COMSOL CONFERENCE 2015 GRENOBLE

HOCHSCHULE FURTWANGEN UNIVERSITY HFU

Primary Current Distribution Model for Electrochemical Etching of Silicon Through a Circular Opening

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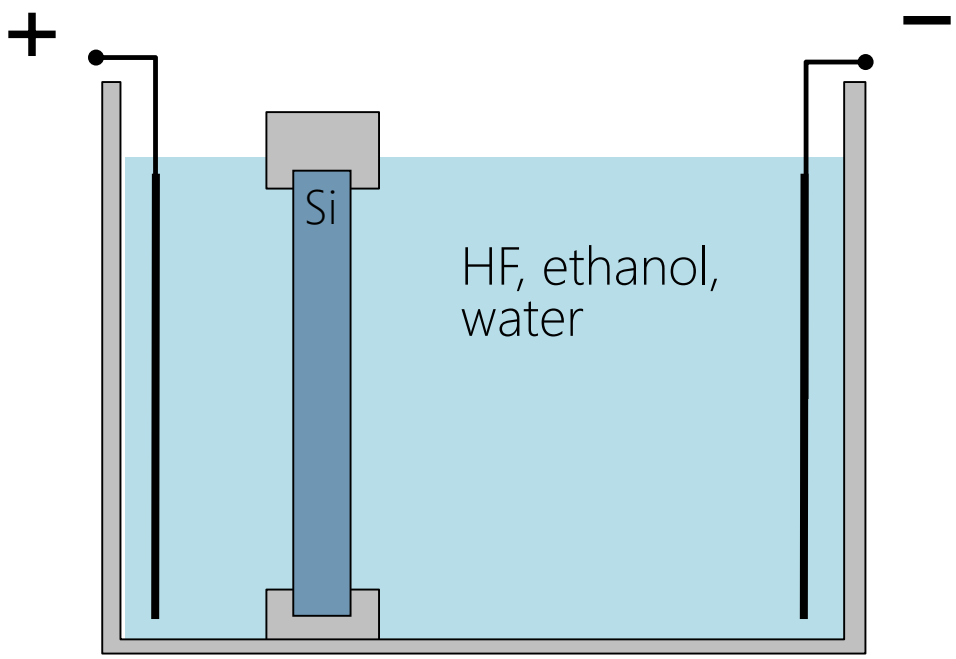
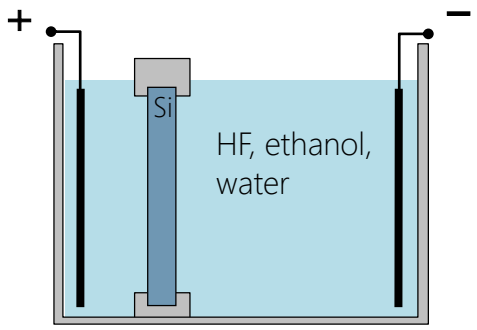
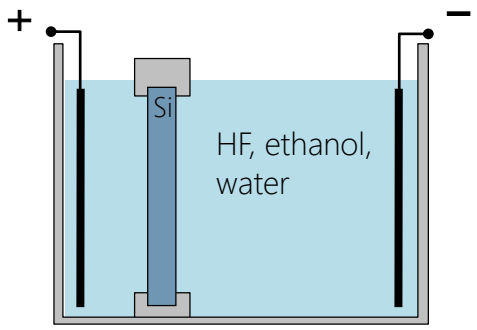

+
−
Si
HF, ethanol,
water



Low current density – divalent process

$$Si + 4HF_2^- + h^+ \rightarrow SiF_6^{2-} + 2HF + H_2 + e^-$$

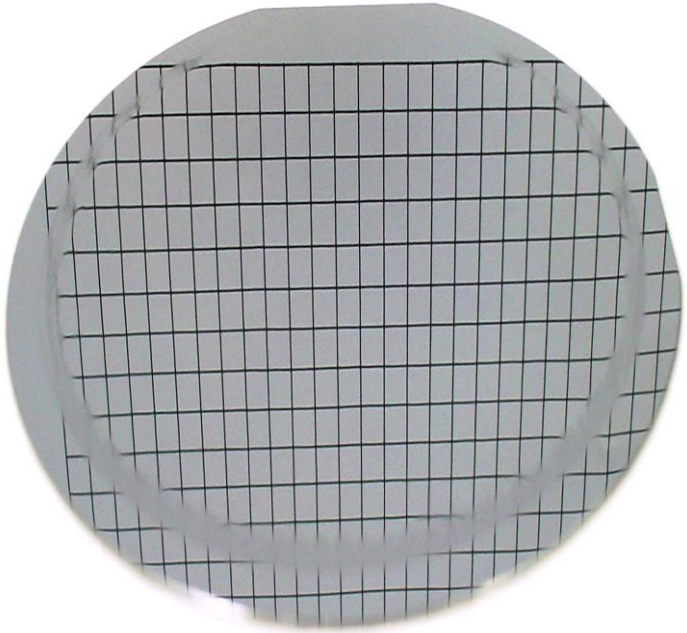
pore formation (porous silicon)



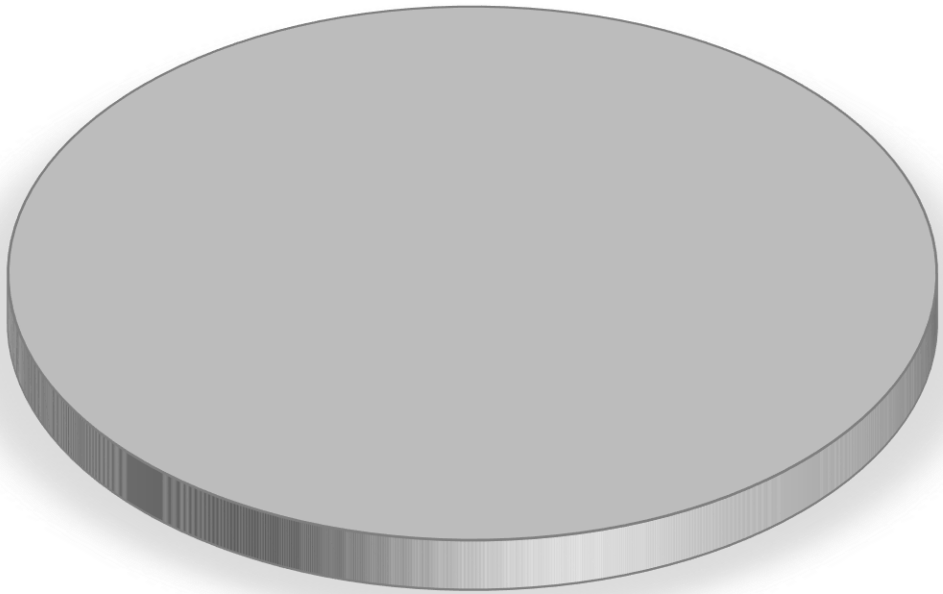
High current density – tetravalent process

