The Development of MEMS-Based Time-Of-Flight SFM

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Outline

1. Introduction.

2. Concept of MEMS-based TOF-SFM.

3. Experimental results.
Conventional methods for chemical analysis

Atom probe: Erwin Müller in 1968 (FIM+MS)

Basic configuration of the AP with TOF-MS

Mass analysis ($m$)

$$m = 2neV_T t^2/L^2$$

Where $t$ is the flight time,

- $e$ is electric charge of electron,
- $L$ is the flight length,
- $V_T$ is applied voltage pulse,
- $n$ # of electrons

Min. field for ion evaporation: $10^8$ to $10^9$ V/m

Drawback: Sample needs to be a very sharp tip

Recent approaches

- Scanning atom probe (SAP): O. Nishikawa in 1994
- Scanning tunneling atom probe (STAP): J. Spence in 1995
TOF-SFM based on MEMS technology

Scanning force microscopy (SFM)
SFM is an important tool to make a 3D surface image of solid surfaces at atomic scale resolution.

Time of flight (TOF) mass spectrometer
Time-of-flight mass spectrometer is a powerful tool to identify the chemical property of solid surfaces.

MEMS-based cantilever device

Combination of advantages in both techniques allows chemical and topographical analyses on a nm scale.
Basic of the TOF-SFM concept

Advantages of this approach for TOF-SFM

1. There is no sample limitation.
2. A short tip-electrode distance to minimize the ion extraction voltage.
3. Fast switching between the SFM and TOF mode (msec's)
SEM of fully assembled cantilever device

To common line
To piezoresistance
To heater

Switchable cantilever
Extraction electrode
In-plane tip

A tip-extraction electrode distance of 10 µm achieved by LEGO microstAGE

Previous systems | MEMS-based switching device | TOF-SFM concept | Design concept | SEM images
Deflection vs. frequency characteristics

Maximum switching speed: ~ 10 msec

TOF-SFM measurements can be done orders of magnitude faster than with currently available systems.
Topographic image at dynamic AFM mode

- Regulated on constant amplitude with integrated piezoresistive detection.
- Pressure $p < 10^{-9}$ mbar.
- Preamplifier in vacuum ($G = 100_{UHV} \times 100_{air}$)

Displacement vs. power  Displacement vs. driving Fr.  **AFM imaging**  Field emission  TOF analysis

2000 nm$^2$; $z \in [0, 0.250]$ nm
1000 nm$^2$; $z \in [0, 0.180]$ nm
500 nm$^2$; $z \in [0, 0.113]$ nm
Field emission behaviors

Pt-coated tip

Turn-on field emission for the Pt-coated tip has demonstrated with an extraction voltage as low as 15 V

Fowler Nordheim plot

Pt-coated tip

Platinum coated TOF Cantilever

Si TOF Cantilever

Displacement vs. power
Displacement vs. driving Fr.
AFM imaging
Field emission
TOF analysis
TOF analysis using the SC with the Pt tip

30 pulses at $U_{DC}=800$ V and $U_P=-240$ V

$Si^+$ and $Pt^{2+}$ peaks of Pt-coated tip at mass to charge ratio of 28 and 97.5