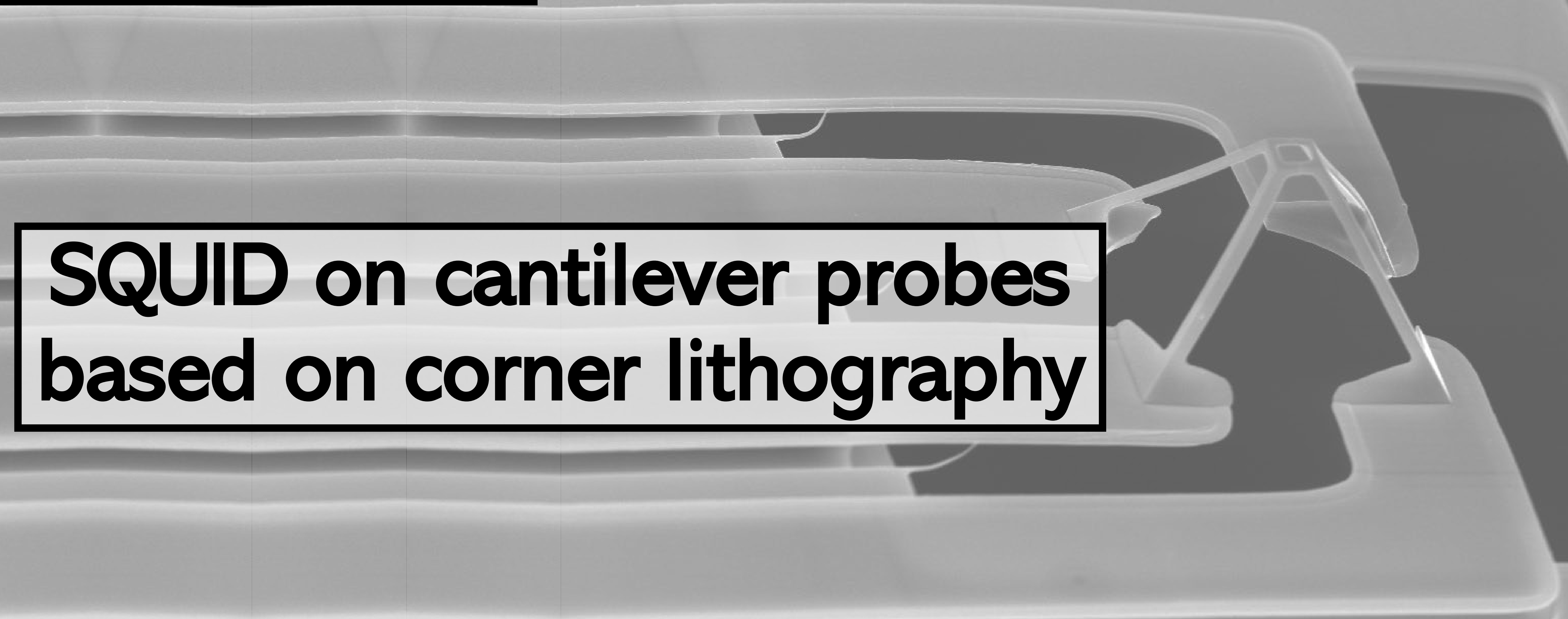
Thijs Roskamp
2024 QuMat year meeting Enschede
11/11/2024

SQUID on cantilever probes based on corner lithography



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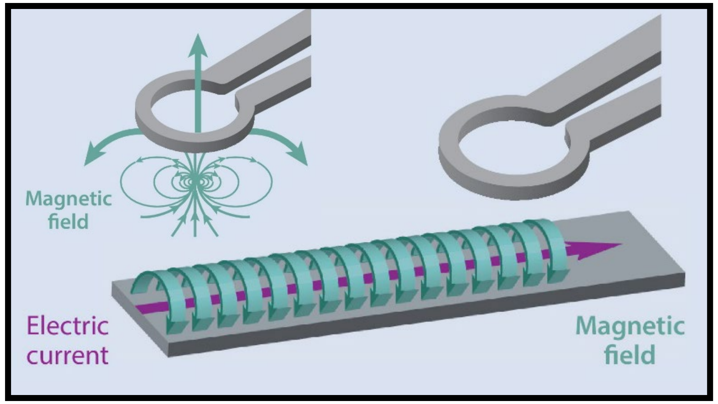
Scanning SQUID microscopy

Scanning SQUID microscopy (SSM) spatially resolves magnetic flux from a surface

Persky *et al. Annu. Rev. of Condens. Matter Phys.* **13**: 385-405 (2022)



- SSM provides high-field sensitivity and noninvasiveness

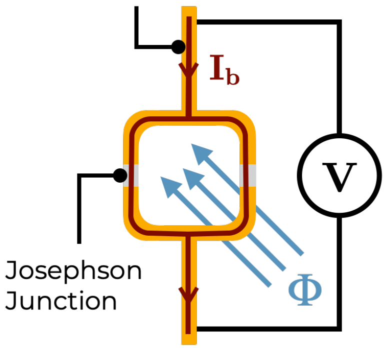
SQUID:

