

AFM Probe Manufacturing

Phil Russell
Appalachian State University

Slides Courtesy of:
Oliver Krause
NanoWorld Services GmbH

Overview

● Fabrication steps of AFM probes

- Silicon tip manufacturing process
 - Undercut tip concept
 - Corner tip concept
- Nitride tip manufacturing process (mold and release concept)

● Tip refinement, extra tips

- Tip shaping
- High Aspect Ratio tips
- Carbon Nanotube tips

● Probe functionalization

- Functional coatings
- Integrated sensors and emitters

● Integration of actuation and beam deflection detection

- Integrated readout
- Actuator integration

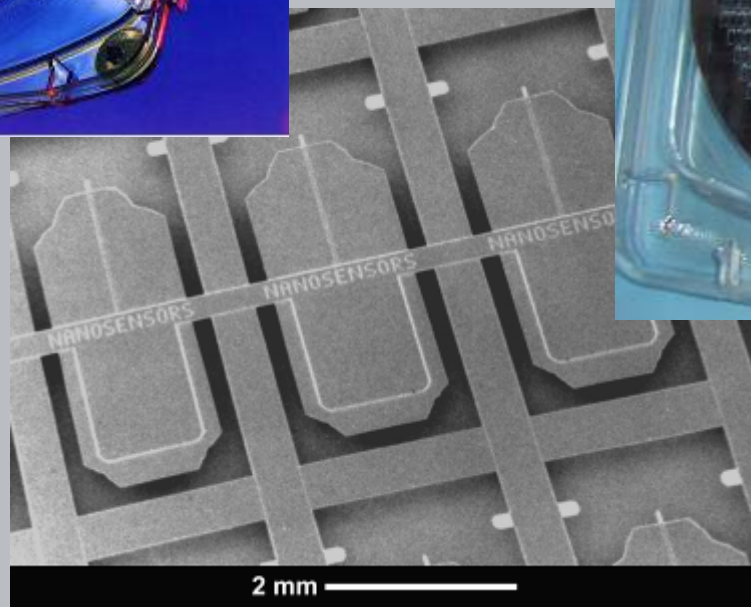
General remarks - Batch Fabrication



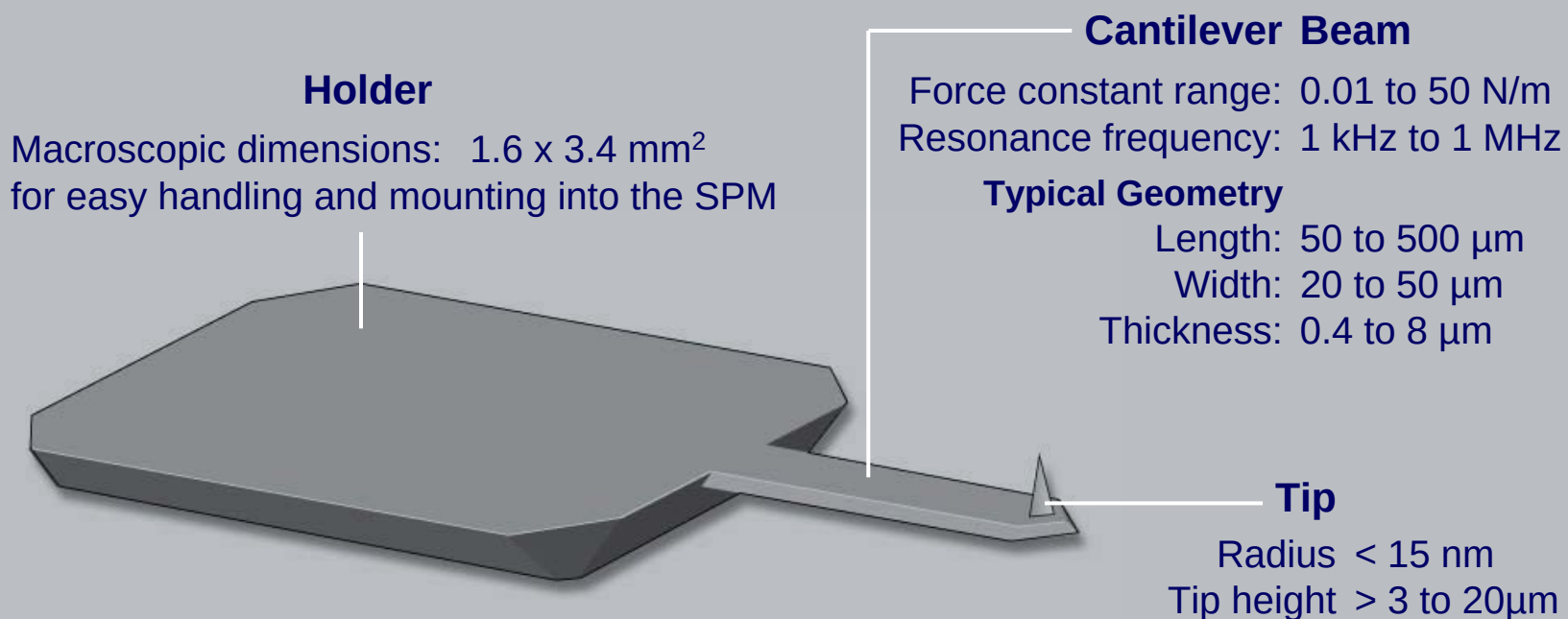
4-inch wafer
with 388 probes



6-inch wafer with more
than 1000 probes



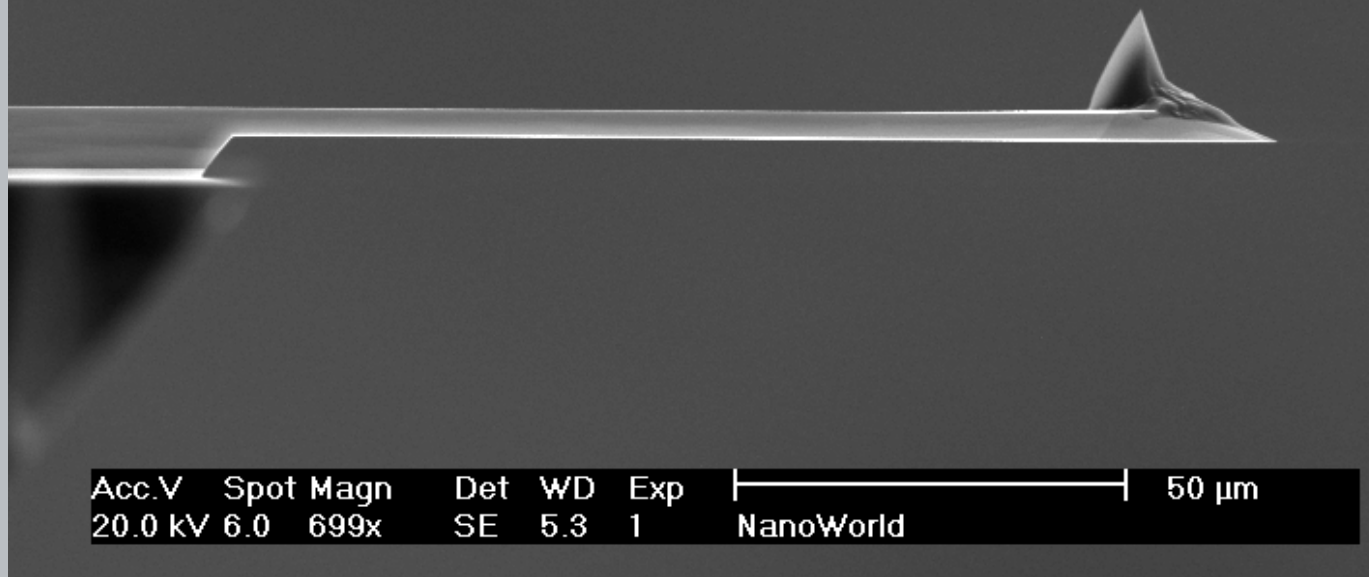
General remarks - AFM probe basics



Material: Single Crystalline Silicon or Silicon Nitride Thin Film

Fabrication steps of silicon probes

Fabrication Steps for Silicon AFM Probes Undercut Concept



Fabrication steps of silicon probes (1/16)

Wafer 4" <100>

Silicon wafer

Fabrication steps of silicon probes (2/16)

1) Oxidation



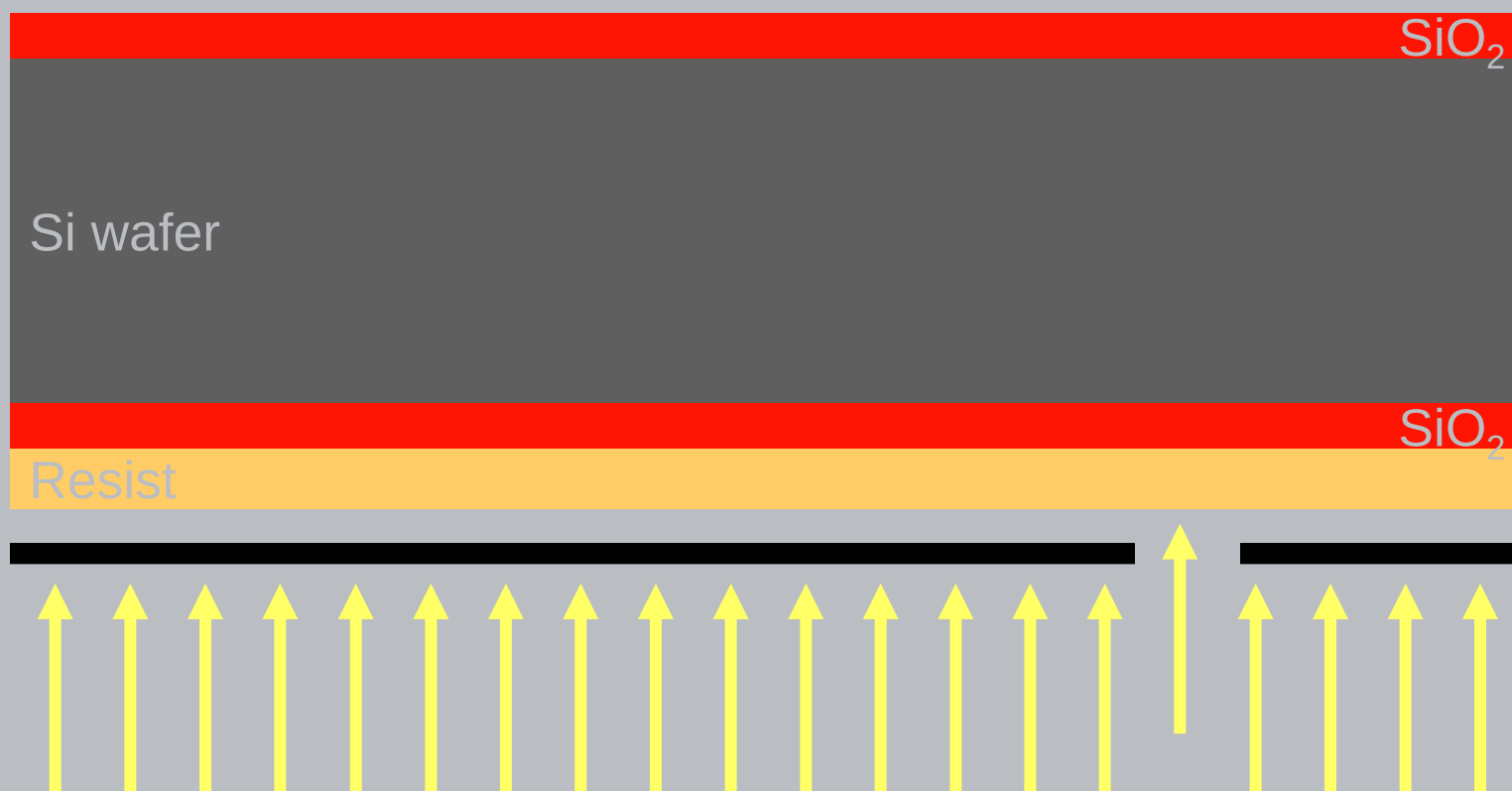
Fabrication steps of silicon probes (3/16)

2) Back side photo resist deposition



Fabrication steps of silicon probes (4/16)

3) Photolithography (exposure of the photoresist through a chromium/quartz mask)



Fabrication steps of silicon probes (5/16)

