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Experimental Investigation Scanning by Atomic Force Microscopy

Amal Jamal Bouker

Tripoli University – Faculty of Education ,
Janzour. Physics Department
Tripoli- Libya
E- mail amal_boukar@yahoo.com

Eman Aleajili Daman

Collage of Engineering Technology
Janzour -Libya
E-maill Damann@gmail.com

Abstract— **The purpose of this paper is investigating a technique of scanning by atomic force microscopy which it has divided to two parts, the first portion gives review about the principle and components of atomic force microscopy (AFM) and investigate AFM tip and cantilever fabrication , the second part is a reference to example of experiment to scan sample which is called Microstructure which has stock pits are about 100 nm in depth and the periodicity of the lattice is 10 µm in x and y axes by using this technique that has been carried out and explain the image analysis whish has been got. In this section the AFM detects the force interaction between a above sample and a very tiny tip (<10nm radius) fixed on a cantilever with a very low spring constant (k) which range about (<10N/m). The force interaction between sample and tip is relevant to the deflection of the cantilever. the more the tip presses into the sample the greater the deflection of the cantilever and the greater the force exercised on the sample, the cantilever must be moved away from the surface or towards the surface depending on how the force changes. This movement is then recorded as topography signal when the tip is scanned over a sample.**

.Keywords— scan, AFM probe, Microstructure , topography ,amplitude.

I. INTRODUCTION

After invention of the scanning tunneling microscope (STM) which was a revolution in the field of high resolution microscopy, however, this technique could only be used to image conducting samples. New scanning probe microscopes (SPM) based on the STM principle have therefore been invented. among those was The success of AFM is due to its capability to achieve atomic resolution and to simultaneously measure topography and other force-related material properties.

AFM could be used to image a huge variety of samples which of course did not need to be electrical conducting samples. The atomic force microscope (AFM) is being adapted by industry as a tool for in line fabrication metrology. The last two decades have witnessed the evolution of the AFM into a versatile instrument, with many new scanning force techniques presently being developed. Consequently, the AFM has wide industrial applications from conventional surface roughness measurement of thin films to the characterization of magnetic domains as related to the information storage industry. [1, 2].

There are a number of challenges that must be resolved in order to fully realize the potential of AFM as future nanoscale inspection tools for the information technology industry. Improvement in AFM tip technology is one of the most important factors for AFM to be fully adapted by industry.

AFM probes are typically micro-fabricated. The single-leg or V-shaped cantilevers are usually made out of silicon, silicon-dioxide or silicon-nitride. Typical cantilevers are several hundred micrometers long, several tens of micrometers large and on the order of one micrometer thick. For silicon these dimensions will result in spring constants between 0.1 and 1N/m and resonance frequencies between 10 and 100kHz.

II. AFM TIPS AND CANTILEVER FABRICATION

The tips are commonly fabricated from silicon, silicon nitride or diamond (for hardness testing only) and are left bare or coated with a special material (metal for EFM and rare-earth boride for MFM) to suit a particular application. The tip is mounted on a thin cantilever whose deflections provide a measure of the interaction. forces. [3]

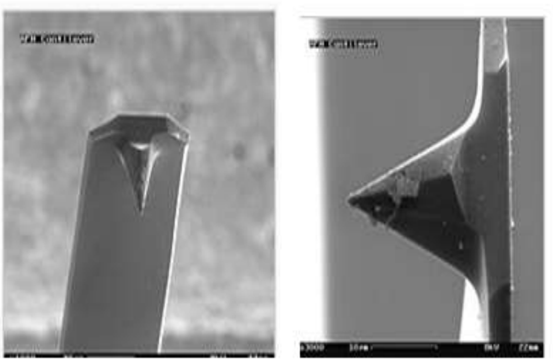

Fig.1 AFM Probe: Tip and cantilever of an AFM probe.

Currently commercially available AFM tips are microfabricated in three geometries, namely: (1) conical, (2) tetrahedral, and (3) pyramidal. Conical tips can be made sharp with a high aspect ratio (the ratio of tip length to tip diameter) making them especially useful for imaging features that are deep and narrow. Conical tips with diameters of 5 nm have been made, but they are easily broken. The pyramidal and tetrahedral tips have lower

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aspect ratios with tip diameter ranging 10nm to 50 nm. These latter tip configurations are duller, but more durable.

