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Micro fabrication of III-V based solar cells for weight reduction and performance improvement

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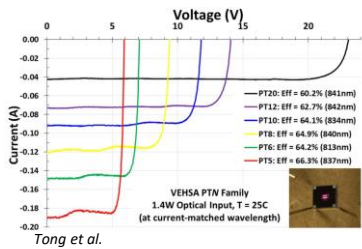


Micro fabrication of III-V-based solar cells for weight reduction and performance improvement

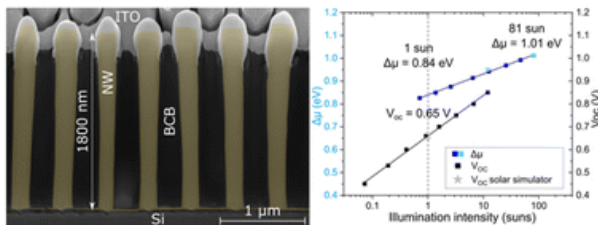
Maxime Darnon,

A. Chapotot, V. Daniel, T. Hanus, N. Paupy, B. Ilaoui, G. Hamon and A. Boucherif

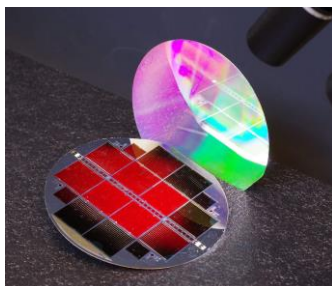
(and many more students)



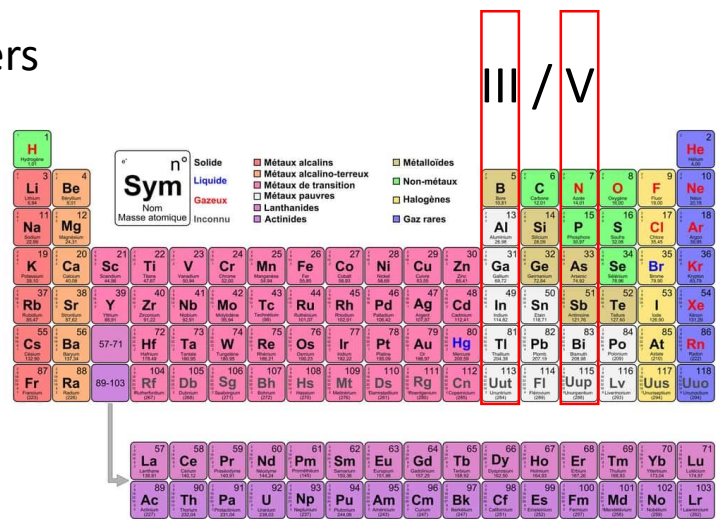
Monochromatic phototransducers



Low TRL concepts



Fraunhofer ISE
Tandem III-V/Si



Toyota
High efficiency

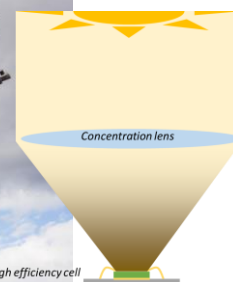


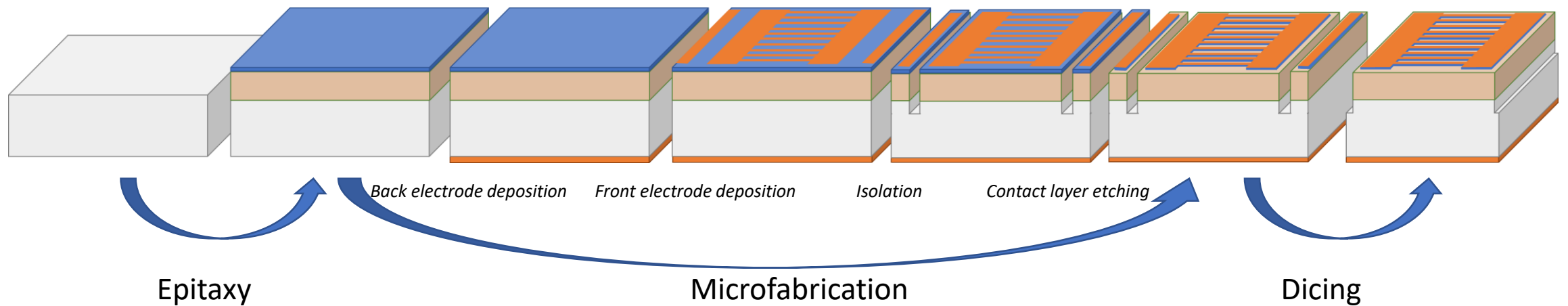
https://compoundsemiconductor.net/article/103961/Azur_boosts_III-V_solar_cell_production_with_Aixtron_system

Space



Concentrator PV





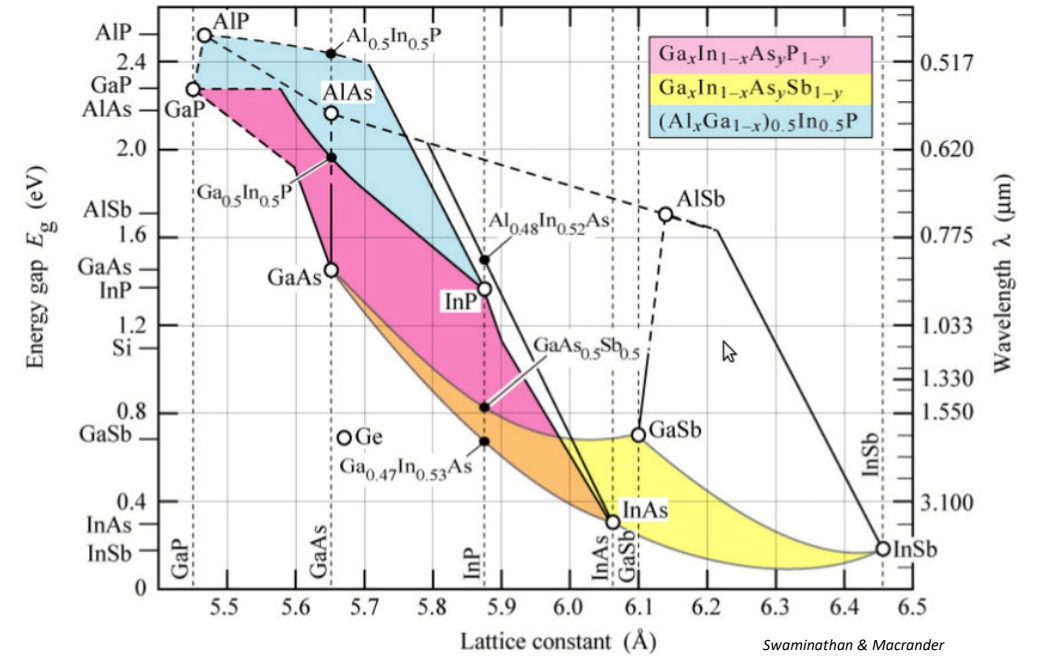
Few basic microfabrication steps needed to make a solar cell

