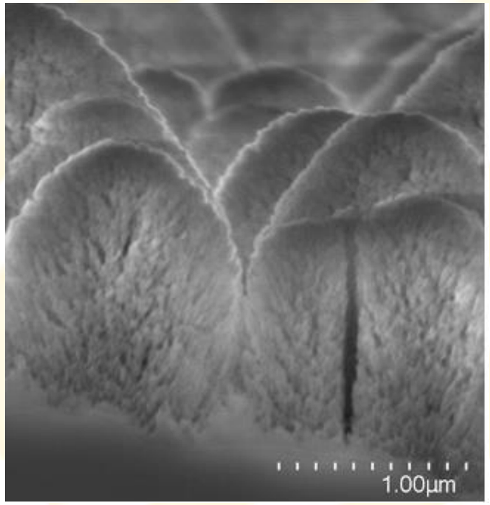

➔ Very low reflectivity potential

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Overview: ADE gas-phase etch applications

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	-	Inverted pyramids + SiO2 etch	

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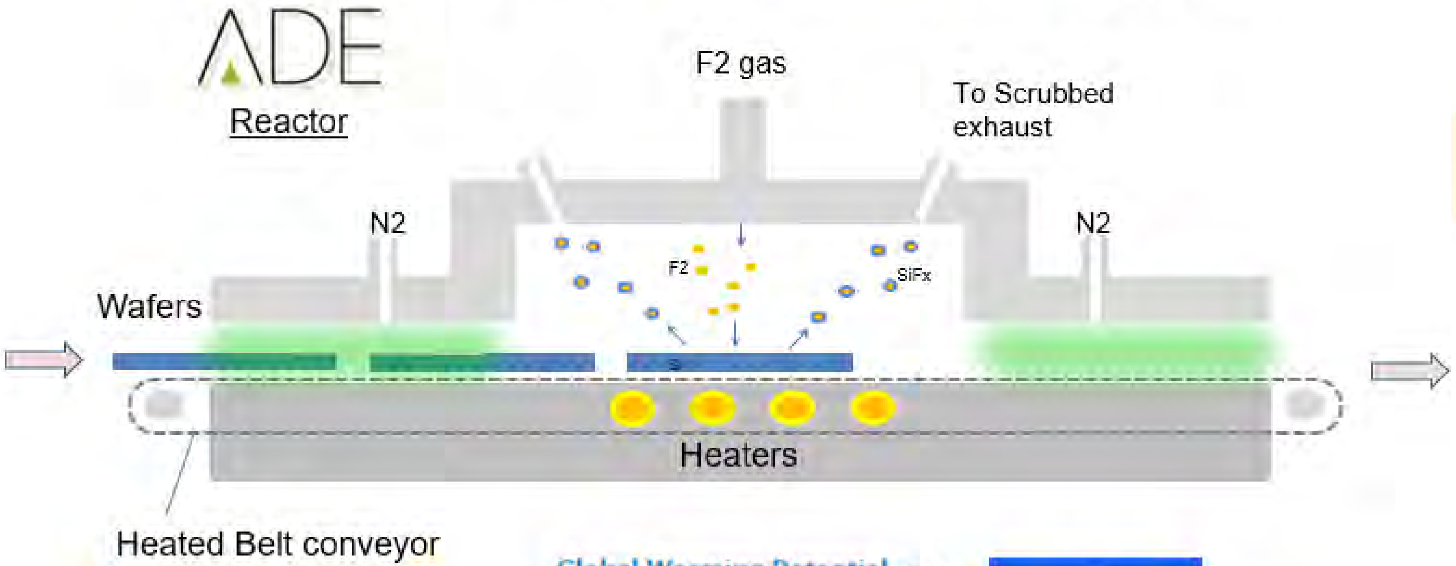
WHAT IS ADE gas-phase etching?

