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TECHNIQUE TO EVALUATE NANOMECHANICS OF CANTILEVER AT NANOSCALE BY USING AFM

Upendra Sharan Gupta[1], Rahul Singh [2] , Savan Parmar[3],
Prasanna Gupta [4] , Vipul Pandey [5]
[1] *Reader Dept. of Mech. Engineering , SVITS, Indore, (India)*
[2,3,4,5]*UG Scholar Dept. of Mech. Engineering ,SVITS, Indore, (India)*

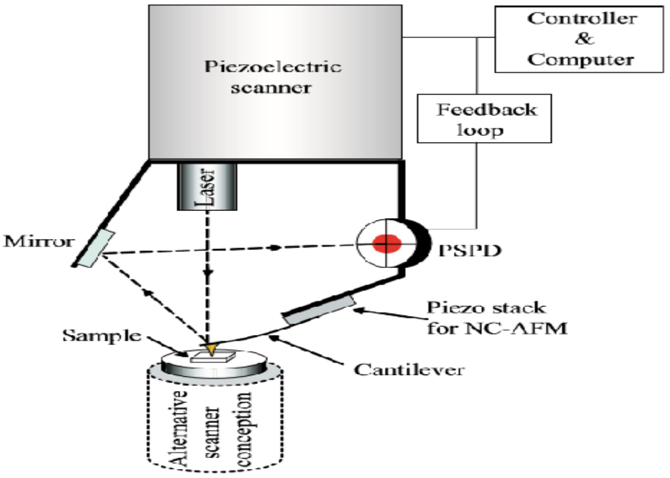
ABSTRACT

The impact of the nanotechnologies on the everyday life issues is not only restricted to the application of the scientific discoveries, but also concerns the exploration of the fundamental processes and interactions that take place in the matter at the atomic level. Nanomaterials are perfect representations of one-, two-, or three-dimensional objects in their simplest forms.. This kind of comparisons between experiments and theory on low dimension objects is helpful to better understand the interactions at the atomic scale. Thus, nanomaterials represent one of the most rapidly expanding and challenging fields of research that crosses many borders between areas of natural sciences and physics. In this paper we study the cantilever properties and it's crucial importance in atomic force microscopy. This paper describes the the mechanics of cantilever used in one of the most important experimental technique use to evaluate nano-structure AFM(Atomic Force Microscopy).

Keywords:* *Nano Tribology, Nano Mechanics, Cantilever

I. INTRODUCTION TO ATOMIC FORCE MICROSCOPY

The atomic force microscope (AFM) is one kind of scanning probe microscopes (SPM).[1] SPMs are designed to measure local properties, such as height, friction, magnetism, with a probe. To acquire an image, the SPM [2] raster-scans the probe over a small area of the sample, measuring the local property simultaneously



Working principle of the AFM: The working principle of an AFM is rather simple. It consists essentially of three systems working together:[3] a force-sensing system, a detection system and a positioning system, the whole managed by control electronics and feedback systems, which are usually realized with the help of a computer. A sketch of the AFM setup is shown in Fig. 1.1

Illustration of the working principle of the AFM. A laser beam is reflected on the back side of a cantilever and then on a mirror, to finally interacts with a PSPD. The displacements of the AFM tip on the surface induce variations in the output voltage of the PSPD. It results, via a feedback loop, in an extension or contraction of the piezoel ectric scanner, which moves the wholes stem (laser-cantilever-mirror-PSPD). Sometimes,inotherAFMconceptions,thepiezoelectric scanner does not move the whole system, but only the sample

1.1 The Force-Sensing System: The force-sensing system is the AFM part in direct interaction with the sample surface[4]. Usually, a flexible leaf spring, called cantilever and ended by a small sharp tip located at its free end, is used as sensor. The AFM tip is the component in contact or in near contact with the surface. The shape of the tip is generally either a pyramid or a cone, but can also be a ball. Forces acting between the AFM tip and the sample surface result in deflections of the cantilever

1.2 The Detection System: The tip-sample interaction is detected by monitoring the deflection of the cantilever. An easy method that is actually the most used in commercial AFM is the laser-beam deflection system. A laser beam is focused on the rear end of the cantilever and rejected into a four-quadrant position sensitive photodetector (PSPD). Bendings and torsions of the cantilever result in the motion of the laser spot on the photodetector and thus, in changes in the output voltage of the photo diode

1.3 Positioning System: The positioning and the fine displacementof the AFMtip relativelytothe surfaceare done via piezoelectric scanners, whereas coarse displacements use stepper motors when available.Piezoelectricmaterialsareceramicsthatchangedimensionsinresponsetoanapplied voltage.