The first step in the fabrication of an AFM tip is the etching of a single-crystal silicon wafer with specific crystalline orientation. This results in the forming of square pyramidal tips with characteristic angles. [4, 5]

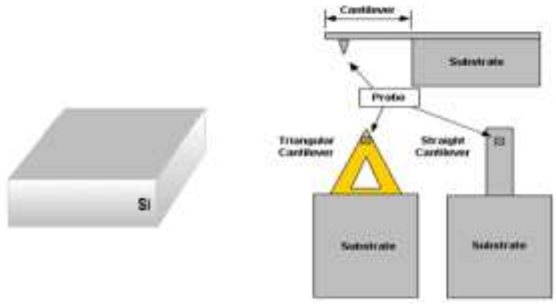


Fig.2 Steps used in fabricating pyramidal AFM tip and cantilever..

In this review a detailed analysis of cantilever has been carried out, cantilevers are not more than a beam. Cantilevers are of various types; this classification is based on the connection of its both ends if it is connected from its one end while the other end is free to move then this type of cantilever is named as fixed-free cantilever. On the other hand if both ends are fixed then it is called fixed-fixed type of cantilevers.

the good cantilever should have a high spring constant for excellent performance, because high spring constant of the value of 10 to 300 N per meter is required to generate the higher pressure around or under the tip of the device .

the Selection of material during fabrication of cantilever is another important factor. the commonly used material for cantilever fabrication is Ni that is in electrodeposited form .

The choice of a compatible material to the process of fabrication is very important to fabricate a high quality cantilever; in some cases an additional deposition of TaN is required as a middle layer for better performance.

There are other materials that are used in small amount to serve various purposes, e.g., Ti layer is use for the protection of Cu material from corrosion or erosion process, moreover people have use Cu as a basic layer in Ni based cantilevers and that is coated by the Ti to avoid oxidation process. But the common process involves the use of silicon. [6]

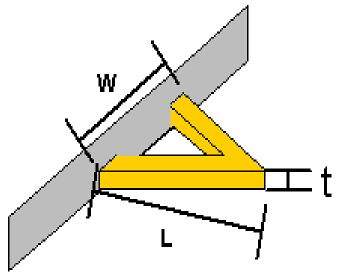
Cantilevers are usually fabricated as triangles or straight. During their use in the instruments, small deflections are normally used, so the forces measured obey Hooke's Law which is:

$$F= - k\, z \quad , \quad f = 1/2\pi$$

In the above relation, the force is F (Newton), the spring constant for the cantilever is k (Newton/meter) and the deflection is z (meter).

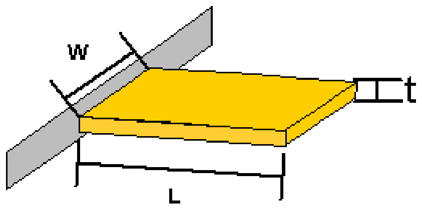
The spring constant (k) of the cantilever is strongly dependent on its physical dimensions (i.e., width - w, length - l, thickness - t) and the elasticity of material (Modulus of Elasticity - E) that it is composed of the spring constant for the triangular cantilever is approximately expressed by this equation :

$$K= E\ t^3\, w/4l^3$$



For the straight cantilevers the spring constant can be estimated by:

$$K= E\, t\, w/\, l$$



III. THE AFM EXPERIMRNT SET UP

basically , the techniqe of AFM is a strighforward and it is not diffecult to scan. A great application of high resonant frequency of cantilever is atomic force microscope. At high resonant frequency cantilever move to the high response band and thus there would be a fast and efficient, less time to scan. At high resonant frequency mode cantilever require less spring constant, all because of less damaging operation in contact mode. While considering the non-contact mode there is another application of the high resonant frequency mode of cantilever, it would have low spring constant that is good to make an image of atoms on a sample surface. It has chossen a sensor which detects the cantilever deflection which needs to be very sensitive and should be implement in different ways, for example a laser deflection system or piezoresistive system. Also, a Sharpe tip which reaching about **(**<10nm radius**)** based on a sensitive cantilever and to regulates the force interaction has chosen a feed-back system then to records movements and controls the feedback has used computer software to measured data. [7].

