Atomic Force Microscope

HOW DID WE GET HERE?

Invention of STM

From their research at IBM Zurich, Gerd Binnig (right-Germany, 1947) and Heinrich Rohrer (left-Switzerland, 1933) invented scanning tunneling microscopy (STM). They received the Nobel Prize in 1986 for their work.

Scanning Capacitance Microscope

3 years later, Martin combined the existing scanning capacitance microscopy (SCAM) from RCA's J.R. Matey with AFM and introduced the technique now known as SCM.

SSRM

During his PhD at the University of Leuven, Peter de Wolf (pictured) worked under Wilfried Vandervorst from IMEC and together they combined Spreading Resistance Profiling (SRP) with AFM to create nano SRP now known as Scanning Spreading Resistance Microscopy or SSRM.

1981

1985

1988

1989

1995

First Atomic Force Microscope

Gerd Binnig was a visiting scientist at Calvin Quate (USA 1923)'s group in Stanford where they were able to demonstrate first AFM together. By 1987, IBM scientists Yves martin and Kumar Wickramasinghe came up with a non-contact AFM.

Sung Park

Sang Il Park

First Commercial AFM

Following the collaboration with Calvin Quate at Stanford, Sang-Il Park and Sung Park founded Park Scientific Instruments and offered the first commercial AFM. As of today, both founders are still working in the frontier of AFM technology development. Sang-Il Park with Park Systems and Sung Park with Molecular Vista.

HOW DOES IT WORK?

Technical Background

AFM is based on what is known as Scanning Probe Microscope (SPM) technology which uses piezo-electric materials for the scanning of sample surfaces with atomic precision. The first SPM was the Scanning Tunneling Microscope (STM, Figure 1) which uses an atomically sharp metal tip to read the surface morphology through tunneling current reading. Even though STM opens a new horizon of direct measurement of sample surfaces at the atomic level, it can only analyze either conductive or semi-conductive samples and is unable to be used for insulating materials. Another limitation of STM is that the analysis can only be made for samples under ultra-high vacuum (UHV) since the surface needs to be clean of the ambient organic contaminants. AFM was invented to extend the SPM technique to non-conducting materials by measuring the interatomic forces between the tip and the sample instead of the tunneling current. Currently, there are more than 40 different variations of SPM technologies.

Figure 1. Typical STM head on UHV flange

The basic mechanism of AFM is shown in Figure 2. Light from a laser is bounced off from the cantilever into a photodetector, which reflects the bending of the cantilever caused by the interaction between the tip end and the surface right below it. The tip can be designed to monitor various types of interactions. This includes not only van der Waals force (typical application of AFM) but also electric, magnetic, electrochemical, fluidic forces, and so on. These days, AFM is even applied to spectroscopic applications such as FTIR (nano-FTIR) and Raman (nano-Raman), which provides extremely surface sensitive (~ 3 nm) material information.

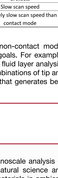

Figure 2. Diagram of the laser beam reflecting off the cantilever surface. (a) A new AFM tip and (b) a used AFM tip

Figure 3. (a) A new AFM tip and (b) a used AFM tip (http://www.nanoscience.gatech.edu/zlwang/research/afm.html)

There are three operation modes–contact mode, tapping mode (TM), and non-contact (NC) mode.

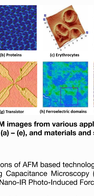

Figure 3. (a) Lennard -Jones potential curve of tip-sample separation illustrating the main interaction during AFM scanning. (b)-(d) The AFM imaging modes for each regime are also shown. (J. Funct. Biomater. 2017, 8, 7)

Operation Mode	Working Principle	Advantage	Disadvantage
Contact	Physical contact	High scan speed and high resolution	Damage to soft sample and image artifacts
Non-contact	No physical contact	No damage to sample	Slow scan speed
Tapping	Intermittent and short contact	High lateral resolution with minimal damage	Relatively slow scan speed than contact mode

Table 1. AFM Modes of Operation

There are three operation modes – Tapping mode, contact mode, and non-contact mode. Operation mode can be selected based on the sample type and analysis goals. For example, contact mode is used for quick imaging of rough samples, tapping mode for fluid layer analysis, and non-contact mode under UHV condition. As there are many different combinations of tip and sample materials, the analyst usually tries all three modes and selects one that generates best quality image data.

