Patterning of silicon layers using a highly selective, single-sided, Gas Phase Process.

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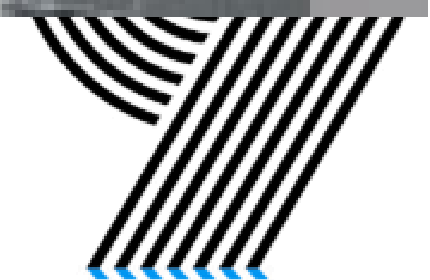
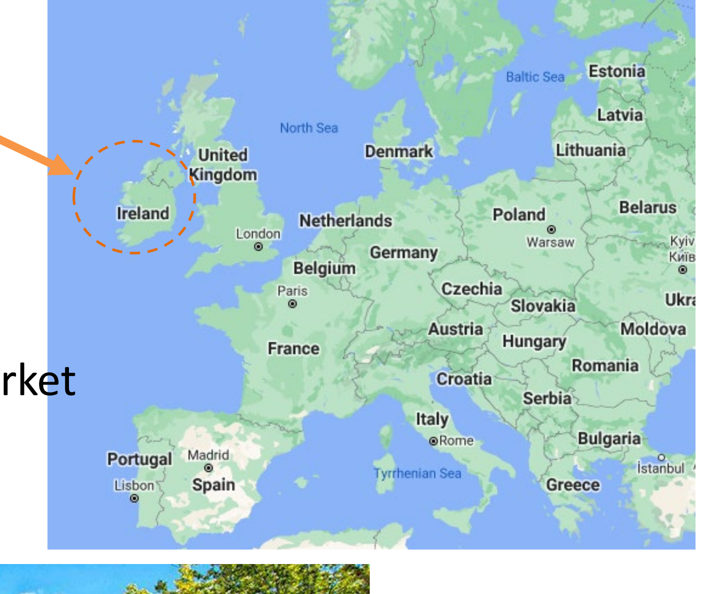


Company introduction

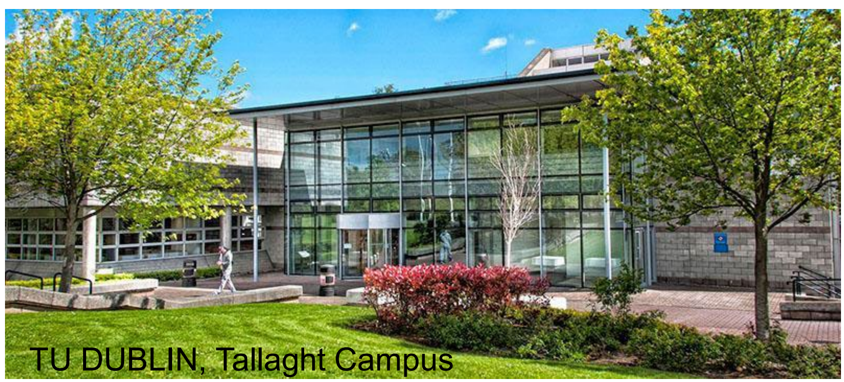
Nines Photovoltaics

- SME Founded in 2010, Based in Dublin, Ireland
- Innovative, R&D focus, European innovation
- Equipment + process development
- Small , focussed team

- **Atmospheric Pressure gas-phase Etching** for the PV market
- Financed through Private investments & EU funds



Synergy Centre



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Why Gas-phase etch ?

The problem - for Multi Gw scale

WET ... ATCH TOOL

20m

- ➔ X-Large ...
- Ma... s : ~1/3 of factory
- Pow... NGRY ! > 300 kW /GW
- ➔ Large CO_2 footprint from tool & HVAC

WET I

WET II

The problem - for Multi Gw scale - WATER

5 GW integrated TOPCON
= 200m³/hr
~ 5,000 m³ /day of Water

~ 2 Olympic swimming pools a day !!

Water outage shutdowns can cost ~ €1.9 M/week

Source: Circular water strategies in Solar cells manufacturing- Solar Energy 273 (2024) 112538

ADE multi-GW PRODUCTION TOOLS

ADE™

SS-POLY-ETCH

M10 : 24,000 wph

ADE™

ADE-3000

Single Side Etch Series

Dry Etching equipment for High efficiency solar cell

ADE SS Poly-Etch - 5 Gw Tool Offer – M10

UNLOAD

LOAD

3.5 M

3.5 M

- ADE SS Poly-Etch - 24,000 Wfr/hr
- 3 Tools ~5 Gw
- Inline, cassette to cassette; modular configurations

ADE™

SS-POLY-ETCH

M10

	ADE-6000-SS Poly-Etch
Footprint	12 m^2 ($6m^2$ without loaders)
Configuration	8 lanes – M10 wafers
Throughput	24,000 wafers per hour