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In AFM the force sensor requires to meet the two following mode:

• Contact Mode: The cantilever spring constant needs to be small, such that sufficient deflection can be detected. Ideally the spring constant should be smaller than the inter atomic spring constant, which is about 10N/m.

• Dynamic mode: in this mode the cantilever is oscillated with much greater amplitude then the tip can touching the surface periodically, The portion of perturbation transmitted to the cantilever is given by the following equation :

$$a_{trans} = a_0 (f_0 / f_{res})^2$$

where f_0 is the excitor vibration frequency with amplitude

a_0 and f_{res} is the resonance frequency. It is therefore usual to use cantilevers with high resonance frequency in order to avoid low frequency acoustic or mechanic perturbation such as building vibrations.

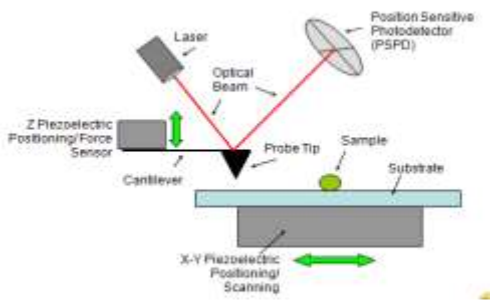

Fig.3 components of an AFM setup.

IV .Scanning Microstructure sample

The microstructure sample consists of a structured silicon dioxide layer on silicon. The structures are regularly distributed squares. Depending on the stock pits are about 100 nm in depth and the periodicity of the lattice is 10 µm in x and y axes, the sample has square silicon dioxide island or square holes in the silicon dioxide layer. This kind of sample is often used to calibrate the orthogonality of a microscope imaging device.

Fig.4 AFM scan head on the sample stage.

A . The Proportional Integral Differential Feedback System

Basically ,it must understand the system work of feedback regulation before taking any measurement and starting scan because this regulation helps the acquisition of an AFM image. As investigated previously, , the cantilever deflection is detected by a sensor. This position is then compared to a set-point, i.e. a constant value of cantilever deflection chosen by the user so, directly the cantilever will be related to the tip-sample interaction force .the error signal is can be generated when There is difference between the actual interaction force and the desired force then error signal is then used to move the tip or sample to a distance where the cantilever has the desired deflection.

When this movement plotted in the function of the lateral position of the tip of atomic force microscopy then is called topography image. The main objectives of the feedback system is to reduce the error in a very fast manner so that the measured topography corresponds to the real topography of the sample..hence the error signal must be amplified by a PID amplifier and therefore PID gains must be adjusted.

b. Experiment measurment:

This kind of sample is in general quite easy to scan and can be straightforward measured and there are not any special settings to be considered. However due to the abrasive characteristics of the oxide layer, the tip quality decreases and quite fast compared to usual tip wear. this sample is ideal to learn and train how to optimize the PID feedback settings and vibration amplitude in dynamic mode. the vibration

amplitude must correspond to the size of the sample features .so, we Set the vibration amplitude to about 40mv and 400mv then the sample structure can be clearly seen at this size. after that Approach the reflective part of the sample then adjust the slope also, Adjust PID gains then we Found the optimum vibration amplitude.

c. Image Analysis:

to achieve the optimum resolution is crucial to Set the vibration amplitude . In Static mode the main parameter to regulate the image quality are PID feedback settings and Set point. In dynamic mode additionally the setting of the vibration amplitude plays a great role. In general the vibration amplitude must correspond to the size of the sample structure features.

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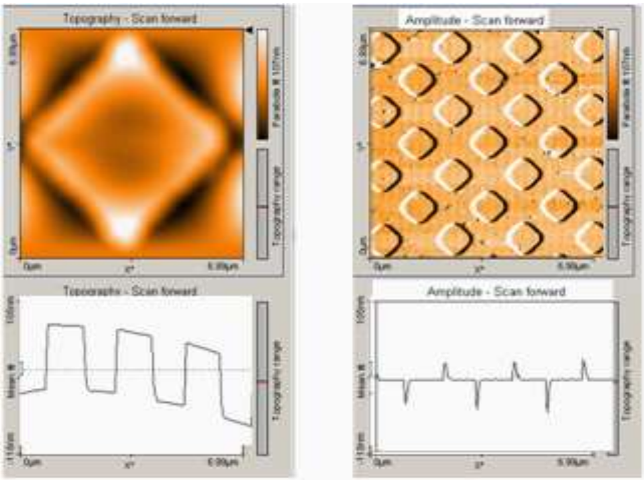

Fig.5: shows the topography and amplitude image of the microstructure sample.