High quality crystalline material is required

- ➔ Epitaxy is needed
- ➔ Crystalline substrate with matched lattice constant

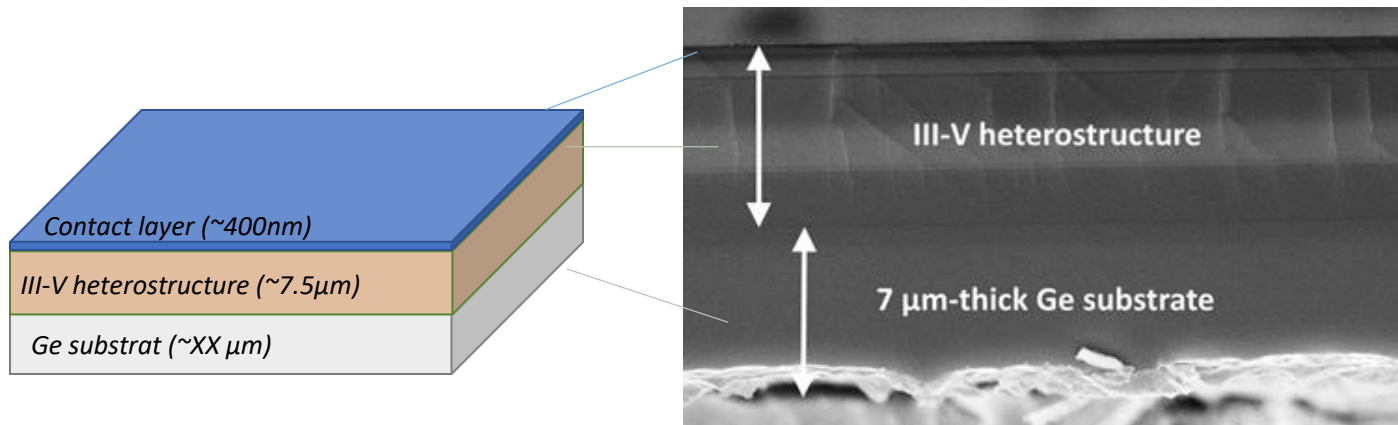
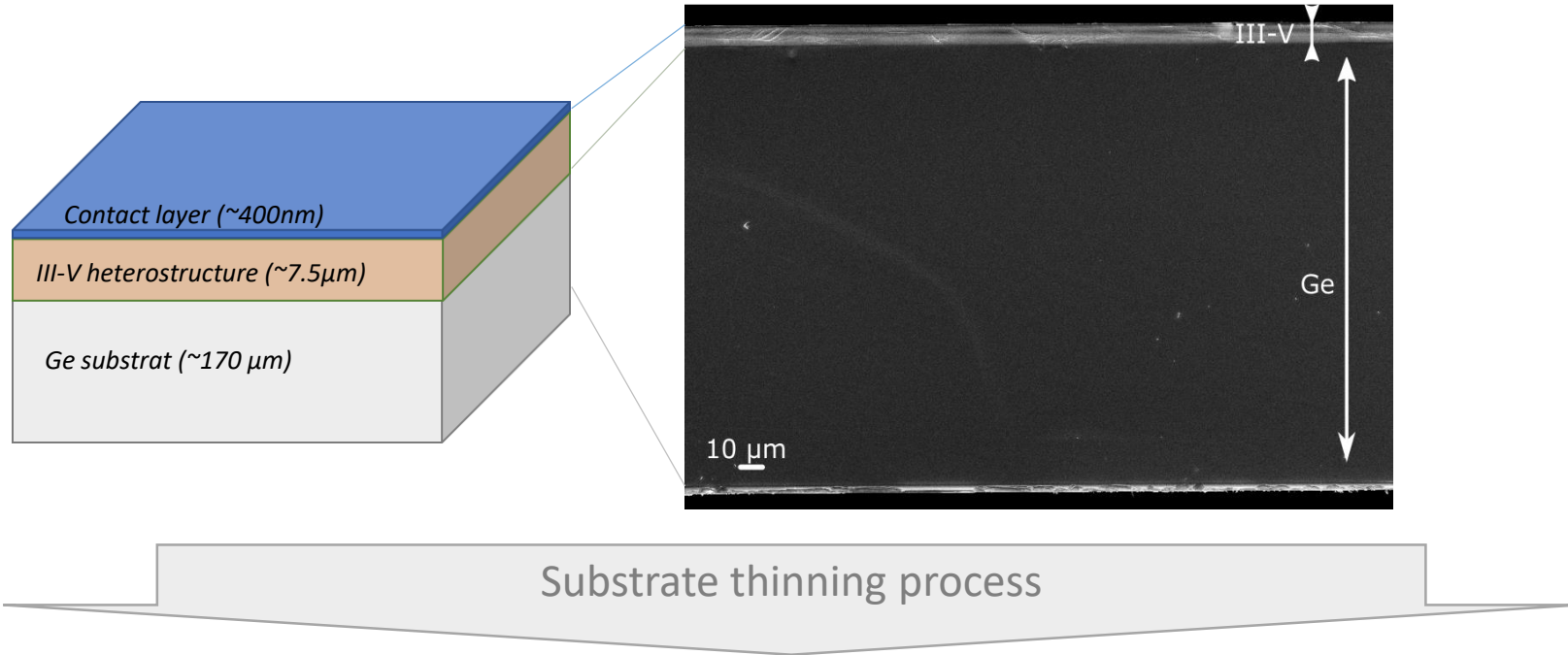
Germanium & GaAs:

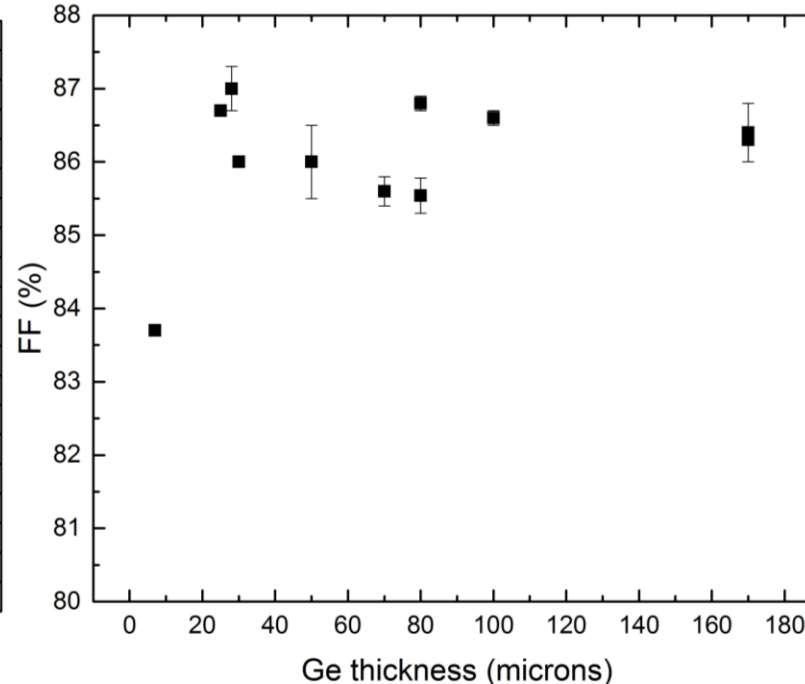
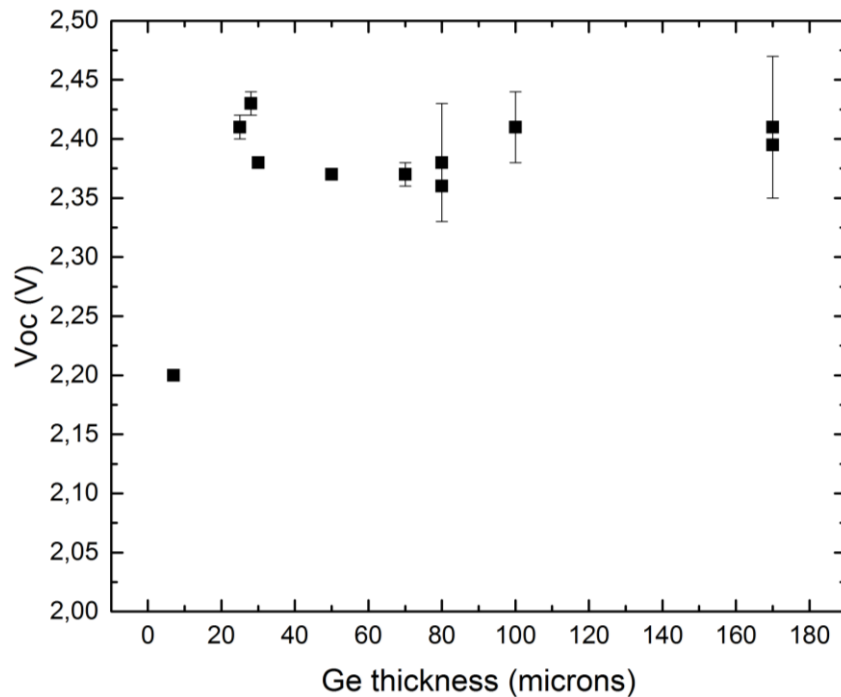
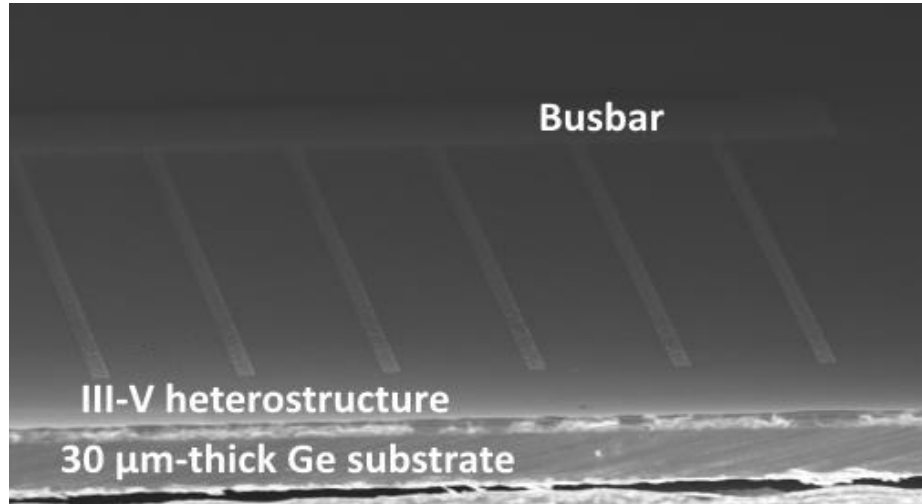
- ~100\$ per wafer (~85% of the cost of the cell)
- ~5.3g/cm³ (~95% of the weight of the cell)



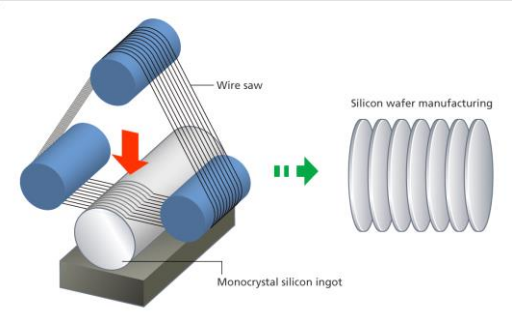
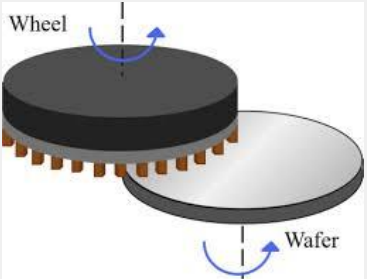
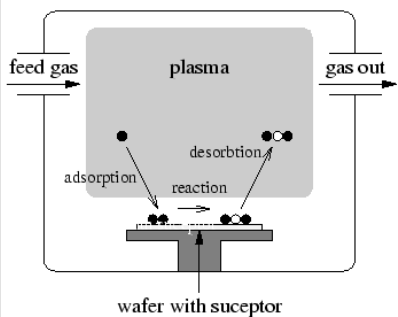
Can we leverage on micro-nanofabrication methods to reduce kg/W ratio?