MOTIVATION: Main Process Advantages of ADE gas-phase etch

ADE™ SS-POLY-ETCH

ADE3000 Industrial tool

Ultra-high etch rate 10x

- Small tool footprint
- High throughput

New processes enabler

- Single sided
- Selective
- Accurate control
- Low temperature

Sustainable

- No G.H.G.
- No D.I. Water
- Low COO
- Reduced carbon footprint

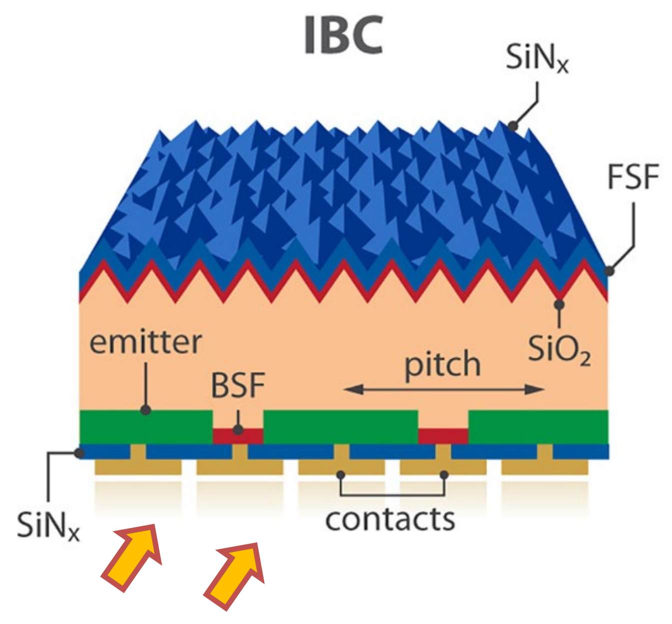
On-site gas generation

Industrial suitability, & scalability for multi-GW factories.

Reduced chemical inventory

Application for BC cells

- Next generation cells require patterning
- IBC needs patterning of the rear poly layers



➔Need for development of patterning methods
➔Exploring Patterning by selective, **single side, gas-phase etching**

MOTIVATION: gas-phase etch with ADE (Atmospheric Dry Etch)

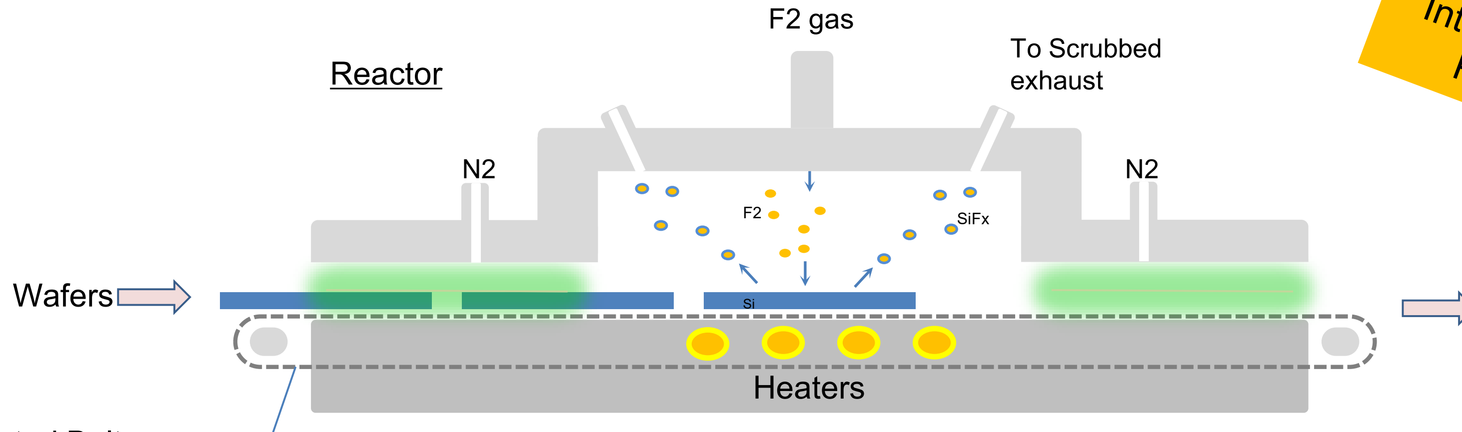
- Thermal process using molecular Fluorine gas (F2)
- Low temperature Chemical etching (NO PLASMA / IONS)
- In-line tool layout with continuous flow of wafers
- Atmospheric pressure process (no vacuum)

Global Warming Potential
(100 year GWP kg CO_2 eq)

F2	0

ADE

Granted International Patent



Etch selectivity

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

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

➔ Surface reaction
➔ Sensitive to surface state

Material	Selectivity vs. c-Si
n-type c-Si	1:1
n-poly Si (Reference)	1:1
i-poly Si	1.4:1
Boron emitter	1:6.5
p-poly Si (activated)	1:11
SiN_x	1:200
SiC	1:1950
BSG	1:2000
Thermal oxide	1:2000

Etch rate [nm/min]: 1, 10, 100, 1000, 10^4

Etch selectivity

Locally Induced selectivity

Mask

n-type c-Si 1:1
n-poly Si Reference 1:1
i-poly Si 1.4:1
Boron emitter 1:6.5
p-poly Si (activated) 1:11
SiN_x 1:200
SiC 1:1950
BSG 1:2000
Thermal oxide 1:2000

selectivity vs. c-Si

1 10 100 1000 10^4

Etch rate [nm/min]

Patterning options with ADE gas-phase etch

Patent pending

Selective etch

- Mask
  - Deposited
    - Added
    - Existing
  - Overlay
- Locally Induced selectivity
  - Local doping
  - Local chemical
  - Local laser