- Thermal process using molecular Fluorine gas (F2)
- Low temperature Chemical etching (NO ~~PLASMA~~ / ~~IONS~~)
- Atmospheric pressure process (no ~~vacuum~~)
- In-line tool layout with continuous flow of wafers



Granted International Patent

Global Warming Potential (100 year GWP kg CO_2 eq)	
F2	0

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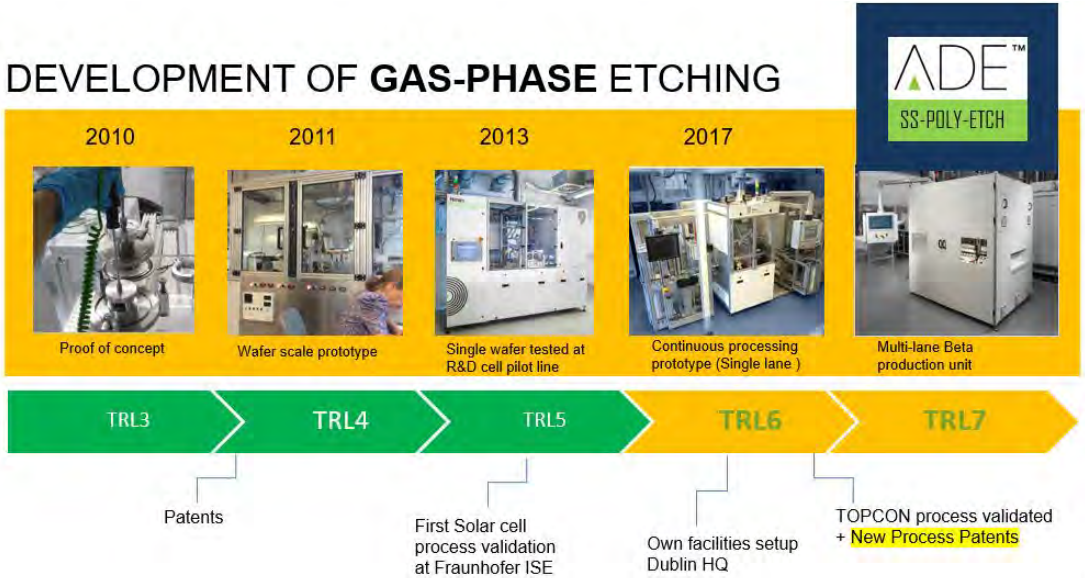


DEVELOPMENT OF **GAS-PHASE** ETCHING

ADE™
SS-POLY-ETCH

2010	2011	2013	2017	
Proof of concept	Wafer scale prototype	Single wafer tested at R&D cell pilot line	Continuous processing prototype (Single lane)	Multi-lane Beta production unit