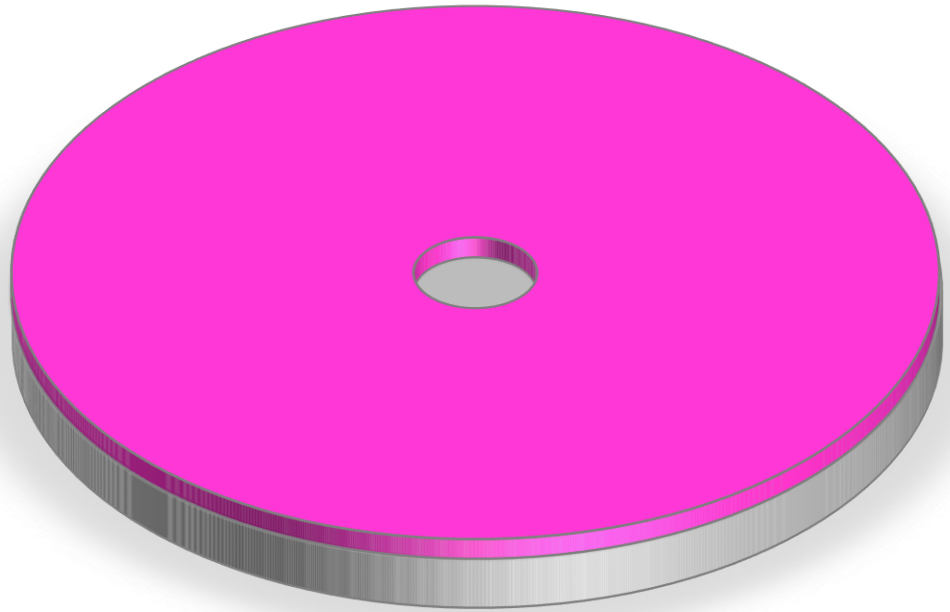
Step 1: $\mathbf{Si + 2H_2O + 4h^+ \rightarrow SiO_2 + 4H^+}$

Step 2: $\mathbf{SiO_2 + 2HF_2^- + 2HF \rightarrow SiF_6^{2-} + 2H_2O}$



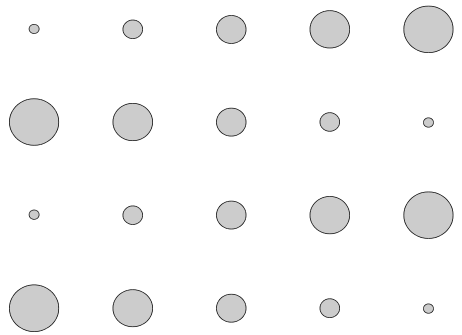
electropolishing (mirror like surface)





Experiment:

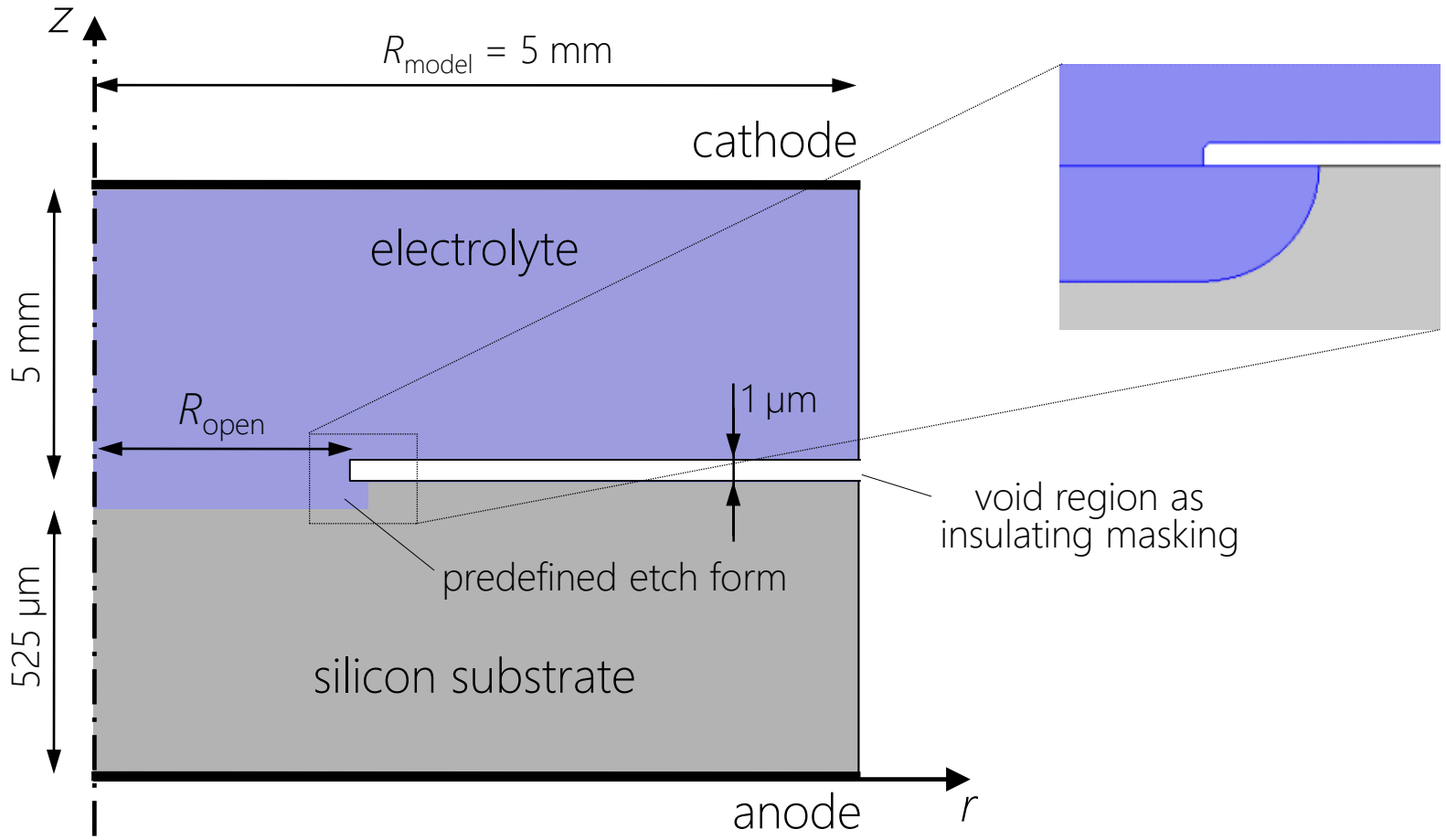
- Frontside mask layout:



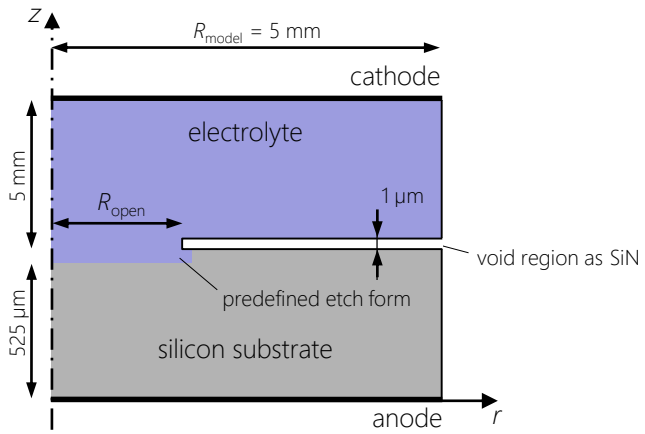
D_{open} 200–1000 µm

- Silicon substrates 10–20 Ohm cm, p-type
- Electrolyte 29.93 m% HF with ethanol
- Initial current density 1–3.5 A/cm^2
- Etch time [1, 5, 10, 20] min
- Porous silicon removed in 1 m% KOH

