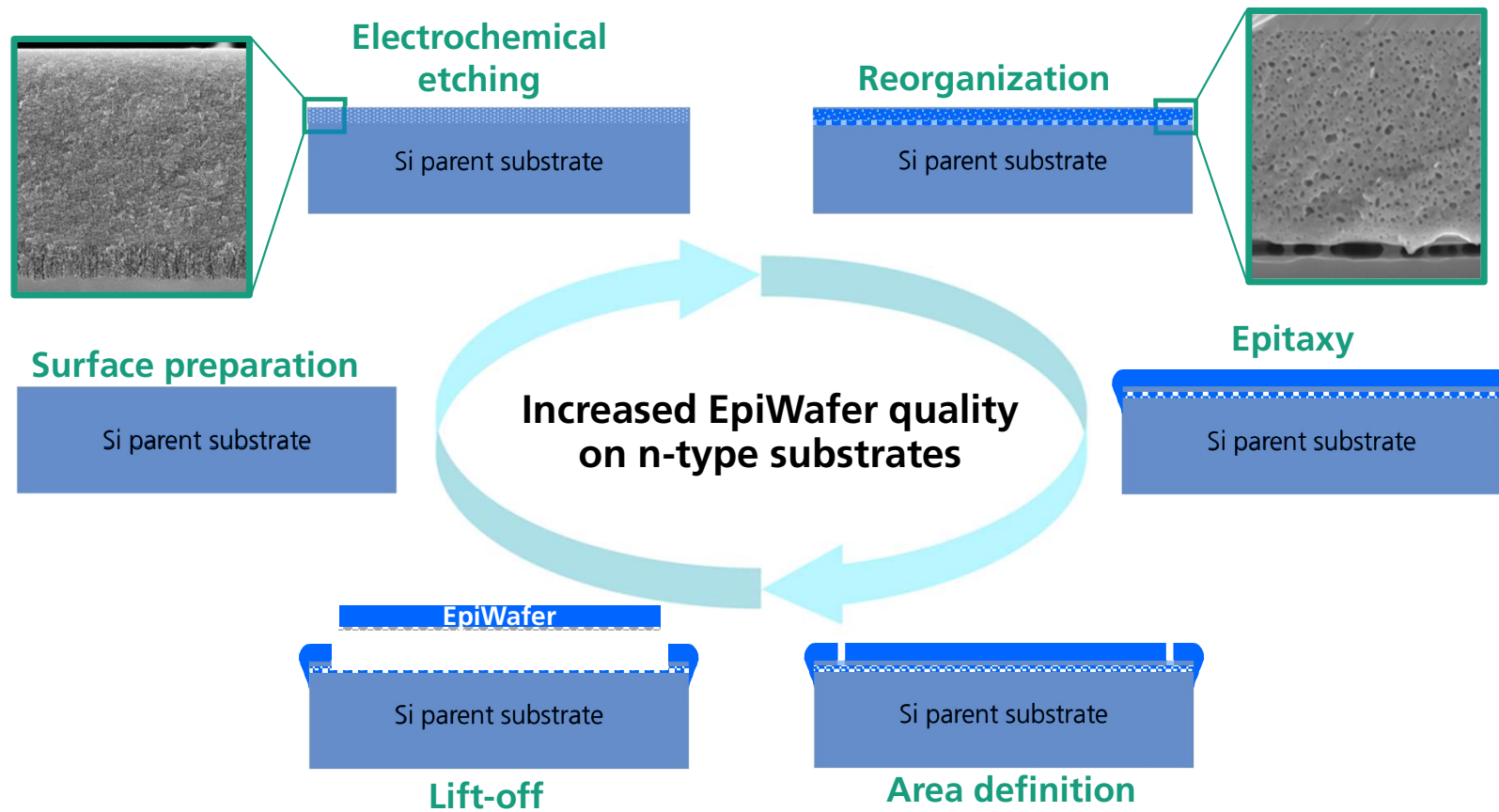


Transfer of Epitaxial Lift-Off Approach to n-type Silicon

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PSST, Brno, 29.04.2024
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Introduction

Epitaxial Lift-Off Approach (ELO)