Superconducting

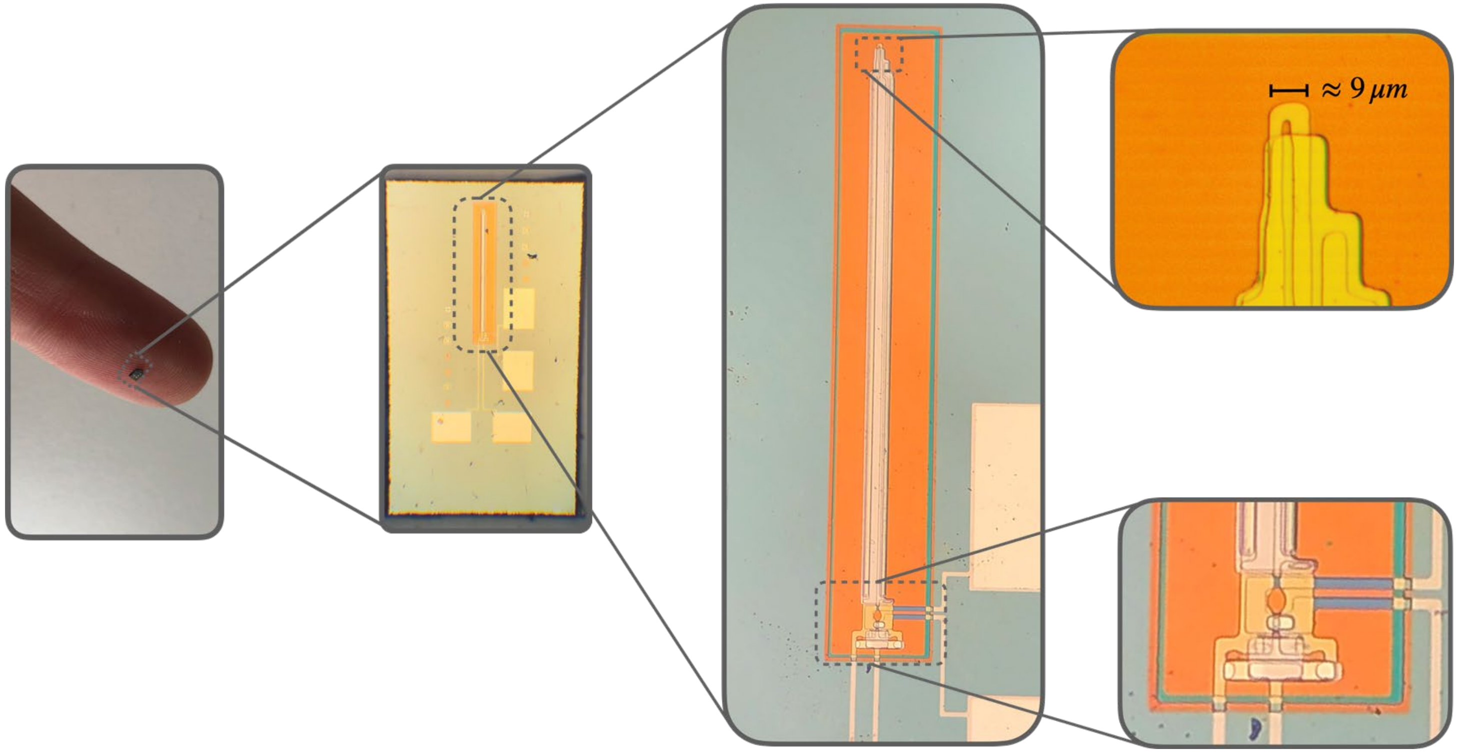
QUantum Interference

Device

- Magnetic flux threading the SQUID loop is related to the voltage measured across it.



Conventional scanning SQUID



- SQUID chip with pickup loop → ~1-5 μm
- Waferscale fabrication and highly reproducible
- Freedom to tune the SQUID washer and integration of field- and modulation coils

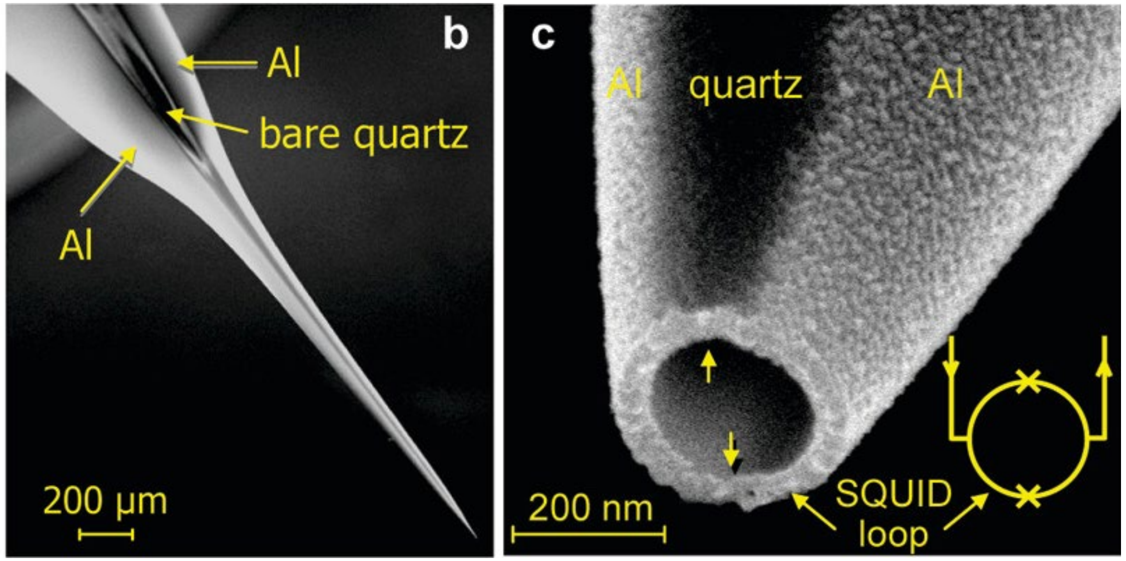
Limited by planar structure in sample surface-pickup loop height

SQUID at the apex of a tip

Scanning SQUID 2.0: **Move the SQUID from the substrate plane to a tip**

2010: SQUID-on-tip (SOT)

