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Modelling of Atomic Force Microscope Probe with Base Motion in Media

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ABSTRACT

The sample can be analysed and characterised at atomic level by using Atomic Force Microscope.The AFM operation is done by allowing an extremely fine sharp tip to either come in contact or in very close proximity to the sample that is being imaged.In this project work Atomic Force Microscope modes, its tip and sample interaction and cantilever are studied. Air media is considered for work. The work is attempted to study these forces and the relationship between the tip and sample. The forces induced are useful to design the cantilever in different shapes and sizes. Analysis is done in ANSYS for stress and deformation.

Keywords— Microcantilever, Tapping mode, AFM, Microscope.

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I. INTRODUCTION

Scanning Probe Microscope (SPM) has two forms

- Scanning tunnelling microscope
- Atomic force microscope.

SPM is used to image and measure properties of material. Scanning tunnelling microscope with stylus forms atomic force microscope (AFM). AFM is invented in the year 1985. Working of AFM is similar as blind person reads a book. AFM has small probe which works similar as blind person's finger. AFM is used both in air and liquid media. Basic essential components of AFM are cantilever with sharp tip, scanner, and feedback control.

1) Tip: This tip is very tiny and sharp which is an order of 1-10 nm and is also available with radius option. Tip may be conical or pyramid shape.

2) Scanner: The movement of the tip or sample in x, y, z coordinate is controlled by piezoelectric tube scanner.

3) Feedback control: The various forces between the tip and sample are measured by amount of bending or deflection of cantilever.

To measure the force, the tip is placed at the end of a cantilever. The amount of force between the probe and sample depends on the spring constant (stiffness) of the cantilever and the distance between the probe and the sample surface. This force is described using Hooke's Law:$F=-k\cdot x$

AFM cantilevers are fabricated from any material that can be fabricated into a spring-like cantilever. First cantilever was fabricated from Tungsten wire by putman and had a probe etched in the silicon. There are two materials commonly used for cantilever: silicon nitride (SiN) and Silicon (Si). The cantilever is also available in coated form as per application. AFM is primarily used for Visualization, Spatial MetrologyPhysical Property Maps and also to check surface topography of any material. It is also used in physics, chemistry, materials, biology, engineering as per the application.

II.WORK DONE BY RESEARCHERS

.Binning et al. and A. Raman et al.introduced the scanning tunnelling microscope (STM) to measure very small forces up 10^{-} N. They develop a new microscope which is able to investigate surfaces at atomic level. So the sensitivity gets increased.Some researchers presented nonlinear Dynamics and Chaos of Micro cantilever-Based tapping mode AFMs with Squeeze Film Damping Effects. They consider micro cantilever as spring mass system and LJ potential is considered to calculate interactive forces.Some introduced a model for AFM micro-cantilever-tip system based on Euler-Bernoulli beam theory and considered cantilever as continuous beam in tapping mode and solved it numerically to study its behaviour. The beam is subjected to changes in tip mass, cantilever density, length and the interaction force between the cantilever-tip and the sample.Some researcher'spresents the theoretical approach to predict the dynamic behaviour of long, slender and flexible micro cantilever affected by squeeze-film damping at low ambient pressures is proposed. A multi-modal analysis on the intermittent contact between an atomic force microscope (AFM) with a soft sample is also done. Its coupling effects are analysed by using Galerkin method. AFM cantilever is also operates in liquid media so some researchers also took liquid as base media.

IV. FORCES ACTING ON CANTILEVER

When cantilever brought in contact with sample then following forces are acted on cantilever:

1. LJ(Lennard-Jones) Potential
2. Damping force
3. Harmonic force

1. LJ potential (F_{LJ}):

$$\frac{A_1 R}{180(Z_0+X)^8} - \frac{A_2 R}{6(Z_0+X)^2}$$

$= 10^{-9}\ N/m$

Where,

A_1 = Hamakar constant for attractive potential.

R= Radius of tip.

Z_0= Gap between tip and sample.

X= Displacement of cantilever.