4) Development of the exposed photoresist



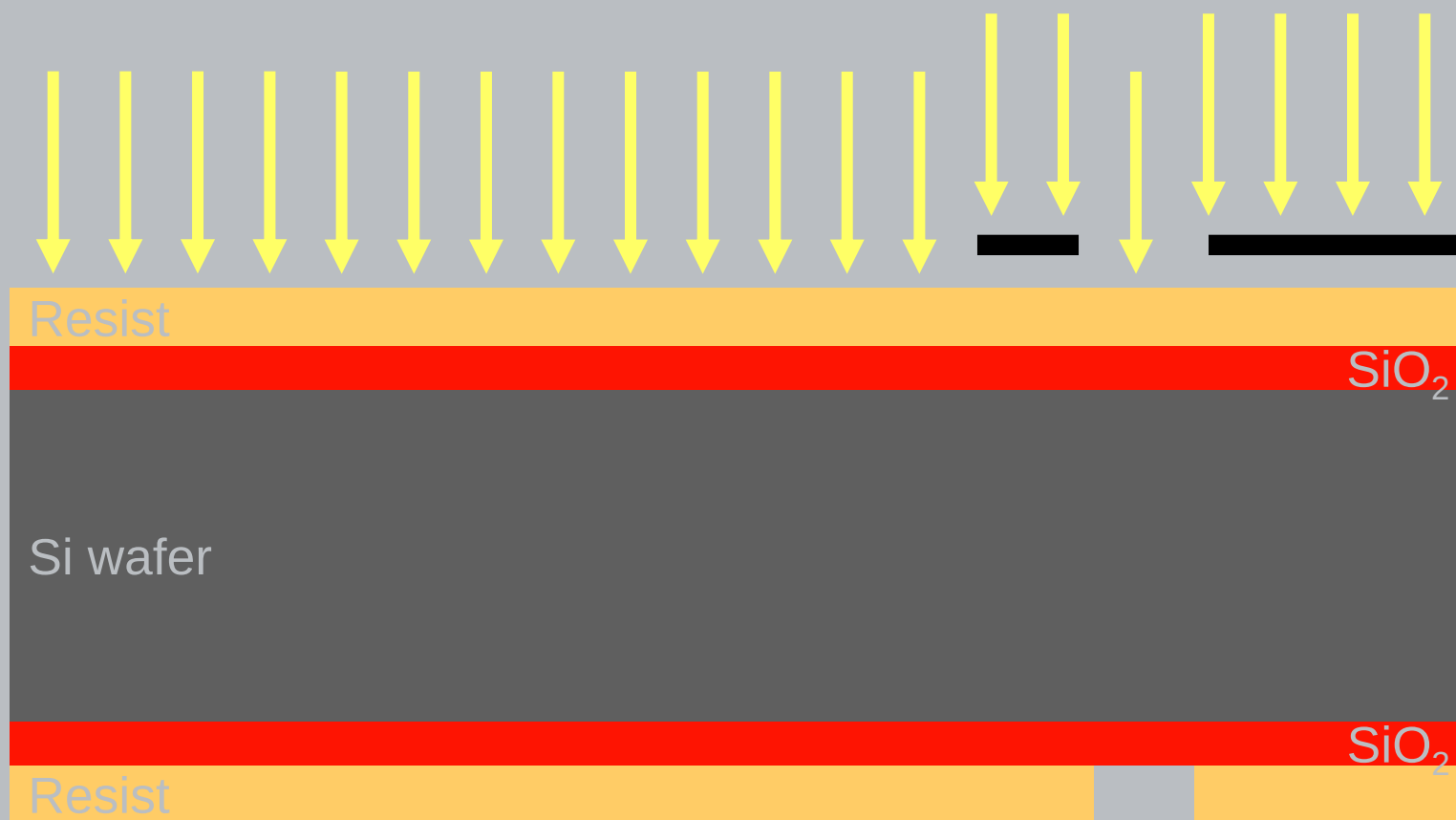
Fabrication steps of silicon probes (6/16)

5) Front side deposition of photo resist



Fabrication steps of silicon probes (7/16)

6) Photolithography (exposure of the photoresist through a chromium/quartz mask)



Fabrication steps of silicon probes (8/16)

7) Development of the exposed photo resist



Fabrication steps of silicon probes (9/16)

8) Isotropic wet etching of silicon oxide



Fabrication steps of silicon probes (10/16)

9) Dissolution of photo resist



A cross-sectional diagram of a silicon wafer. The main body is a dark gray rectangle labeled "Si wafer". On the right side, there is a central trench and two side structures. The trench is a V-shaped cutout. The side structures are trapezoidal shapes on either side of the trench. The top and bottom surfaces of these structures are labeled SiO_2 in white text. The wafer itself is labeled "Si wafer" in white text on the left side.

Fabrication steps of silicon probes (12/16)

10) Anisotropic wet etching of silicon by KOH

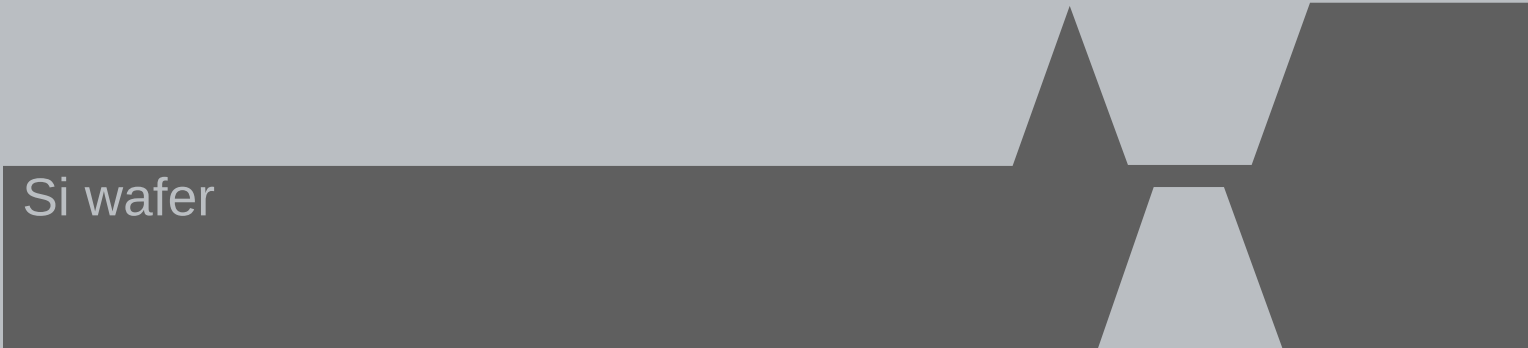
The formation of the tip is finished when the „oxide shield“ falls off



Fabrication steps of silicon probes (13/16)

11) Isotropic wet etching of silicon oxide

Si wafer



Fabrication steps of silicon probes (14/16)

12) Deposition of a silicon nitride layer to protect the tip side of the probe



Fabrication steps of silicon probes (15/16)

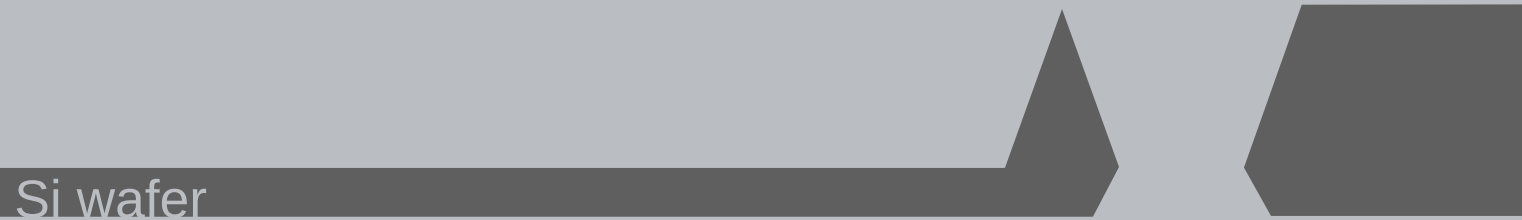
13) Anisotropic wet etching of silicon by KOH

The thickness of the cantilever is determined during this step



Fabrication steps of silicon probes (16/16)

14) Isotropic wet etching of silicon nitride



Si wafer

The diagram illustrates the isotropic wet etching of silicon nitride. It shows a long, thin rectangular block on the left, labeled 'Si wafer'. An arrow points from the right end of this block to a trapezoidal block on the right. The trapezoidal block has a wider top edge and a narrower bottom edge, representing the cross-section of the etched silicon nitride layer.

Silicon Probes – Undercut Tips

● Features

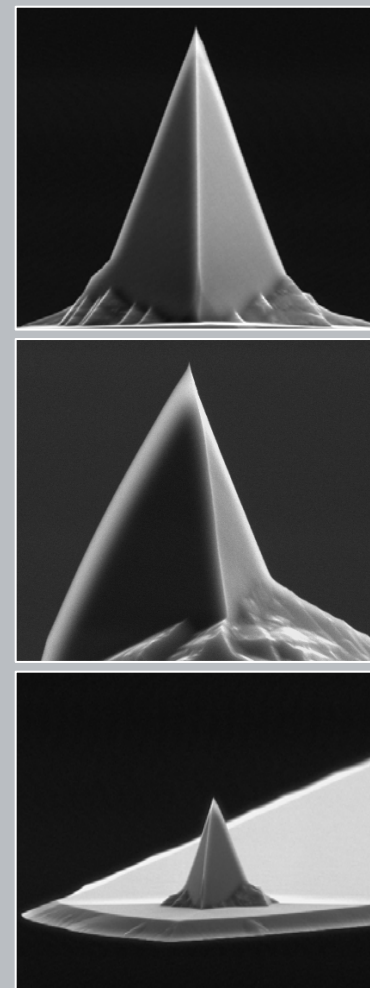
- High aspect ratio tips
- Low tip radii
- Thick cantilevers possible
- Monolithic design
- Easily detachable

● Applications

- All application modes
(contact, non-contact ,special)

● Potential

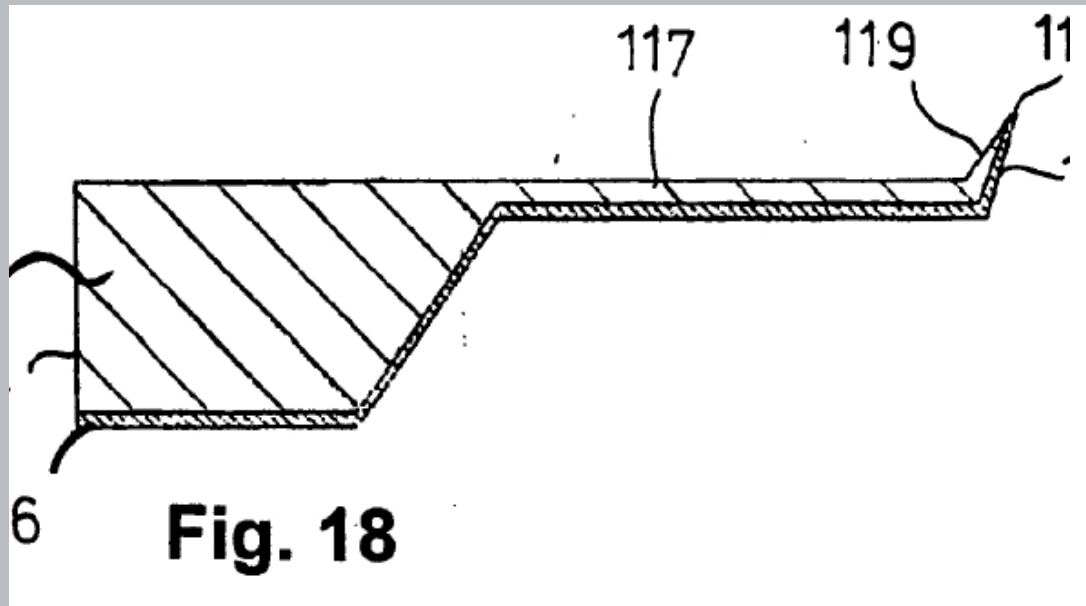
- Integration of piezoresistive
beam deflection detection
- Integration of sensors
(semiconductor)



Silicon Probes – Corner Tips

● “Corner tips”

- Etching of corner structures with steep sidewalls
- Sidewall protection
- Anisotropic silicon etching



● Features

- Tip exactly at the free end of the cantilever
- Thick cantilevers possible
- Monolithic design
- Reliable tip shape

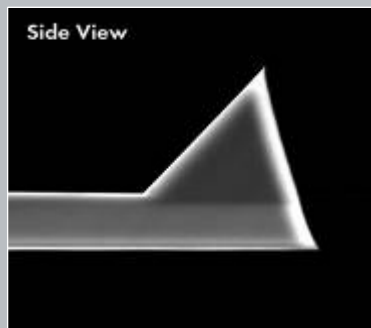
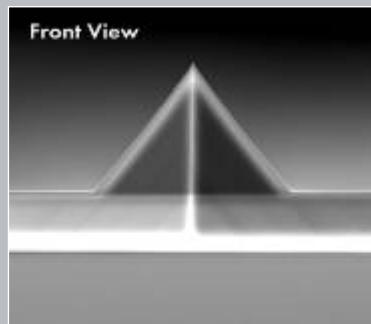
● Applications

- All application modes (contact, non-contact, special)

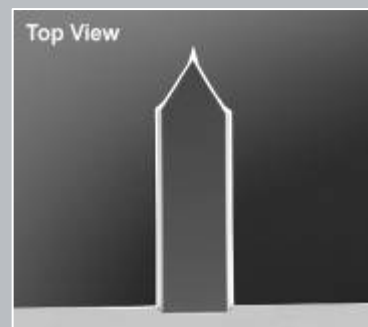
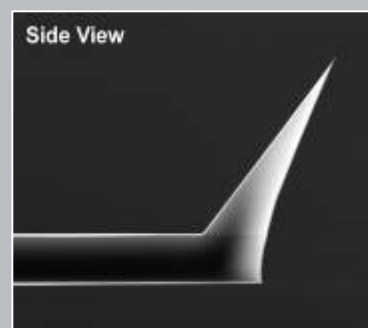
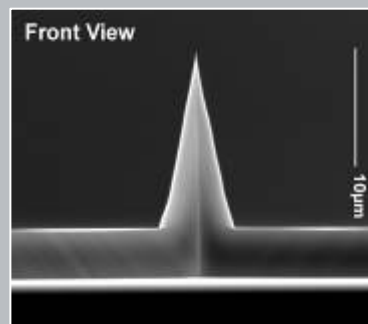
● Potential

- Probing with multiple tips

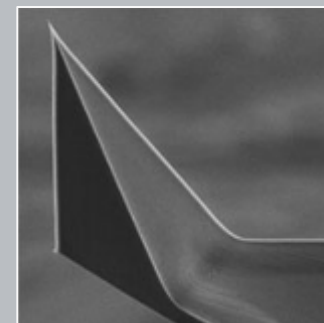
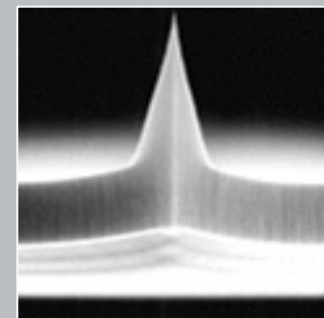
Silicon Probes – Corner Tips Examples