(Zeldov group, Weizmann Institute of Science, Israel)



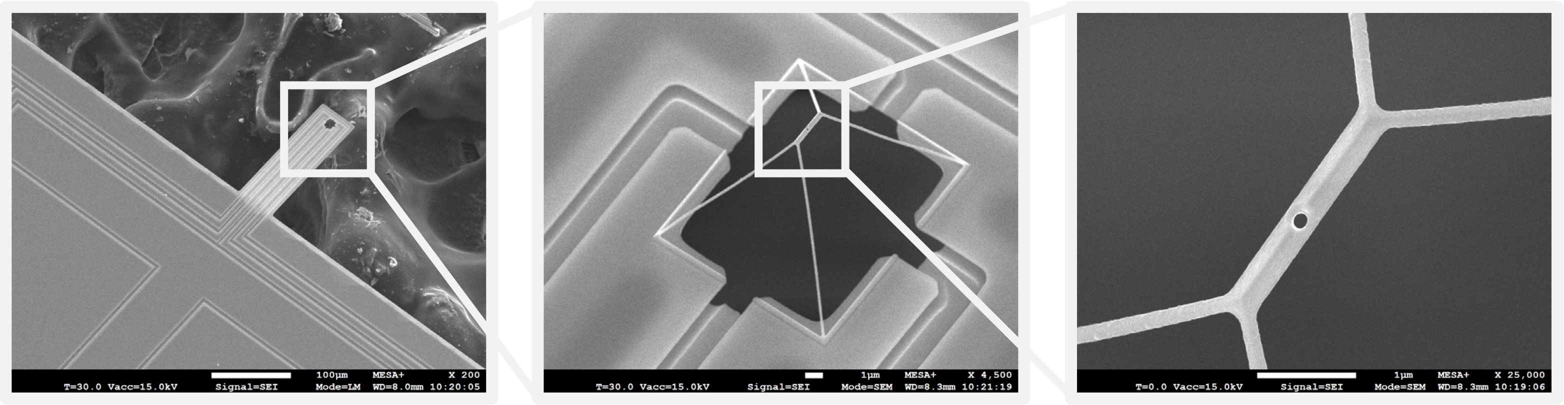
Finkler *et al. Nano Lett.* **10**: 1046-1049 (2010)

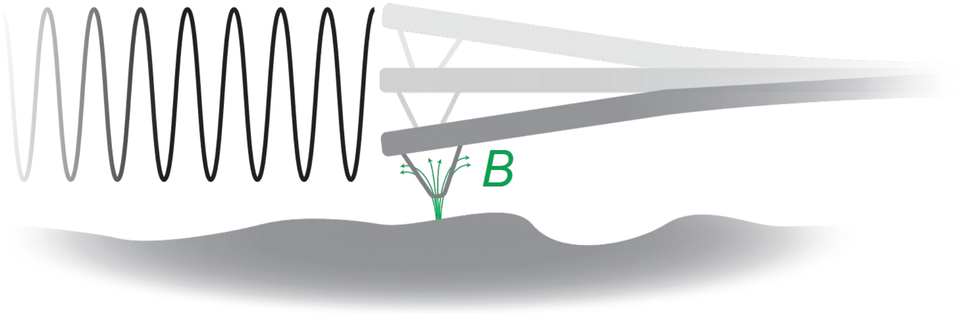
- Three-step thermal evaporation of Nb, Pb, Al etc. on pulled quartz tube

1. Loop diameters down to 50 nm
2. Tip–sample distance ~50–200 nm (QTF)

SQUID on AFM cantilever

- Power of AFM scanning/height control
- Multi-function probe: Magnetometry and Topography

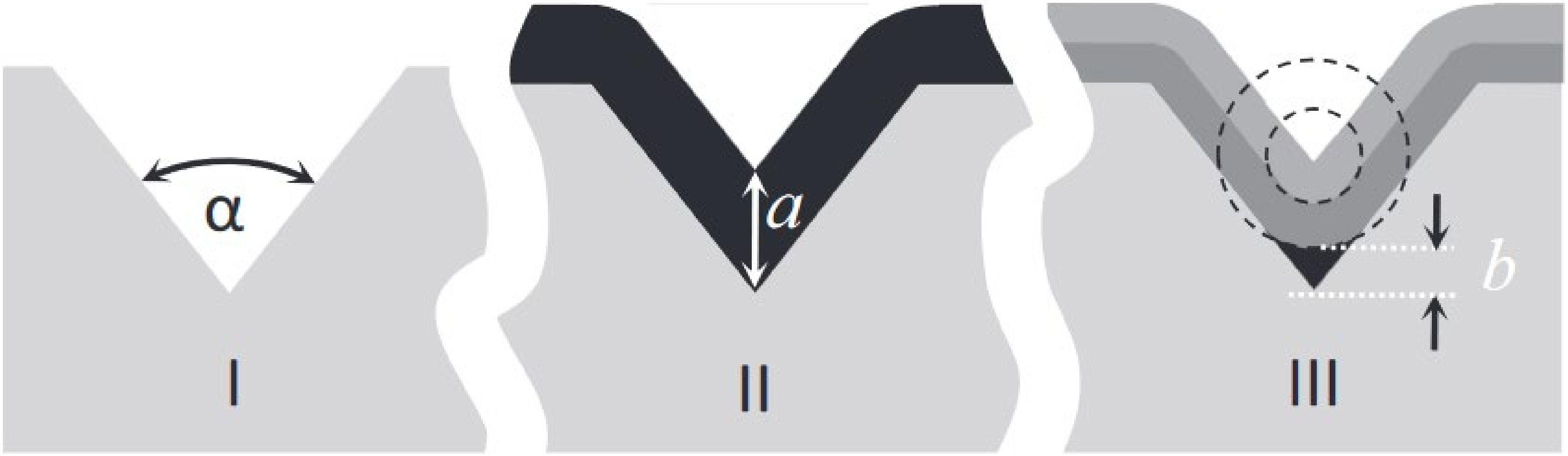




- Wafer scale templates using conventional silicon processing and corner lithography
- Simple deposition of superconductor by magnetron sputtering
- Focused-ion beam milling to SQUIDs