APPLICATIONS

AFM is one of the most effective imaging techniques being used at the nanoscale analysis of surfaces. It has been applied to multiple problems across the field of natural science and engineering, since AFM can record a range of material surface properties materials in ambient, liquid, and UHV condition. Disciplines areas includes:

- Semiconductor science and technology
- Thin film and coatings
- Tribology (surface and friction interactions)
- Surface chemistry
- Polymer chemistry and physics
- Cell biology
- Molecular biology
- Energy storage (battery) and energy generation (photovoltaic) materials
- Piezoelectric and ferroelectric materials

Another emerging application of AFM is the study and characterization of graphene composite materials.

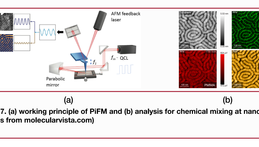

Figure 4. AFM images from various applications. Life science (a) – (e), and materials and surface science (f) – (j)

Other Varieties of AFM

Among more than 40 variations of AFM based technologies, we will briefly cover three advanced technologies – 1. Scanning Capacitance Microscopy (SCM), 2. Scanning Spread Resistance Microscopy (SSRM) and 3. Nano-IR Photo-Induced Force Microscopy (PiFM).

1. SCM measures the electrostatic capacitance between the surface and the probe end generating line scan or mapping data. The probe tip end is coated with highly conductive metal material such as Co/CR or Pt/Ir so that it forms either metal-insulator-semiconductor (MIS) capacitor or Schottky capacitor with the sample surface depending on the existence of surface oxide layer. With the alternating bias to the probe, the varying capacitance property between the probe end and the surface is monitored as the surface capacitance changes.

Traditionally, the analysis of dopant type and distribution in reverse engineering of devices was done by wet staining, which began to show its limitation as interfaces tends to be destroyed during the wet process with the shrinking dimension of devices. As SCM reads the capacitive property, it is now a perfect replacement of the wet staining in dopant analysis for nano-scale device dimensions. The other applications are P-N junction delineation and front-end failure/leakage analysis. In the SCM operation, you can collect both topography and capacitive mapping together which helps the understanding of the dopant distribution through the topography.

(a) (b)

Figure 5. (a) SCM setup and (b) SRAM twin-well structure imaged by SCM (Images from (a) Park Systems and (b) MA-tek)

2. SSRM is a SPM version of Spreading Resistance Probe (SRP) which measures the cross-sections as opposed to the beveled surface by SRP. Like SCM, SSRM also uses conductive probes but with higher loading force to make the spreading resistance the dominant contribution to the resistance. SSRM is an efficient way to measure the resistance profiles defined by the distribution of dopant atoms to surface normal direction. It started to be used for reverse engineering of semiconductor devices quite recently.

(a) (b)

Figure 6. (a) SRP vs SSRM (b) Comparison of topography and SSRM images (Images from (a) folk.uio.no and (b) hitachi.com)

3. PiFM is a newly emerging technology that extends the SPM technology to the nano-scale spectroscopy regime. It consists of a conventional AFM equipment coupled with a laser light source that excites the specific polarization of the material between the probe tip and surface which affects the metalized AFM tip in generating the spectra corresponding to the various nanostructures. Considering the sampling depth of traditional FTIR is a few um, PiFM generates highly surface sensitive signal (typically less than 5nm) and provides chemical mapping with high spatial resolution (< 5 nm). Therefore, PiFM serves well for the characterization of nano-scale thin films for applications in semiconductor industry. IR PiFM spectra agree well with bulk FTIR spectra when the sample is homogeneous in nanoscale so that the existing IR spectral database can be used to identify unknown nano-sized defects. However, if the sample is heterogenous in nanoscale, then the FTIR spectrum will be an ensemble of the nanoscale IR PiFM spectra from different regions.

(a) (b)

Figure 7. (a) working principle of PiFM and (b) analysis for chemical mixing at nanoscale (Images from molecularvista.com)

CUSTOMER SERVICE WORKFLOW

STEP 1 — Consult with Our Technologists

STEP 2 — Provide Your Samples

STEP 3 — Receive In-Depth Report

STEP 4 — Debrief with Our Technologists

WHY CHOOSE OUTERMOST TECHNOLOGY FOR AFM?

1. Top quality services using the latest AFM tool
   - NX20 from Park System for AFM/C-AFM/SCM/SSRM
   - VistaScope from Molecular Vista for PiFM
2. Good turnaround time of 3 – 4 days (for AFM)
3. Unbeatable pricing
   - From *$180 per sample which include 3 images
   - Minimum order of 3 samples
4. Advanced AFM modes (C-AFM, SCM, SSRM)
5. Comprehensive analytical reports
6. Quality Assurance Program (QAP) to guarantee quality

VistaScope from Molecular Vista

N20 from Park System