TRL3 → TRL4 → TRL5 → TRL6 → TRL7

Patents

First Solar cell process validation at Fraunhofer ISE

Own facilities setup Dublin HQ

TOPCON process validated + New Process Patents

- Low COO process
- Ultra high throughput

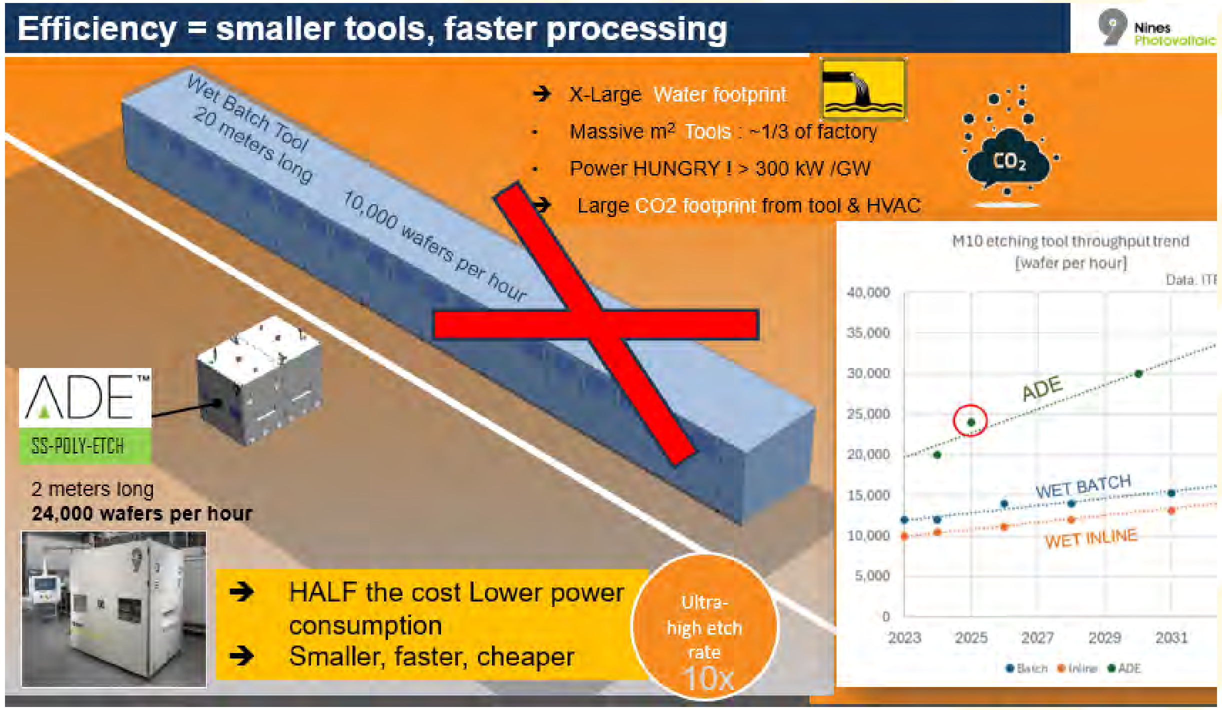
ADE multi-GW PRODUCTION TOOLS

➔Poly-Si removal

ADE™
SS-POLY-ETCH

M10 : 24,000 wph

ADE™
ADE-3000
Single Side Etch Series
Dry Etching equipment for High efficiency solar cell



Efficiency = smaller tools, faster processing

Nines Photovoltaic

Wet Batch Tool
20 meters long
10,000 wafers per hour

- ➔ X-Large Water footprint
- Massive m^2 Tools : ~1/3 of factory
- Power HUNGRY ! > 300 kW /GW
- ➔ Large CO2 footprint from tool & HVAC