Corner Lithography

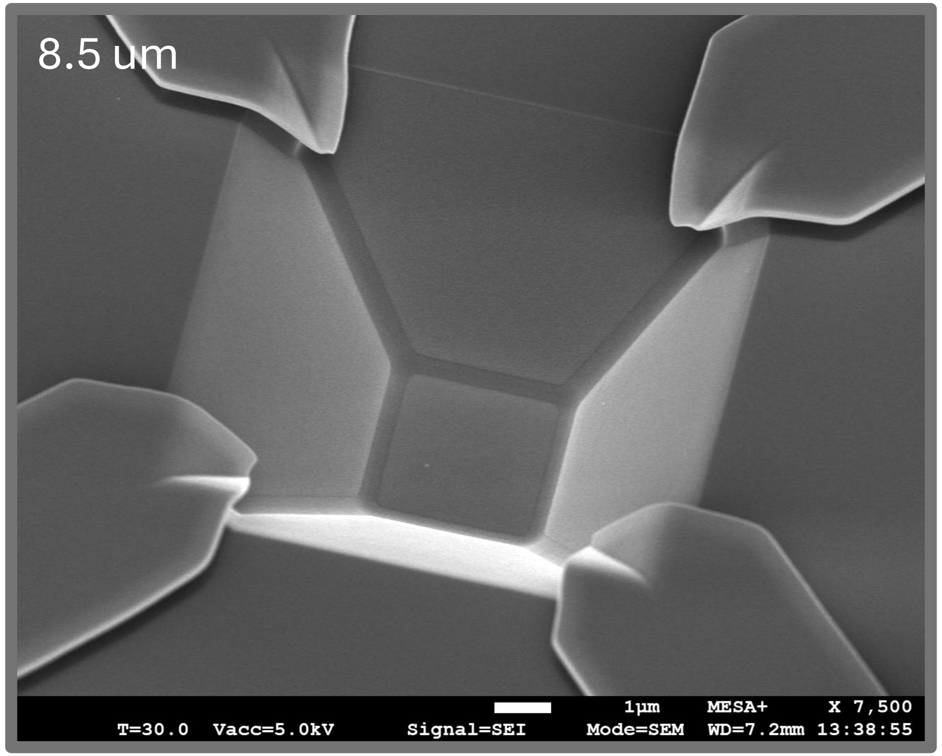
Berenschot *et al. Small* **8**: 3823-3831 (2012)