II. CANTILEVERS

cantileversare chosen in function of the experiment that has to be performed. The optical and chemical properties of a cantilever are generally managed via special coatings or functionalization o f its outer surface and might be specifically adapted to a particular experiment. Numerous of designs are commercially available for cantilevers.They are generally build in silicon oxide or silicon nitride through different processes of fabrication, like lithography, bulk silicon micromachining or thin film deposition and etching.

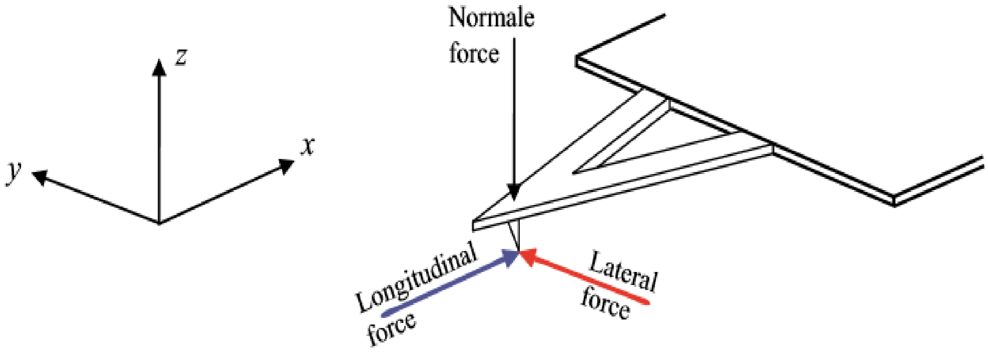


Figure 2: Sketch of the Forces Experienced by an AFM Tip

2.1 Cantilevers Mechanics And Forces

The normal, torsional and lateral spring constants of the cantilever, respectively kN, kT and kL, are used in the force calibration of the AFM. Finite element methods (FEM) and continuum mechanics are generally used to calculate the spring constants of the cantilever, in contrast with experimental techniques that probe the cantilever on or with calibrated samples or loads to determine its mechanical properties. Referring to Fig. 2.9, the normal force FN is applied on the top of the conical AFM tip, perpendicularly to the cantilever plane.The lateral force FL acts at the end of the pyramidal tip, perpendicularly to the plane of symmetry of the cantilever. It causes a torque T that twists the cantilever. Note that another force makes the cantilever bend. It is the longitudinal force F Long acting also at the end of the pyramid al tip with a direction parallel to the cantilever length. FN and F Long result both in the bending of the cantilever, but the related stiffnesses are not the same . We consider now the mechanics of a beam and a V-shaped cantilever submitted to FN or FL,in a Cartesian coordinate system as shown In Fig.2..The the orypresented here Is based on simple continuum mechanics of beam theory and gives access to the relations between the force and the deformation. In the case of the V-shaped cantilever, we present only the interesting results and the details of the method might be found in Ref. [5]. Referring to Fig.3,both cantilever shave a tip of heighth positione data distanced from the cantilever free end.