ADE™
SS-POLY-ETCH

2 meters long
24,000 wafers per hour

- ➔ HALF the cost Lower power consumption
- ➔ Smaller, faster, cheaper

Ultra-high etch rate 10x

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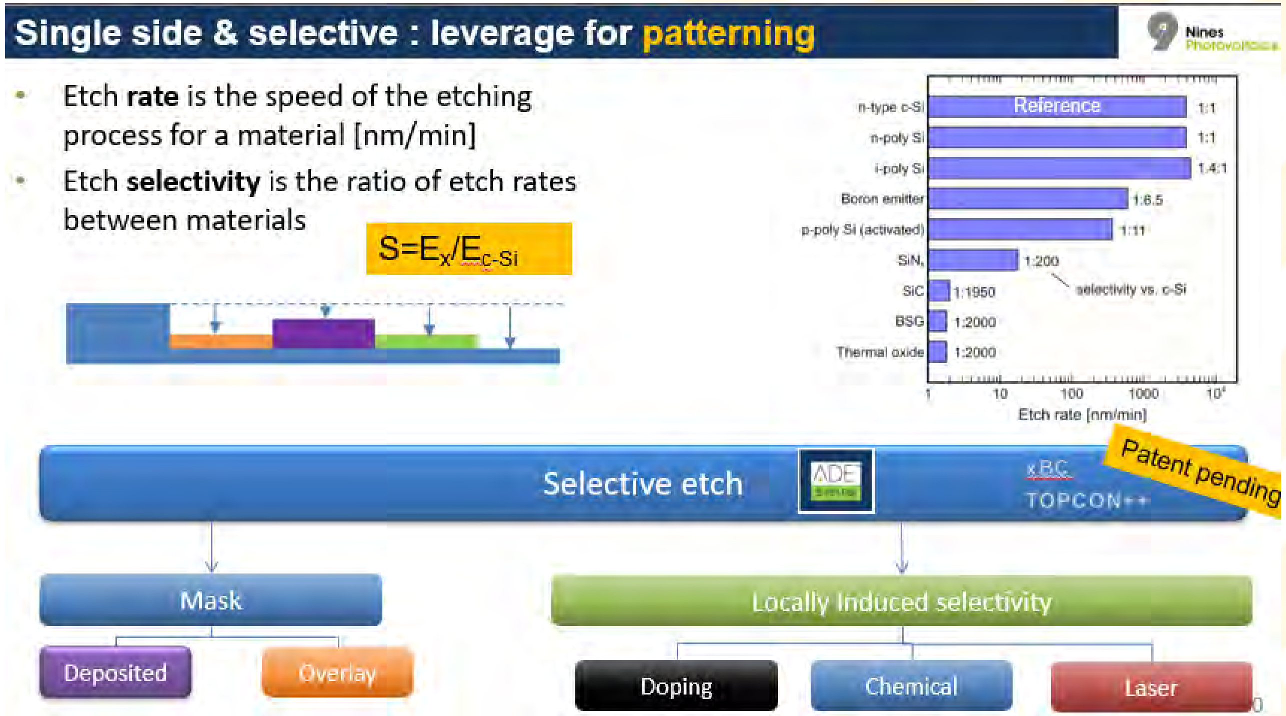
Relevance:

- Single side etching
- Selective
- High throughput

Under specific conditions:

- Nano-texturing



Single side & selective : leverage for patterning

- Etch **rate** is the speed of the etching process for a material [nm/min]
- Etch **selectivity** is the ratio of etch rates between materials