2. Damping force (F_S) :

$$\frac{\mu_{eff} B^3 L}{(Z_0+X)^3}\dot{x}$$

Where,

μ_{eff}= Effective dynamic viscosity.

$= \frac{\mu}{(1+9.638\ k_n)^{1.159}}$

$=1.4696 * 10^{-5}\ Ns/m^2$

$\dot{x}$= instantaneous velocity.

$=70\ m/s$

B= Width of cantilever.

= 28 μm

L= Length of cantilever.

= 225μm

Z_0 = 670nm.

X=70μm

F_s = 1.4397* $10^{-8}\ N/m$.

3. Harmonic force:

$F_0 \cos \omega t$

Where,

F_0 = Amplitude of excitation.

= 275 nm

μ= frequency of excitation.

= 1.088* $10^6\ rad/sec$

t = minimum time.

= 10^{-6} sec

Harmonic force= 2.7495* $10^{-7}\ N/m$

Total force acted on cantilever when come in contact to the sample is

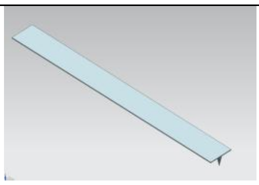
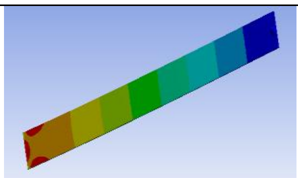
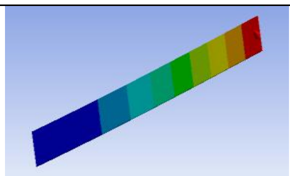
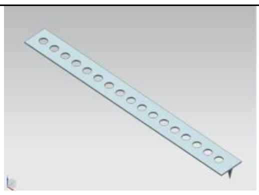
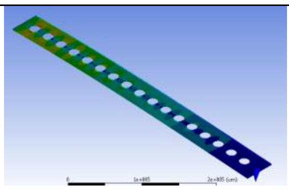
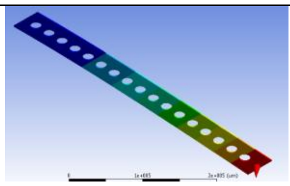
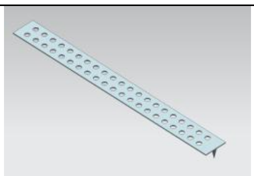
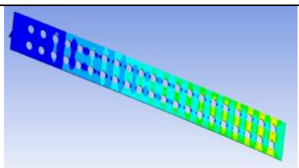
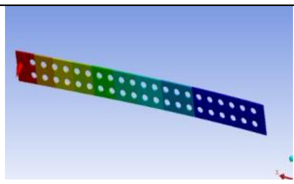
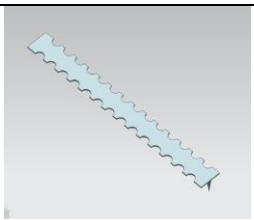
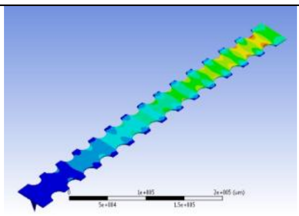
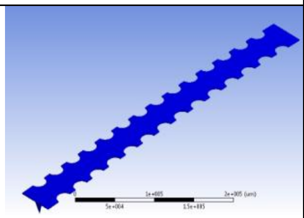
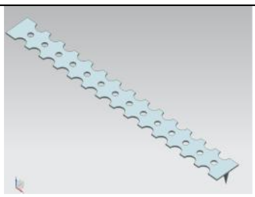
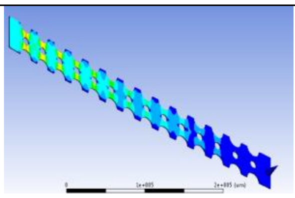
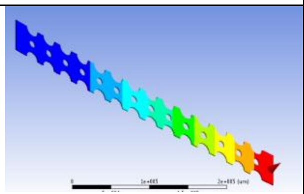
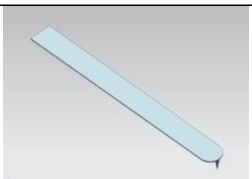
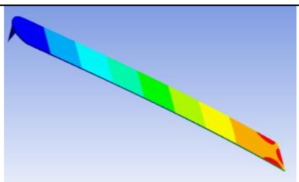
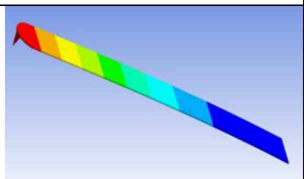
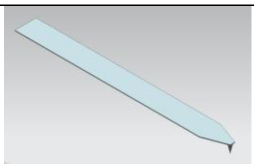
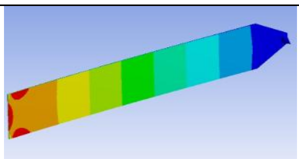
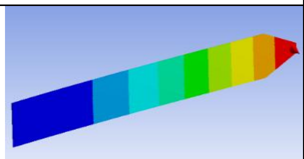
2.90347* $10^{-7}\ N/m$