Electrochemical Etching

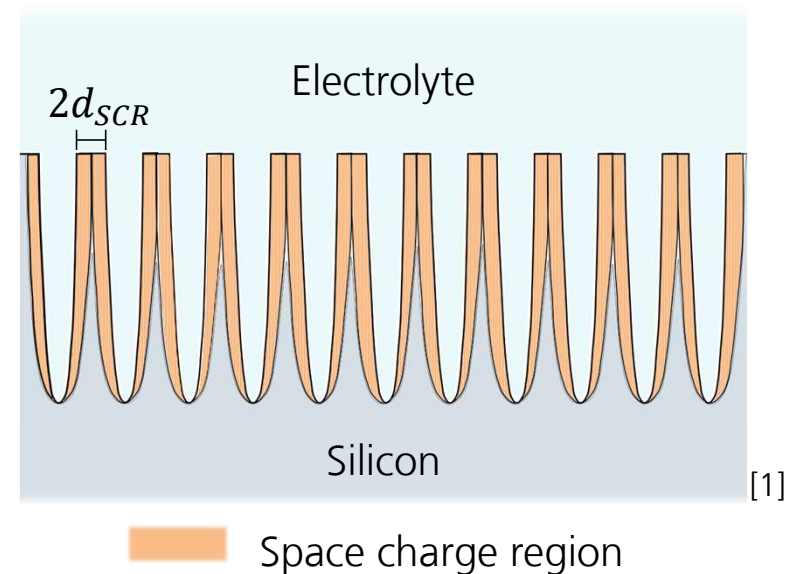
Highly-doped Si

- Morphology determined by space charge region
- Charge carrier tunnel through barrier at pore tip

$$d_{SCR} = \sqrt{\frac{2\epsilon_s\epsilon_0\phi_s}{qN_D}}$$

ϕ_s - barrier height

N_D - dopant concentration



Electrochemical Etching

Impact of Dopant Reduction

- Anodic regime ...

... p-Si under forward bias

→ $\phi_s \downarrow$

... n-Si under reverse bias

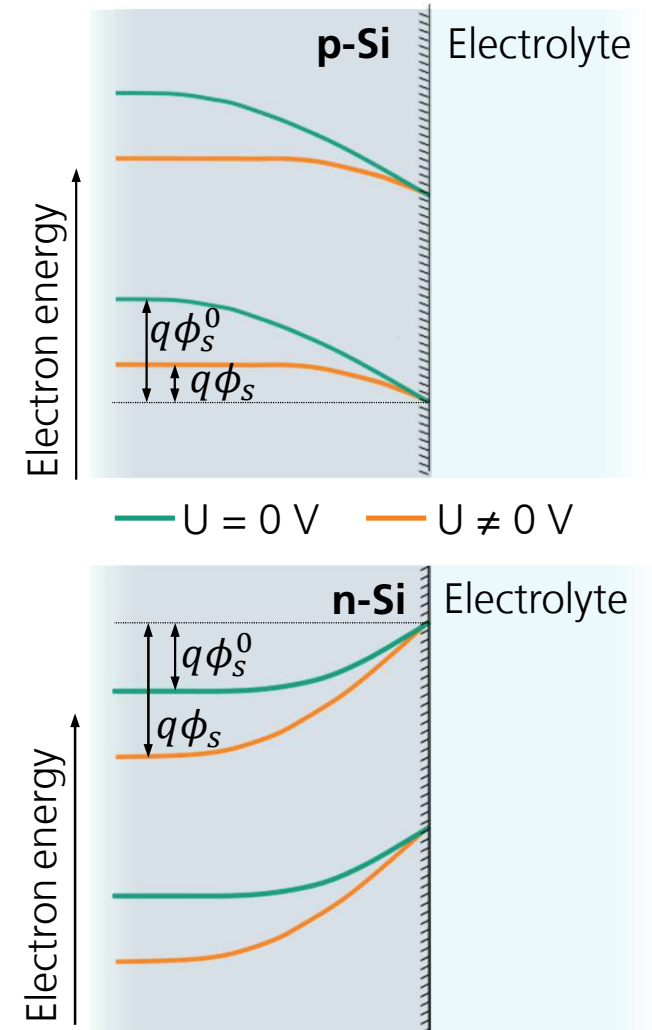
→ $\phi_s \uparrow$

$$d_{SCR} = \sqrt{\frac{2\epsilon_s\epsilon_0\phi_s}{qN_D}}$$

ϕ_s - barrier height

N_D - dopant concentration

- At similar N_D tunneling inhibition on n-Si but not on p-Si



First Experiments on n-Si

Etching under constant current

Etching conditions

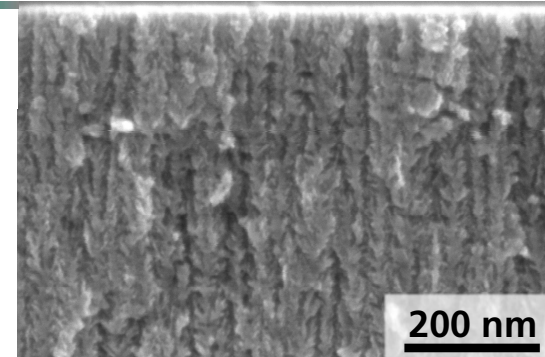
- Electrolyte: HF + H₂O + acetic acid
- Current density: 150 mA/cm²