$S=E_x/E_{c\text{-}Si}$

Selective etch

Mask
- Deposited
- Overlay

Locally Induced selectivity
- Doping
- Chemical
- Laser

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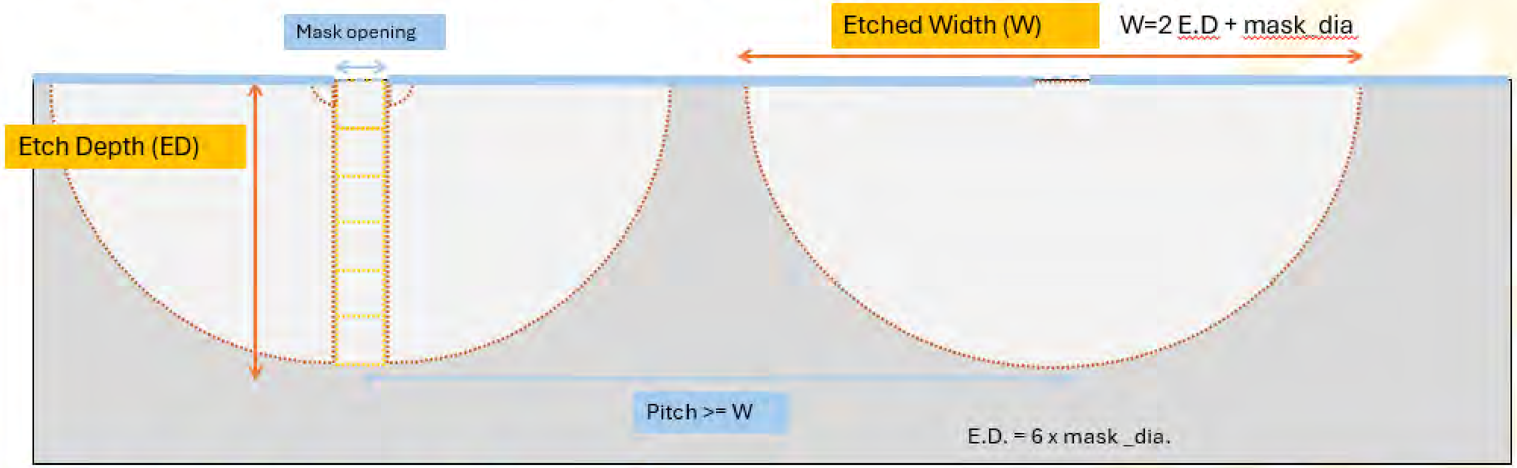
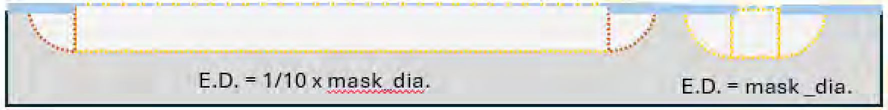
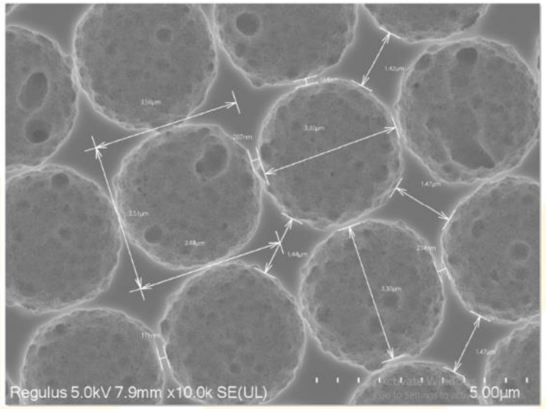
	Colloidal lithography		exploratory
	Laser opening		Inverted domes
RANDOM	-	**ADE** gas-phase etching	

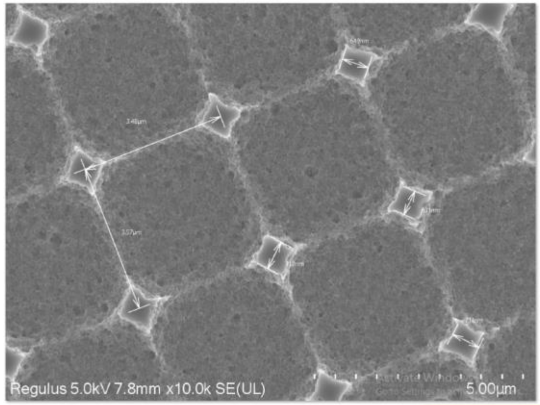
ISOTROPIC ETCH: equal etch in all directions