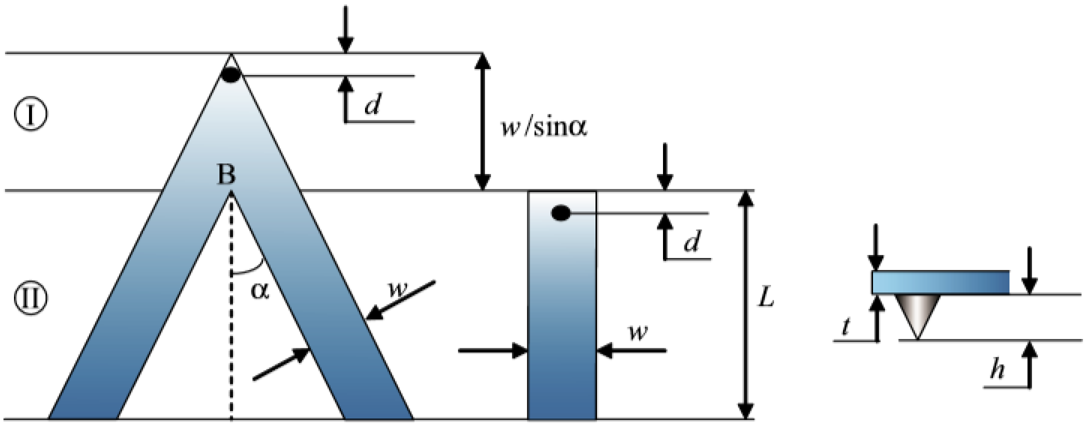


Figure 3: Geometry of A V-Shaped and A Beam Cantilever.

Their thickness is t for a width w that corresponds, in the case of the triangular cantilever,to the width of one of its arms. L is a parameter describeing the cantilever length. For the beam cantilever, it is equal to its exact length, whereas it represents, in the case of the triangular cantilever,the distance between the cantilever support and the point B where the two arms of the V-shaped cantilever join forming an angle 2α. For the rectangular beam cantilever, the relations between the force and the cantilever spring constants are given by [6,7]

$$FN = kN\Delta z = 3EI/(L-d)^3\Delta z = Et^3 w/4(L-d)^3\Delta z \quad \ldots\ldots\ldots\ldots(1)$$

$$FL = kL\Delta y = Gt^3 w/3(L-d)h^2\Delta y \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where E and G are respectively the Young and shear moduli. I = wt3/12 is the moment of inertia of the beam respective to its long axis. Δz and Δy are respectively the normal and lateral deflection of the free end of the beam. Moreover, the change in angular orientation of the cantilever free end when submitted to small vertical displacements is given by

$$\theta =\{6(L-d)^2 / Ewt^3 \}FN =3\Delta z/ 2(L-d) \ldots\ldots\ldots\ldots (3)$$

Equ.2.1highlightstheimportanceofthecantileverthicknessmeasurementinthecalculationofitsmechanicalpropertiesasthethicknessappearstothepowerthree.Aneasyway to measure the cantilever thickness is to measure its resonance frequency f. The relation between f and kN is then given by [8]

$$f =(1 /2\pi)*(kN\ m)^{0.5} = (t/ 2\pi L^2)*(E/ \rho)^{0.5} \ldots\ldots\ldots\ldots (4)$$

where m is the cantilever mass and ρ the material density. By this way, it becomes possible to extract the thickness value from resonance frequency measurements. One method to determine the normal,lateral or torsional spring constantsofaV-shaped cantilever is to subdivide it into two parts: a triangular plate (I) and two prismatic beams (II)forwhichthedeformationsareaccessibleunderelasticbeamtheory.Adoptingthisconfiguration, the deformation of a clamped triangular plate (I) loaded with the normal force FN is given by

$$\Delta I =(3N /Et^3 \tan(\alpha))[\{ w/ \sin(\alpha) -2d\}^2 -d^2*2\log w /d\sin(\alpha)+1\}] \ldots\ldots (5)$$

$$\theta I =6N /Et^3 \tan(\alpha)[w/ \sin(\alpha) -d-d\log w/ d\sin(\alpha)] \ldots\ldots\ldots (6)$$

where ΔI is the normal deflection relatively to its free position and θI is the corresponding angle of rotation occurring at the tip basis. Then, this triangular plate exercises forces and moments on each of the beams (II) resulting again in a normal deformation ΔII and a rotation θII expressed by the relations

$$\Delta_{II} =NL^2 /Ewt^3 \cos^2(\alpha)\ [2L /\cos(\alpha)+3(w\cot(\alpha)-d\cos(\alpha)-r\sin(\alpha))] \ldots\ldots (7)$$

$$\theta_{II} =3NL(1 + \nu)/ Ewt^3 \cos(\alpha)[w /\sin(\alpha) -d + r\cot(\alpha)] \ldots\ldots\ldots (8)$$

with the length r defined by

$$r =[L\tan(\alpha)+(w-d\sin(\alpha))(1-\nu)\cos(\alpha)] /[2-(1-\nu)\cos^2(\alpha)] \ldots\ldots\ldots\ldots (9)$$