Observations

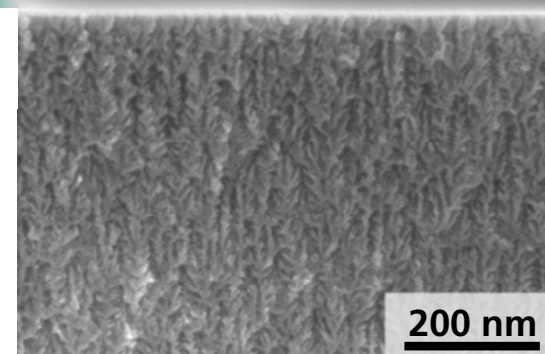
- 3 - 16 mΩcm: tunneling possible
- 35 mΩcm: tunneling inhibited

→ Compensation by illumination? $d_{SCR} = \sqrt{\frac{2\epsilon_s\epsilon_0\phi_s}{q(N_D+N_{photo})}}$

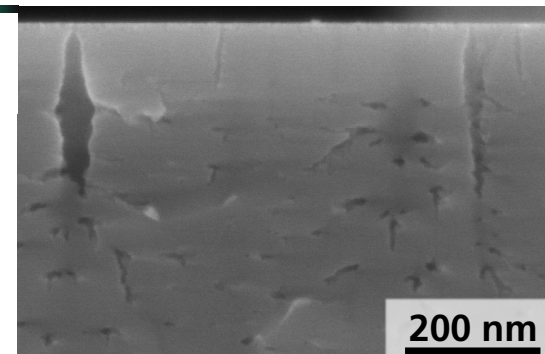
3 mΩcm
2.2 · 10¹⁹ cm⁻³



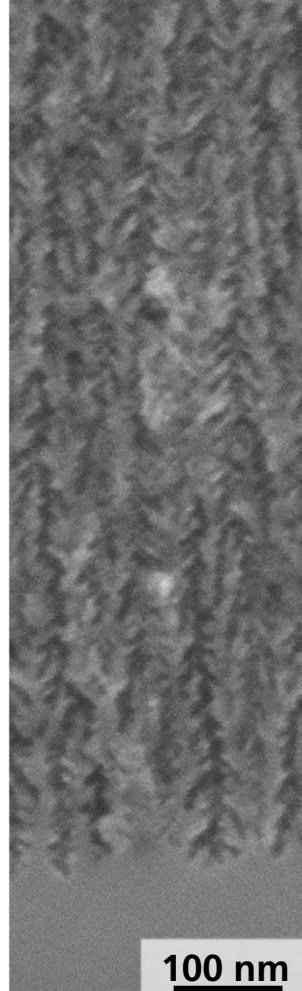