I. Template preparation
II. Deposition of conformal layer
III. Time-controlled selective isotropic etching of layer

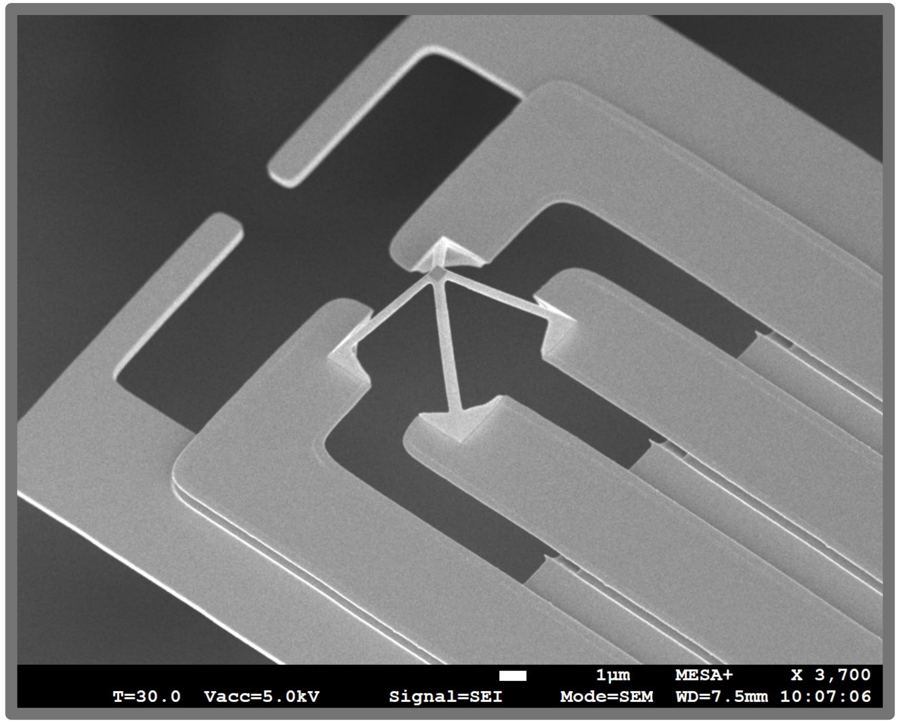
Corner lithography

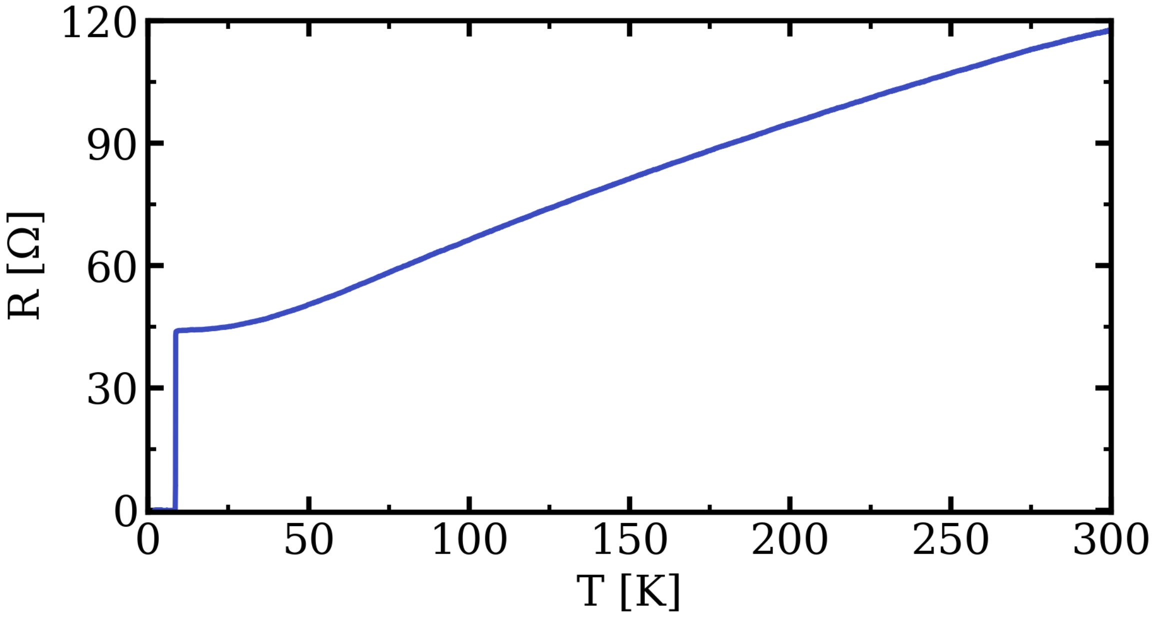
- Timed etching to perform corner lithography and keep nitride in all concave corners

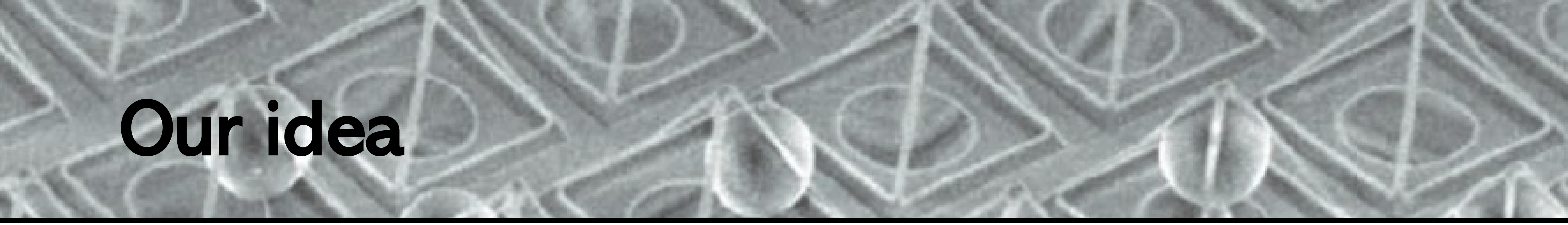


A SQUID on a cantilever (iii)

- Magnetron sputtering of Ti/Nb/Pd
- Superconducting at 8.4 K; I_c ~ several mA







Our idea

✓ Wafer scale templates using conventional silicon processing and corner lithography

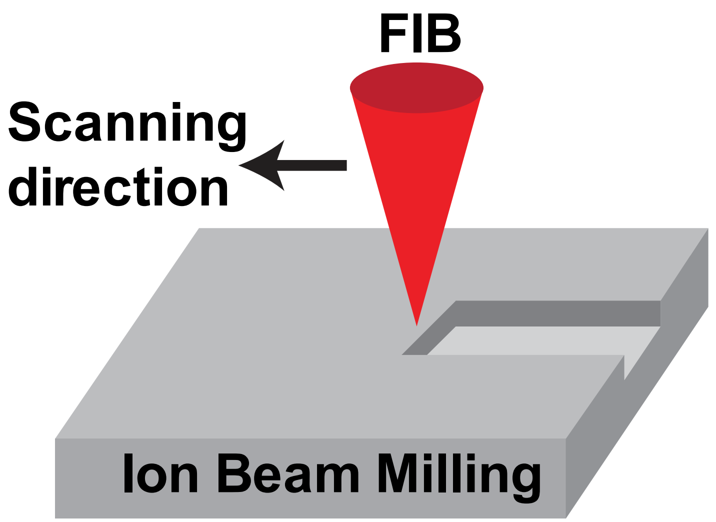
✓ Simple deposition of superconductor by magnetron sputtering by exploiting shadow effects

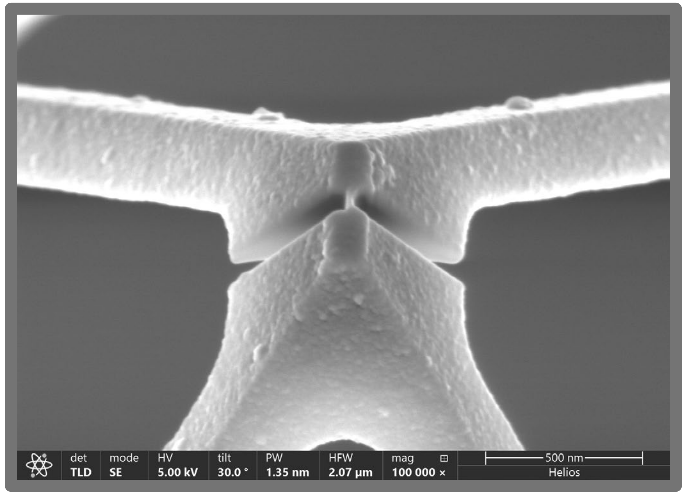
- Focused-ion beam milling to create weak links and loops at the apex of corner lithography wireframe pyramids