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SS-POLY-ETCH

Patterning options with ADE gas-phase etch

Selective etch

- Mask
  - Deposited
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Localised Laser pre-conditioning

Lasered lines at various intensities

Before etch process

a-Si:H/SiOx/c-Si/SiOx/a-Si:H, localised laser processing
300 nm a-Si:H, 15 nm PECVD SiOx on M2 c-Si wafer

25um

100um

1mm

3x3cm cross

Increased laser power

Localised Laser pre-conditioning

Surface after ADE process of the whole wafer:

Pre-conditioned lines

25um

100um

1mm

Areas without pre-con

a-Si:H left overs

S5

S1

→ Lasered poly areas etch faster
→ Locally Induced selectivity

Patterning options with ADE gas-phase etch

Selective etch

- Mask
  - Deposited
    - Added
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  - Overlay
- Locally Induced selectivity
  - Local doping
  - Local chemical
  - Local laser

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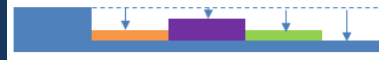
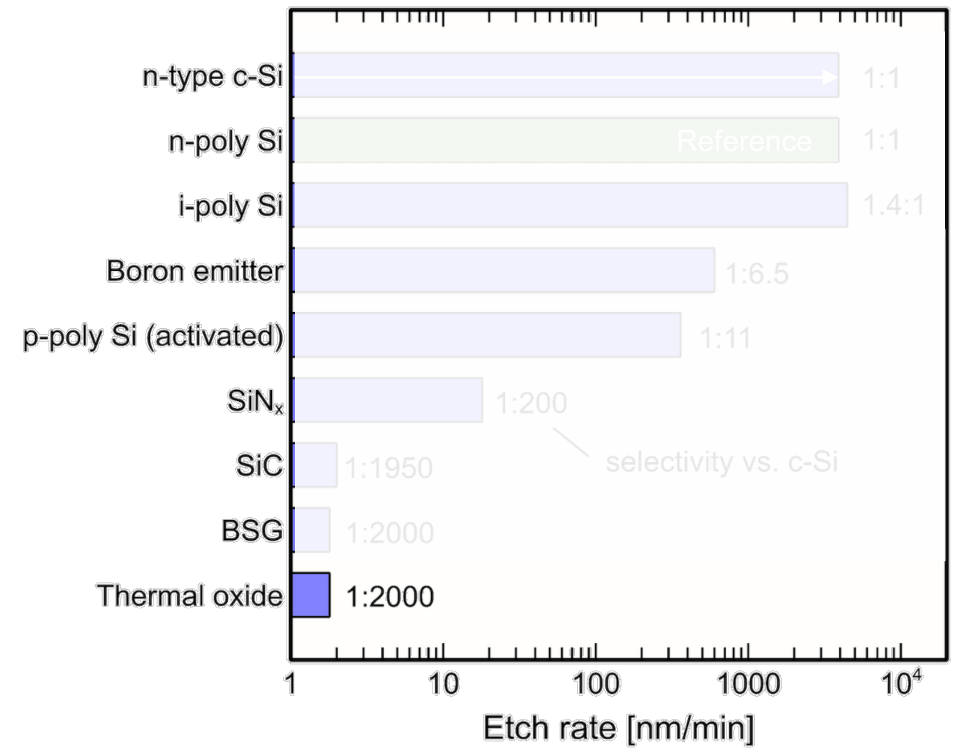
1 – Etch selectivity



- Thermal oxide etch rate 2000 times slower

➔ More “traditional” mask technic



Deposited mask – “Semi” process

OXIDATION:

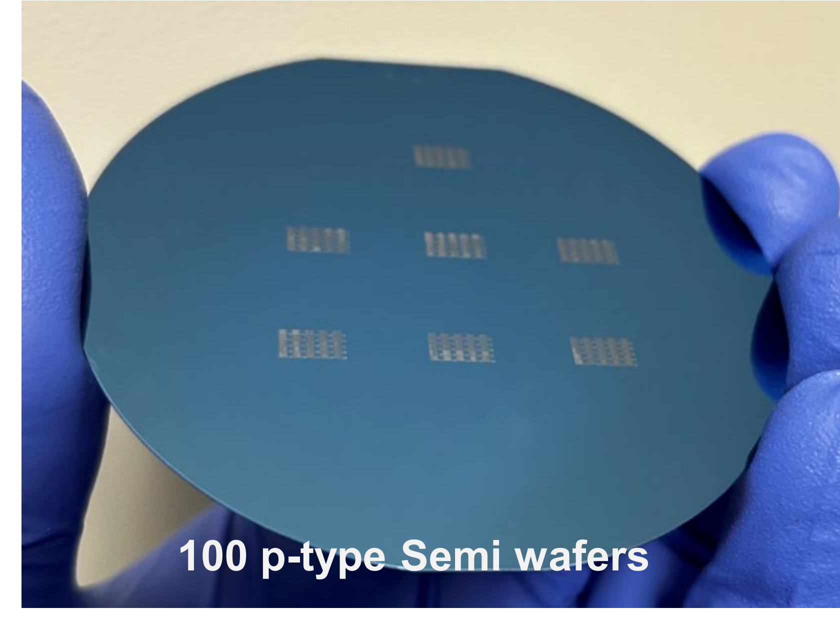
- Dry oxidised @ 1100 °C ➔ Oxide thickness of circa 120 nm

