Agilent Technologies AFM e-Seminar:
Understanding and Choosing the Correct Cantilever for Your Application

Why Probes Look the Way They Do
Concepts and Technologies of AFM Probes Manufacturing

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Overview

- **Introduction**
  - Tip sample convolution
  - General remarks

- **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

- **Integration of actuation and beam deflection detection**
The AFM image is a convolution / dilation of tip and sample. To image the sample as correctly as possible the „ideal“ tip shape would be: a delta function shaped tip with an orientation perpendicular to the sample surface.
General Remarks - Batch Fabrication

4-inch wafer with 388 probes

6-inch wafer with more than 1000 probes
General Remarks - AFM Probes Buildup

**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 20µm

**Material:** Single Crystalline Silicon or Silicon Nitride Thin Film
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Fabrication Steps of Silicon Probes - Undercut Tips

- **The undercut tip concept**

- Manufacturing by wet chemical (isotropic) etching of silicon
- Tip formation by underetching of masking layers
Fabrication Steps of Silicon Probes - Undercut Tips

- **Features**
  - High aspect ratio tips
  - Low tip radii
  - Thick cantilevers possible
  - Limitations in minimal cantilever thicknesses (very soft cantilevers) because of initial wafer thickness variations
  - Monolithic design

- **Applications**
  - All application modes (contact, non-contact, special) excluding operations in fluid.

- **Potential**
  - Integration of piezoresistive beam deflection detection
  - Integration of sensors
The “corner tips” concept

1. Isotrope silicon etching
2. Removal of masking layer, masking, top side mask removal
3. Tip formation by isotrope silicon etching

Manufacturing by combinations of dry (anisotropic) and wet chemical (isotropic) etching of silicon (patented technology)
Silicon Probes – Corner Tips Examples

**Features**
- Tip exactly at the free end of the cantilever
- Thick cantilevers possible
- Limitations in minimal cantilever thicknesses (very soft cantilevers) because of initial wafer thickness variations
- Monolithic design
- Reliable tip shape

**Applications**
- All application modes (contact, non-contact, special) excluding operations in fluid.
The mold and release concept

1. Isotropic etching of pyramids

2. Deposition of Silicon Nitride or various other materials. Structuring of the deposited material to define the cantilever.

3. Removal of the silicon. The deposited material acts now as tip and cantilever.
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

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BudgetSensors®
BS-SiNi

NanoWorld
Pyrex-Nitride
The shape of the probes apex could be modified from extremely sharp (2nm radius) to smoothly rounded (some hundred nanometers radius).
Tip Refinement – High Aspect Ratio Tips

- Samples with extreme topographies like steep edges or deep trenches could not be imaged properly with pyramidal shaped tips.
- To get tips with high aspect ratios material could be removed (advanced etching or Focussed Ion Beam milling) or an extra tip could be grown (Electron Beam Induced Deposition).

**Focussed Ion Beam milling**

- Sophisticated etching
- Electron Beam Induced Deposition
- Tilt compensated Focussed Ion Beam milling

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To get tips with high aspect ratios material could be removed (advanced etching or Focussed Ion Beam milling) or an extra tip could be grown (Electron Beam Induced Deposition).
Imaging High Aspect Ratio Features

- **Pyramidal**
- **FIB milled**
- **FIB milled, tilt compensated**

The hole will be measured most reliable with the tilt compensated Focused Ion Beam milled tip (green line in the section below).
Tip Refinement – Carbon Nanotubes

Multi Wall Carbon Nanotube

Single Wall Carbon Nanotube
Functional Coatings - Reflex Coating

Bulk silicon

Bare silicon cantilever

Silicon cantilever with Aluminum reflex coating
Magnetic Force Microscopy with coated SPM probe

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

Polycrystalline diamond
(Thickness: 100 nm)

Structuring of silicon by nano-indentation with diamond coated tips
Functional Coatings
Conductive Diamond Coated Tips

Applications:
- Scanning Spreading Resistance Microscopy (SSRM)
- Tunneling AFM (TUNA)
- Scanning Capacitance Microscopy (SCM)

Cross-section of a CMOS transistor (SEM)

Surface potential images of a transistor under working conditions
(gate width: 0.3 µm, source potential: 0 V, drain potential: 1 V), courtesy of IMEC
Functional Coatings

- **Platinum**
  - EFM, Surface Potential Imaging

- **Gold**
  - Functionalization for biological application

- **Diamond Like Carbon**
  - Wear-out protection
Integrated Actuation and Readout Hybrid-Approach – “Akiyama-Probe”

A self-sensing and -actuating probe based on a quartz tuning fork combined with a micromachined cantilever for dynamic mode AFM

www.akiyamaprobe.com
Integrated sensors and actuators for individually addressable cantilevers

www.pronano.org

Array of individually addressable cantilevers with integrated silicon tip

32D  50 μm
Thank you for your attention