16 mΩcm
1.9 · 10¹⁸ cm⁻³



35 mΩcm
4.5 · 10¹⁷ cm⁻³

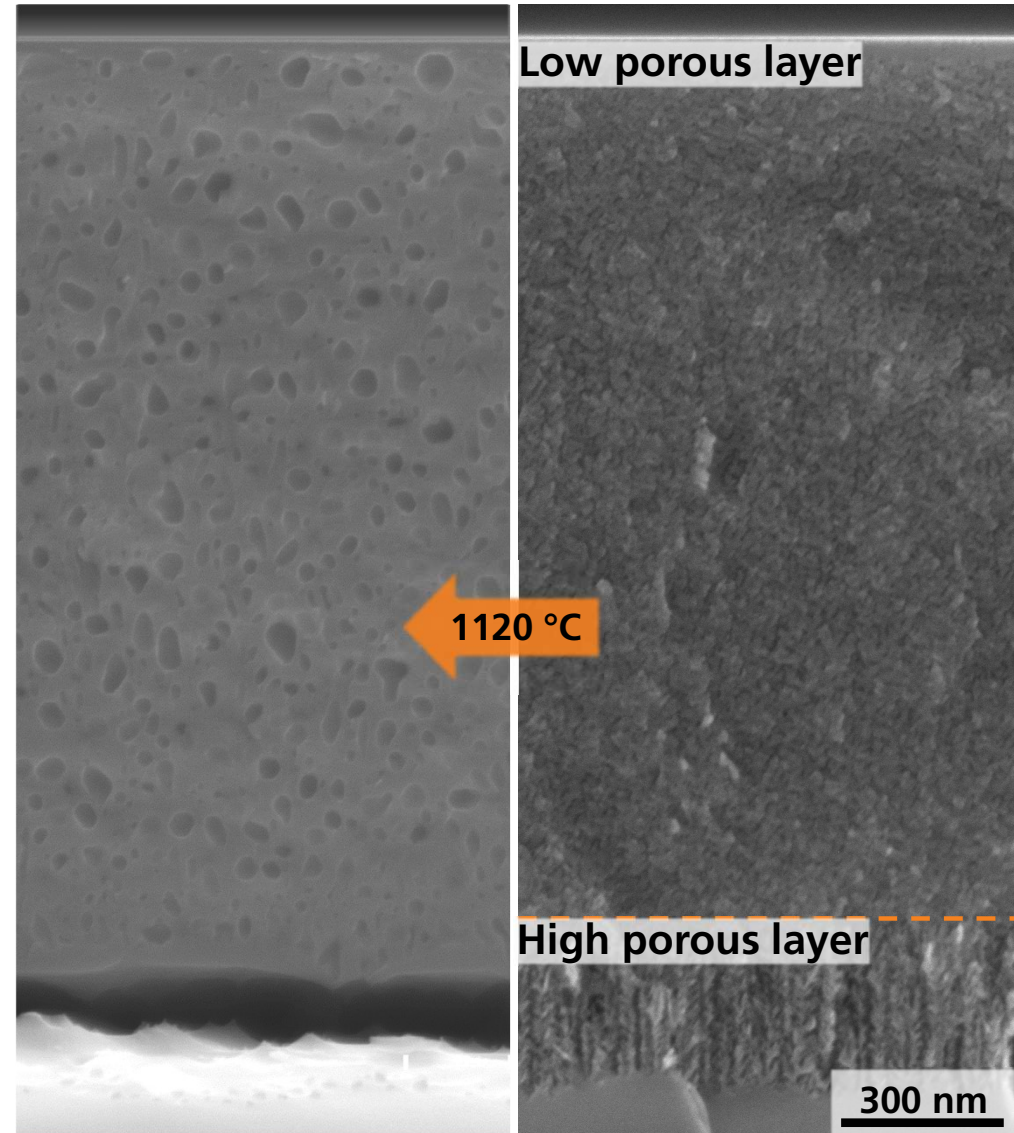


p-Si, 10 mΩcm,
3.1 · 10¹⁸ cm⁻³



First Experiments on n-Si Multilayers for ELO Approach

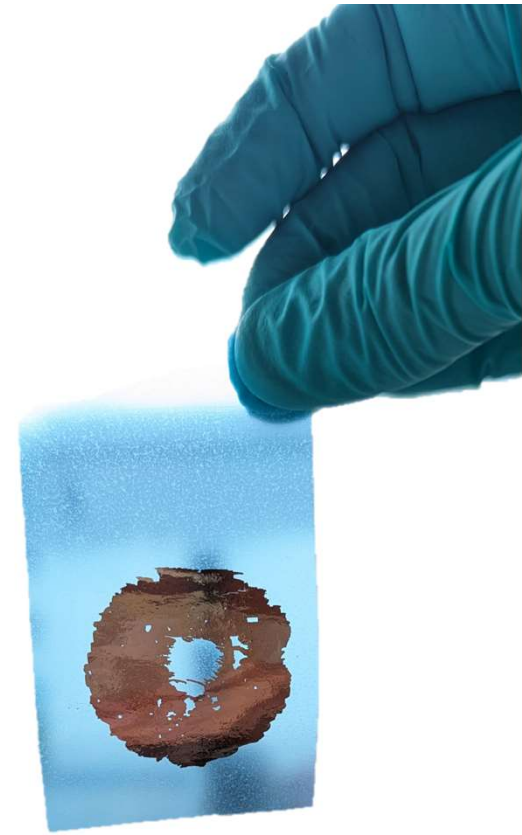
- Basic layer stack for Epitaxial Lift-Off
 - (1) Low porous layer
 - (2) High porous layer