Substrate thinning

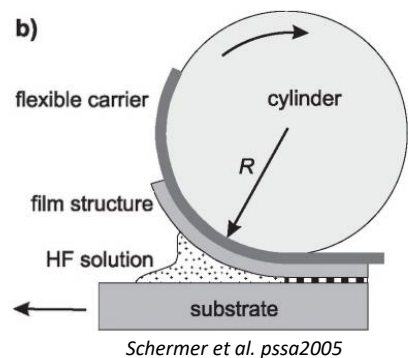




No significant cell performance degradation with thin Ge substrate (>25 μm)
→ 80% kg/W reduction

Approach	Schematic	Problems
Thinner wafers	 <p>Source: Nikon</p>	<ul style="list-style-type: none"> ➤ Defectivity ➤ Handling thin wafers ➤ Kerf losses
Back side grinding	 <p>Wu et al. Journal of Mechanics, 2023, 39, 191–198</p>	<ul style="list-style-type: none"> ➤ Recycling products ➤ Mechanical stress ➤ Cost
Etching	 <p>Source Scicalglass</p>	<ul style="list-style-type: none"> ➤ Chemical / GHG use ➤ Recycling ➤ Cost

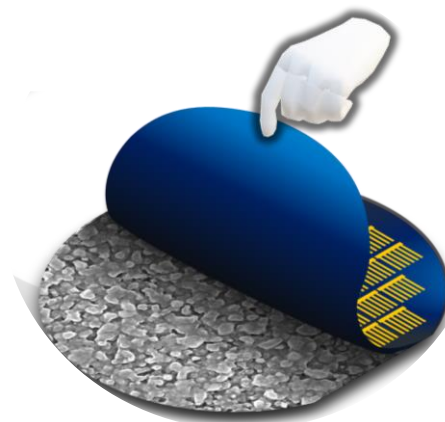
Chemical separation (Lift off)



e.g. Alta device

- Long process (~30mm/hr)
- Needs a sacrificial layer

Mechanical separation with a weak layer

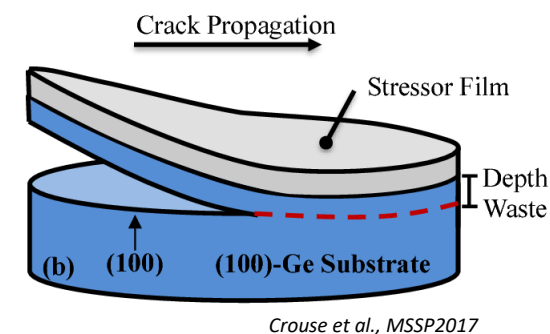


Source: V. Daniel

e.g. smartcut, Ge on nothing, porous lift off

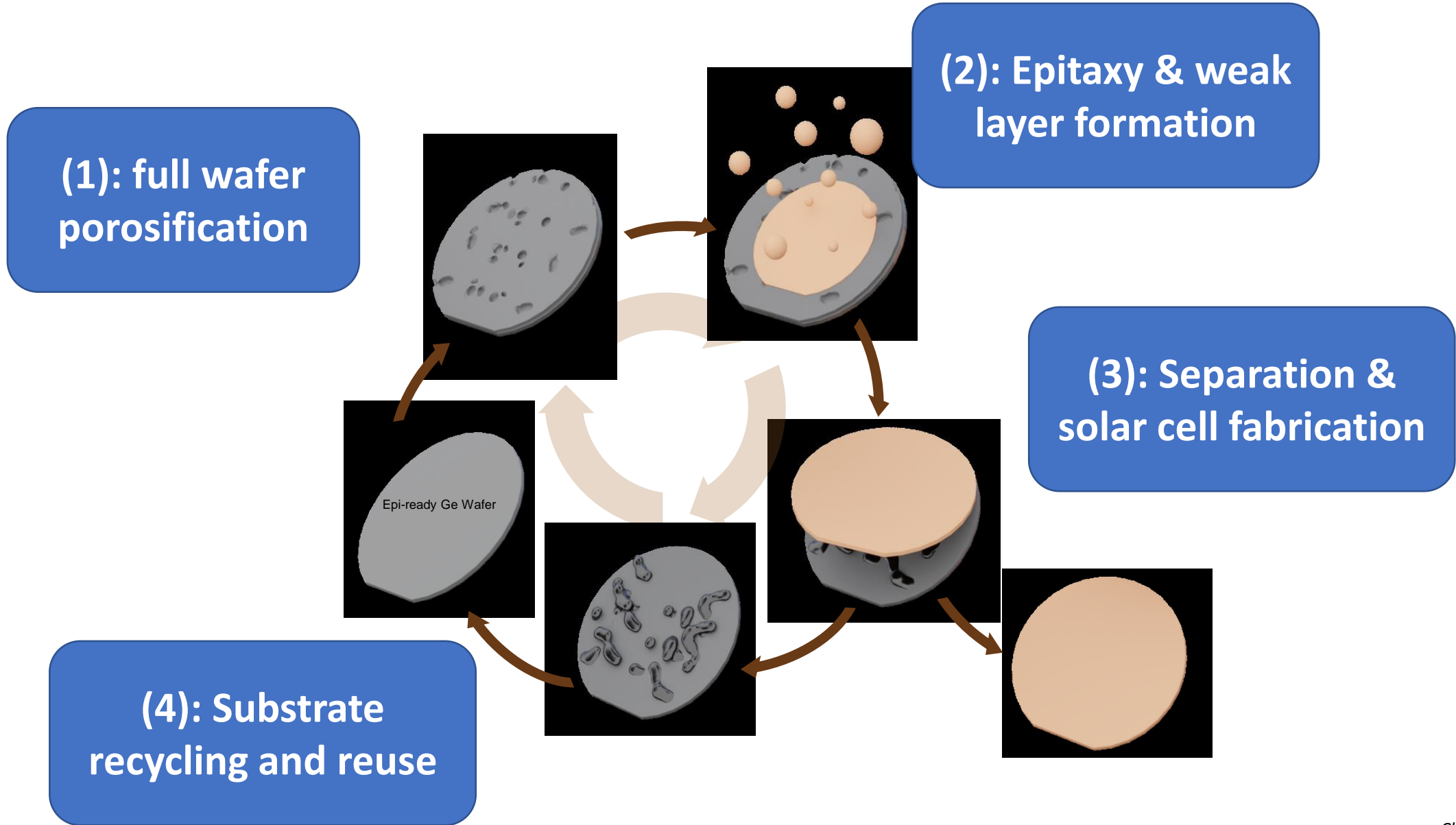
➔ Need for a weak layer

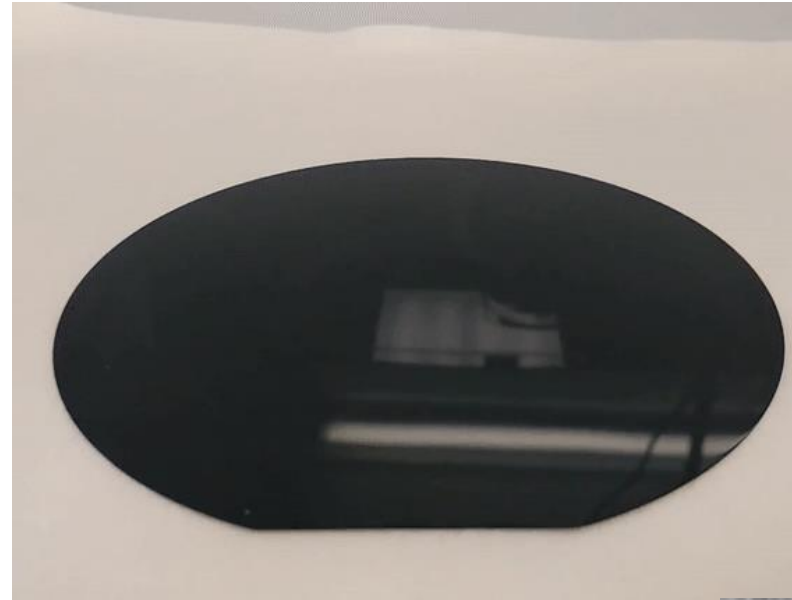
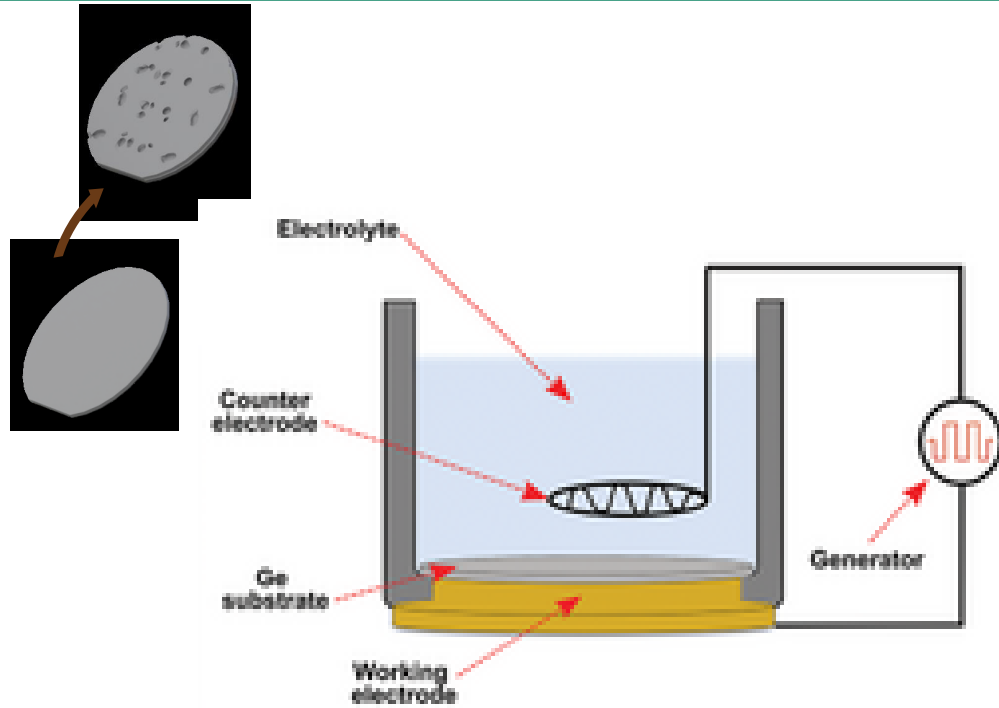
Mechanical separation (spalling)