This total force is used in ANSYS software for stress and deformation calculation.

After application of force at the tip of cantilever, the analysis is done for stress and deformation study. The probes (cantilevers) with different shapes and dimension are studied. ANSYS is very useful CAE tool to investigate the various parameters like stress, strain, deformation, frequency response, thermal analysis, structural analysis, electric analysis, fluid flow analysis, modal analysis, vibration analysis etc.

The following table shows the cantilever with varying dimensions and stress and deformation diagrams with its maximum and minimum values. By referring this table we can see probe which is suitable. Other probes can also be modelled and analyse.

V. ANSYS RESULTS OF VARIOUS PROBES (CANTILEVER)

Sr. No.	Model	Stress	Total Deformation	Stress Value		Total Deformation Value	
				Max.	Min.	Max.	Min.
1				$6.0669 * 10^{-12}$ MPa	$8.3703 * 10^{-17}$ MPa	$2.7526 * 10^{-9}$ μm	0
2				$1.1039 * 10^{-11}$ MPa	$8.0467 * 10^{-17}$ MPa	$3.5464 * 10^{-9}$ μm	0
3				$1.288 * 10^{-11}$ MPa	$9.6695 * 10^{-19}$ MPa	$3.7598 * 10^{-9}$ μm	0
4				$1.2014 * 10^{-13}$ MPa	$5.4516 * 10^{-19}$ MPa	$3.978 * 10^{-11}$ μm	0
5				$1.9217 * 10^{-11}$ MPa	$6.3954 * 10^{-17}$ MPa	$4.7581 * 10^{-9}$ μm	0
6				$6.0707 * 10^{-12}$ MPa	$1.4911 * 10^{-16}$ MPa	$2.7563 * 10^{-9}$ μm	0
7				$6.1154 * 10^{-12}$ MPa	$1.4897 * 10^{-16}$ MPa	$2.7573 * 10^{-9}$ μm	0

The area of interest for designing the new probe is to identify the probe which is having suitable area to bear the required amount of force. Reduction of too much area cannot sustain the force. Due to which there are chances of failure of probe. The above models are modelled in NX which is CAD package. Analysis is carried out in ANSYS for stress and deformation. The above result analysis shows model 4 is having less stress (Maximum and minimum) as well as less deformation which is 1.2014 $* 10^{-13}$ MPa (Max.), 5.4516$* 10^{-19}$ MPa (Min.) stress and 3.978$* 10^{-11}$μm (Max.), 0 (Min.) deformations.

VI. CONCLUSIONS

Materials performance, physical and surface properties, processes are investigated by Atomic force microscope at Nano scale. The measurements are used to know textures uniformity and roughness. Failure analysis is also done by using AFM. AFM has large applications in almost every field. The work may be done to design the cantilevers in different shapes and sizes, also stability issues are required to be considered.

The various forces are acting on cantilever when it comes in contact with sample. The forces are analytically calculated. The total force is applied on the tip of cantilever. In ANSYS this force is applied at its tip and analysis is done for stress and deformation. These values are compaired to know the cantilever which can replace the previous cantilever.

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