NanoWorld
Arrow™

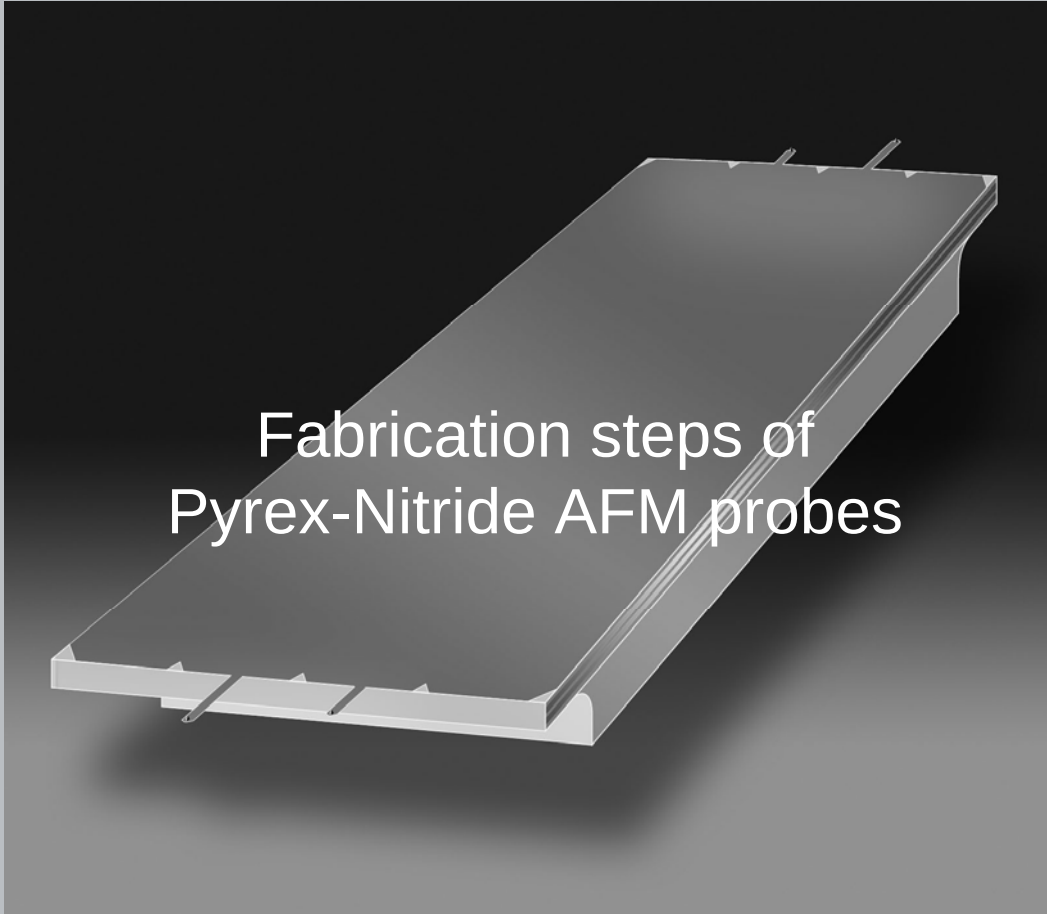


NANOSENSORS™
AdvancedTEC™



Olympus
Silicon Tip

Fabrication steps of nitride probes



Fabrication steps of
Pyrex-Nitride AFM probes

A 3D perspective rendering of a rectangular, thin-layered substrate, likely a Pyrex-Nitride AFM probe. The object is shown at an angle, revealing its top surface and side edges. It has a smooth, light gray top surface and a slightly darker, possibly layered or etched, bottom surface. The edges are clean and sharp, suggesting a precision-fabricated component. The object is set against a dark, gradient background.

Fabrication steps of nitride probes (1/28)

- 1) Wafer, silicon 4" <100>
Oxidation



Fabrication steps of nitride probes (2/28)

2) Tip photolithography on front side:

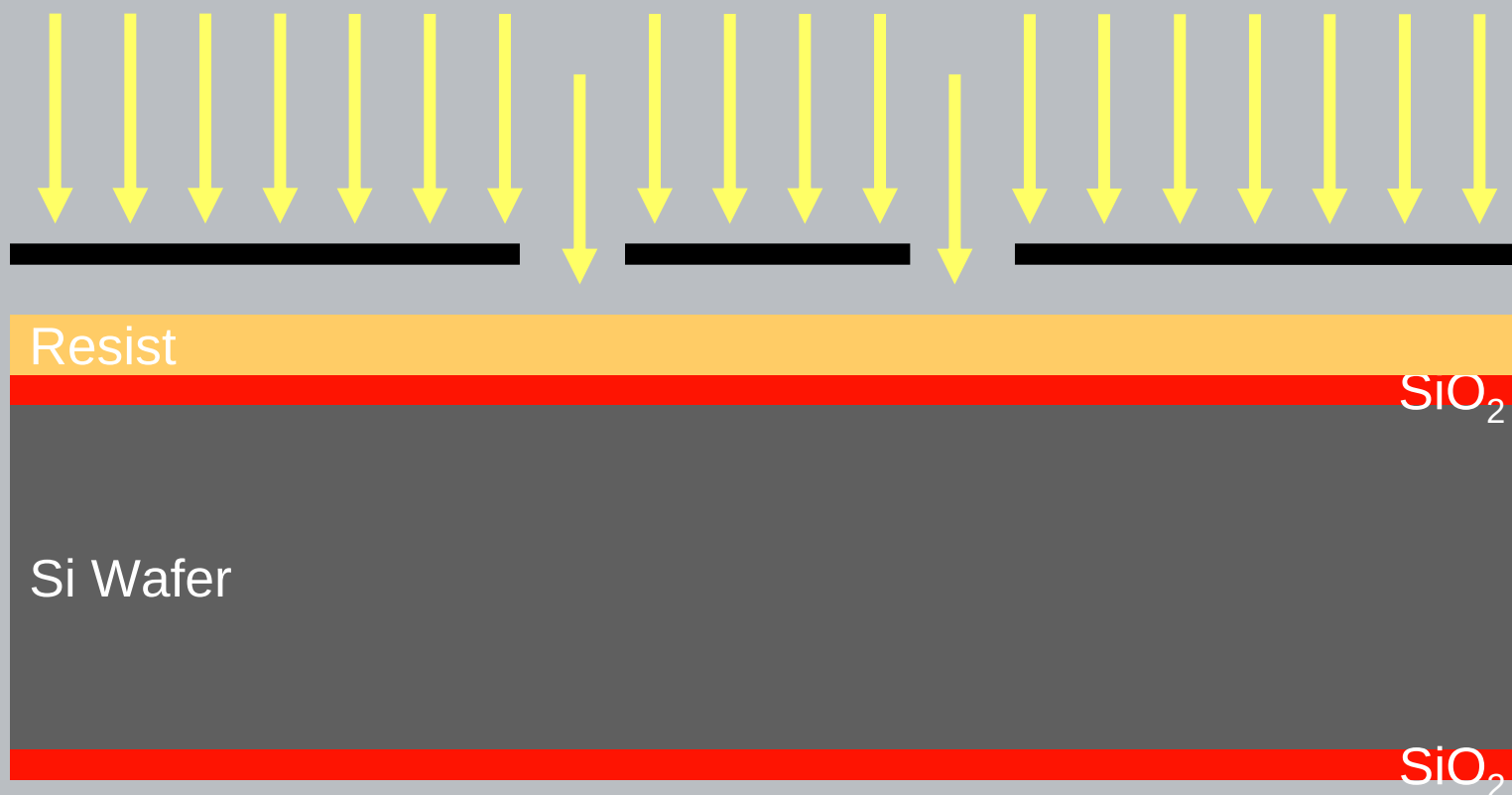
a) Spin coating of photosensible resist + Bake



Fabrication steps of nitride probes (3/28)

2) Tip photolithography on front side:

b) Exposure through a chromium/quartz mask (UV light)



Fabrication steps of nitride probes (4/28)

- 2) Tip photolithography on front side:
- c) Development of the exposed resist



Fabrication steps of nitride probes (5/28)

2) Tip photolithography on front side:

d) Spin coating of protection resist on back side + Bake



Fabrication steps of nitride probes (6/28)

3) Oxide etching in BHF



Fabrication steps of nitride probes (7/28)

4) Stripping of resist in Acetone/Isopropanol



Fabrication steps of nitride probes (8/28)

5) Tip etching in KOH



Fabrication steps of nitride probes (9/28)

6) Oxide removing in BHF



Si Wafer

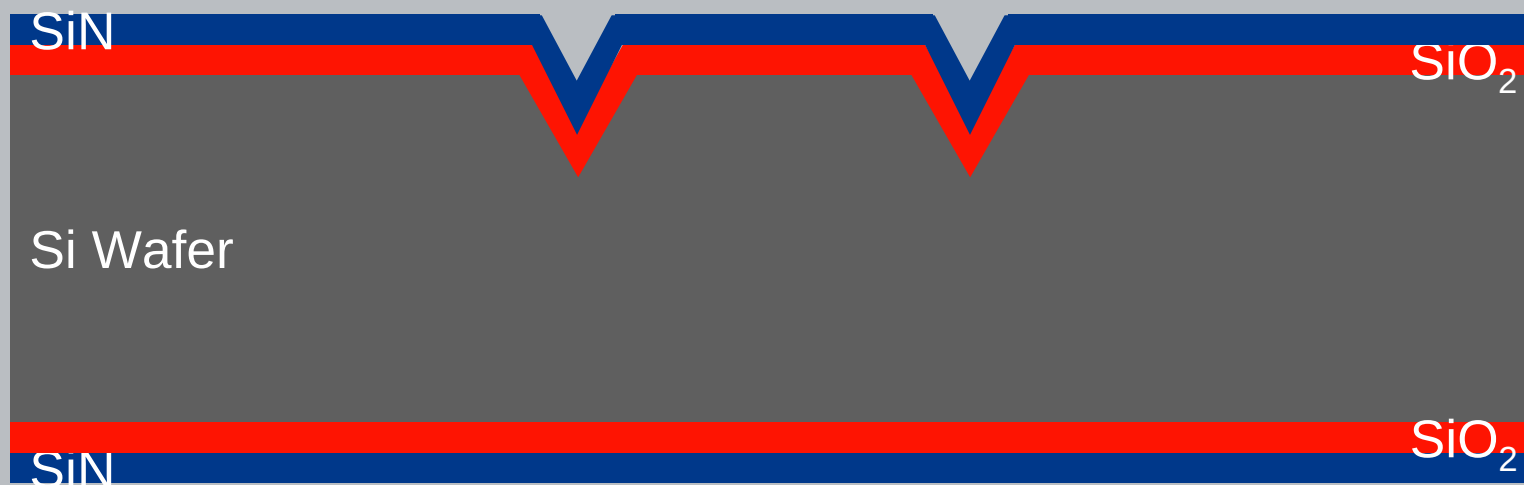
Fabrication steps of nitride probes (10/28)

7) Oxidation



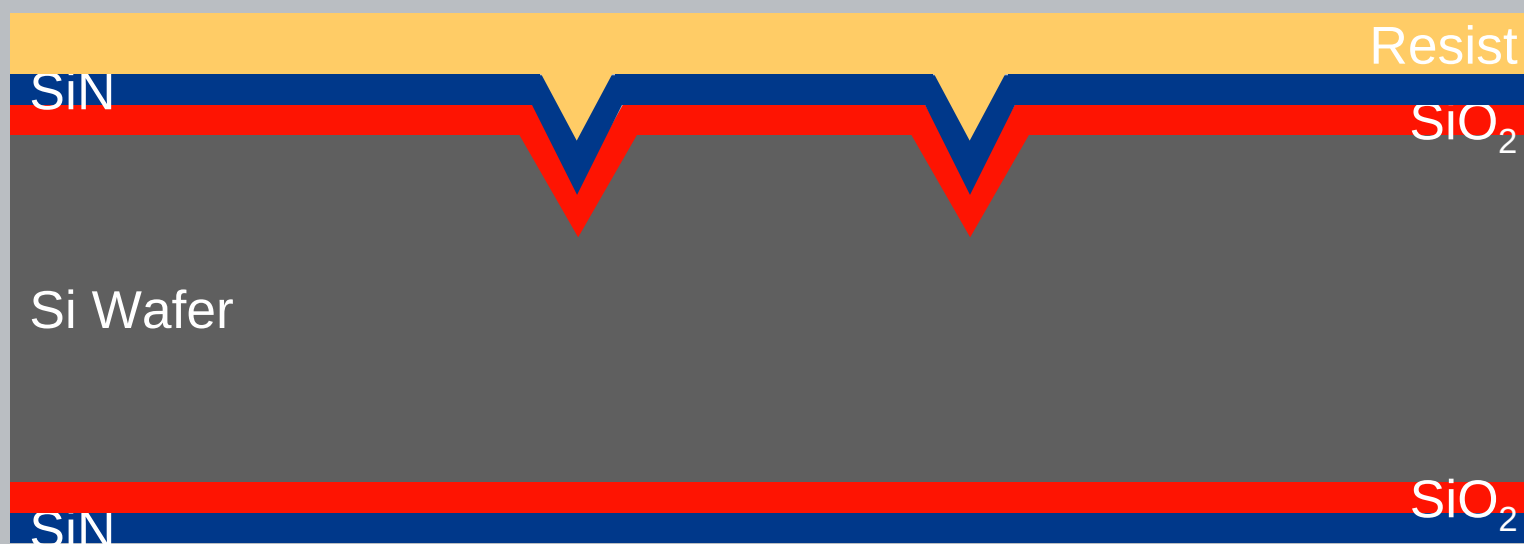
Fabrication steps of nitride probes (11/28)