- Need for stressor
- Wavy surface

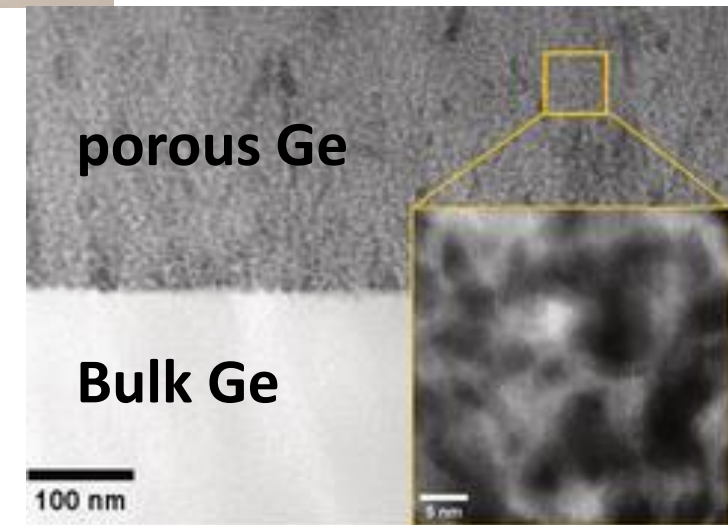
Porous Ge as a weak layer for mechanical separation ➔ PEELER process



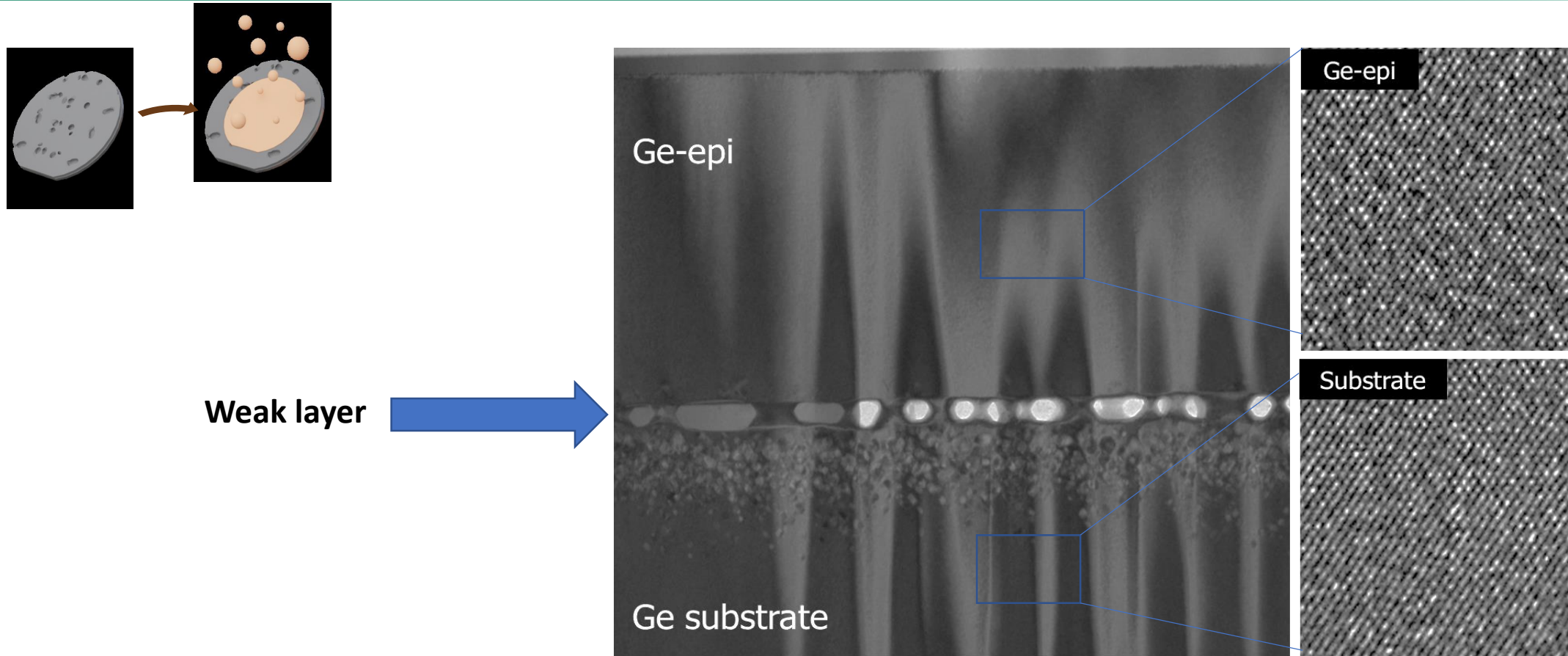


Electrochemical porosification of Germanium

- Low cost, controllable and fast process
- Compatible with large scale wafers
- Keeps crystallinity of germanium



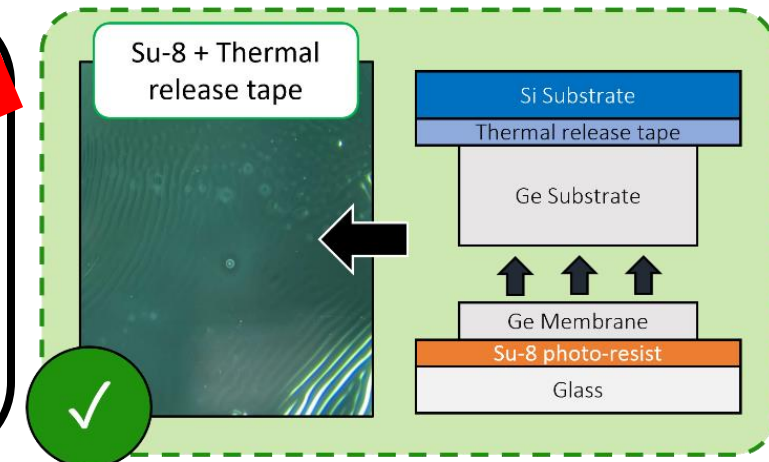
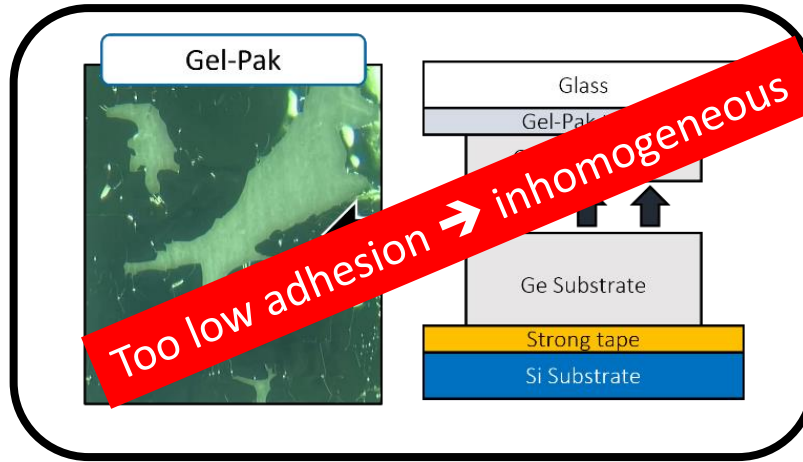
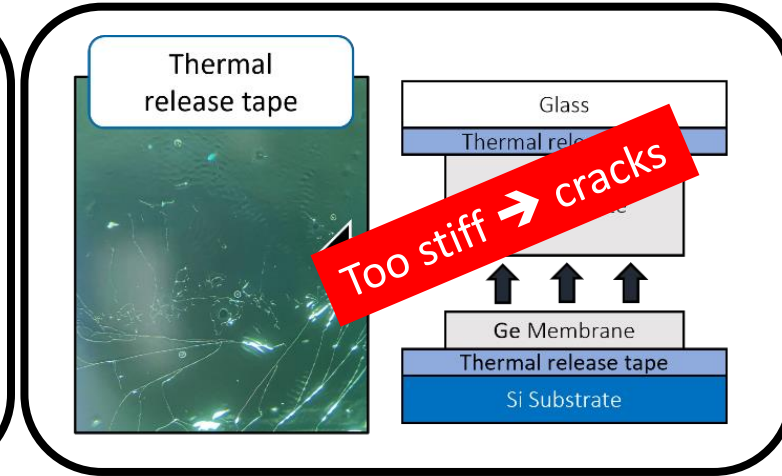
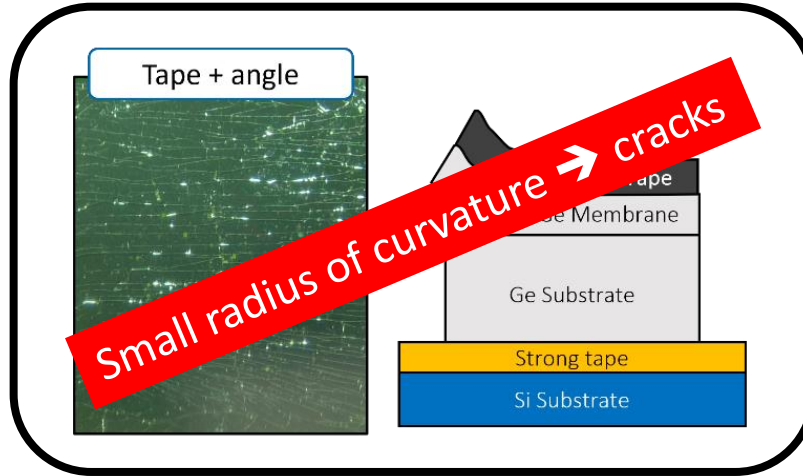
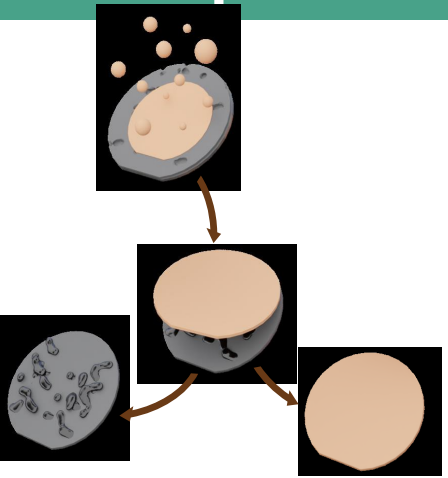
T. Hanus et al., *Advanced Materias Interfaces*, 2023