The total normal deflection Δz and rotation θ under FN relatively to its unloaded position is given by

$$\Delta z = \Delta_I + \Delta_{II} + \theta_{II}[w \sin(\alpha) -d] \equiv FN /kN \ldots\ldots\ldots\ldots (10)$$

$$\theta = \theta_I + \theta_{II} \ldots\ldots\ldots\ldots (11)$$

Equ. 10 defines the normal stiffness kN = FN/Δz. Then for the lateral or torsional stiffnesses,weconsideratorqueT = FLhactinginthex-directiononthetipbasisandresulting in a total torsion φ = φI + φII, whereφI and φII are the rotation of the triangular plate (I) and the beams (II). The twist formulas are expressed a

$$\varphi = \varphi_I + \varphi_{II}$$

$$= T3(1 + \nu)/ ET^3 [(1/ \tan(\alpha)\log)*(w/ d\sin(\alpha))+(L\cos(\alpha)/ w)-(3\sin(2\alpha) /8)] \ldots\ldots\ldots (.12)$$

The torsional stiffnesskφ and the later alstiffness kL are related to their corres ponding forces T and FL through the relation

$$\Phi = T/k_\varphi = T/k_L h^2 = F_L h/k_L h^2 \text{……………….}(13)$$

For small angles, we have the approximation φ ~ = Δy/h and Equ. 13 becomes

$$k_L = k_\varphi/h^2 = F_{L/}\Delta y \text{……………….}(14)$$

2.3 Tip-Surface Convolution

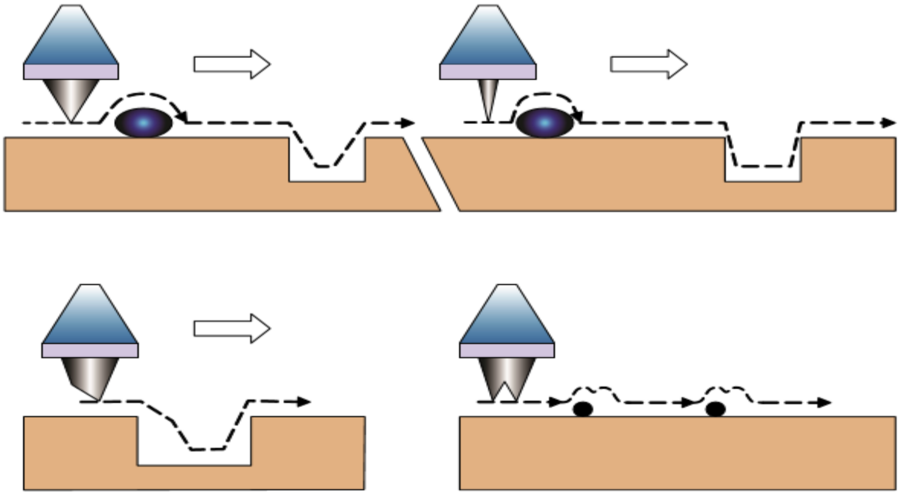


Figure 4: Illustration of the Tip-Surface Convolution. The Top Images Compare the Resolution Difference Obtained With A Large and A Sharp Tip. The Bottom Left Image Illustrates the Case of A Non Symmetric Tip. The Bottom Right Image Schematically Highlights the Artifacts Arising From a Double Tip.

Another critical parameter of the cantilever is the shape of the tip. It can be a cone, a pyramid, a ball, or sometimes, an integrated needle like a carbon nanotube. The extreme part of the tip interacts directly with the surface and is characterized by a radius of curvature RT. The size of this radius is important for quantitative experimental studies of forces andmechanicsatsurface,butalsosimplyfortheimageconstructionofthesurface.Thetip sharpness is a limiting factor of the AFM image resolution. In fact, we do not see the real surfacewithanAFM,butonlytheresultoftheconvolutionbetweenthetipandthesurface geometry.Featureswithsharpedgesorhighaspectratio(e.g.wideandverydeep)willnot beproperlyresolvedbytheAFMtip.Thisphenomenonisgenerallymoresignificantinthe lateral resolution than in the vertical one. Actually, very sharp tip with a nanometer size radius(RT ~ 1−2nm)arecommerciallyavailable.Theyaregenerallyusedfornon-contact mode since any contact with the surface might blunt the tip and decrease the resolution. Fig. 2.11 presents few classical examples of the spatial convolution of the tip with surface features, giving rise to the so-called probe artifacts. The dashed lines correspond to the topographic images obtained for the different features as function of the tip shapes.