8) LPCVD low-stress nitride deposition
(LPCVD: Low Pressure Chemical Vapor Deposition)



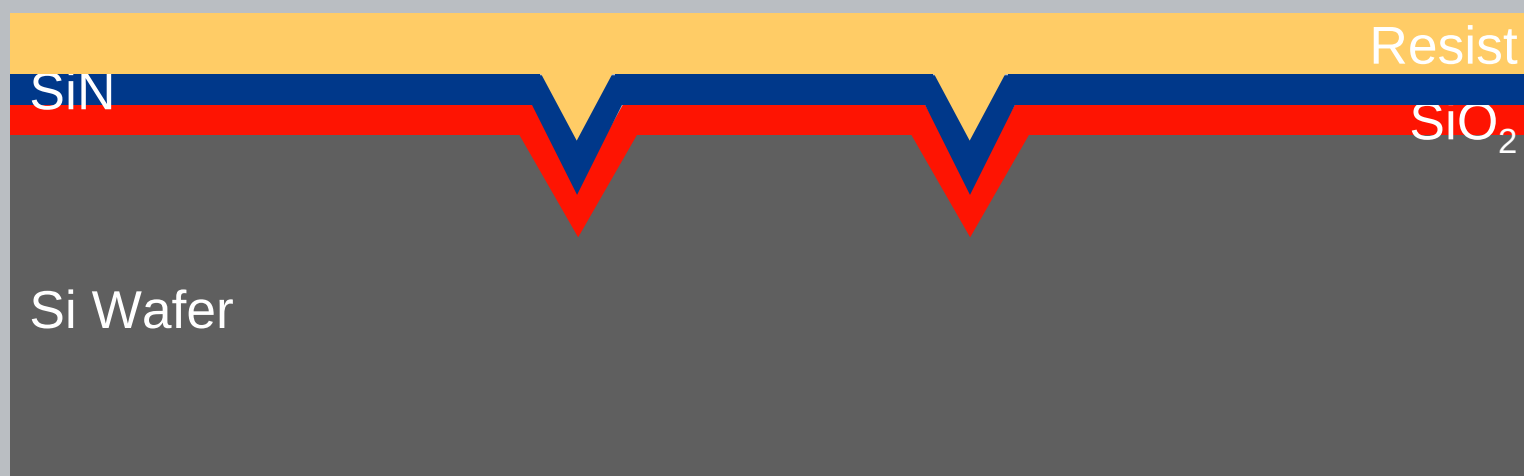
Fabrication steps of nitride probes (12/28)

9) Spin coating of protection resist on front side



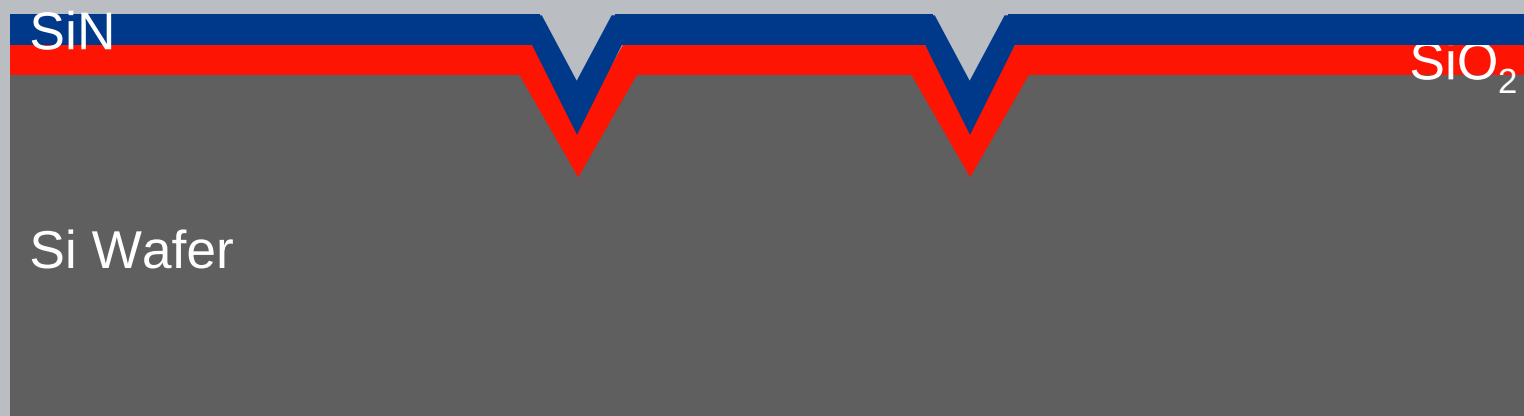
Fabrication steps of nitride probes (13/28)

10) Removing of oxide and nitride on back side



Fabrication steps of nitride probes (14/28)

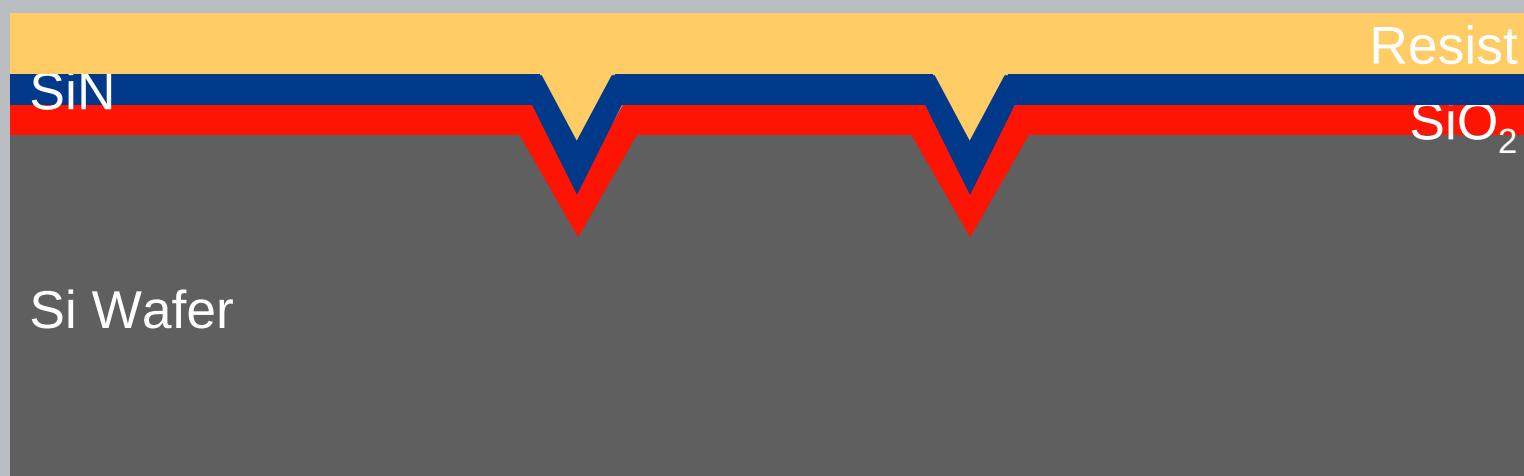
11) Stripping of resist in Acetone/Isopropanol



Fabrication steps of nitride probes (15/28)

12) Cantilever photolithography on front side:

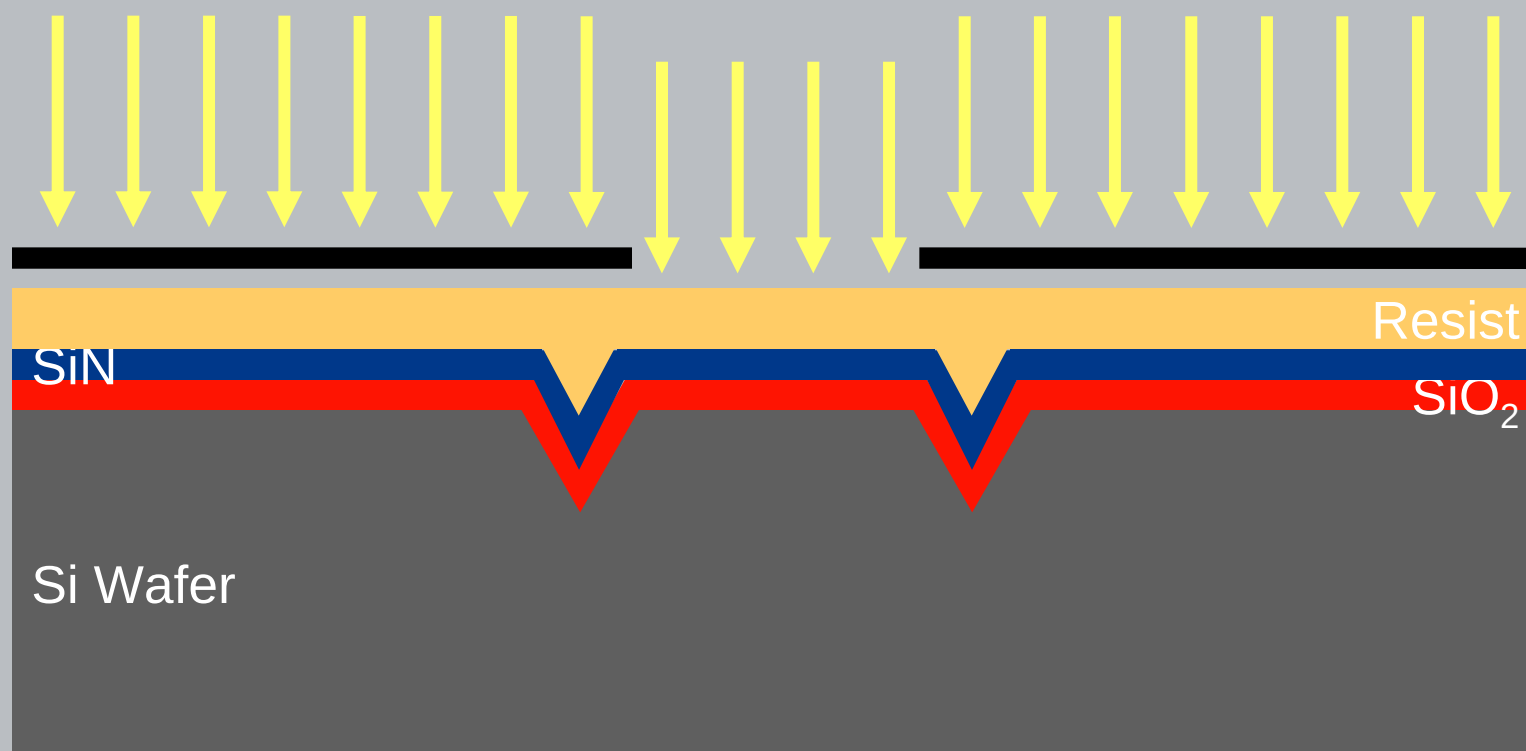
a) Spin coating of photosensible resist + Bake



Fabrication steps of nitride probes (16/28)

12) Cantilever photolithography on front side:

b) Exposure trough a chromium/quartz mask (UV light)



Fabrication steps of nitride probes (17/28)

12) Cantilever photolithography on front side:

c) Development of the exposed resist



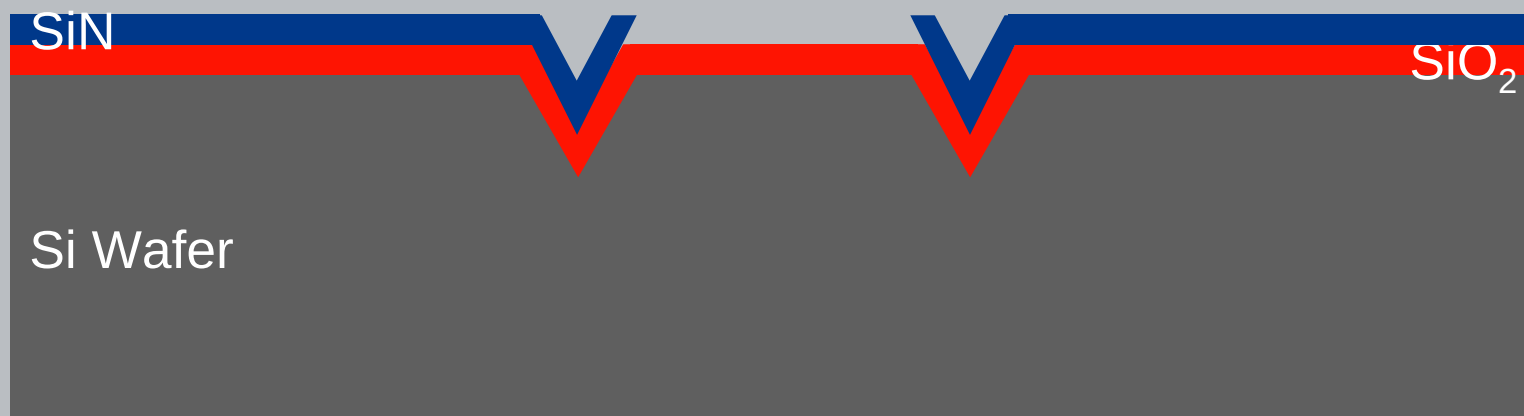
Fabrication steps of nitride probes (18/28)

13) Nitride dry etching



Fabrication steps of nitride probes (19/28)

14) Stripping of resist in Acetone/Isopropanol



Fabrication steps of nitride probes (20/28)

Pyrex wafer - to be used as a ~ handle

Pyrex Wafer

Fabrication steps of nitride probes (21/28)