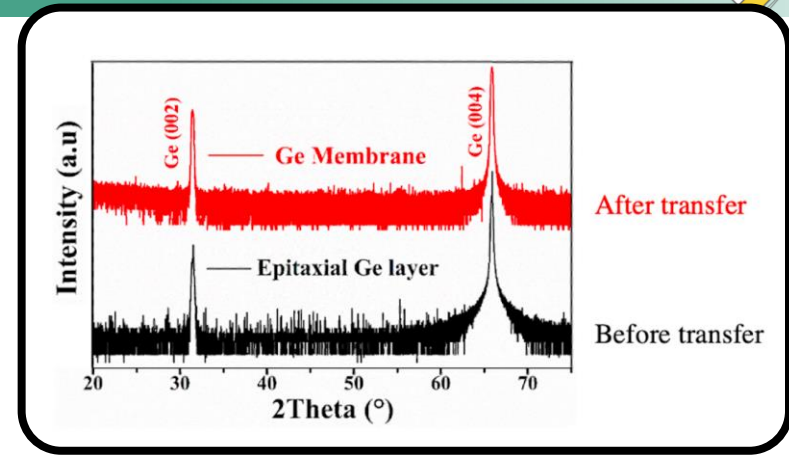
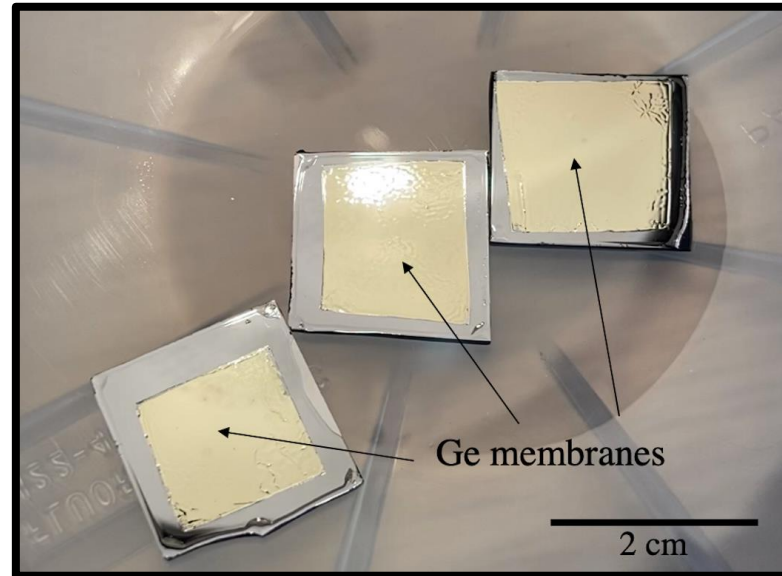
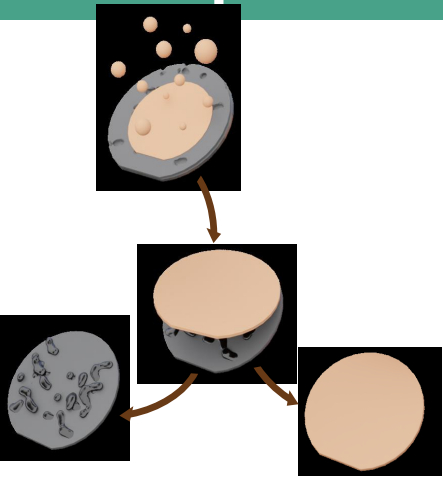
- Conservation of Ge crystalline quality
- Porous layer restructuring into a weak layer

N. Paupy, Z. Oulad Elhmaid, A. Chapotot, T. Hanus, J. Arias-Zapata, et al., Nanoscale advances, 2023

Separation

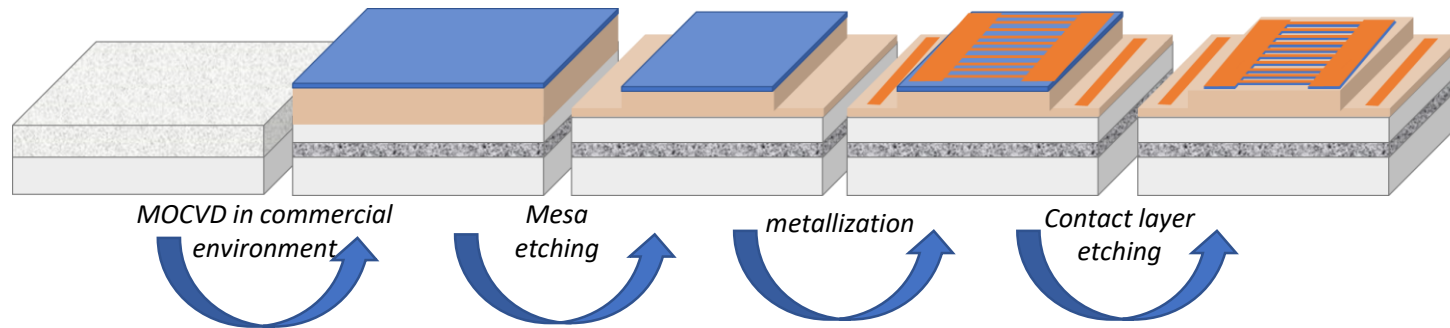
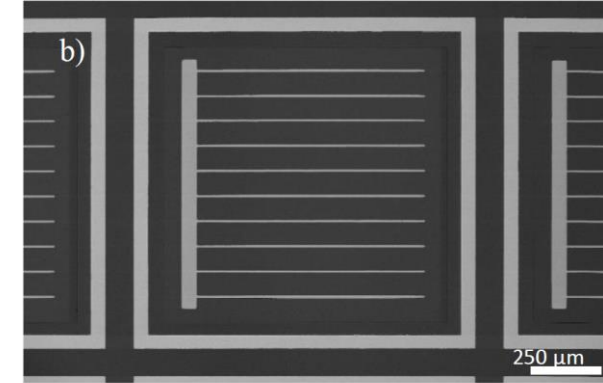
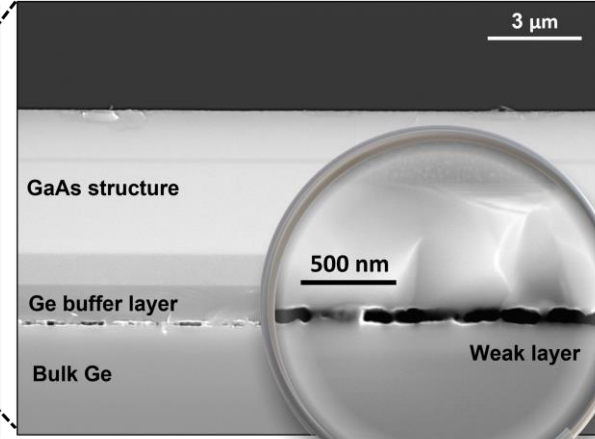
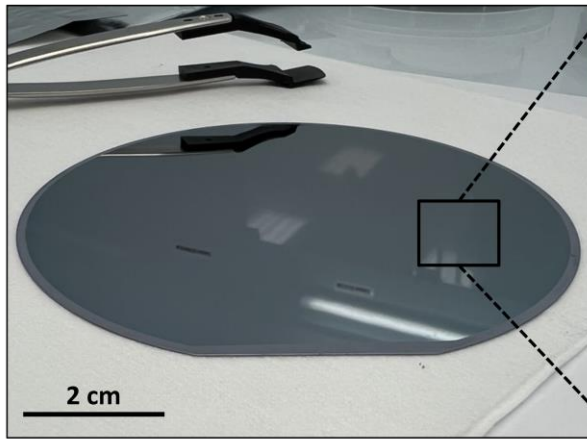
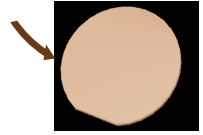