PHOTORESIST:

- Photoresist (S1818 G2) and soft baked @ 115 °C for 60 sec
- Exposed pattern (using a Polos uPrinter)
- Developed pattern (Microsposit 351 developer)
- Hard baked PR @ 135 °C for 180 sec to create etch mask for the SiO2

ETCHING

- Etch exposed SiO2 back to the Si surface (10:1 BOE for 120 sec)
- Photoresist strip (Microposit SVC175 PR stripper)
- **ADE Gas-Phase etch of the exposed silicon**
- Remove remaining SiO2 (HF etch)



4/6 samples

1

PR pattern

2

BOE and PR stripped

3

After ADE etch

4

After ADE etch + SiOx removal

Patterning options with ADE gas-phase etch

Selective etch

- Mask
  - Deposited
    - Added
    - Existing
  - Overlay
- Locally Induced selectivity
  - Local doping
  - Local chemical
  - Local laser

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Overlay

Poly wafer

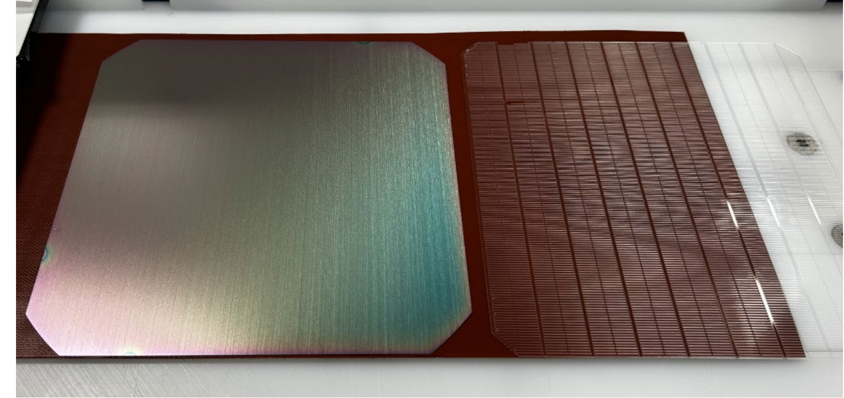
Quartz disc

➔ Schemes with more elaborated shadow masks need to be explored

Overlay

Poly wafer

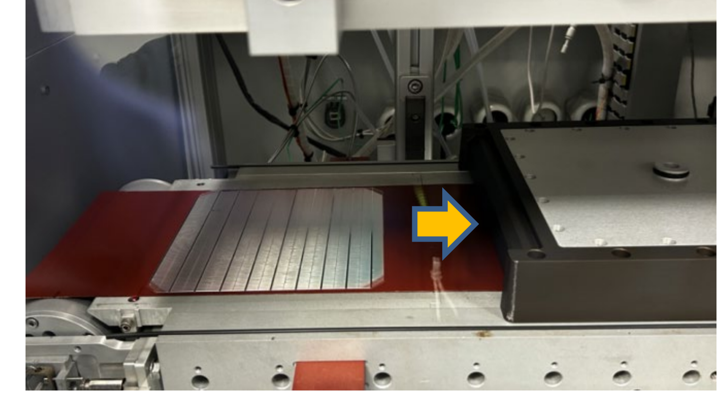
Glass mask



Glass mask on top of wafer

- M2 wafer
- 80nm SiNx + 150nm a-Si:H

➔ Allows easy visual inspection



Overlay

Deposition

Process
Shadow mask
Substrate

type

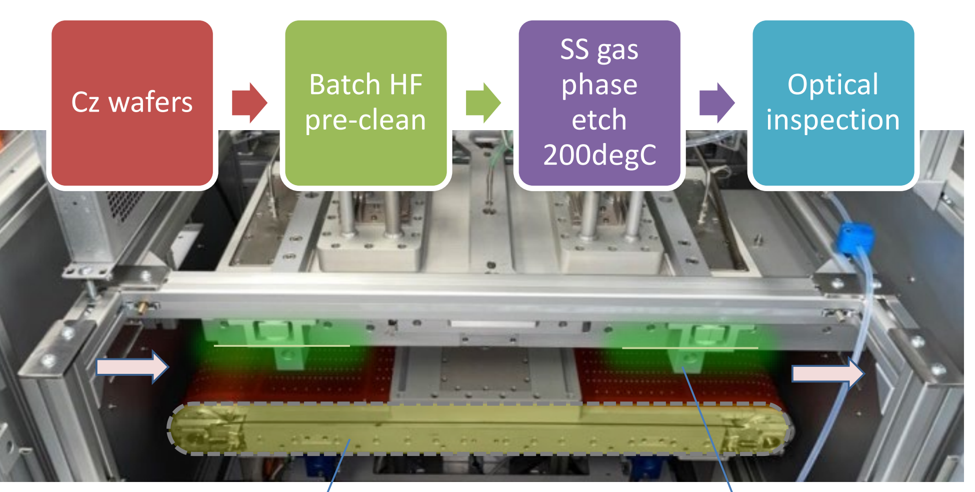
- ➔ "shadow mask"
- ➔ Equal deposition on mask an substrate