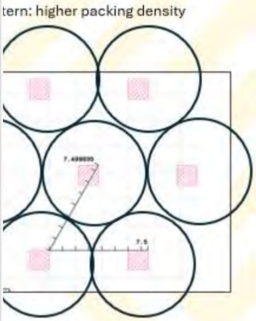


Minimum Pitch required:	Pitch >= W
Max Aspect ratio:	ED/W <= 0.5 Max









- ➔ Limited aspect ratio
- ➔ Sensitive to contamination

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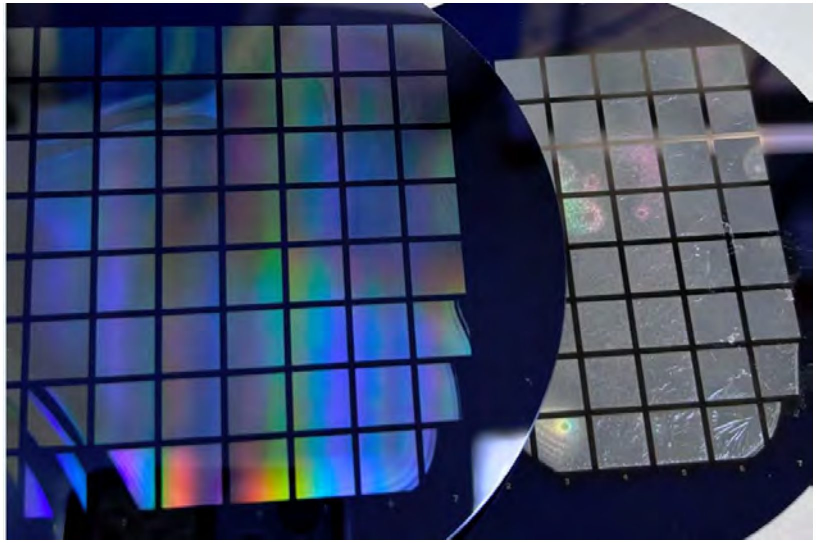
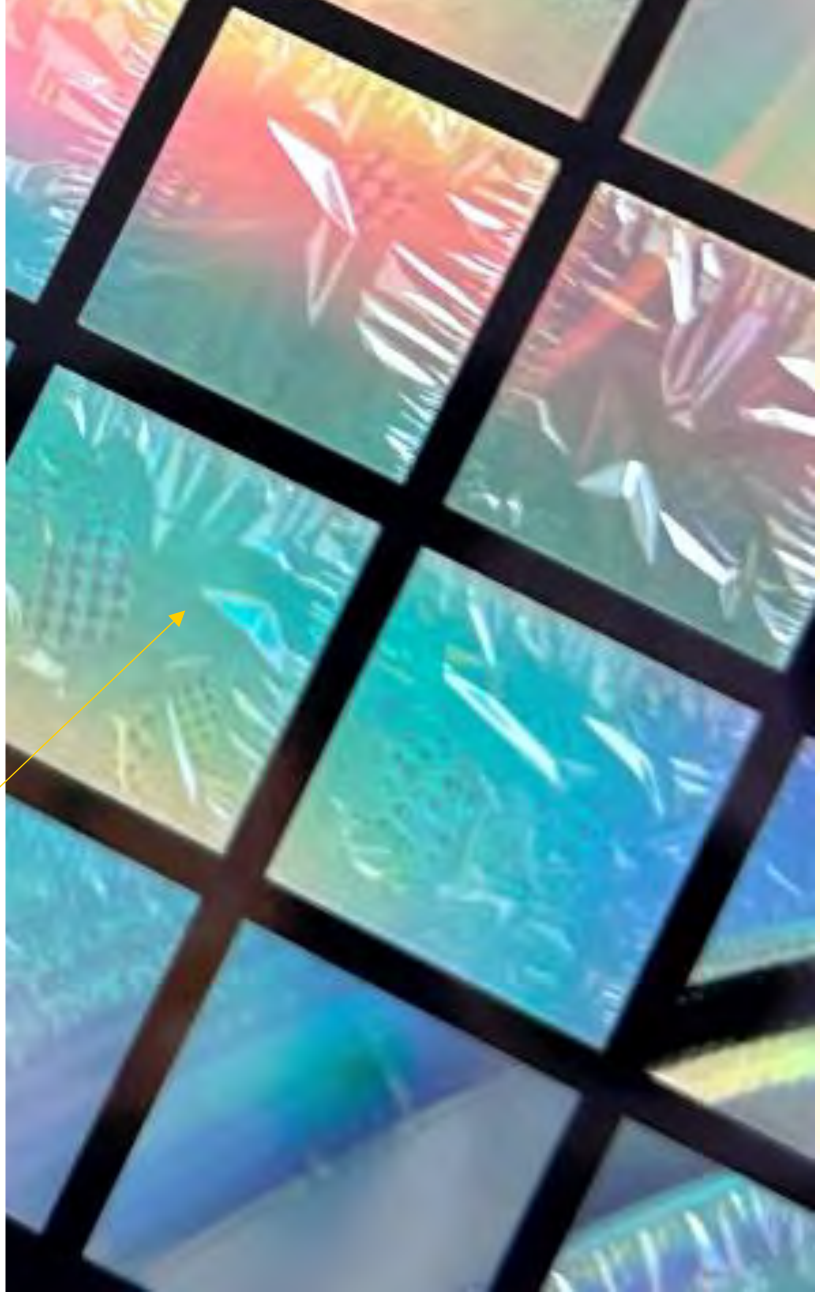