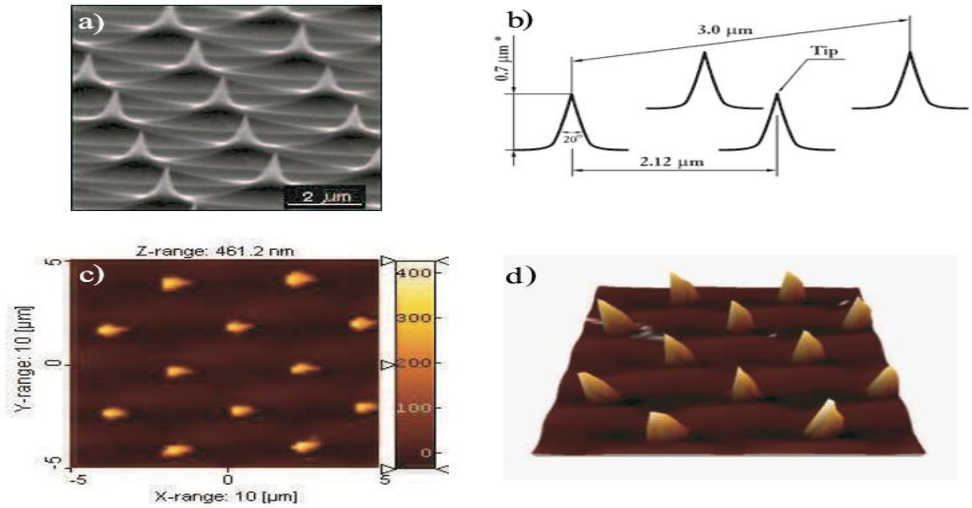


Figure5: Illustrationofagratingusedforthedeductionofthetipshape.Thegratingconsistsin sharp Dirac peaks (a) and with a well-known morphology (b). The topographic images (c) and (d), obtained from the scan of the grating, are then used to deduct the tip radius and shape.

The importance of a small tip radius is highlighted and effects due to a non symmetric tip or doubletipareillustrated.Theconvolutionisalsousedtodeterminethetipradiusbyusing well-known surface features as presented in Fig. 5.

III. CONCLUSION

This Paper deals with the characterization of the cantilever properties is of crucial importance in atomic force microscopy. This versatile element determines on the one hand the interaction with the surface, and, on the other hand, the reading and the transmission of the corresponding information. Its geometrical, optical, chemical and mechanical properties are at the basis of the interpretation of AFM results, and strongly related to the applied forces to the surface,the inten sity of there flected bea morth eimagingre solution.Therefore,cantileversare chosen in function of the experiment that has to be performed. The optical and chemical propertiesofacantileveraregenerallymanagedviaspecialcoatingsorfunctionalizationof its outer surface and might be specifically adapted to a particular experiment. Numerous designsarecommerciallyavailableforcantilevers.Theyaregenerallybuildinsiliconoxide or silicon nitride through different processes of fabrication, like lithography, bulk silicon micromachining or thin film deposition and etching.

REFERNCES

[1] J. M. Sancho, A. M. Lacasta, K. Lindenberg, I. M. Sokolov, and A. H. Romero, Phys. Rev. Lett. 92, 50601 (2004).

[2] G. Binnig and H. Rohrer, Helv. Phys. Acta 55, 726 (1982)

[3] G. Binnig, H. Rohrer, C. Gerber, and E.Weibel, Physica 109&110B, 2075 (1982).

[4] S. M. Hues, R. J. Colton, E. Meyer, and H. J. Guntherodt, MRS Bulletin 18, 41 (1993).

[5] J. M. Neumeister and W. A. Ducker, Rev. Sci. Instrum. 65, 2527 (1994)

[6] T. J. Senden and W. A. Ducker, Langmuir 10, 1003 (1994)

[7] U. D. Schwarz, P. Köster, and R.Wiesendanger, Rev. Sci. Instrum. 67, 2560 (1996).

[8] J. P. Cleveland, S. Manne,D. Bocek, and P. K. Hansma, Rev. Sci. Instrum. 64, 403 (1993).