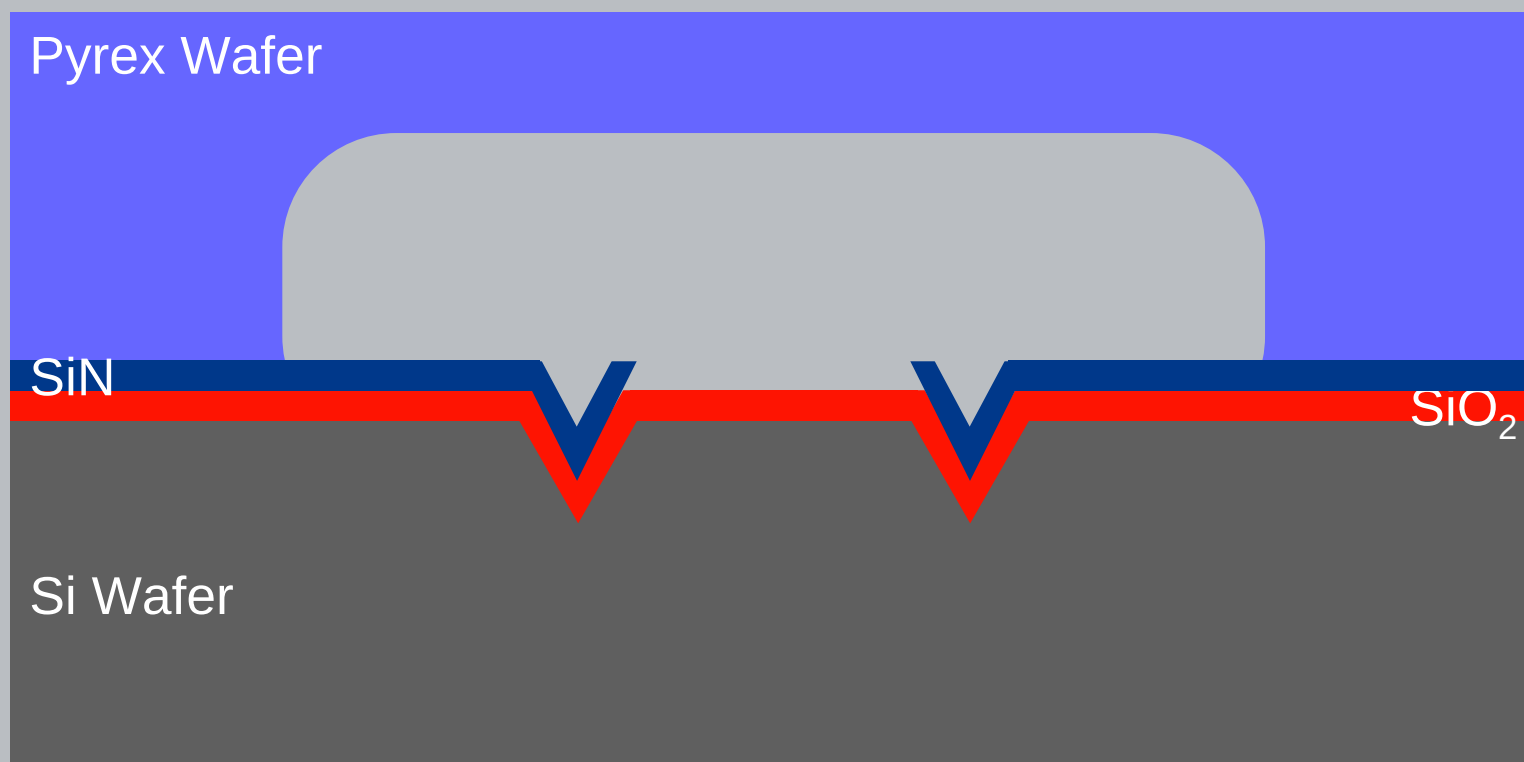
15) Dicing

Pyrex Wafer



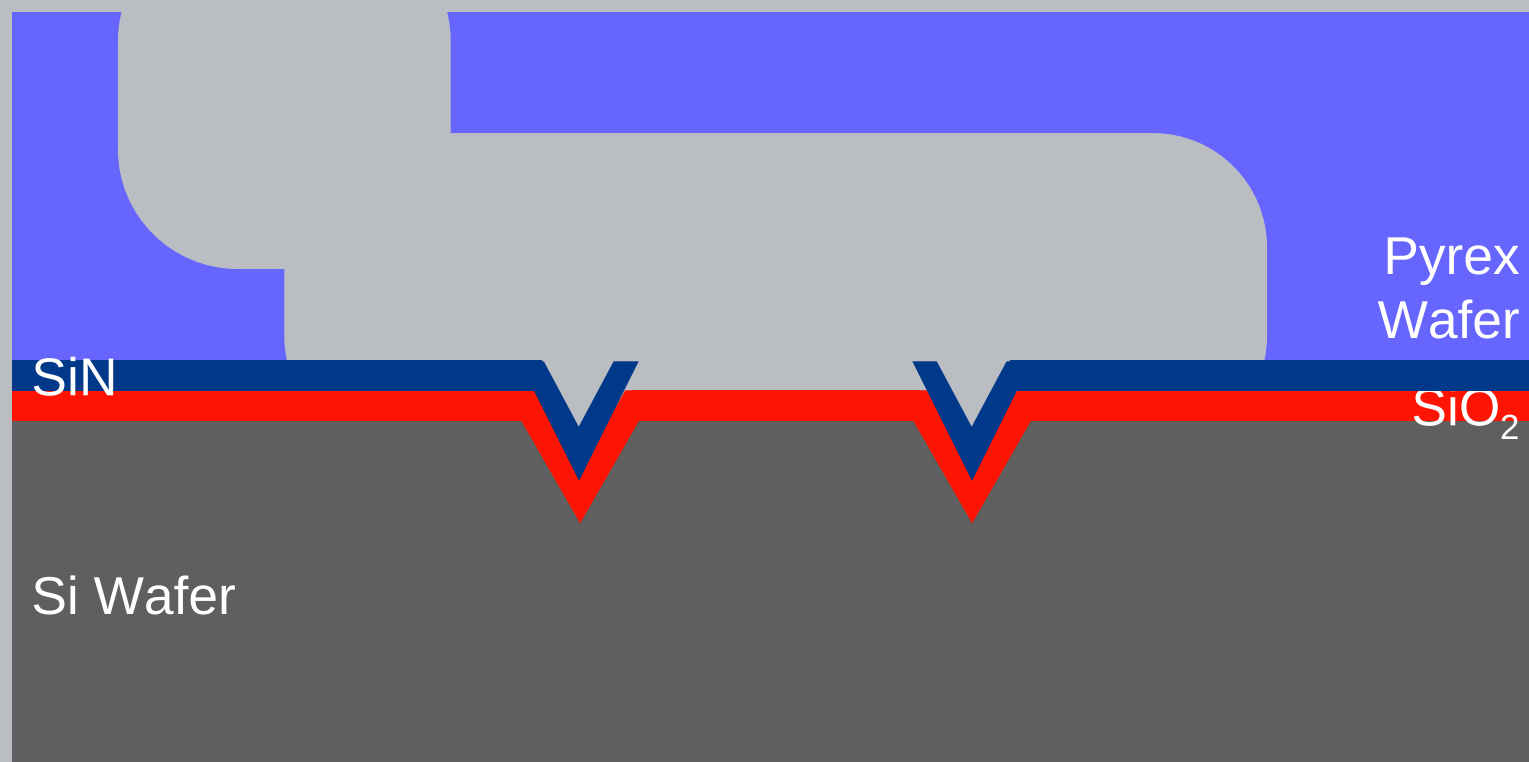
Fabrication steps of nitride probes (22/28)

16) Anodic bonding between the Silicon and the Pyrex wafer



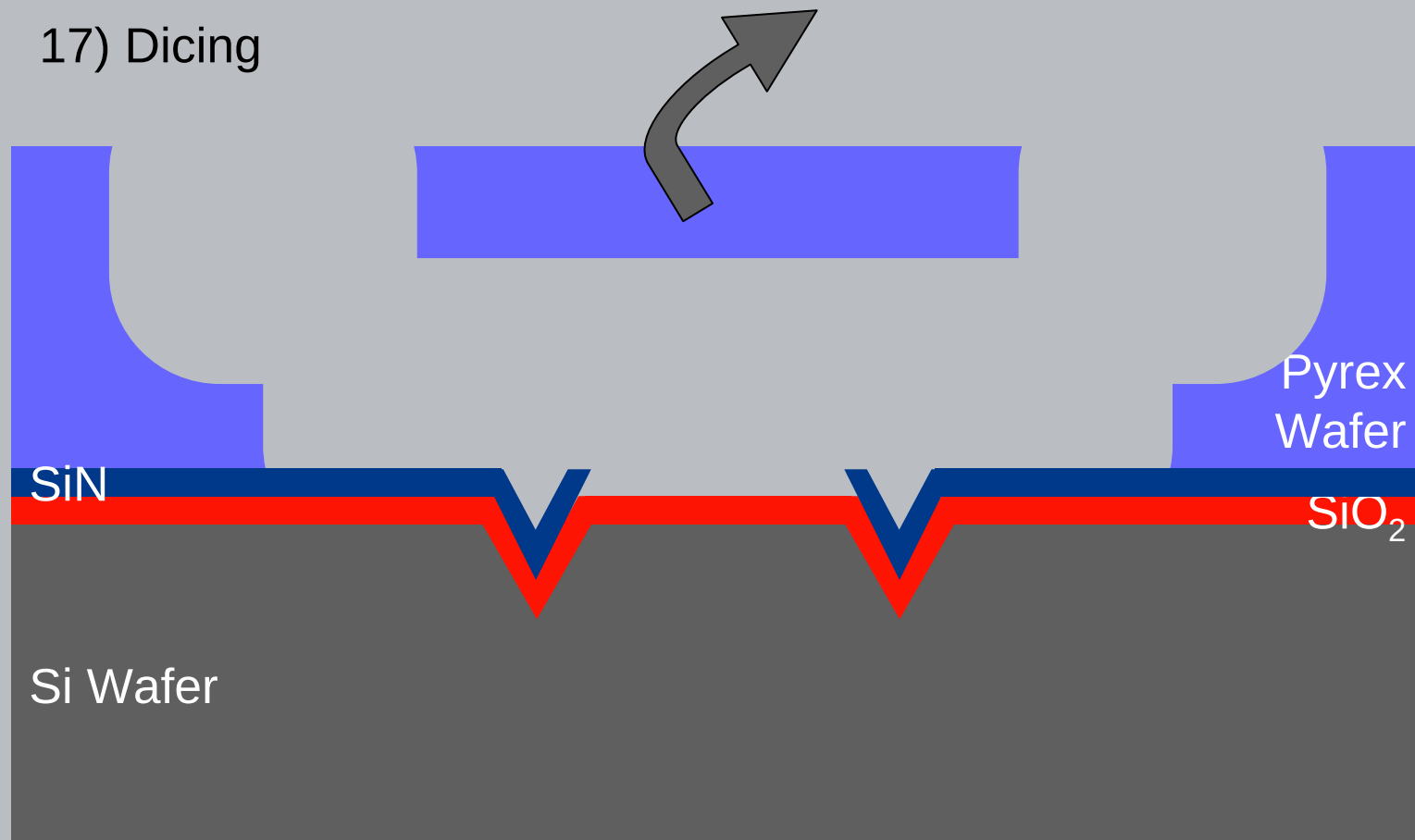
Fabrication steps of nitride probes (23/28)

17) Dicing



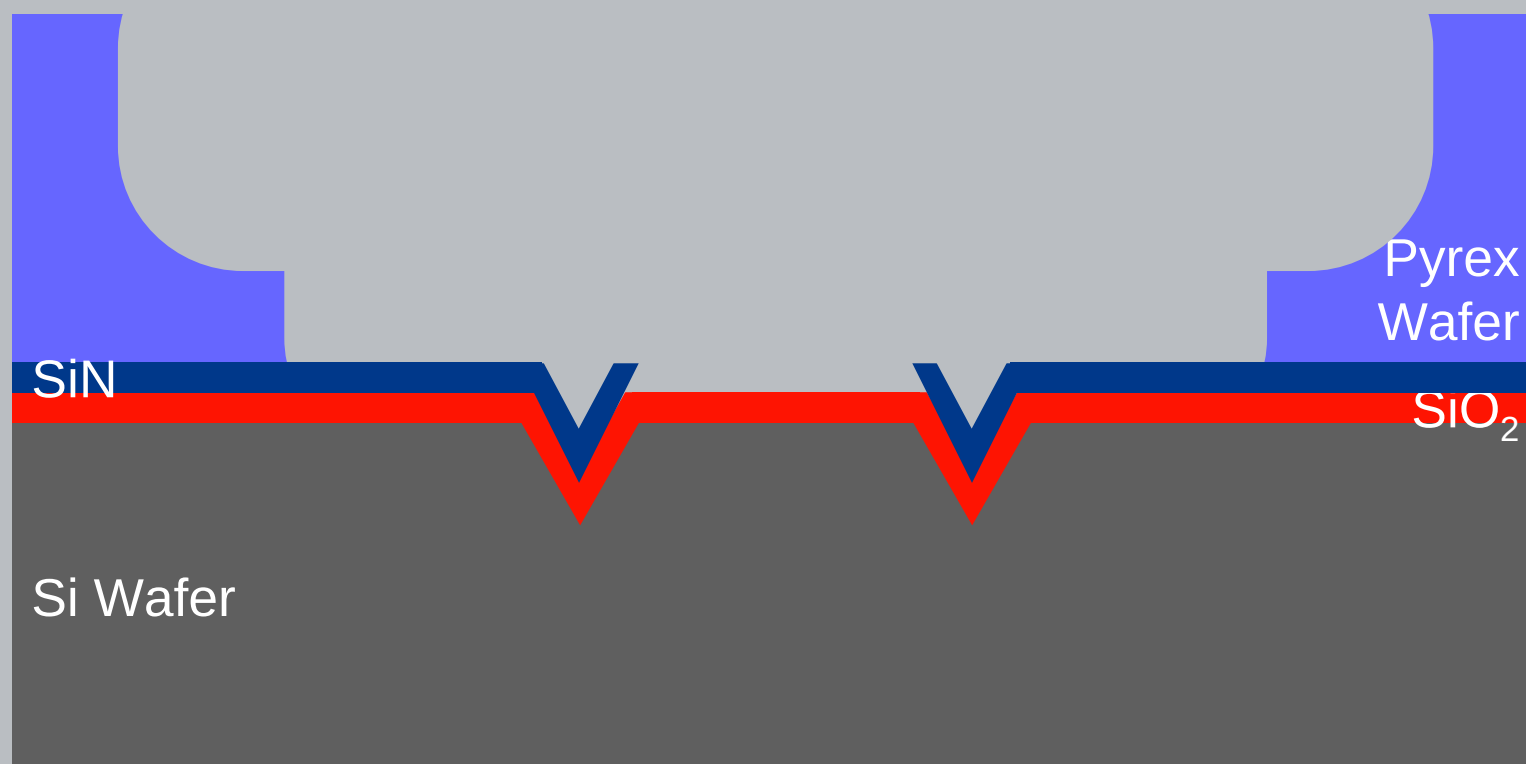
Fabrication steps of nitride probes (24/28)