Before

After

Over-etched samples ➔ SiOx film is preserved



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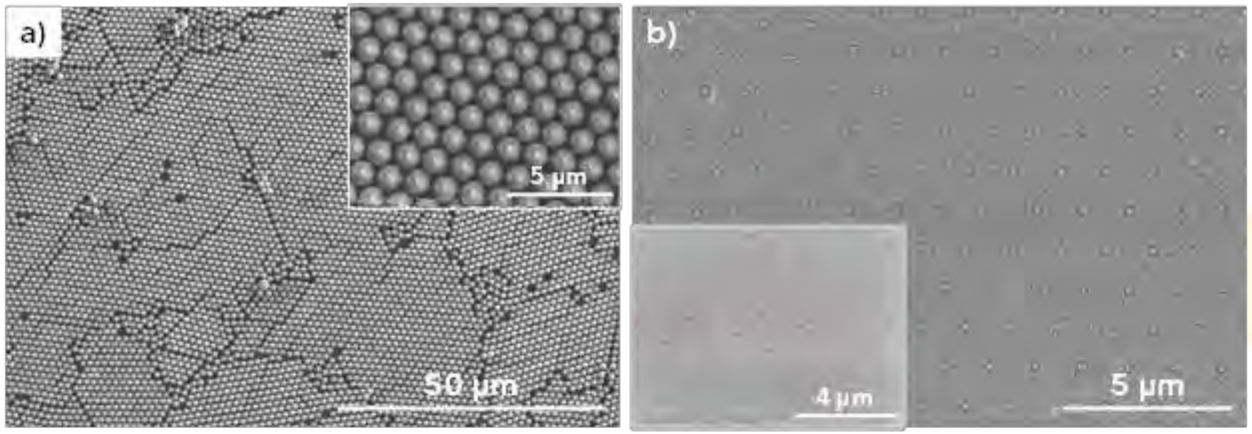
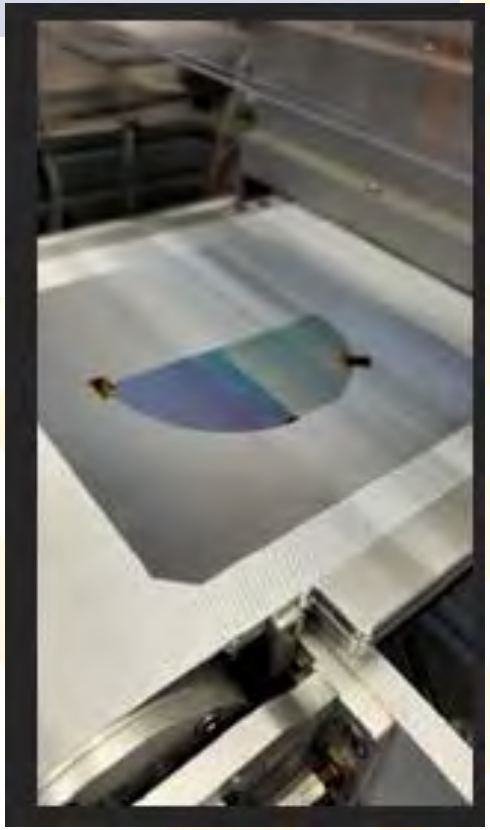
	Colloidal lithography		exploratory
	Laser opening		

- Using polystyrene spheres as a mask within ADE etching



Before lift-off After lift-off



➔ Sphere can withstand ADE process (at low temperature)
➔ "Spot etching" very localised at point of contact
➔ On-going development to improve optical surface property