Weakening the superconductor: FIB

- FIB: Focused Ion Beam
  1. Gallium ions etch away material
  2. Small beam width ~15 nm
- FIB and superconductors
  1. Modify Current-Phase Relation → weak links

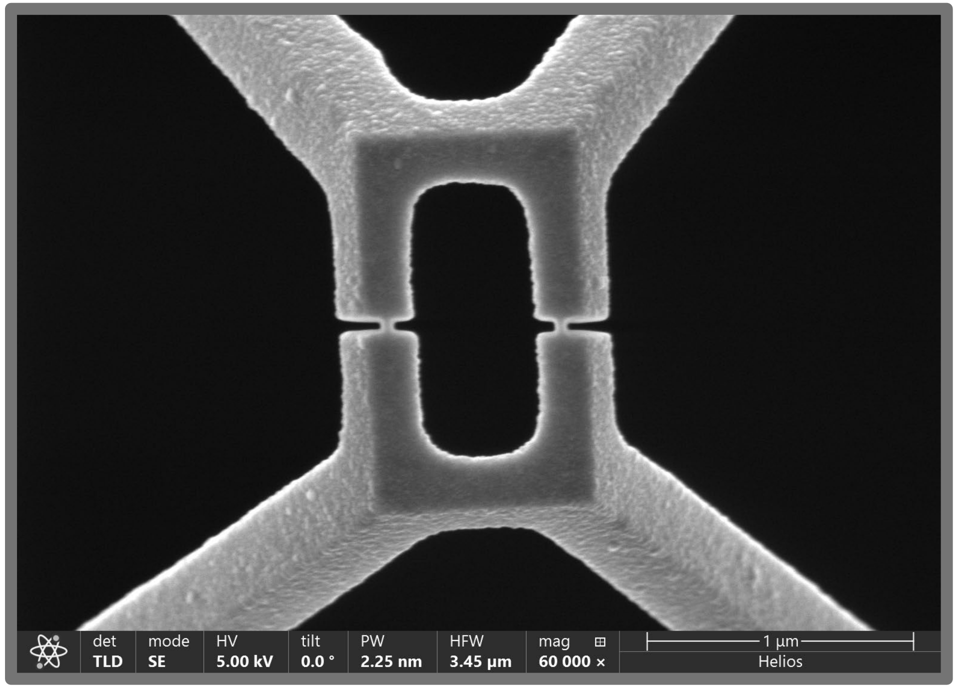
→ **Dayem bridges (constrictions)**

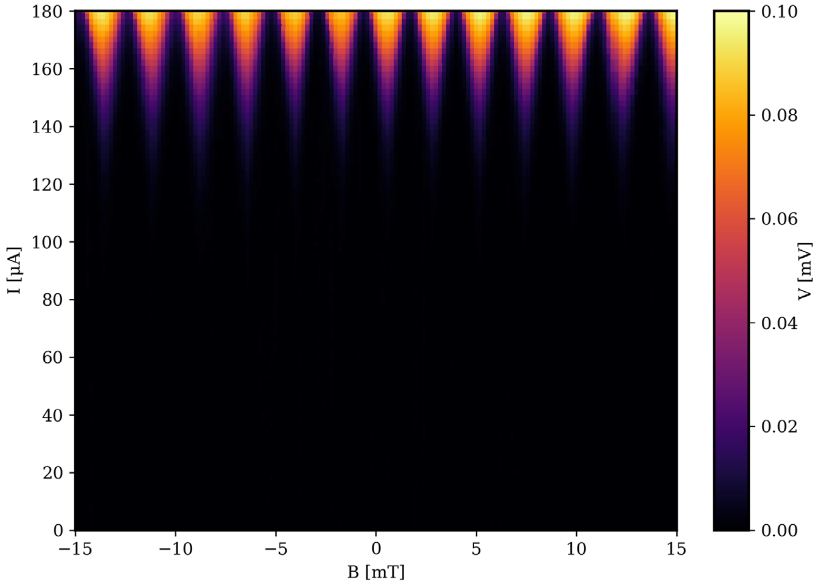


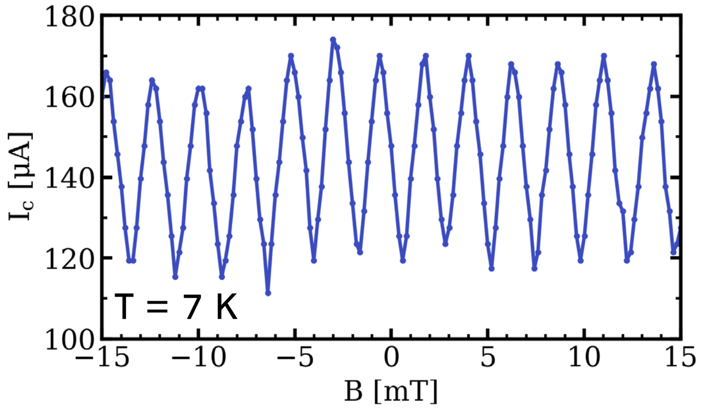


A SQUID on a cantilever (i)

- FIB → Dayem bridges of L x W ~ 40 x 40 nm
- SQUID oscillations: $\Delta B = 2.1\ \mathrm{mT} \rightarrow a = \sqrt{\frac{\Phi_0}{\Delta B}} = 992\ \mathrm{nm}$