Control of adhesive and release method is key to large scale detachment

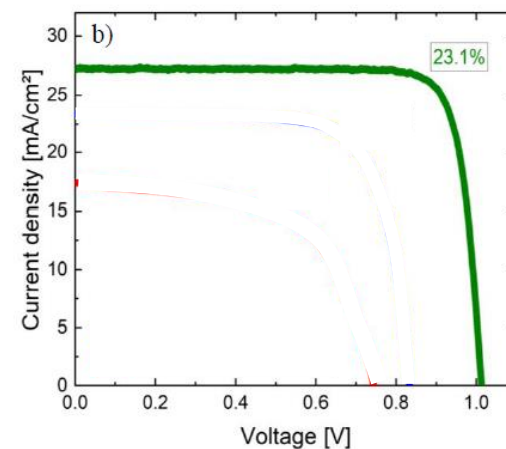
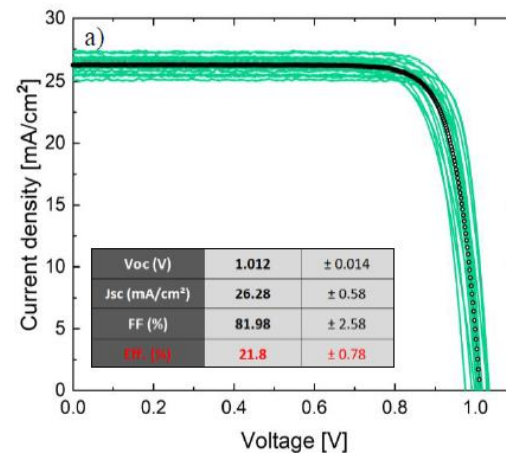
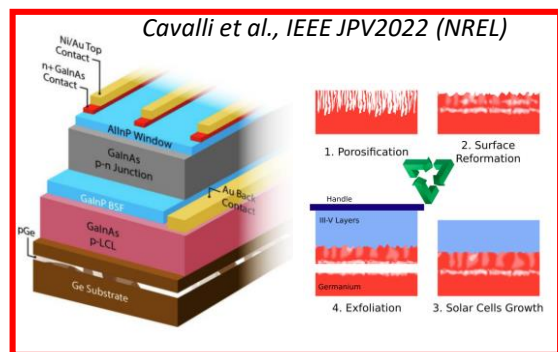
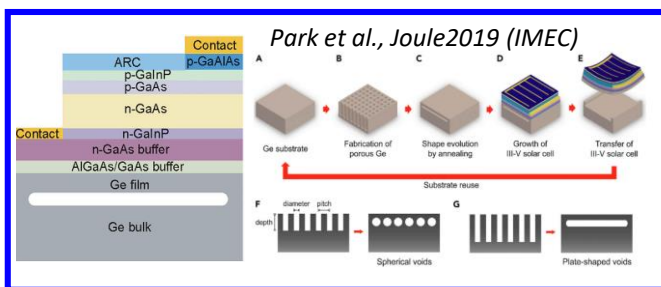
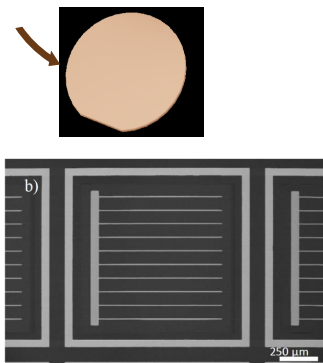


Wafer-scale separation of crystalline material





Engineered wafers are compatible with microfabrication methods

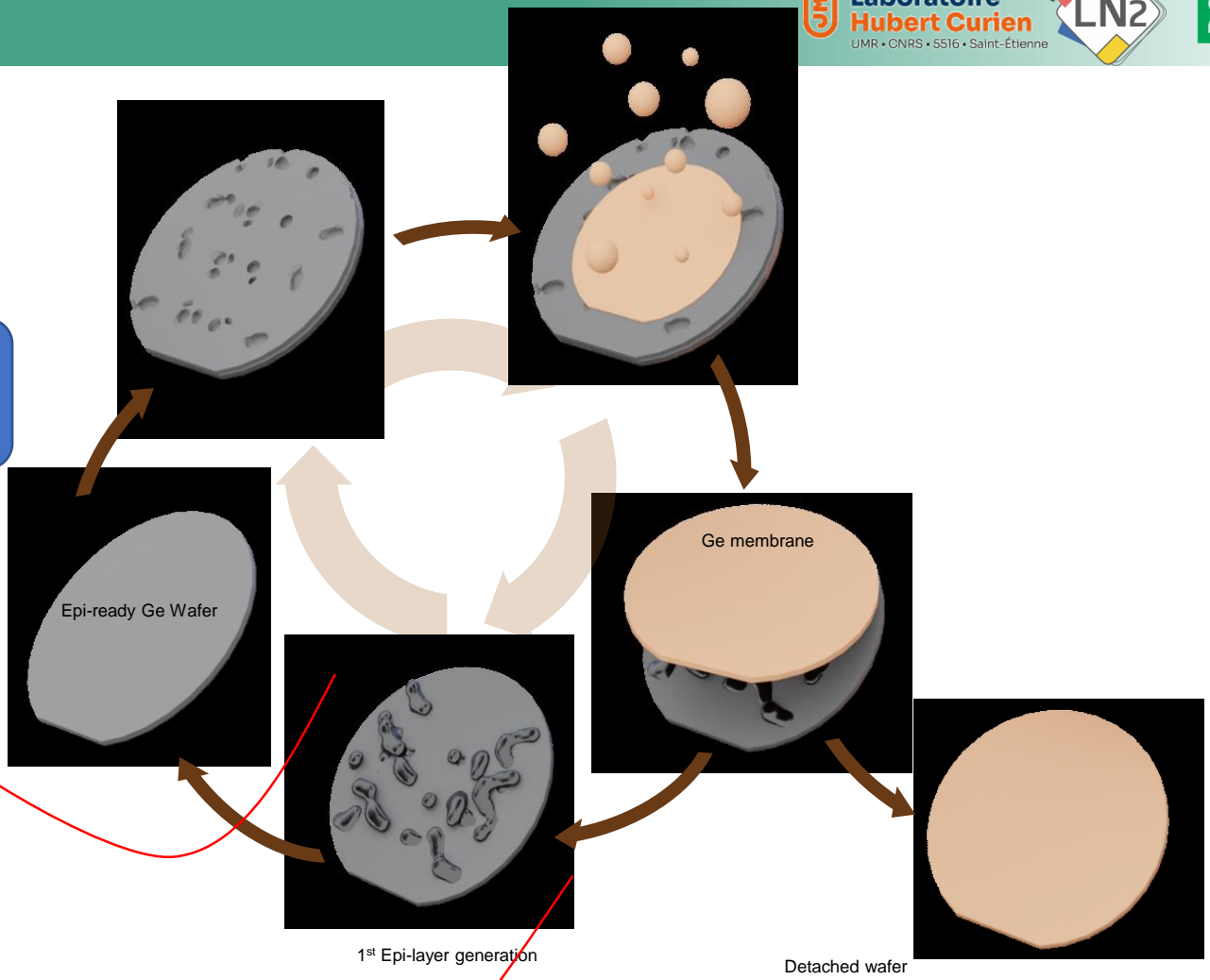
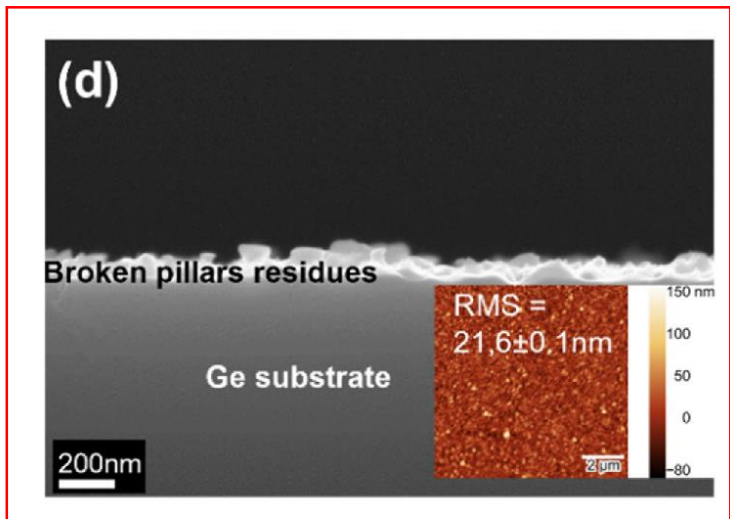