17) Dicing



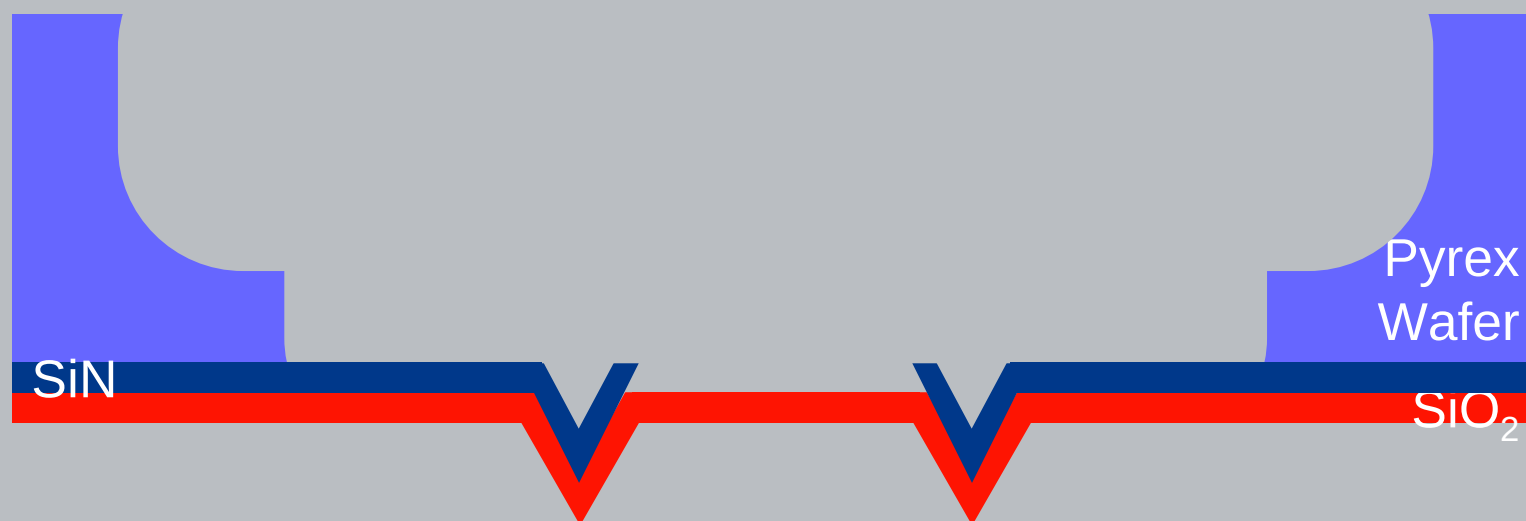
Fabrication steps of nitride probes (25/28)

17) Dicing



Fabrication steps of nitride probes (26/28)

18) Silicon etching in KOH



Fabrication steps of nitride probes (27/28)

19) Oxide etching in BHF



Fabrication steps of nitride probes (28/28)

20) Coating of Gold for laser reflexion



Silicon Nitride Probes - Examples

● Features

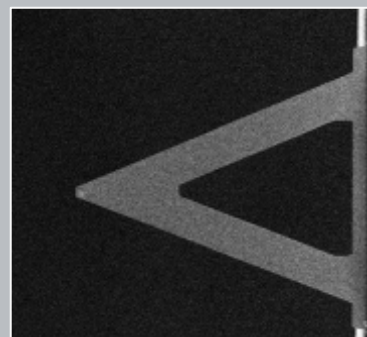
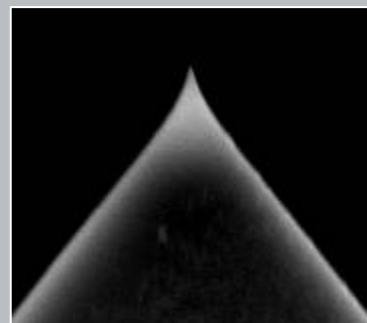
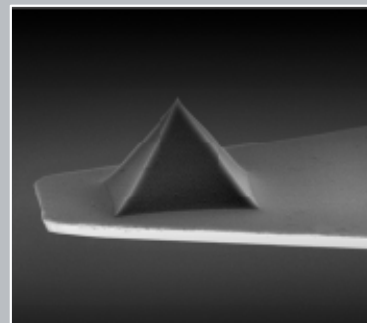
- Soft cantilevers (thin film)
- Variable cantilever shape
- Pyramidal tip shape

● Applications

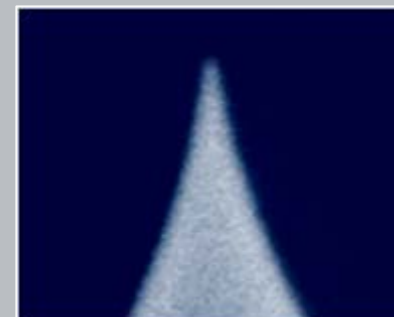
- Contact mode
- Measurement in fluid

● Potential

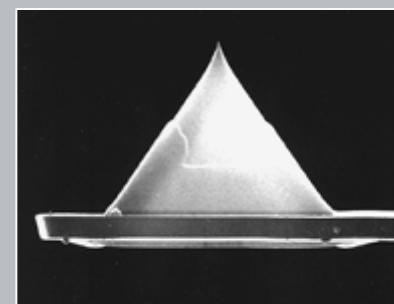
- Applicable for other materials as diamond, metal or SiO_2



NanoWorld
Pyrex-Nitride

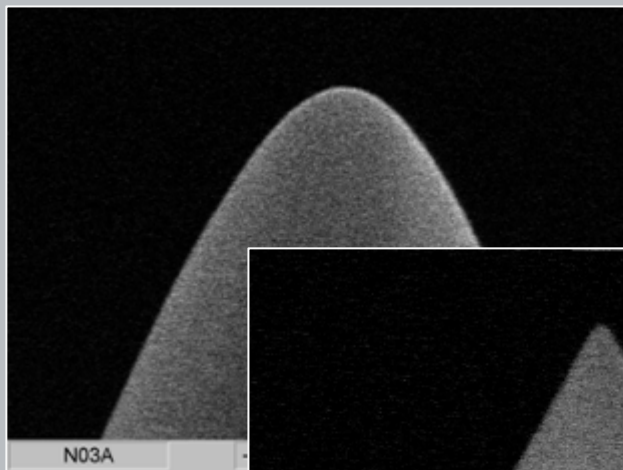


BudgetSensors®
BS-SiNi

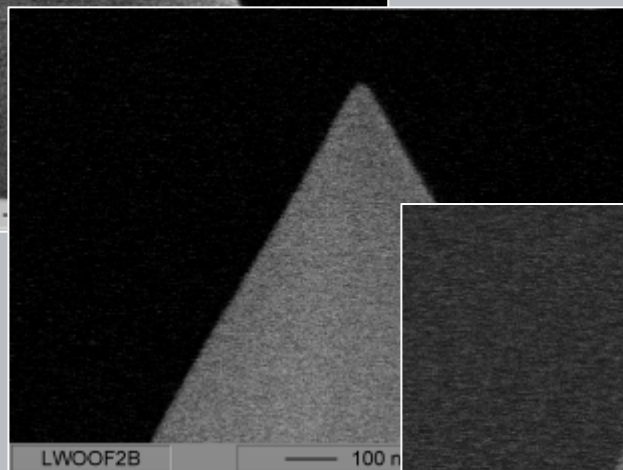


Olympus
SiN-Series

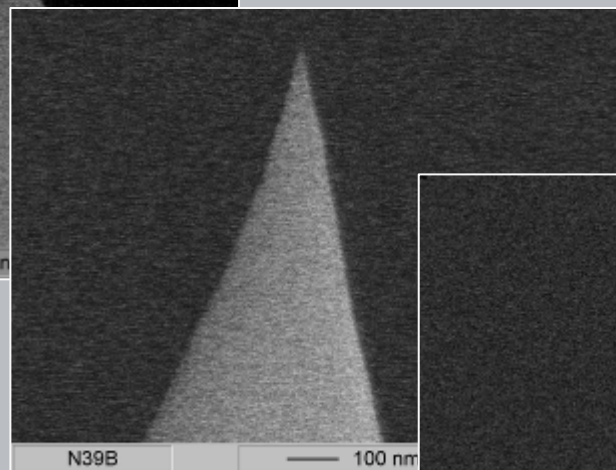
Tip shaping



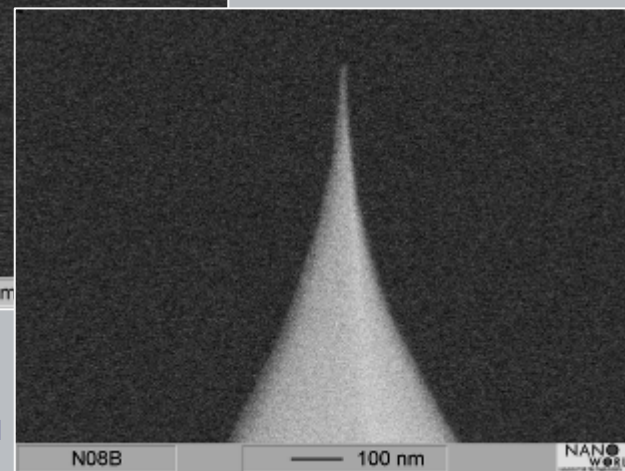
Rounded tip



Low wear out tip



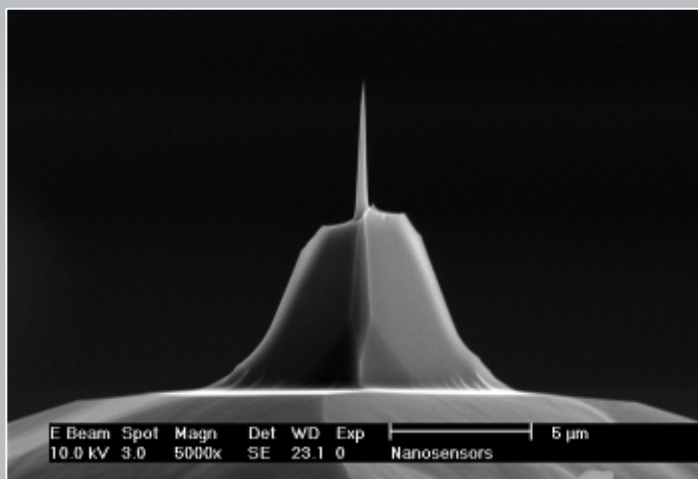
PointProbe®Plus



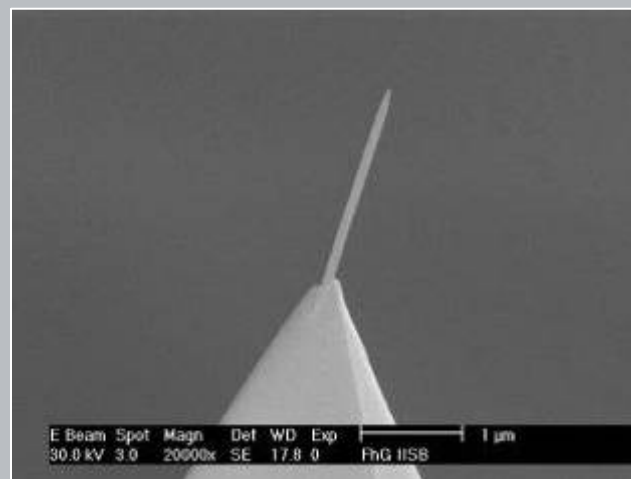
(courtesy NANOSENSORS™)

SuperSharpSilicon™

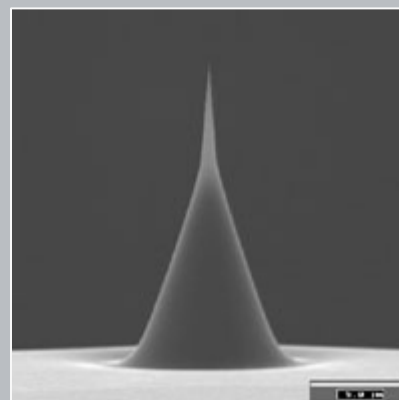
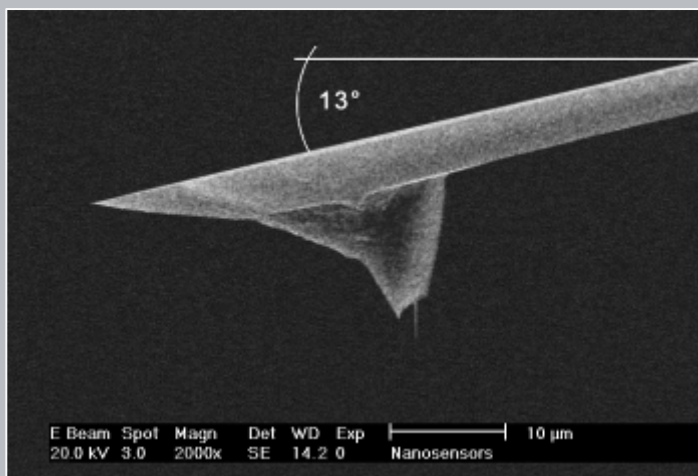
Tip refinement – High Aspect Ratio