It can be seen from the image Topography and amplitude of the microstructure sample. The line graphs show a cross section of the images above at the position indicated by the arrow. The vibration amplitude was set to 400mV**.** It is clearly visible that the in the topography the slopes are steep and after each perturbation the amplitude signal is also corrected to the Set point value very quickly.

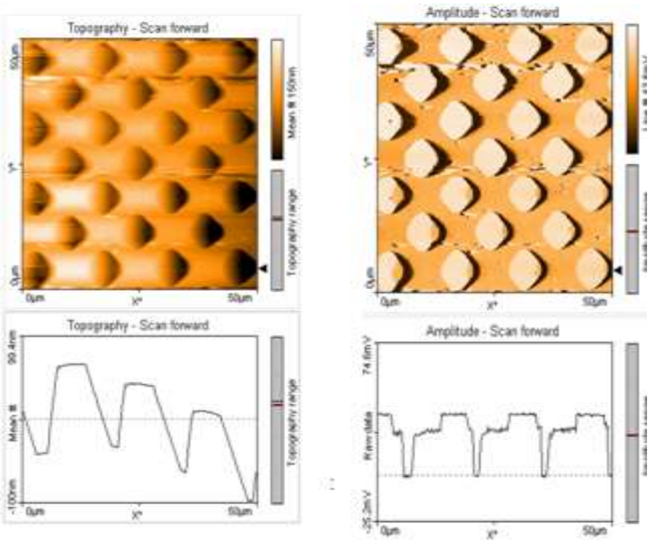

Fig.6: shows the topography and amplitude image of the microstructure sample at Vibration Amplitude Setting.

The line graphs presents a cross section of the images above at the position indicated by the arrow. The topography image is smeared out and the topography line graph shows a too small slope because of too low vibration amplitude.. The reason therefore can be found in the amplitude signal but the peaks are larger which mean that the correction to the amplitude to the Set point value is not quick .

d. The position image:

Another critical part of the AFM is the deflection measurement system. Ideally, the sensing system must be able to measure the deflection of the cantilever with angstrom resolution and must not perturb the cantilever in any way. The most used detection system is therefore an optical technique based on the reflection of a laser beam on the cantilever.

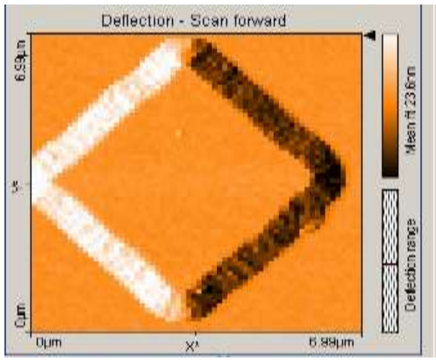

Fig7. shows deflection image of the microstructure sample.

A laser beam is focused on the very end of the cantilever which reflects it back on a segmented photo diode. The deflection angle of the cantilever is thereby enhanced, i.e. a small displacement of the cantilever results in a bigger displacement of the reflected laser beam on the photo diode. The further away the diode the bigger this mechanical amplification. However the photo diode can't be placed to far away because of external perturbation. One reason for that is that the laser deflection method is sensitive to the ambient light, the light reflected by the sample or the cantilever and other possible sources of light.

v. Conclusion

This paper described an investigation of one of the most success technique in the field of atomic resolution microscopy which is atomic force microscopy AFM that can make nanometer scale resolution measurements of topography and several other properties of a sample and presents summarizes about tip-cantilever fabrication which typically fabricate the tip from si or siN for ease fabrication and many variations depending on application and cantilever has law spring constant and law weight for high resonance frequency which coated for reflectivity. also, gives examples of experiment of scanning by using AFM technique . it shown that Topography and amplitude image of the microstructure sample as example measurement also explore Another critical part of the AFM which is the deflection measurement system. this experiment gives a unique opportunity to gain a new physical appreciation for that populate our world.

VI.REFERENCES

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