Etching

- ➔ Negative version
- ➔ Selective etching of poly layer

Experimental

- Cz wafers pre-cleaned in 5%HF solution
- Wafers are etched in an inline gas-phase etch tool (ADE100) at around 200 DegC
- <20s process time

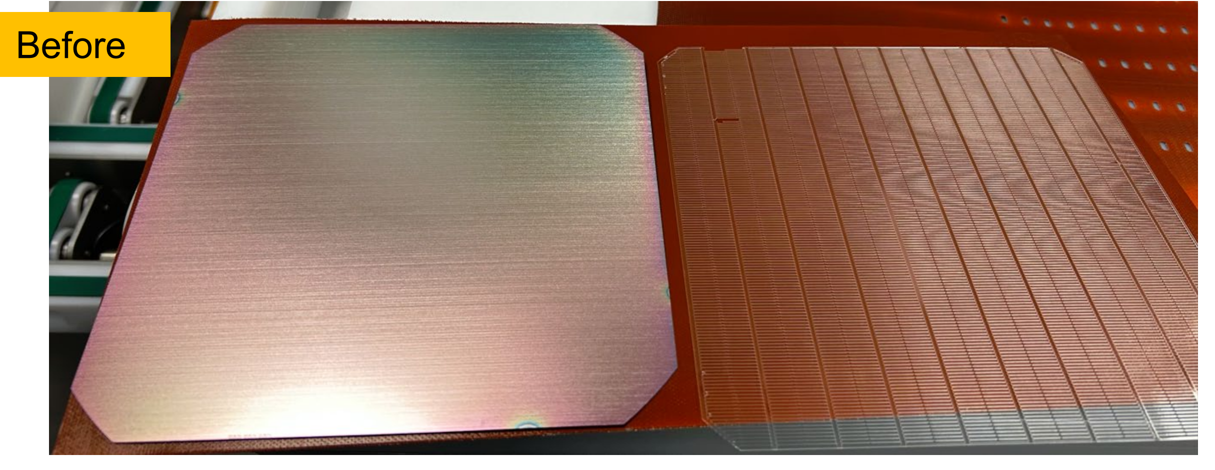