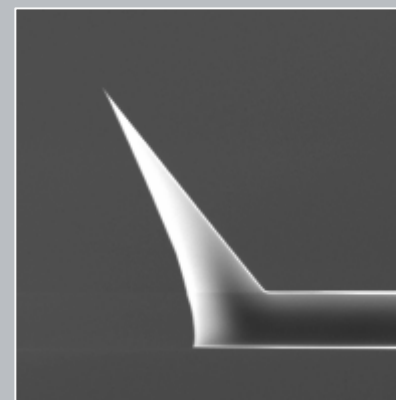
Focussed Ion Beam Milling



Electron Beam Induced Deposition



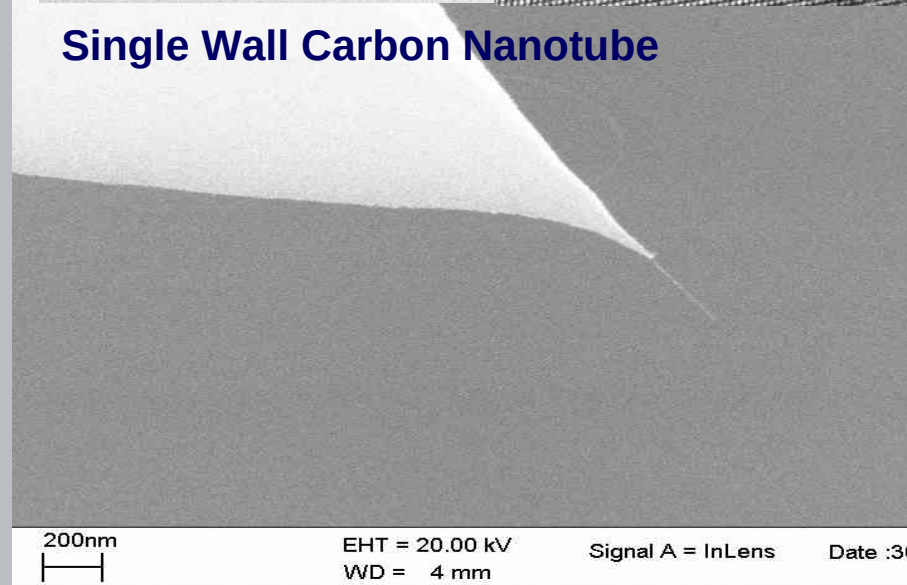
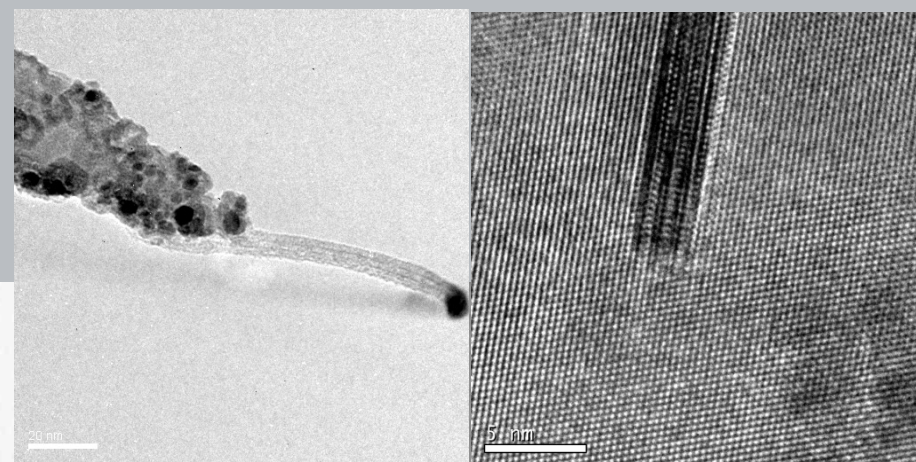
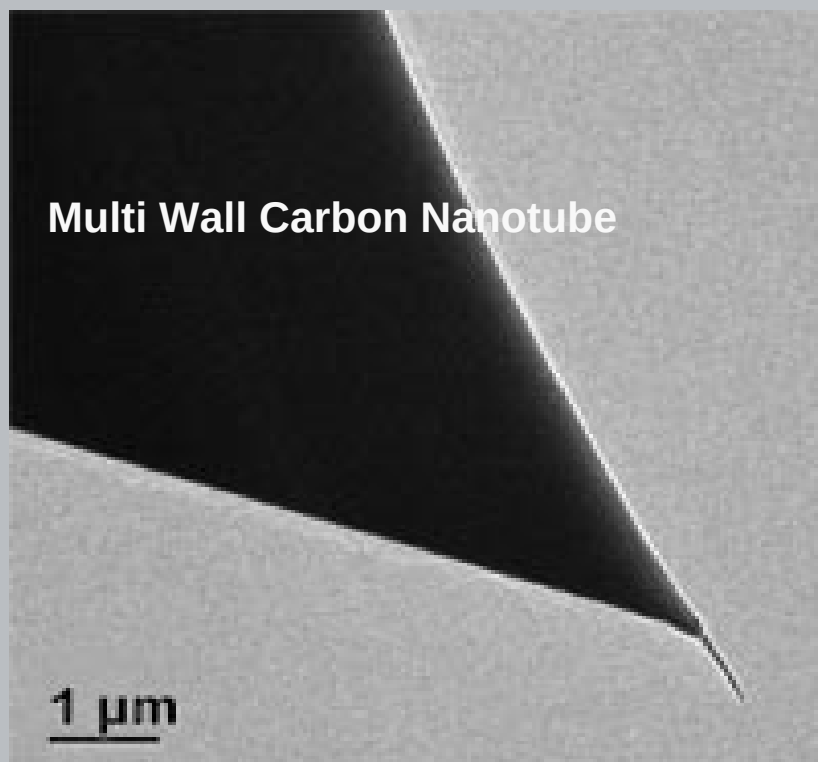
Team Nanotec GmbH



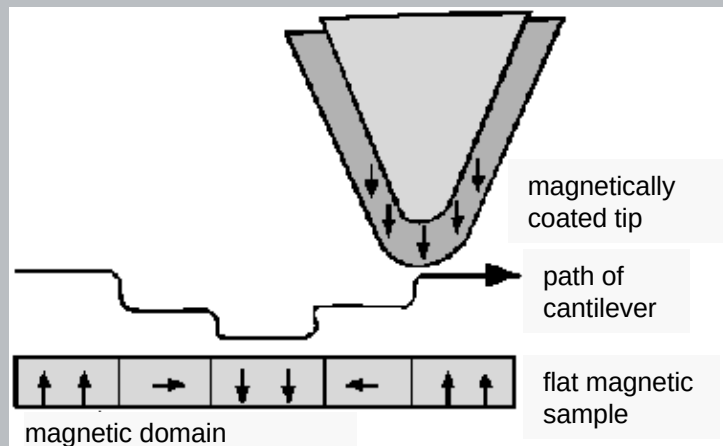
NANOSENSORS™ ATEC

Sophisticated Etching

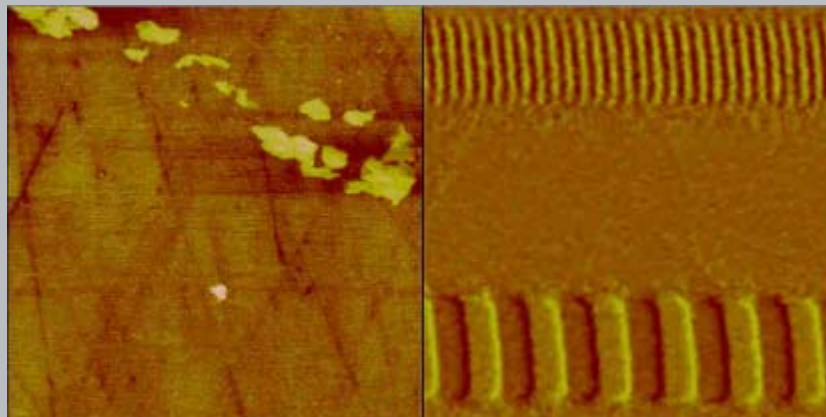
Tip refinement – Carbon Nanotubes



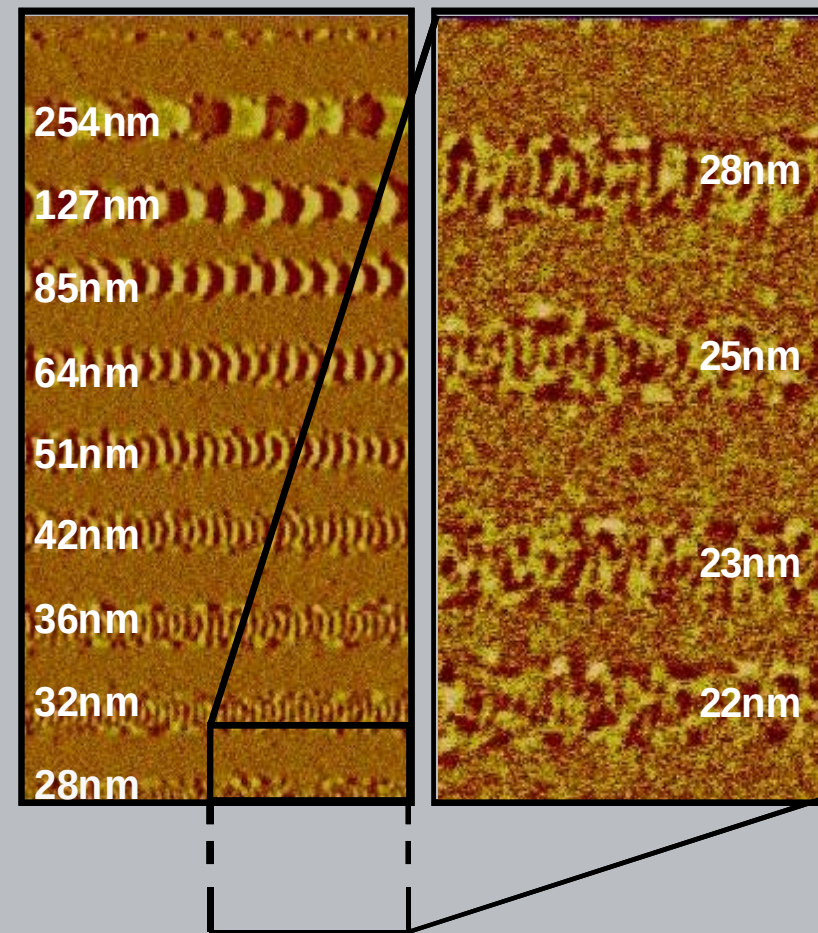
Functional coatings - Magnetic coatings



Magnetic Force Microscopy with coated SPM probe

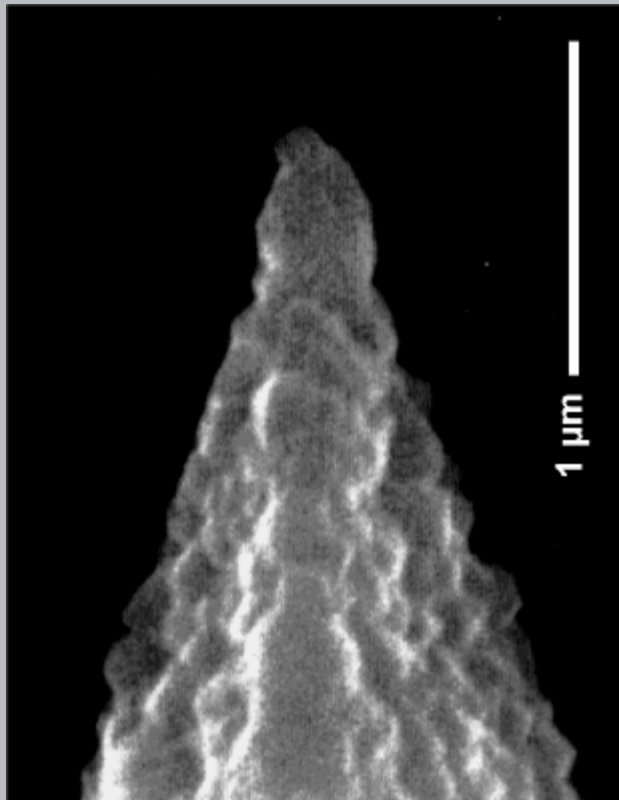


Experimental hard disc examined with a conventional MFM probe (Scan size: $14 \times 14 \mu\text{m}^2$)