Model:


z
R_{model} = 5 mm
cathode
electrolyte
5 mm
R_{open}
1 µm
void region as
insulating masking
predefined etch form
525 µm
silicon substrate
anode
r

Model:



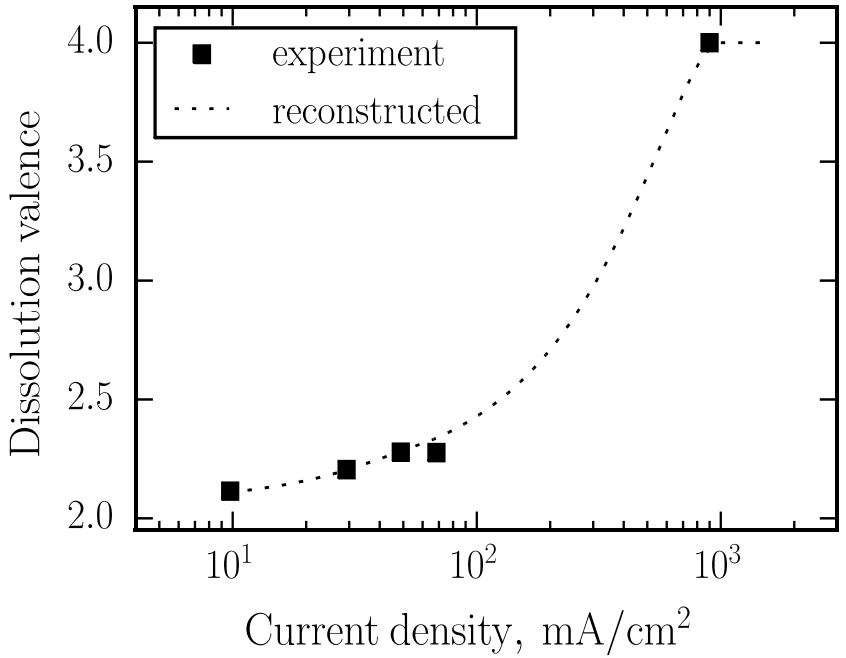
- 2D geometry with axial symmetry
- Electrodeposition physics interface (*edsec*)
- Diameter of the opening 200–1000 µm
- Initial current density 1–3.5 A/cm^2
- Conductivity of electrolyte 34.11 S/m (29.93 m% HF)
- Conductivity of silicon 7.5 S/m

Model:

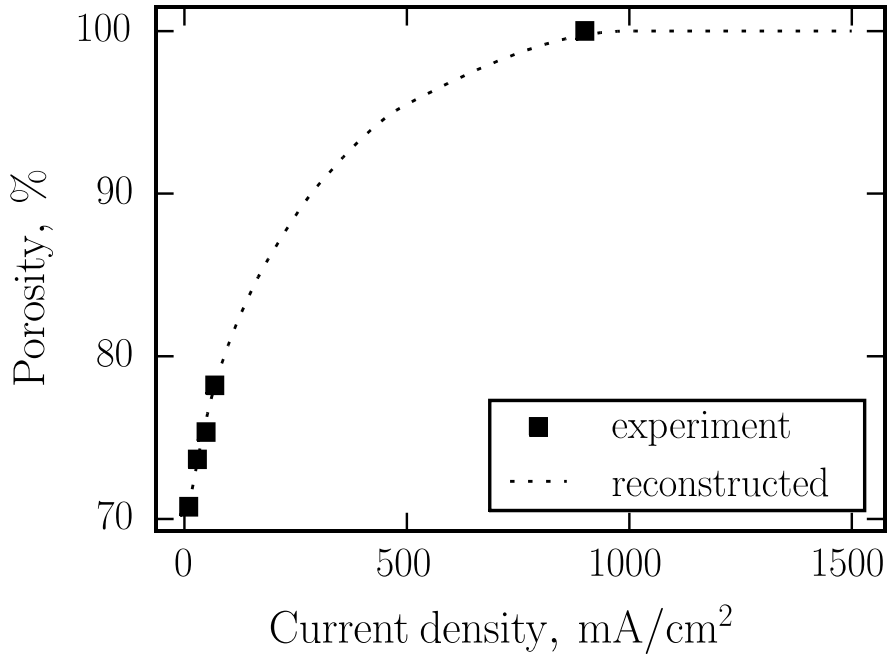
Etch front movement (Faraday's law):

$$R_{\text{etch}} = \frac{j}{n_{\text{e}} e} \cdot \frac{\nu M_{\text{Si}}}{\rho_{\text{Si}} N_{\text{A}}}$$