First Experiments on n-Si

Multilayers for ELO Approach

- Basic layer stack for Epitaxial Lift-Off
 - (1) Low porous layer
 - (2) High porous layer
 - First liftable stack on n-Si ($16 \text{ m}\Omega\text{cm}$, $1.75 \cdot 10^{18} \text{ cm}^{-3}$)
 - 50 - 80% less dopant concentration than on p-Si
- Start operation of illumination system



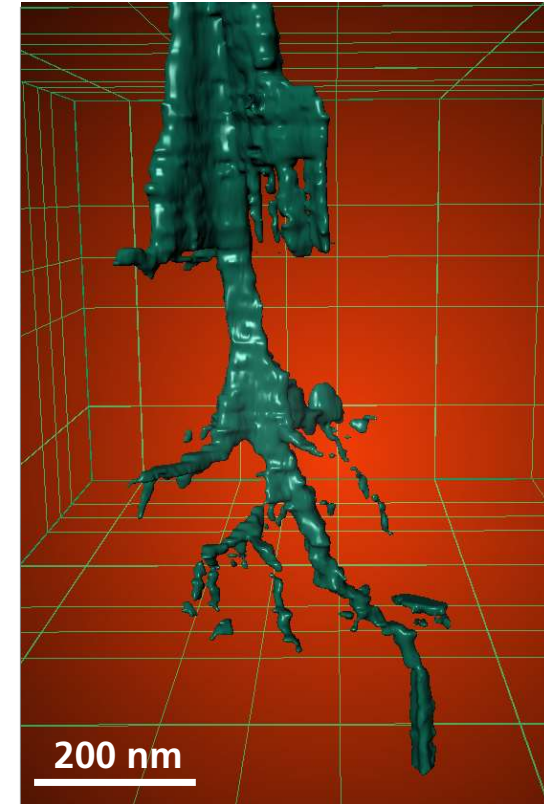
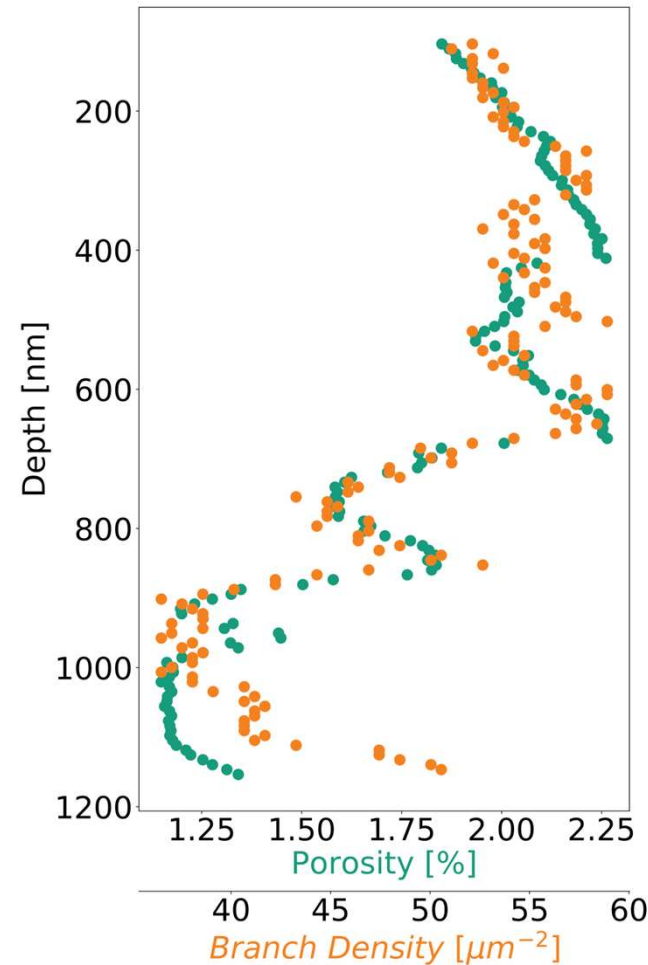
Characterisation

Detailed Analysis

Focused Ion Beam Milling (FIBM)

- Erosion of porous layer in 7 nm thick slices
- Analysis of SEM images
 - Pore reconstruction
 - Porosity profiles