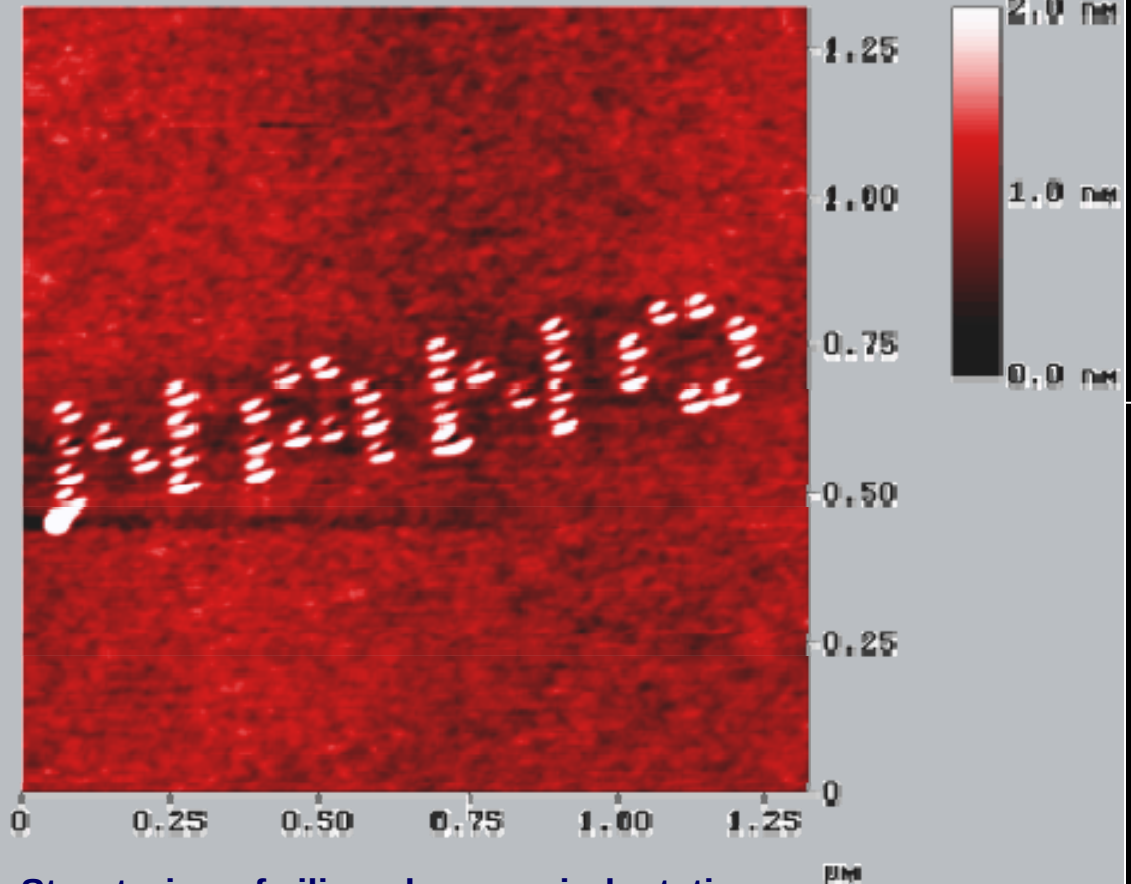


Performance test of a high resolution MFM probe at an state-of-the-art experimental hard disc (courtesy Maxtor Inc.)

Functional coatings: Diamond Coating

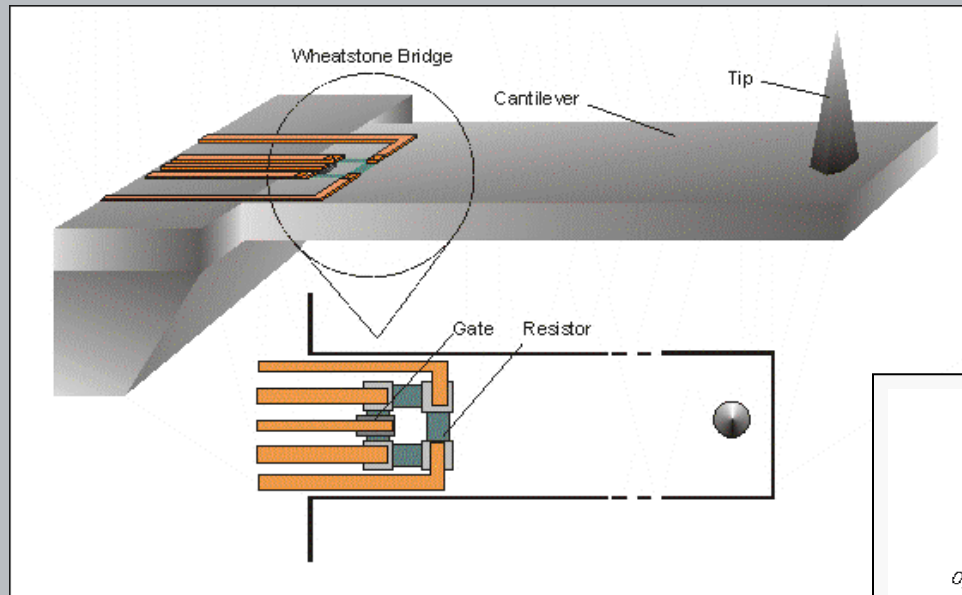


Polycrystalline diamond
(Thickness: 100 nm)

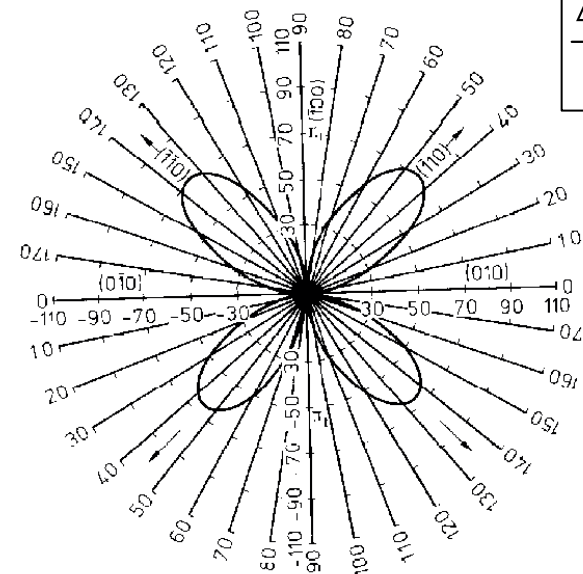


Structuring of silicon by nano-indentation
with diamond coated tips

Integrated Beam Deflection Detection Piezoresistive Strain Gauge



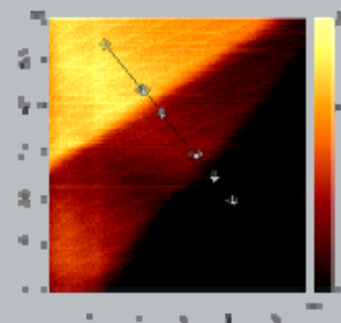
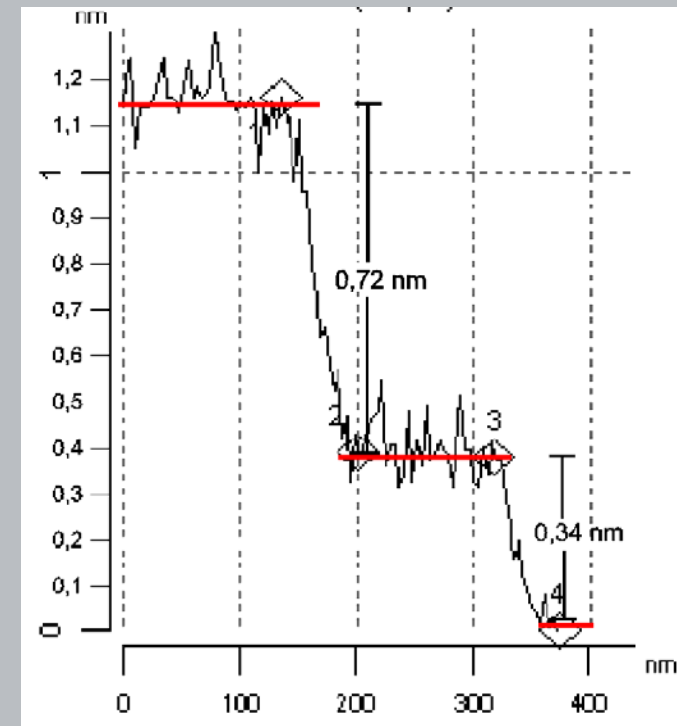
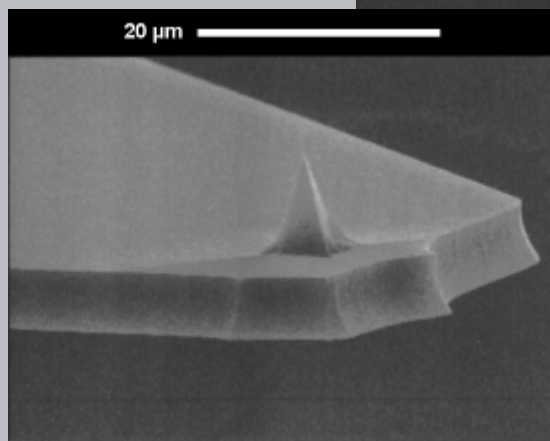
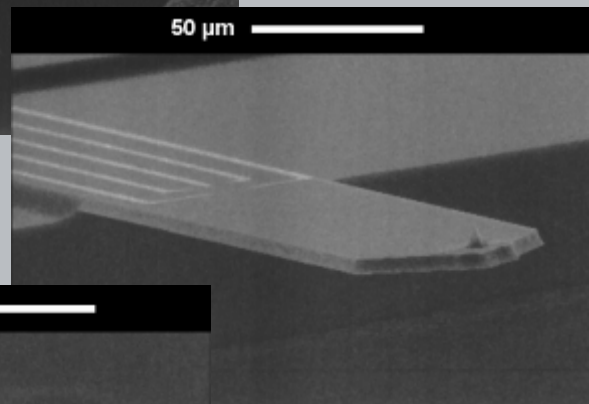
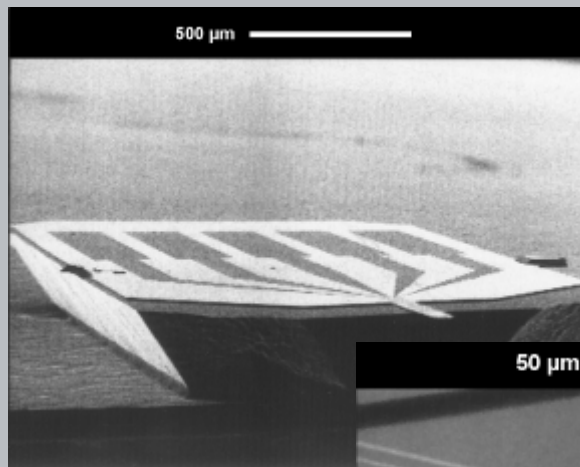
Cantilever beam with integrated piezoresistive strain gauge



$$\frac{\Delta R}{R} = K \frac{\Delta L}{L}$$

Piezoresistive effect with respect to the crystal orientation in p-doped silicon
(Y. Kanda, IEEE Trans. Electr. Dev. ED-29, 64 (1982))

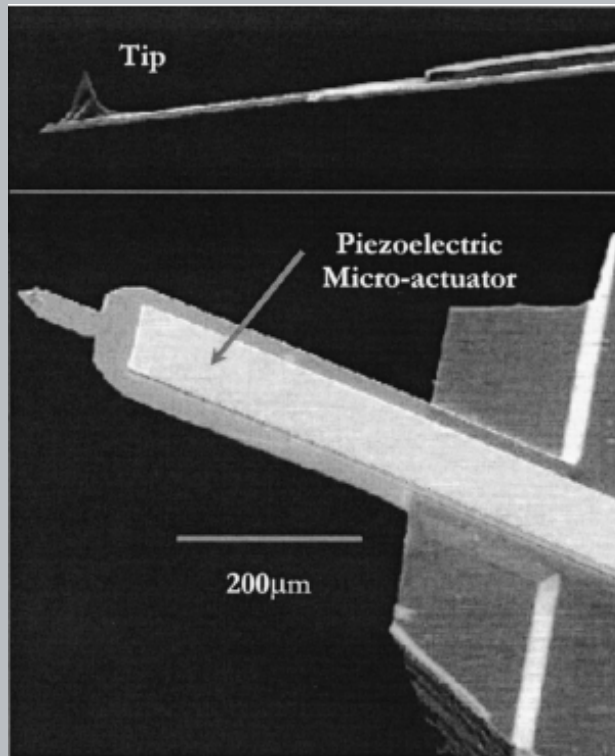
Integrated Beam Deflection Detection Piezoresistive Strain Gauge



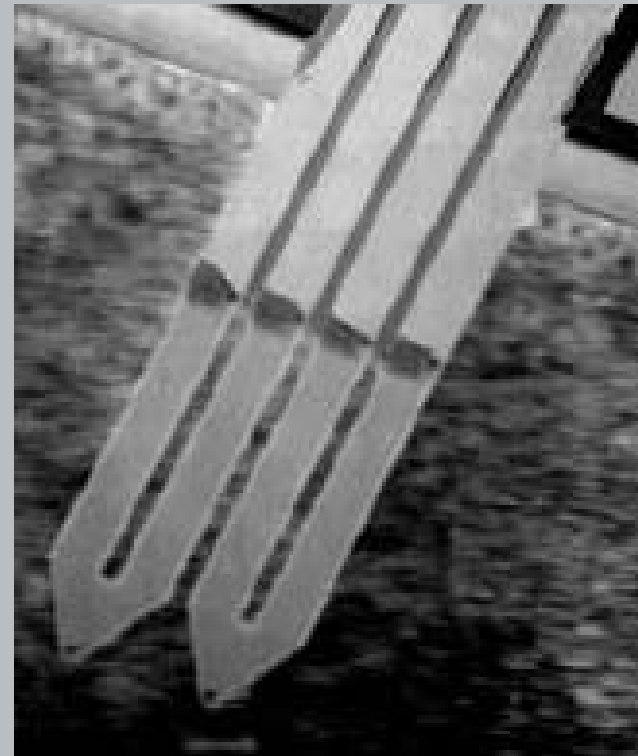
**AFM image of
graphite steps**
Scan size: 600x600 nm²

Integrated Actuator

Piezoelectric / thermal bimorph



„Active Probe“ with integrated ZnO actuator (courtesy: Veeco probes)



Piezoelectric actuator

S. Minne, et. al., Stanford University

Acknowledgement

Thanks to Oliver Krause for use of his excellent
Tip fabrication slides!