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The BURST project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101146684

Overview: ADE gas-phase etch applications

Type of Structure	Masking method	Pattern transfer	Structure obtained
PERIODIC	Std Lithography	**ADE** gas-phase etching	Inverted domes
	Colloidal lithography		exploratory
	Laser opening		Inverted domes
RANDOM	-	**ADE** gas-phase etching	
	-	KOH pyramids + **ADE**	Micro + Nano
MIXED	-	Inverted pyramids **+ ADE**	

Main Focus for the rest of the project

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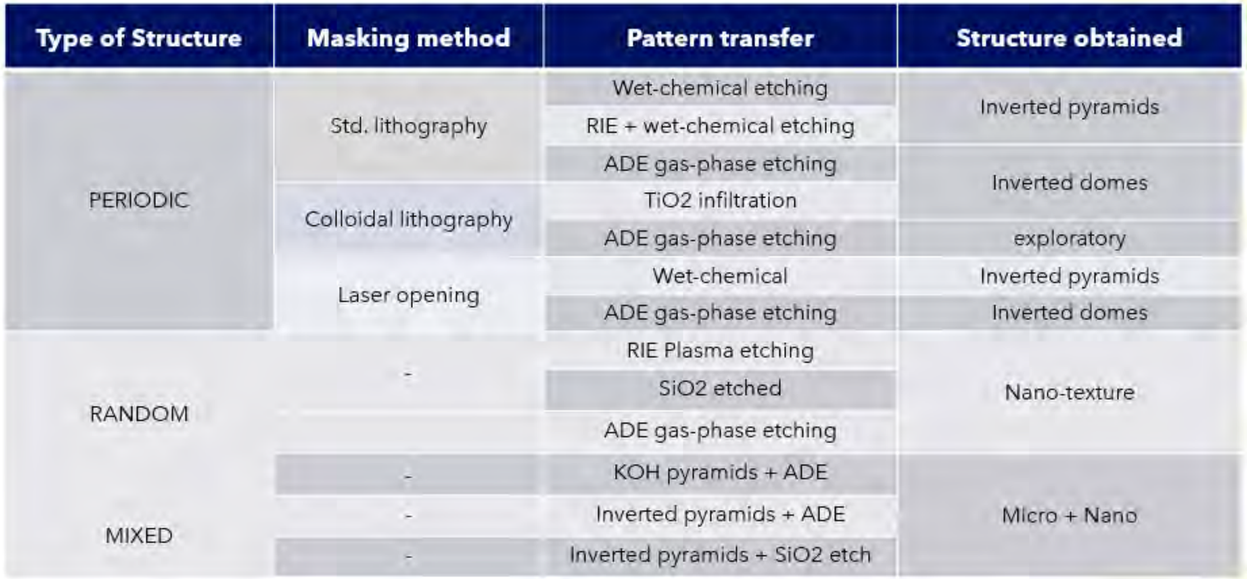
CONCLUSION

- Multiple approaches to front surface reflection being investigated
- Periodic structures have not shown clear optical advantages
- Double-texture (micro+nano) approach now most promising option
- Alternative to litho process being developed using high throughput tools (laser split beam + ADE)



Type of Structure	Masking method	Pattern transfer	Structure obtained
PERIODIC	Std. lithography	Wet-chemical etching	Inverted pyramids
		RIE + wet-chemical etching	
		ADE gas-phase etching	Inverted domes
	Colloidal lithography	TiO2 infiltration	
		ADE gas-phase etching	exploratory
	Laser opening	Wet-chemical	Inverted pyramids
		ADE gas-phase etching	Inverted domes
RANDOM	-	RIE Plasma etching	Nano-texture
		SiO2 etched	
		ADE gas-phase etching	
MIXED	-	KOH pyramids + ADE	Micro + Nano
	-	Inverted pyramids + ADE	
	-	Inverted pyramids + SiO2 etch	

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