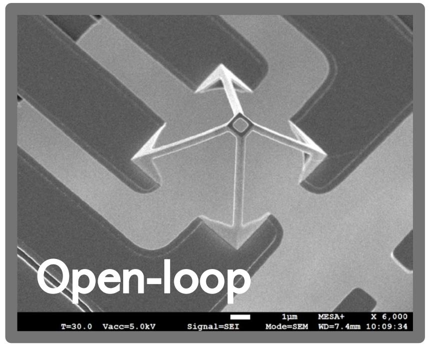


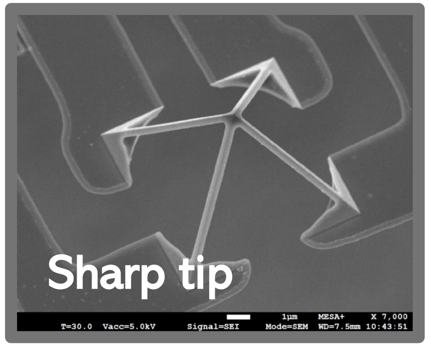


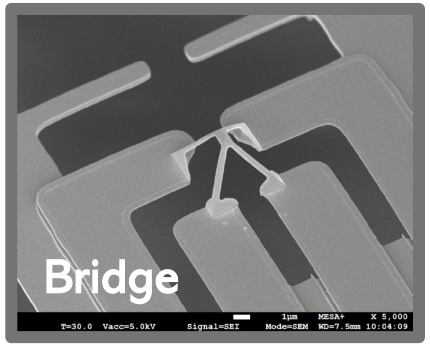


A SQUID on a cantilever (ii)

- Different tip structures possible
- FIB → Entire SQUID

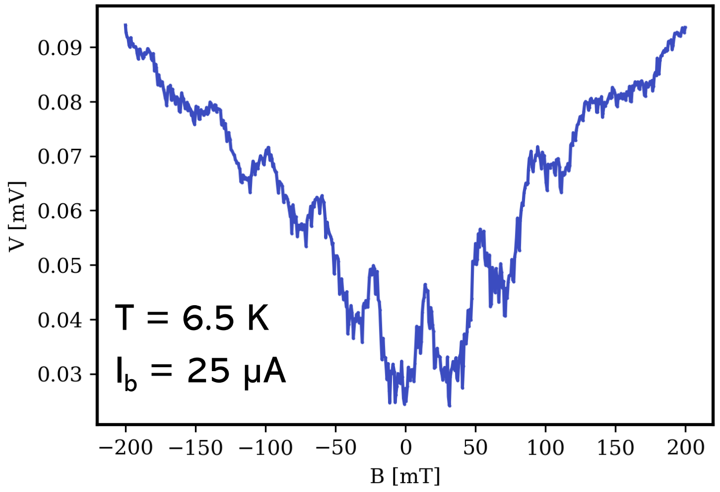


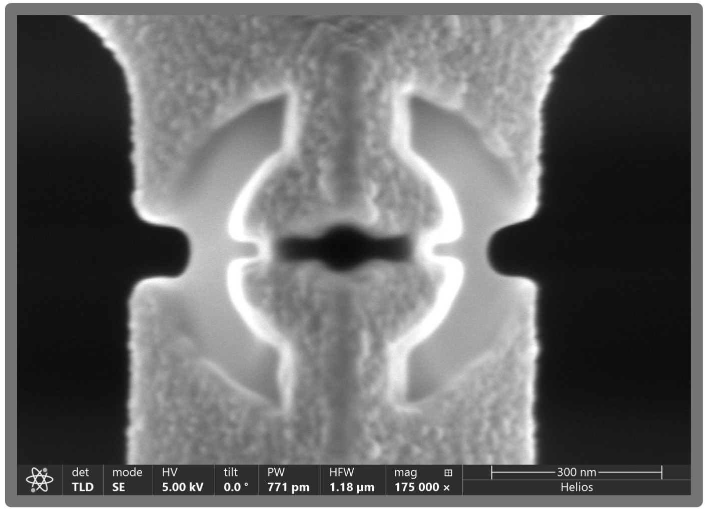




SQUID oscillations: $\Delta B = 37\ \mathrm{mT}$

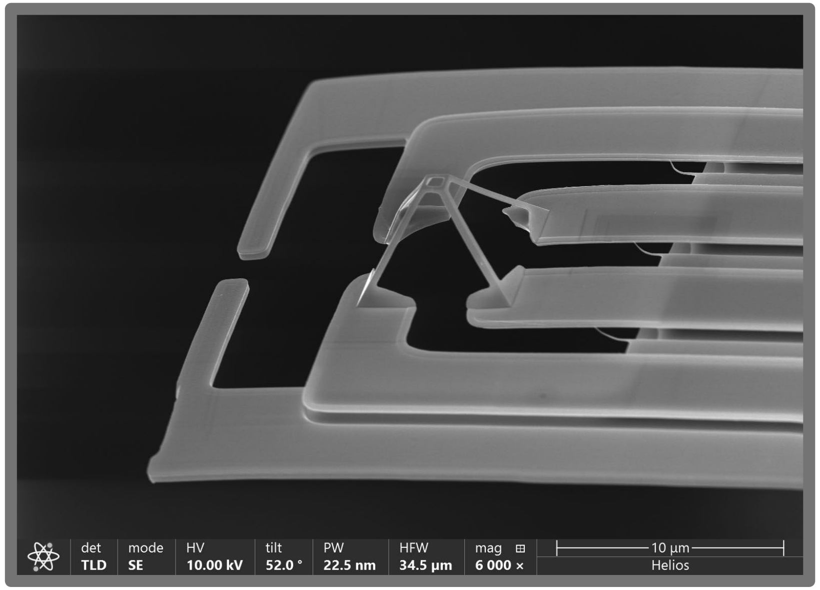
$$d = 2\sqrt{\frac{\Phi_0}{\pi \Delta B}} = 270\ \mathrm{nm}$$