n_{e}

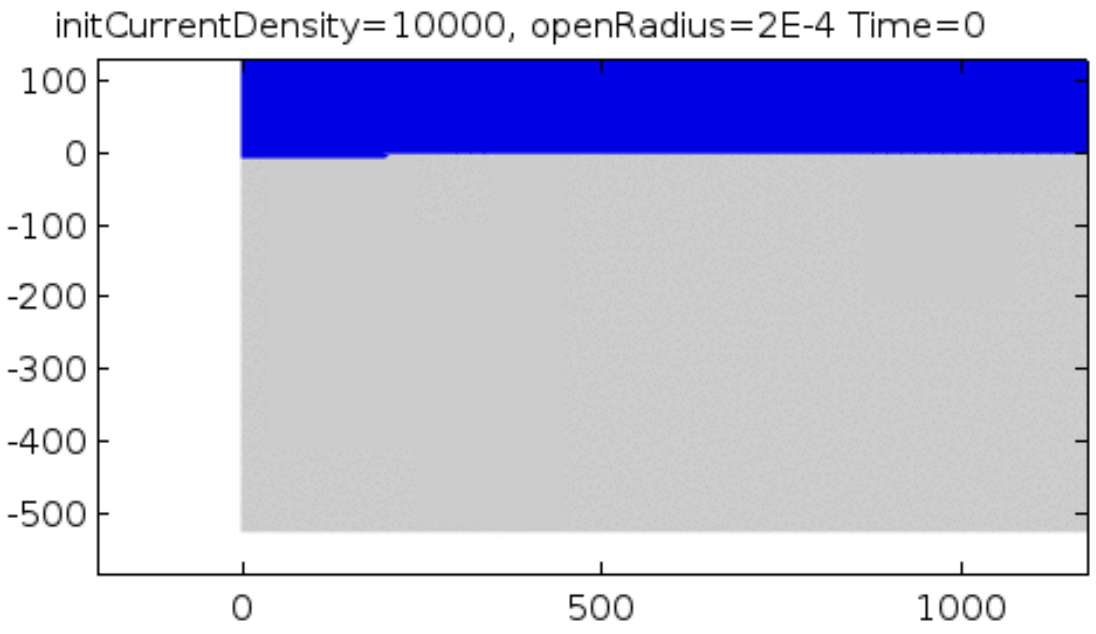


$\frac{1}{\nu}$

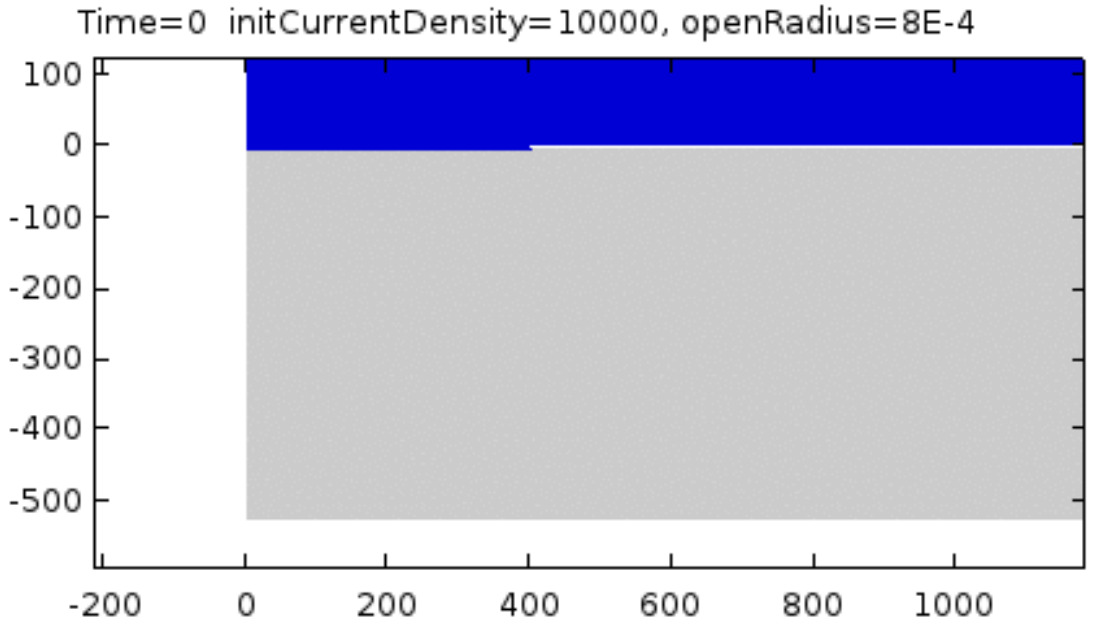


Simulation:

1 A/cm^2, D_{open} = 400 µm

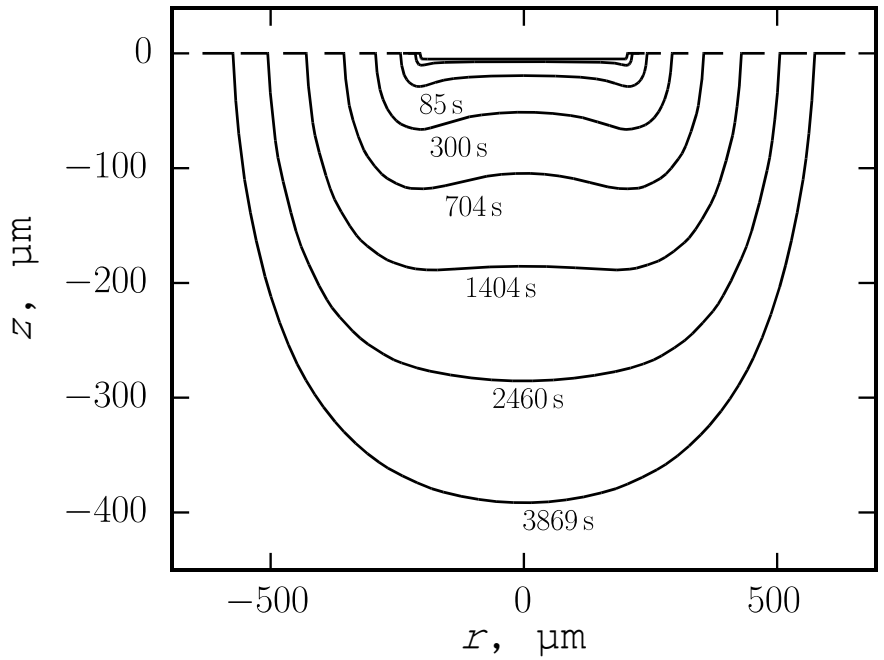


1 A/cm^2, D_{open} = 800 µm

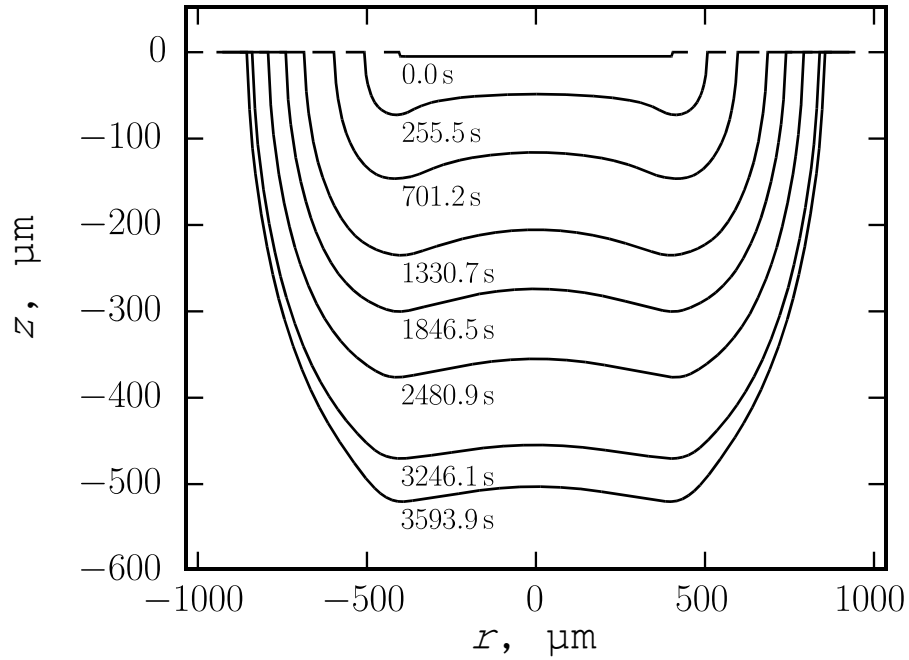


Simulation:

1 A/cm^2, D_{open} = 400 µm

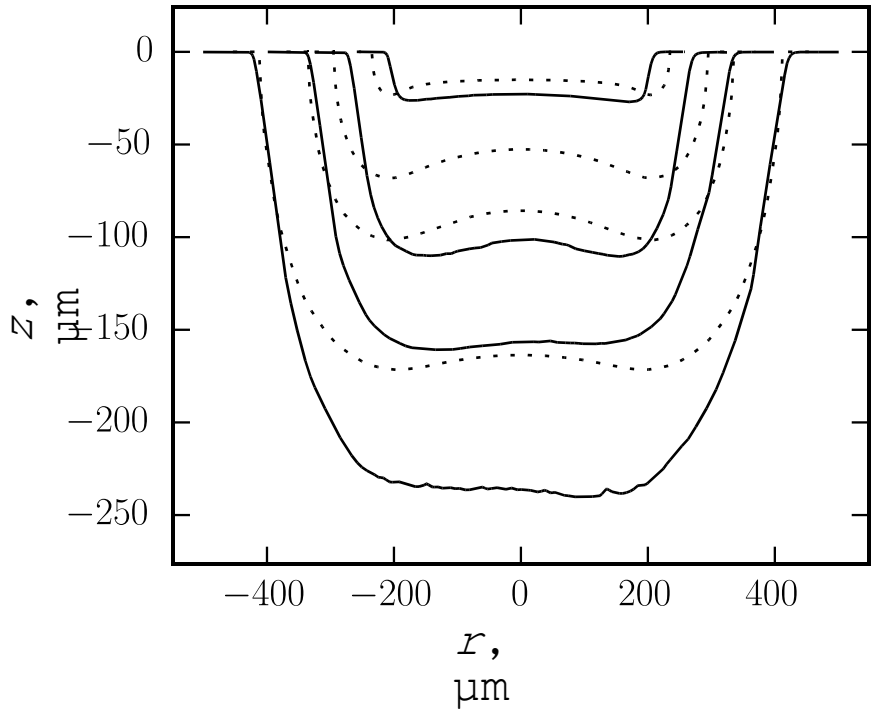


1 A/cm^2, D_{open} = 800 µm

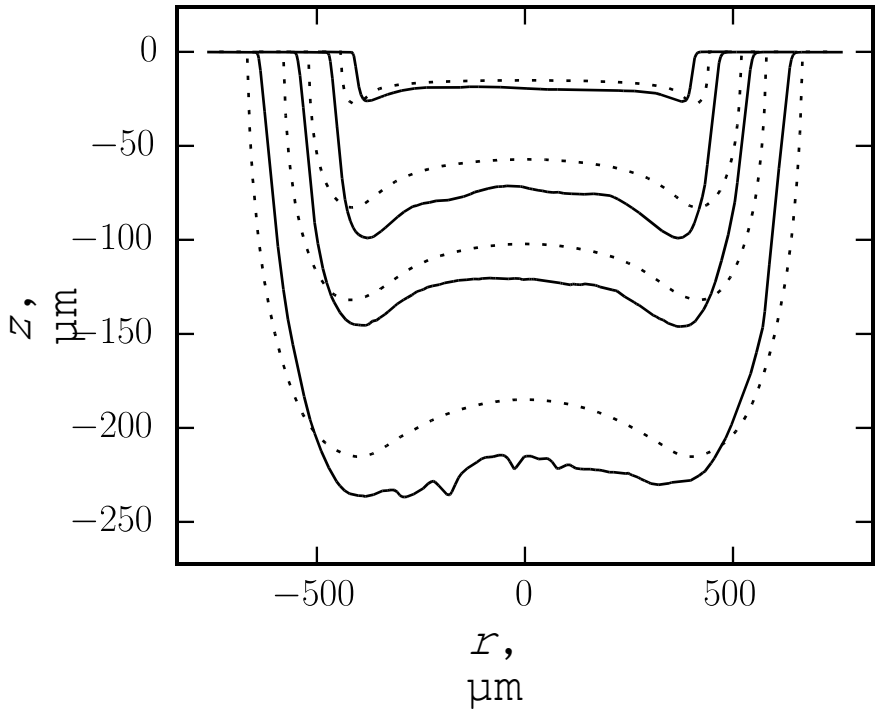


Simulation vs. experiment:

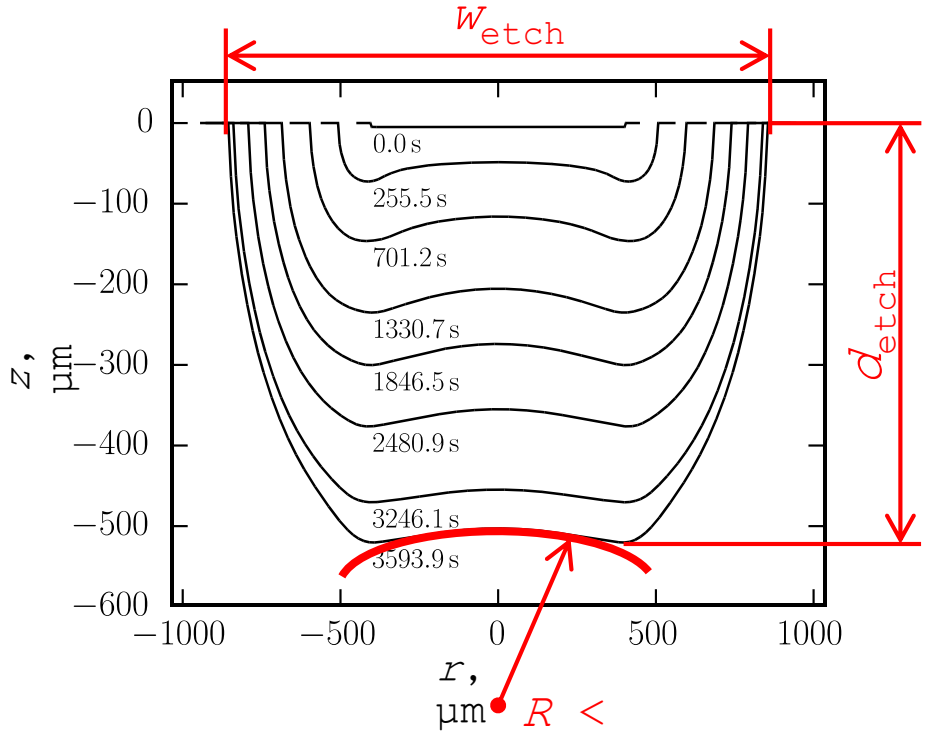
1 A/cm^2, D_{open} = 400 µm

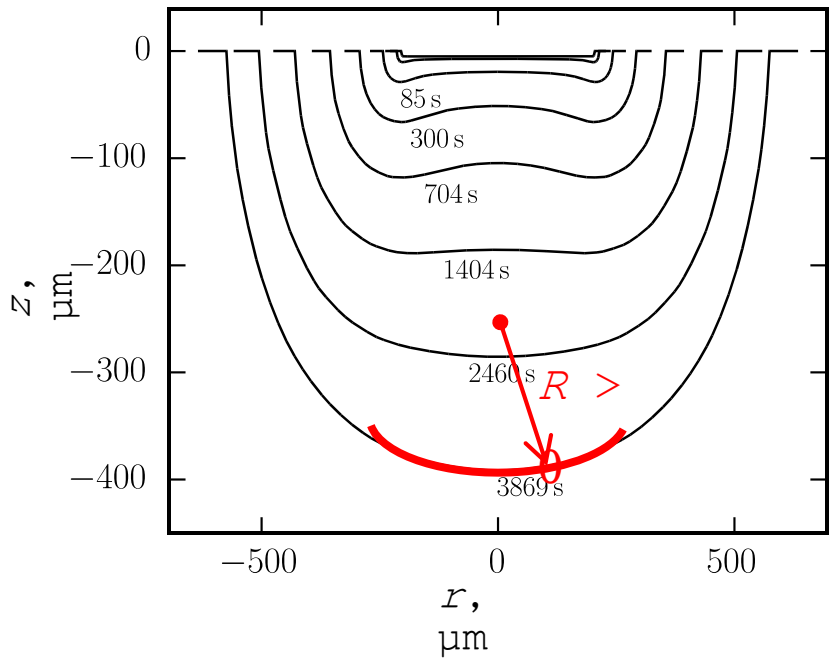


1 A/cm^2, D_{open} = 800 µm



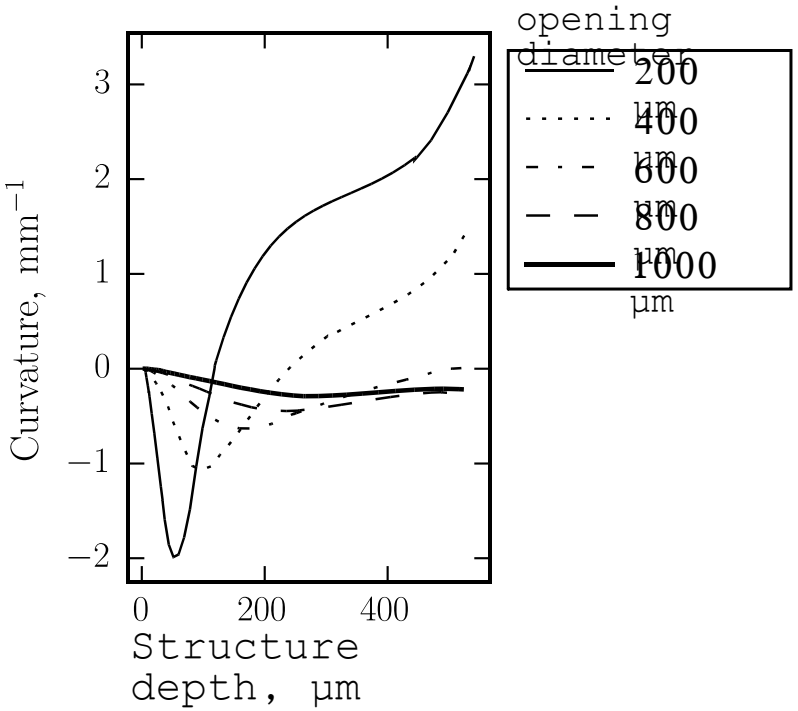
Shape characterization:



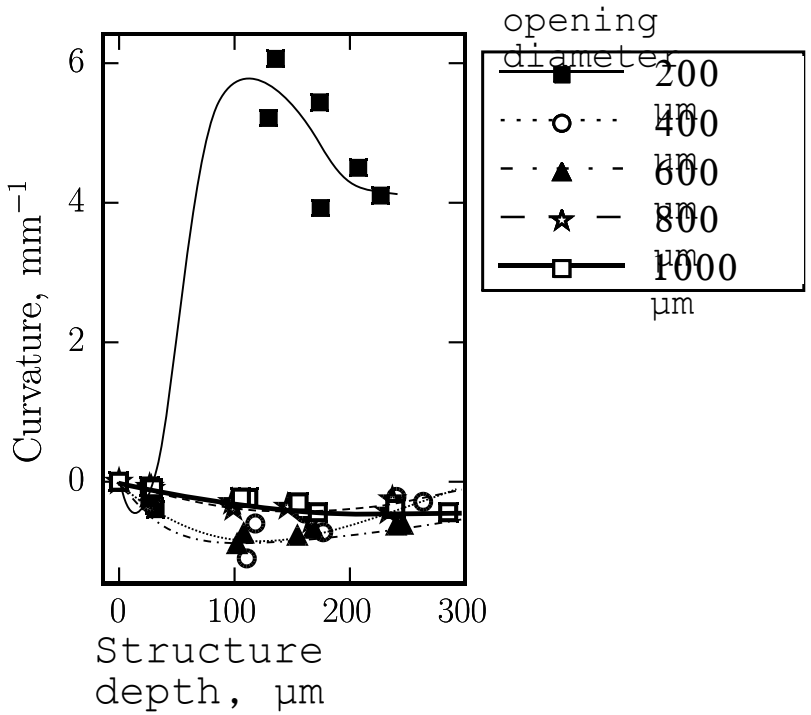


- Curvature at the bottom $\kappa = \frac{1}{R}$
- Anisotropy factor $A_f = 1 - \frac{0.5 w_{etch} - R_{open}}{d_{etch}}$