- Single junction GaAs cells
 - AM1.5G 1sun I-V characterization
 - No anti reflective coating
 - Front side-contacted cells
- ➔ 22/25 cells functional (88% yield)

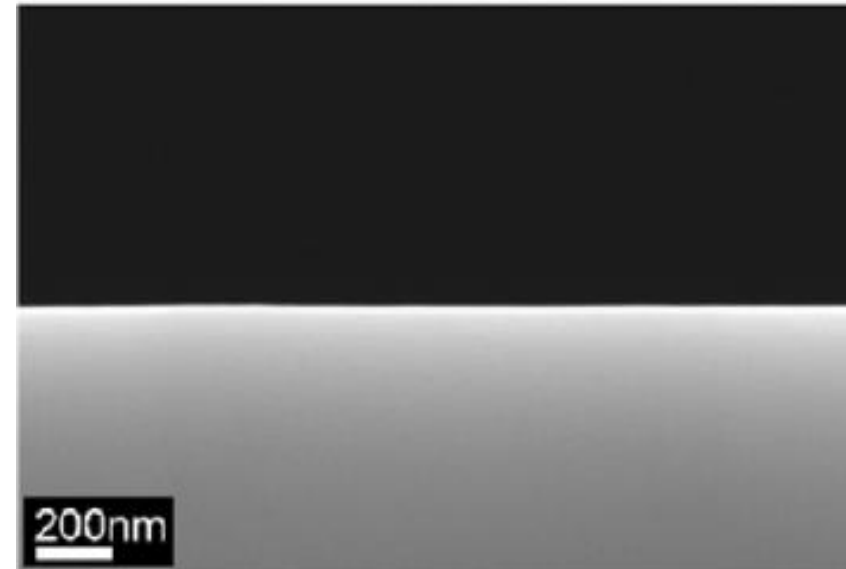
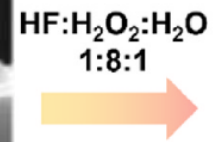
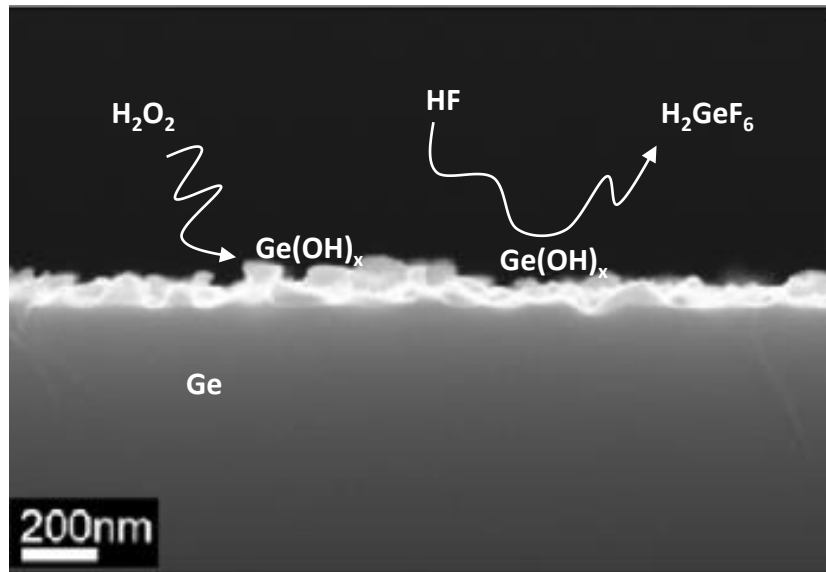
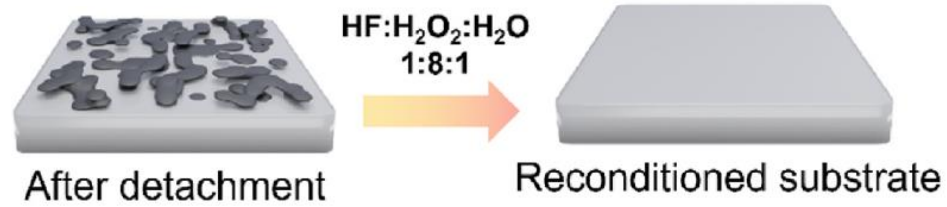
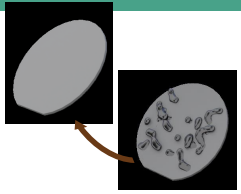
State of the art performance of cells fabricated on engineered wafers

Can we recover Ge surface quality after separation?

Broken pillars residues after separation
→ High surface roughness

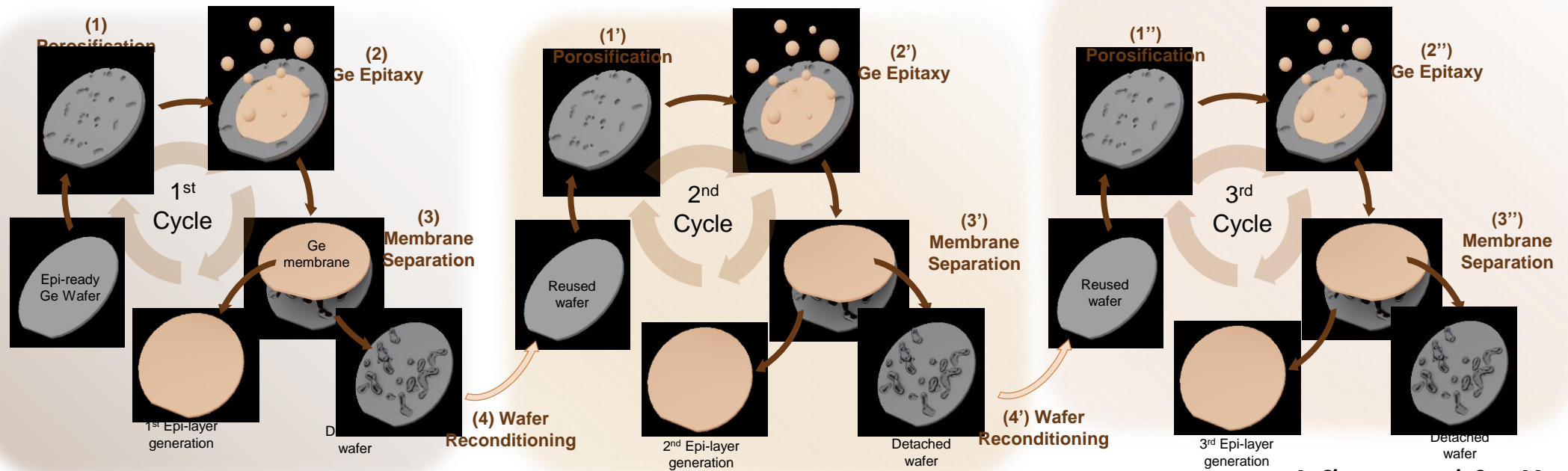
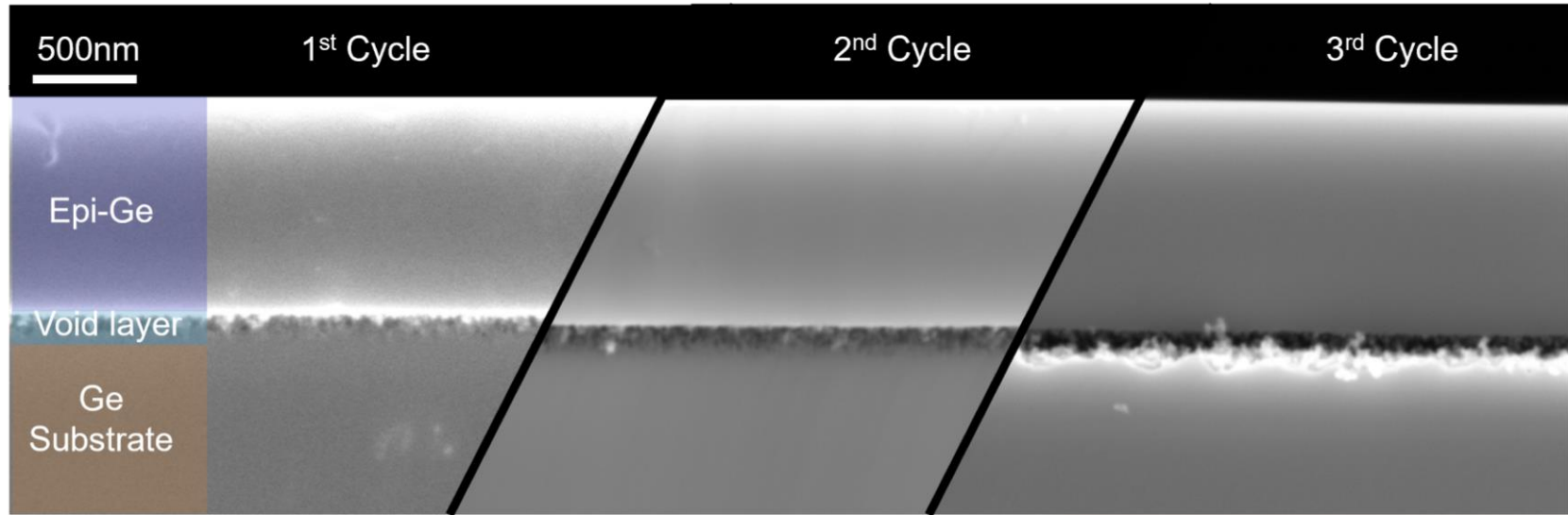
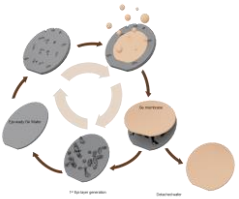