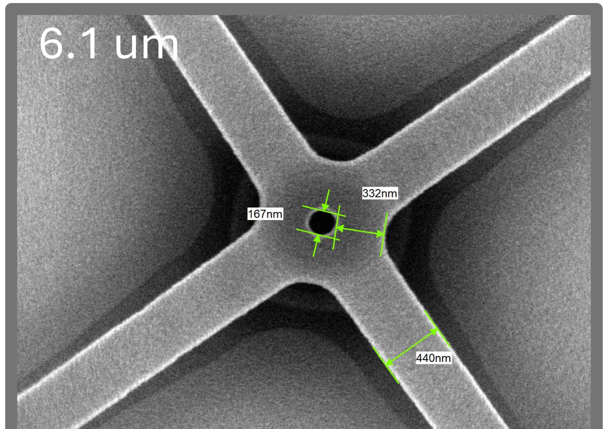


Conclusion and Outlook

- Reliable nanofabrication of 3D pyramid nanowireframe and integration onto conventional silicon nitride cantilever
- Successful fabrication of superconducting probe
- Successful FIB-milling of SQUIDs and Dayem bridges at the apex of the probe



  - Sub-100 nm SQUID loops; Much freedom to tune loop sizes
  - Possibility for modulation or field coil
  - Other superconductors; HTS?



Acknowledgements

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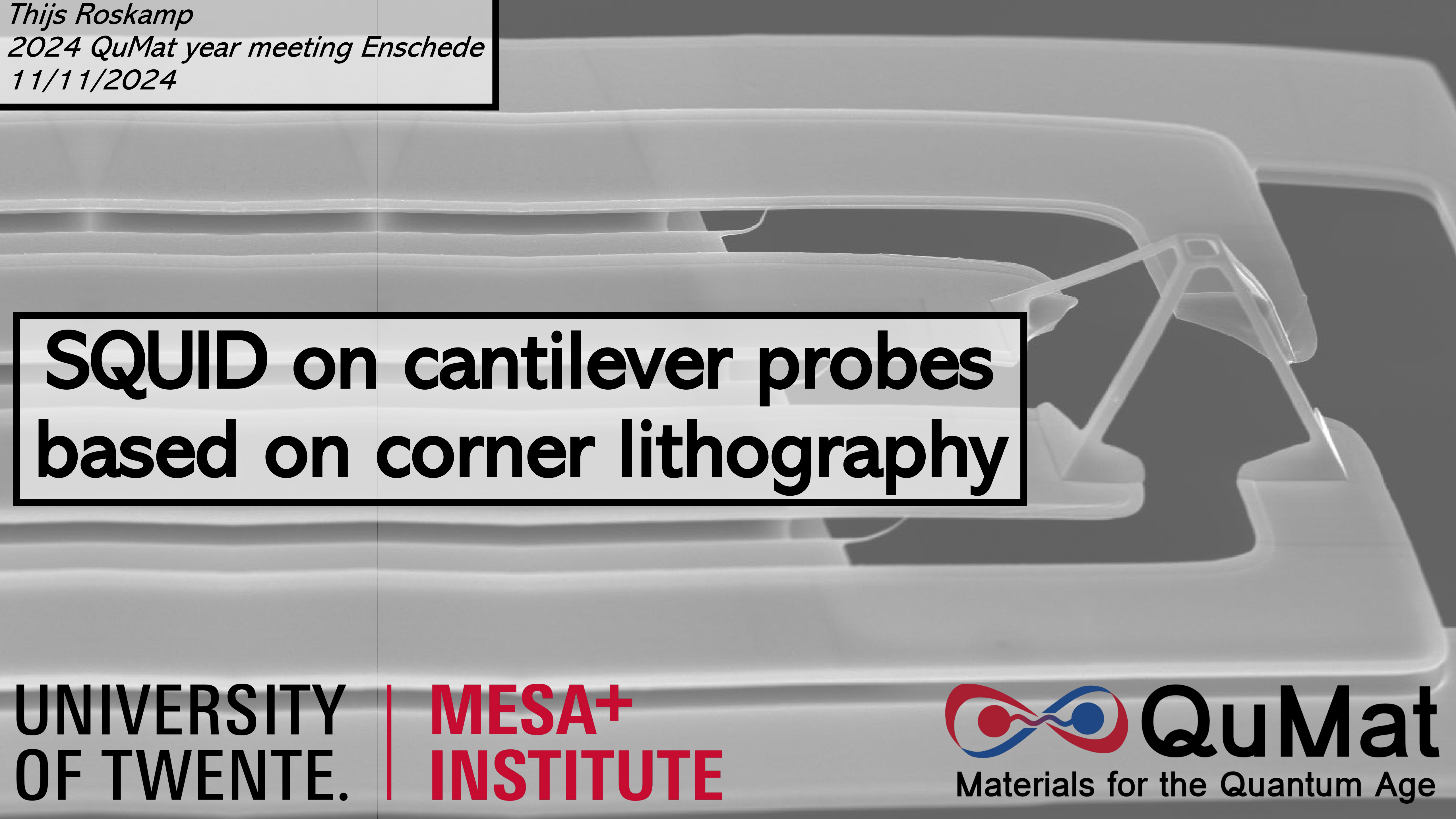

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