→ Introduction of Deep Learning

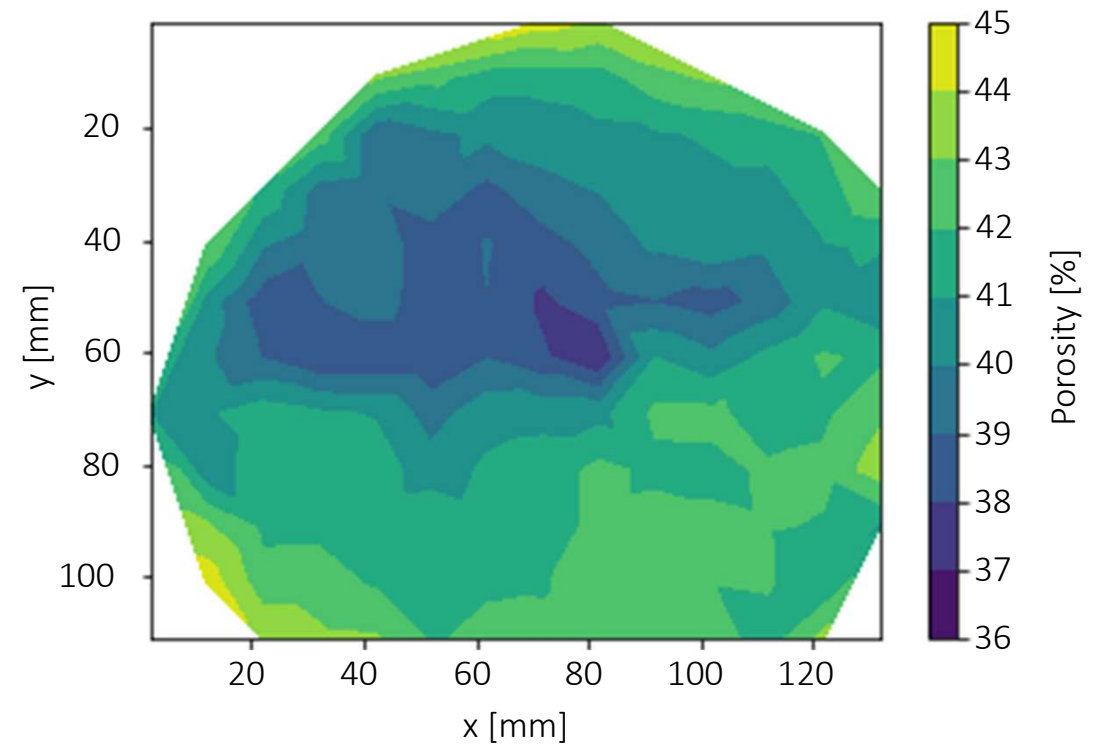


Characterisation

Large Area Analysis

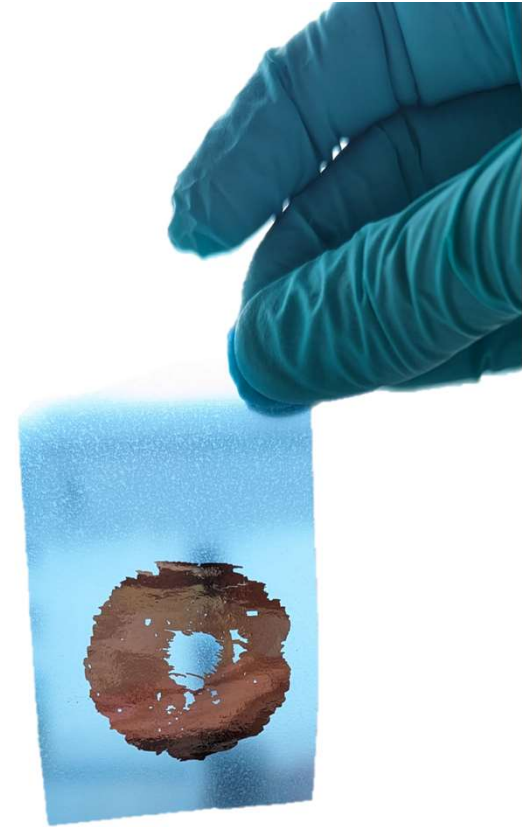
Fitting of Reflexion Spectra [1]

- Calculation of porosity & layer thickness
 - Mappings up to M10 wafers available
 - Check adjustment of electric field & illumination
- Tool to enable full area lift-off



Summary

- Successful transfer of detachable layer stack from p- to n-Si
 - Observation of morphology transition due to broadening of space charge region
 - Characterisation available for analysis of homogeneity & pore morphology
- Refine understanding of etching under illumination
- Transfer process to 6" round and 166 x 166 mm² wafers



Thank You for Your Attention!

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