AFM Probe Manufacturing

Phil Russell
Appalachian State University

Slides Courtesy of:
Oliver Krause
NanoWorld Services GmbH

All mentioned company names and trademarks are property of the respective companies.
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

**Holder**
Macroscopic dimensions: 1.6 x 3.4 mm² for easy handling and mounting into the SPM

**Cantilever Beam**
Force constant range: 0.01 to 50 N/m
Resonance frequency: 1 kHz to 1 MHz

**Typical Geometry**
- Length: 50 to 500 µm
- Width: 20 to 50 µm
- Thickness: 0.4 to 8 µm

**Tip**
- Radius < 15 nm
- Tip height > 3 to 20 µm

**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

Si wafer

SiO₂

SiO₂
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

Diagram:
- Si wafer
- SiO₂
- 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
10) Anisotropic wet etching of silicon by KOH
done in several steps
10) Anisotropic wet etching of silicon by KOH
The formation of the tip is finished when the „oxide shield“ falls off
11) Isotropic wet etching of silicon oxide
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
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

Front View

Side View

Top View

NanoWorld Arrow™

NANOSENSORS™ AdvancedTEC™

Olympus Silicon Tip

NanoWorld

AdvancedTEC™
Fabrication steps of nitride probes

Fabrication steps of Pyrex-Nitride AFM probes
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
2) Tip photolithography on front side:
   b) Exposure through a chromium/quartz mask (UV light)

Fabrication steps of nitride probes (3/28)
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
12) Cantilever photolithography on front side:
   a) Spin coating of photosensible resist + Bake
12) Cantilever photolithography on front side:
   b) Exposure trough a chromium/quartz mask (UV light)
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
15) Dicing

Pyrex Wafer
16) Anodic bonding between the Silicon and the Pyrex wafer
Fabrication steps of nitride probes (23/28)

17) Dicing

SiN

SiO₂

Pyrex Wafer

Si Wafer
Fabrication steps of nitride probes (24/28)

17) Dicing
Fabrication steps of nitride probes (25/28)

17) Dicing

- Pyrex Wafer
- SiO₂
- SiN
- Si Wafer
Fabrication steps of nitride probes (26/28)

18) Silicon etching in KOH
Fabrication steps of nitride probes (27/28)

19) Oxide etching in BHF

[Diagram showing the process involving Pyrex Wafer and SiN]
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 SiO₂
Tip shaping

- Rounded tip
- Low wear out tip
- PointProbe®Plus
- SuperSharpSilicon™

(courtesy NANOSENSORS™)
Tip refinement – High Aspect Ratio

Focussed Ion Beam Milling

Electron Beam Induced Deposition

Team Nanotec GmbH
Sophisticated Etching

NANOSENSORS™ ATEC
Tip refinement – Carbon Nanotubes

Multi Wall Carbon Nanotube

Single Wall Carbon Nanotube
Functional coatings - Magnetic coatings

Magnetic Force Microscopy with coated SPM probe

Experimental hard disc examined with a conventional MFM probe (Scan size: 14x14 µm²)

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

Piezoresistive effect with respect to the crystal orientation in p-doped silicon
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!