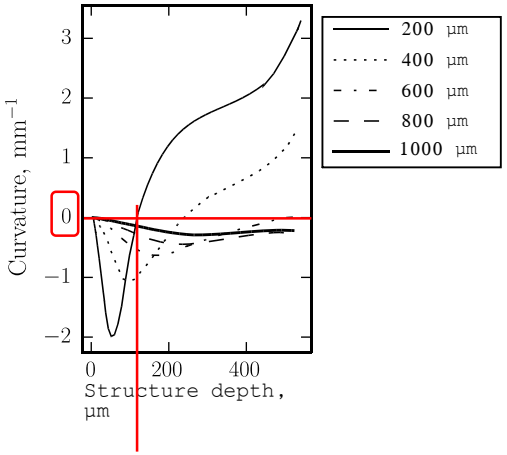
simulation



experiment

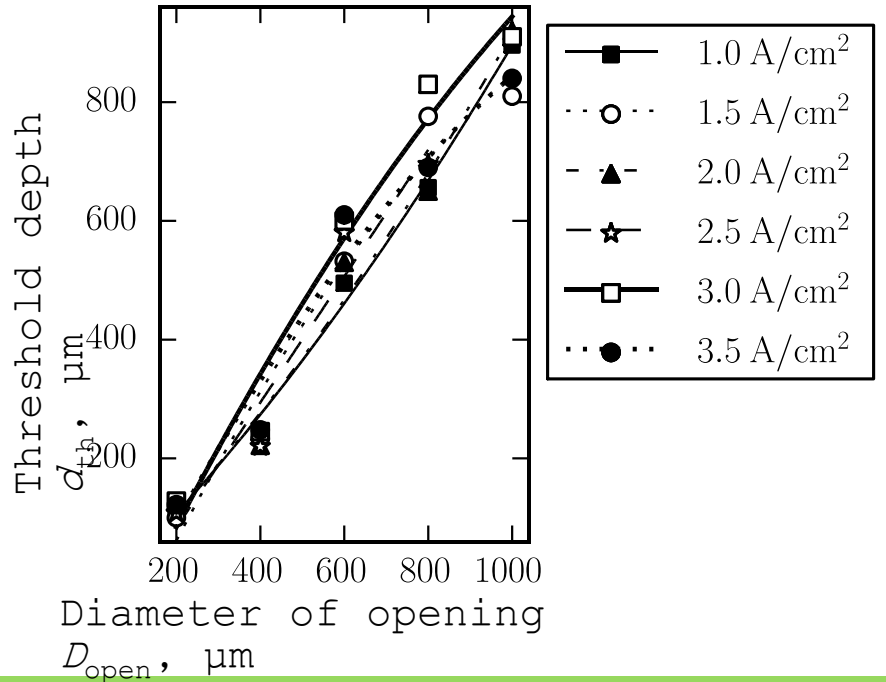


Initial current density 1 A/cm^2

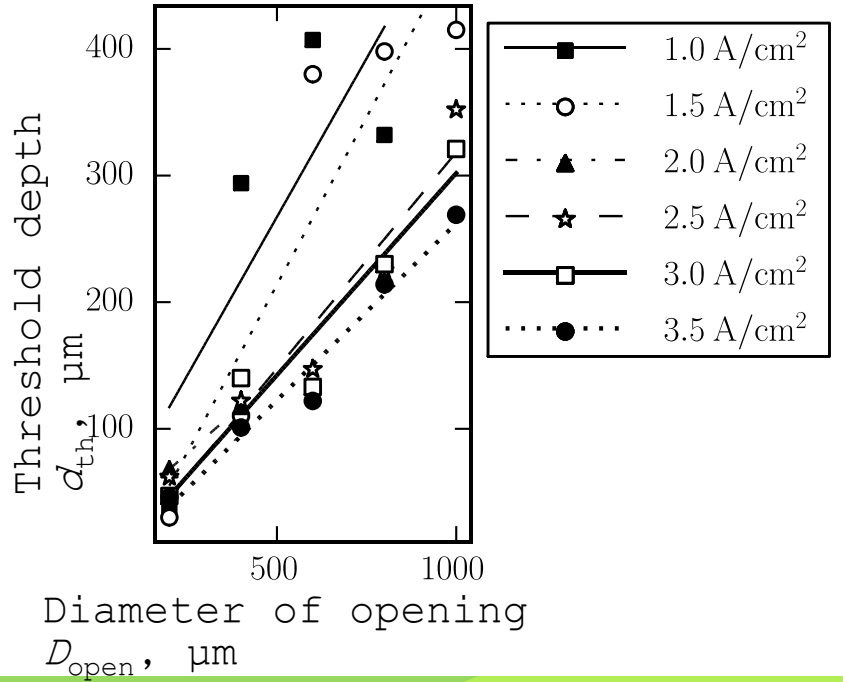


threshold depth d_{th}

simulation

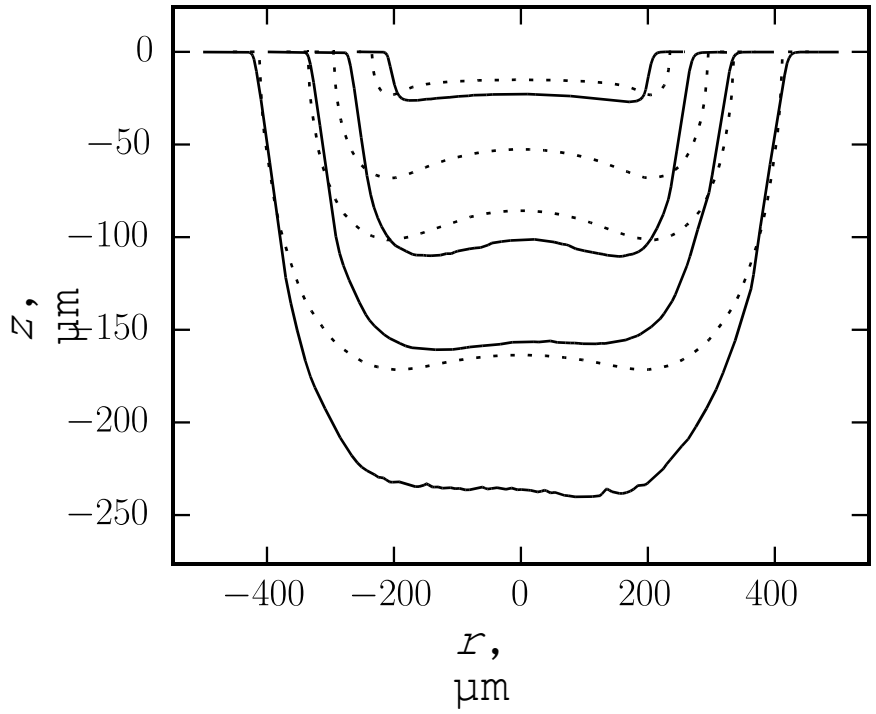


experiment

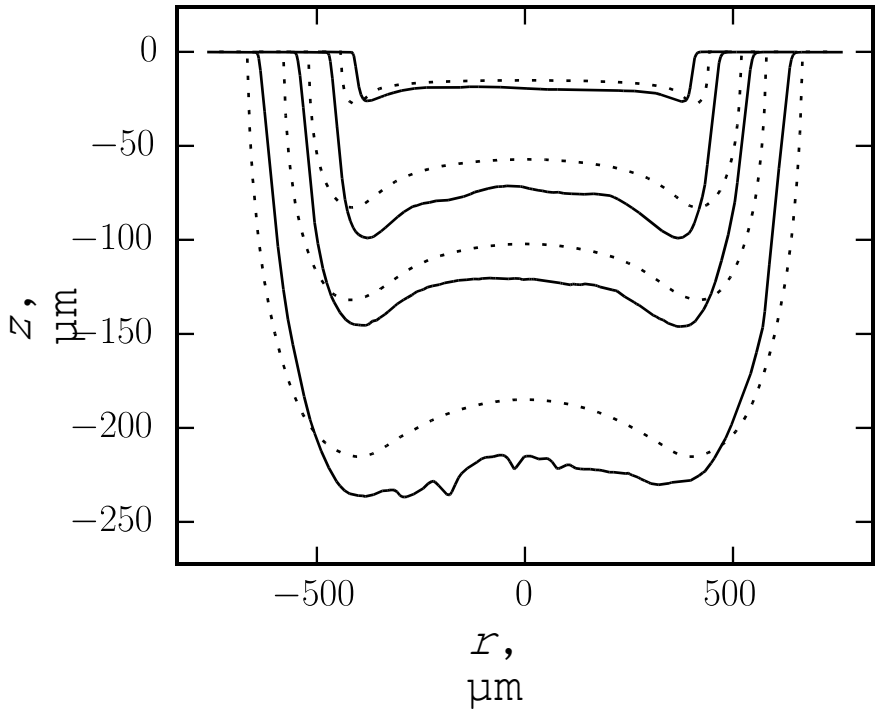


Anisotropy factor:

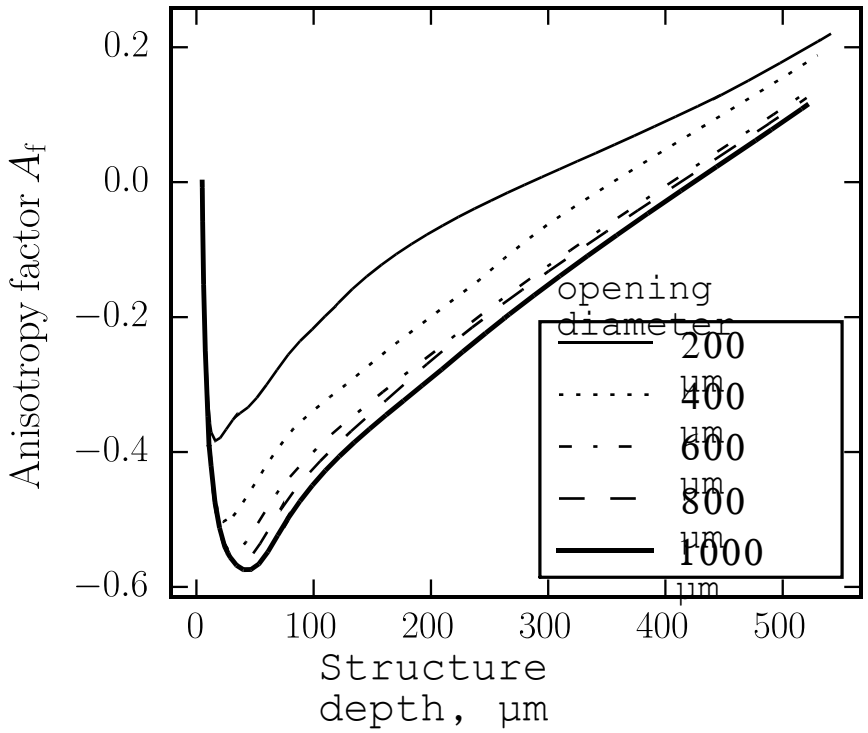
1 A/cm^2, D_{open} = 400 µm



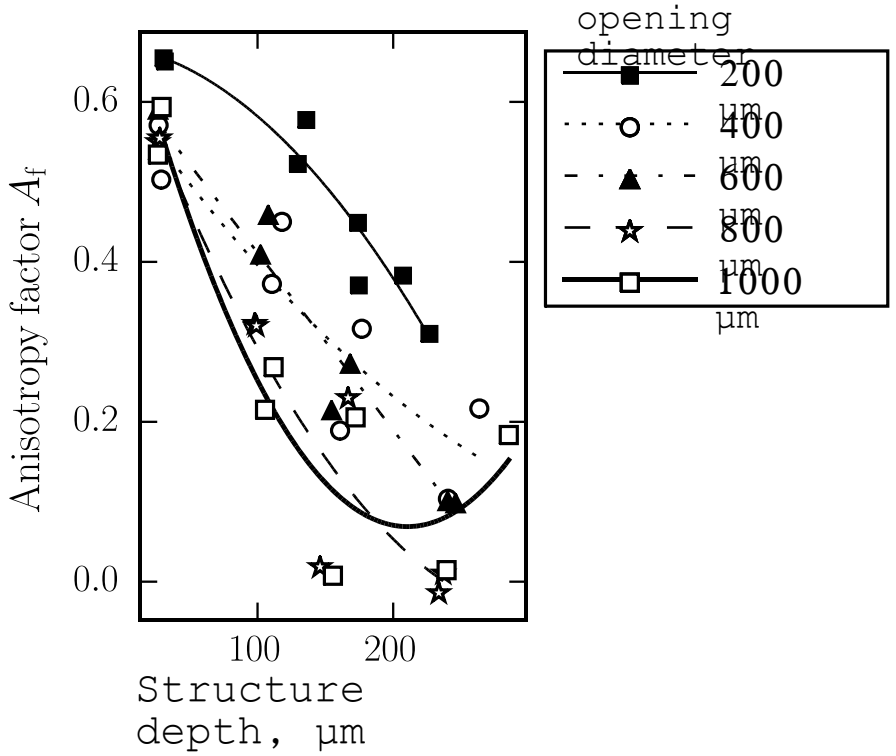
1 A/cm^2, D_{open} = 800 µm



simulation



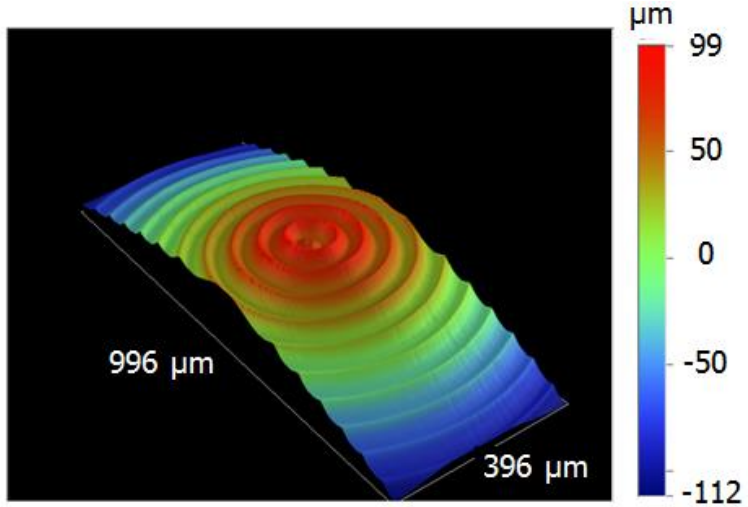
experiment

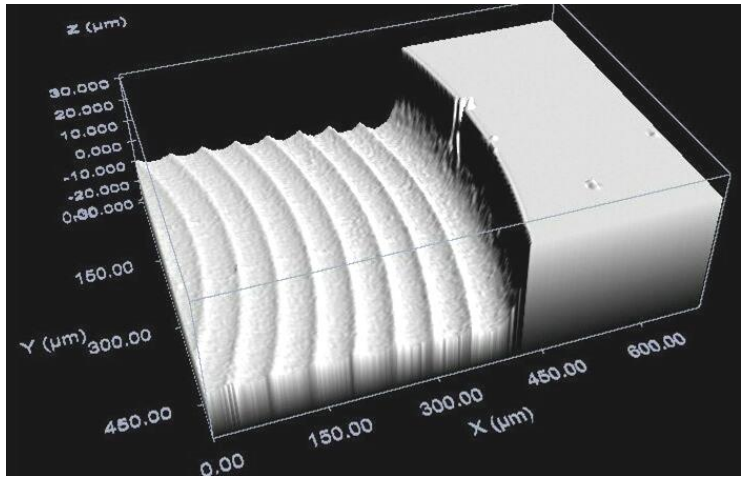


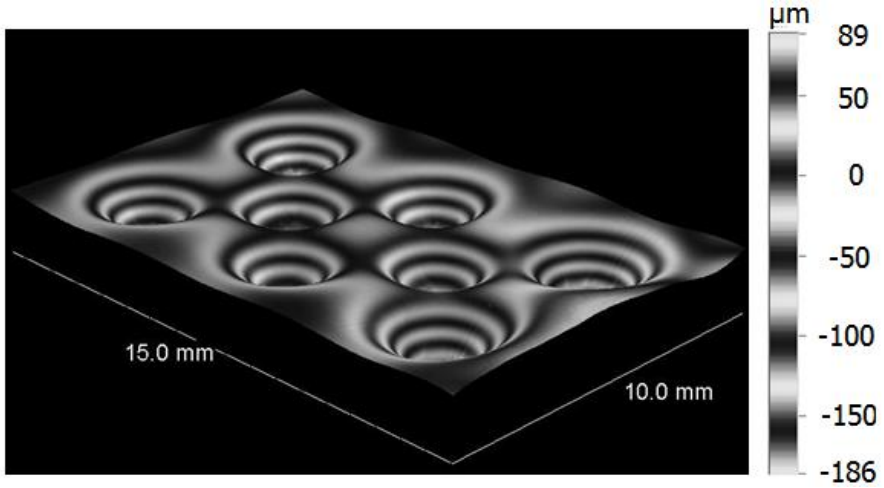
Initial current density 1 A/cm^2

Conclusions

- Primary current distribution model for anodization of silicon through an opening was developed
- The model describes both pore formation and electropolishing regimes
- Similar etch form development convex – concave observed in the model and experiment
- Threshold depth dependence strongly on the opening size both in simulation and experiment
- The current density dependence of threshold depth was not observed in the model
    - Lack of concentration polarization in the model?
- High positive anisotropy in the experiment and negative anisotropy in the model could not be explained with lack of activation and concentration polarization
    - Another anisotropic mechanism in the process?







Acknowledgement:

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Thank you for your attention!