Substrate reuse – wet etch process

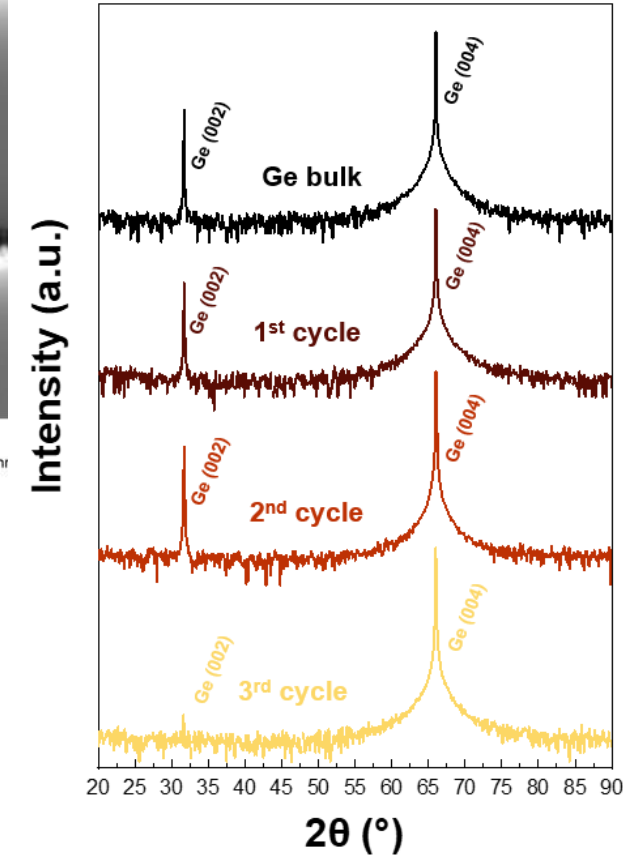
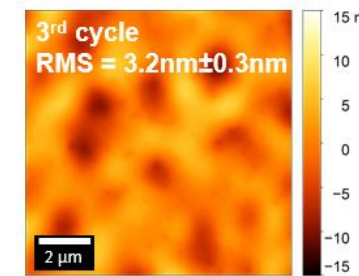
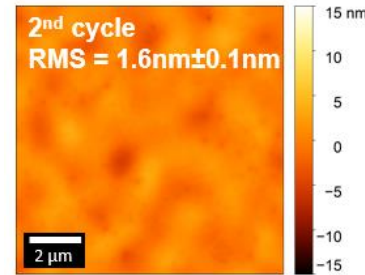
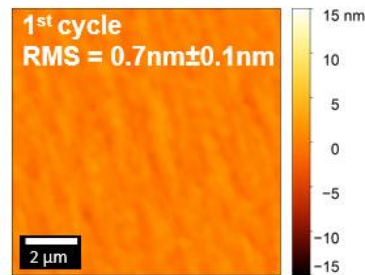
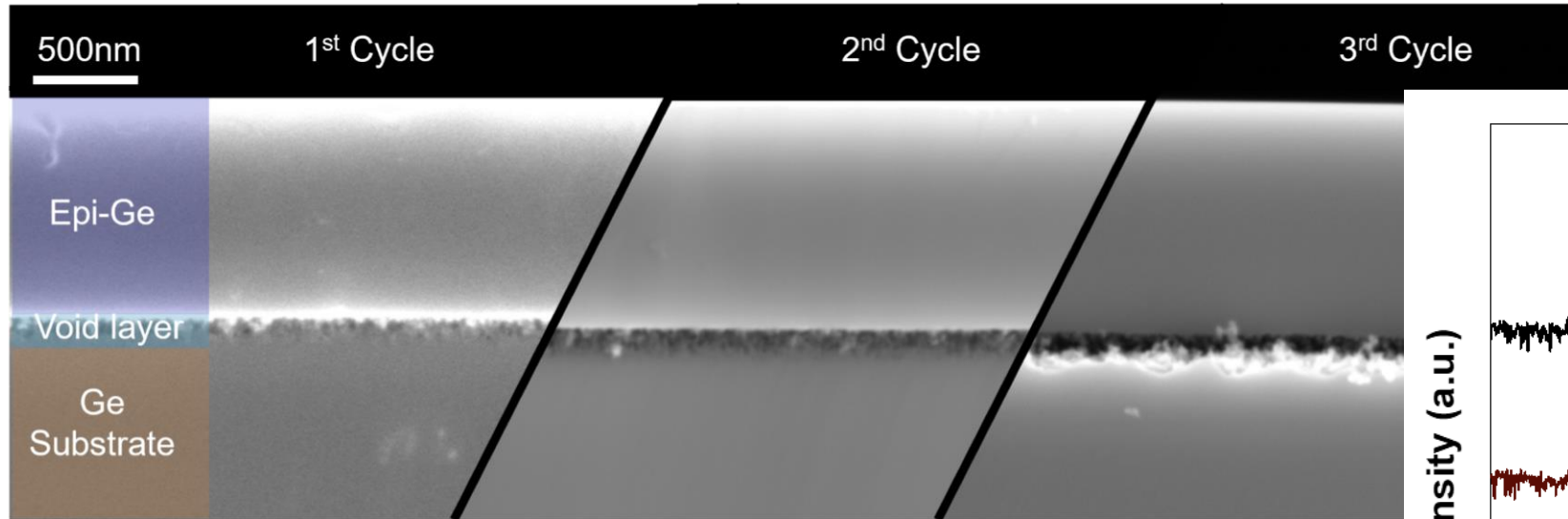
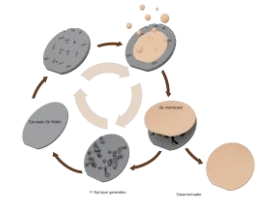


Wet chemical etching after detachment
smoothens the germanium surface

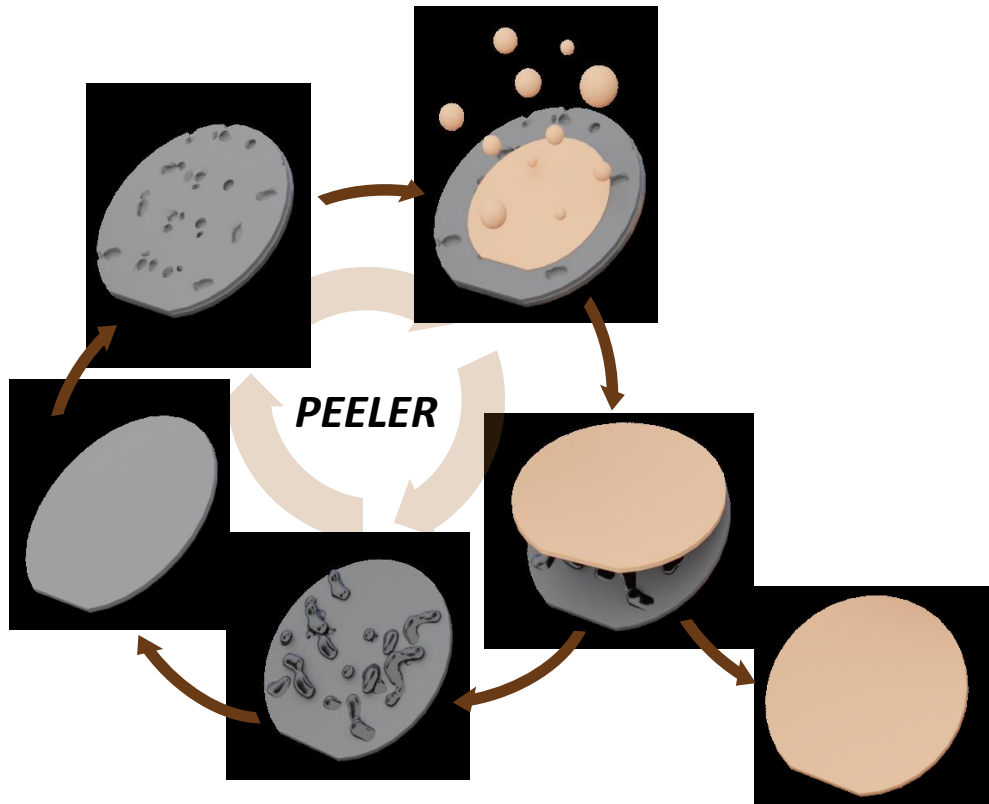
Multicycling



A. Chapotot et al., Sust Mat Technol 2024



Smooth surface and high crystalline quality of epi Ge after 3 cycles



- III-V-based multijunction cells can be thinned down without performance degradation
- Possibility to recycle the Ge wafer for multiple cells fabrication

“PEELER” approach

- ➔ Wafer-scale electrochemical porosification
- ➔ Compatible with commercial epitaxy
- ➔ State of the art solar cell performance
- ➔ Recycling using simple wet bench processes

Prospective and promises:

- Towards 80% reduction in kg/W
- Towards more sustainable germanium use
 - ➔ 75% Ge content reduction with 3 recycling cycles^a
 - ➔ >95% Ge content reduction with infinite recycling^b

^aA. Chapotot et al., *Sust Mat Technol* 2024

^bN. Paupy et al., *Nanoscale Adv.* 2023



Thank you for your attention

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