Heated Belt conveyor

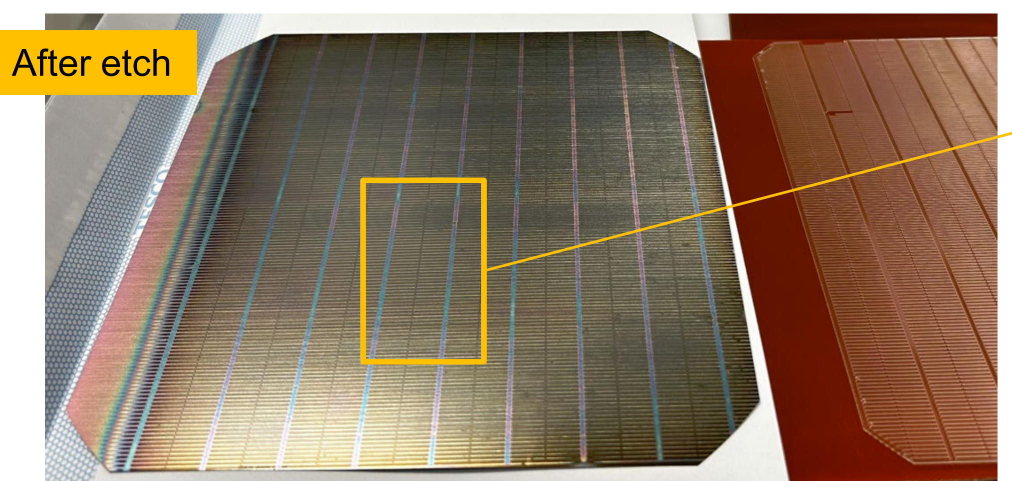
N2 Purge curtain

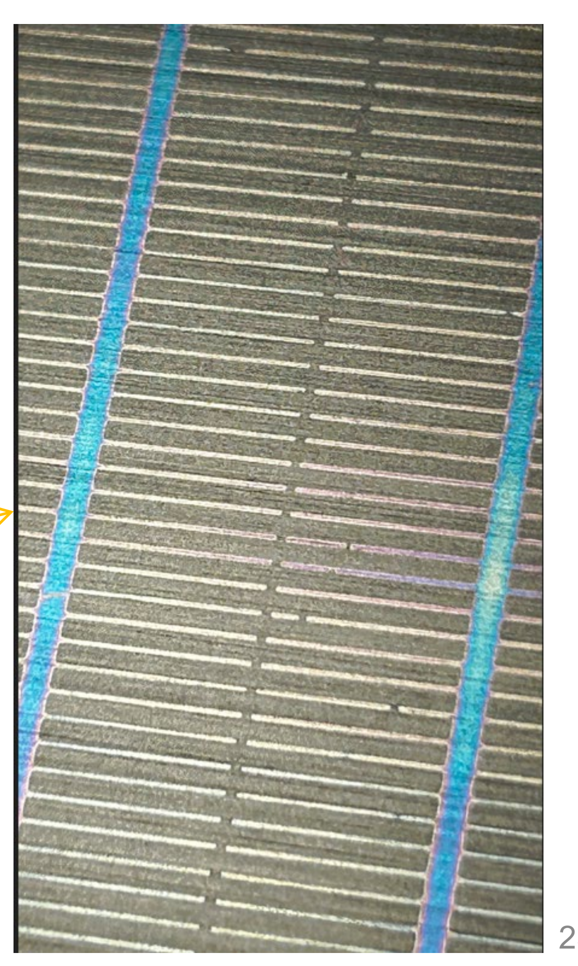
Overlay

Before



After etch





Results

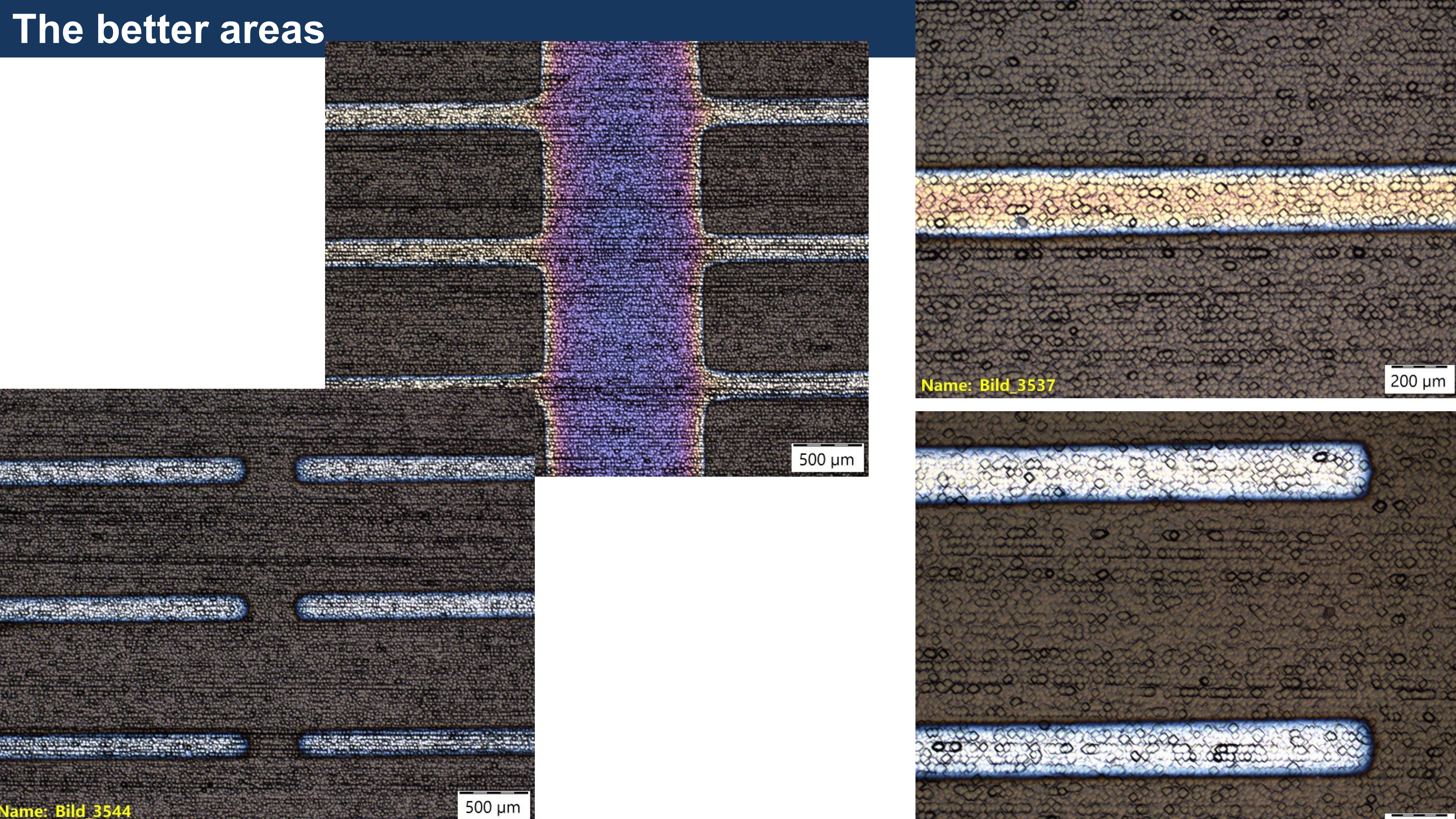
Opening: 750um

Glass: 250um

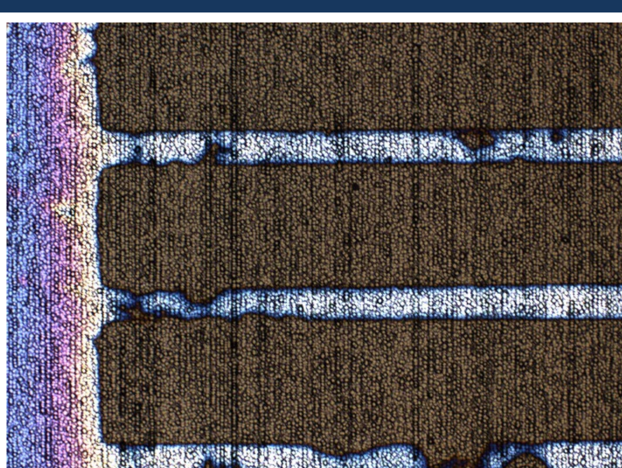
Name: Bild_3547

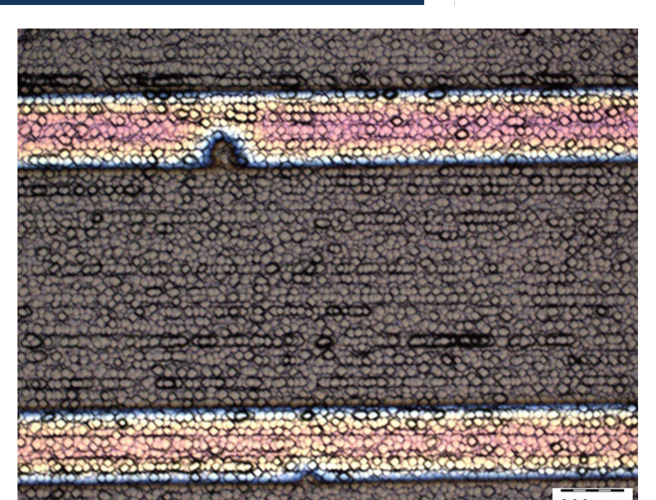
500 µm

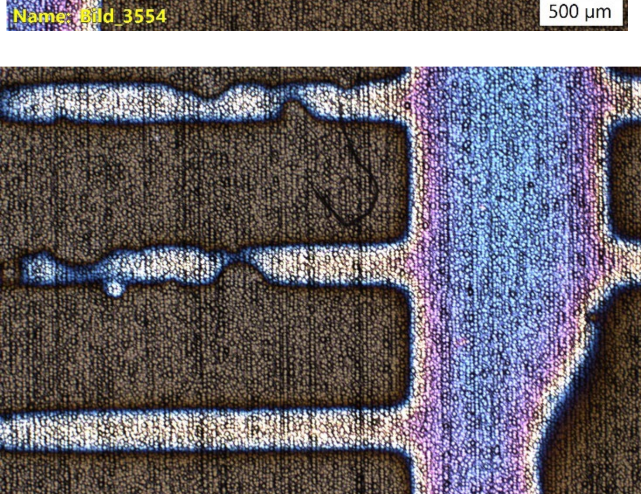
The better areas

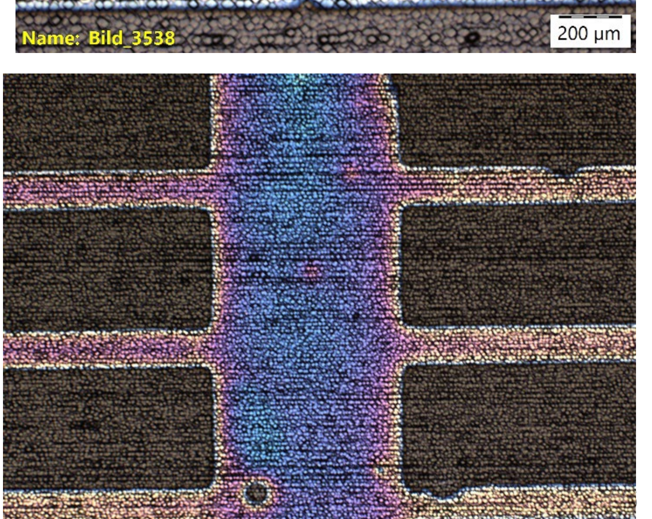


Some defect area









Finger width variations

Measured finger width (um)

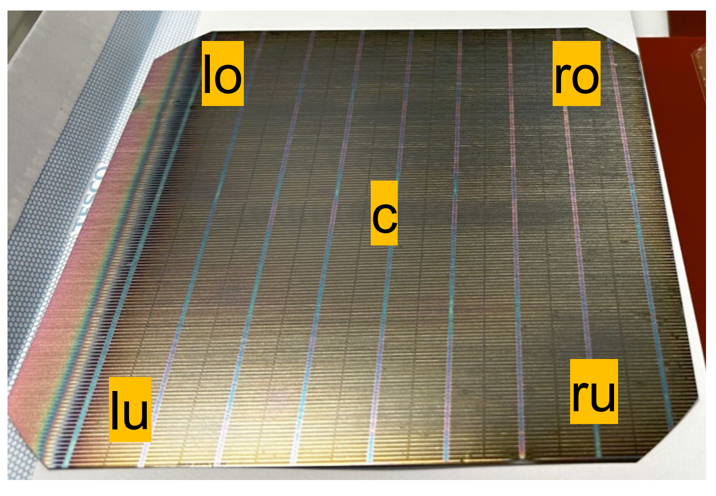
350
300
250
200
150
100

c lo lu ro ru

position on sample

250µm

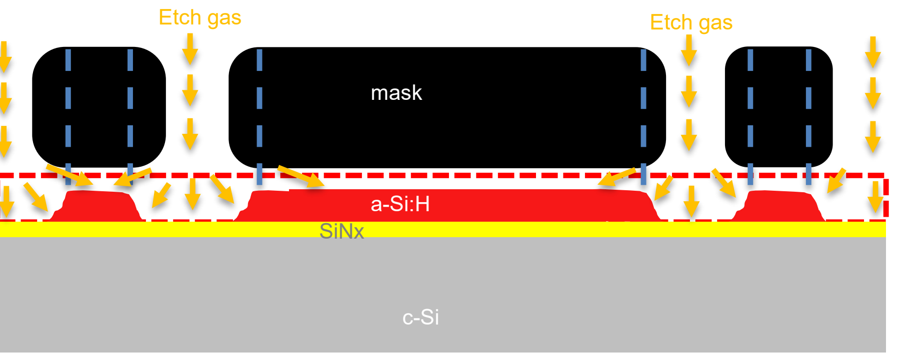
Position on sample



➔ Large enough relative variation

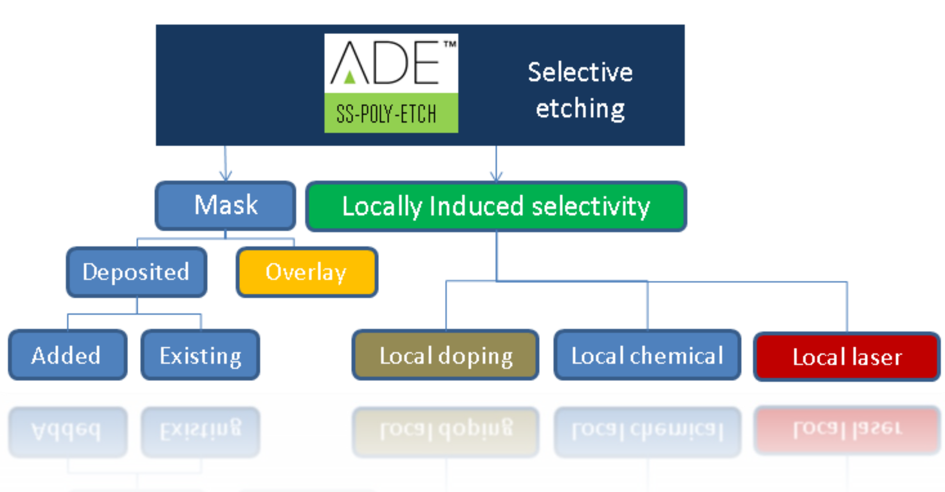
Next

- Fine process tuning
- Understanding of “reach”
- Optimization of mask & uniformity
- Trials without etch stop under-layer



Take away :

- High selectivity of ADE single-side gas-phase etch
- Enables several paths and **options for patterning** poly-silicon layers
- ➔ masking
- ➔ Locally induced selectivity
- Let's take advantage of it !



BURST Project

Funded by the European Union

WaMTec

cet Partnership

Synergy Centre

THANK YOU FOR YOUR ATTENTION…

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Nines
Photovoltaics

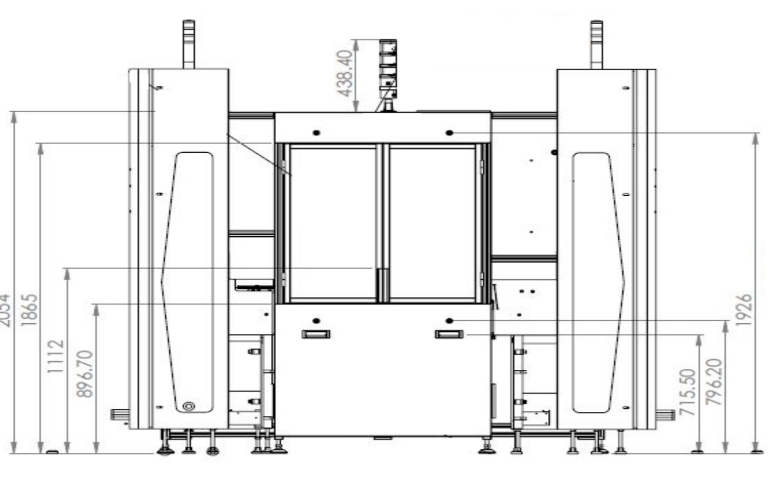
ADE100 – R&D Pilot line

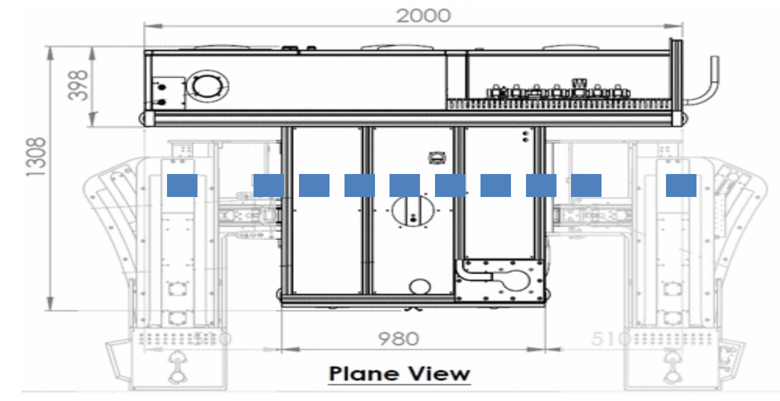
ADE™

ADE-100

Single Side Etch Series

Dry Etching equipment for High efficiency solar cell





Shown with loaders