ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume VII (XVII), 2008

TRIBOLOGICAL CHARACTERIZATION OF MICRO-NANO COMPONENTS

Marius PUSTAN [1], Andreea DAN [1]
[1] TECHNICAL University of Cluj Napoca, Department of Machine Elements and Tribology
E-mail: Marius.Pustan@omt.utcluj.ro, dan.v.andreea@gmail.com

Keywords: Atomic force microscope, tribology, friction

Abstract: This paper presents analysis of tribological properties of micro/nano-structures by use of Atomic Force Microscope (AFM). A method for measuring the coefficient of friction for micro/nano-components is presented, respectively. The coefficient of friction was determined by using the lateral force module of the sample fabricated from gold and the p-silicon tip of AFM cantilever. An equation for the friction force has been determined using the deflection of the AFM cantilever during the probe scanning.

1. STATE-OF-THE ART TRIBO-CHARACTERIZATION ON MICRO-NANO SCALE

Tribology is the science of two interacting surfaces in relative motion. The popular equivalent is friction, wear, and lubrication. Friction is the dissipation of energy between sliding bodies [1]. Most surfaces are rough on atomic scale and when placed in contact touch only the tips of their asperities. The real area of contact will generally be much smaller than the apparent. At these regions of real contact, if the surfaces are clean, the atoms on one surface will attract those on the other and produce strong adhesion. When sliding occurs, these adhesions have to be overcome, that is, the junctions have to be sheared. The force to shear the junctions is the primary cause of the friction between clean surfaces. If in addition, one surface is harder than the other, the roughnesses on it will plough out grooves in the softer and this constitutes a second cause of friction [5].
Three empirical laws of friction have been known since the work of da Vinci and Amonton: (a) there is proportionality between the maximum tangential force before sliding and the normal force when a static body is subjected to increasing tangential load; (b) friction force is independent of the apparent contact area; (c) friction force is dependent of the sliding speed.

The proportionality between friction force and normal load has led to the definition of “kinetic” and “static” coefficients of friction. They are referred to as “properties” of certain combinations of materials. This approach is very simplistic since the coefficients of friction are dependent on parameters such as temperature and sliding speed and, in some cases there is no exact proportionality between friction force and normal load. Recently, it has been found that much of the characteristics of friction are a result of the properties of rough surfaces in contact. Also, the concentration of frictional energy (heat) over small localized areas has a significant influence on friction and wear. Local temperatures can rise to very high values even with a relatively small input of frictional energy, causing the surface layers of a material to expand [7]. Moreover, for any given pair of surfaces the friction is roughly proportional to the load so that the coefficient of friction μ is a constant.

Real surfaces are composed of surface features ranging from individual atoms to visible grooves and ridges. Most surface features affect wear and friction. The topography of the contacting surfaces therefore has a decisive effect on wear and friction.

The micro/nanotribological studies are needed to develop fundamental understanding of interfacial phenomena on small scale and to study interfacial phenomena in micro/nanostructures used in magnetic storage systems, MEMS (microelectromechanical systems), and other industrial applications. There is a wide variety of studies related to this field and many of them are realized using the Atomic Force Microscope.

Atomic force microscopy (AFM) techniques are increasingly used for tribological studies of engineering surfaces at scales ranging from atomic and molecular to microscales. An AFM with a suitable diamond tip can be used to measure microwear and nanoindentation behavior of solid surfaces and thin films. Wear precursors can be detected at early stages of wear using localized surface potential measurements. Localized surface elasticity maps of composite materials with penetration depths of less than 100 nm can be obtained. Nanoindentation hardness and Young's modulus of elasticity can be measured with a depth of indentation as low as 1 nm. Scratching and indentation on nanoscales are the powerful ways to screen for adhesion and resistance to deformation of ultrathin films. These studies provide insight into failure mechanisms of materials and thin films. Furthermore, in situ surface characterization of local deformation of materials helps to develop better understanding of fracture mechanisms and the brittle to ductile transition in materials. These studies are directly applicable to interfacial phenomena of microdevices and magnetic storage devices [2].

Also, Atomic Force Microscopes (AFM) are used to study tribological properties of metal-particle tapes with two roughnesses, Co-γFe_2O_3 tapes (unwiped and wiped), and unlubricated and lubricated thin-film magnetic rigid disks (as-polished and standard textured). Nanoindentation studies showed that the hardness of the tapes through the magnetic coating is not uniform. These results are consistent with the fact that the tape surface is a composite and is not homogeneous. Nanoscratch experiments performed on magnetic tapes using silicon nitride tips revealed that deformation and displacement of tape surface material occurred after one pass under light loads (approx. 100 nN). A comparison between friction force profiles and the corresponding surface roughness profiles of all samples tested shows a poor correlation between localized values of friction and surface roughness. Detailed studies of friction and surface profiles demonstrate an excellent correlation between localized variation of the slope of the surface roughness along the sliding direction and the localized variation of friction. Micro-scale friction in magnetic media and natural diamond appears to be due to adhesive and ratchet (roughness) mechanisms. Directionality in the local variation of micro-scale friction data was observed as the samples were scanned in either direction, resulting from the scanning direction and the anisotropy in the surface topography. Micro-scale coefficient of friction is generally found to be smaller than the macro coefficient of friction as there may be less ploughing contribution in micro-scale measurements [3].

On the other hand, a novel experimental technology for studies of biological and bioengineered materials and structures has been developed. Artificial hips, knees, elbows and fingers cannot yet fully mimic the functional and tribological performance of the biological joints. Ocular tribology deals with friction in contact lenses and eyelids. Tests have been conducted to analyze tribological and mechanical properties of biomaterials [4].

2. METHOD FOR ANALYSIS OF TRIBOLOGICAL PROPERTIES OF MICRO/NANO COMPONENTS BY USE OF AFM

The Atomic Force Microscope is a very high resolution type of scanning probe microscope, with demonstrated resolution of fraction of a nanometer. It can measure ultrasmall forces (less that 1 μN) present between the AFM tip surface and the sample surface. AFMs can be used for measurement of all engineering surfaces which may be either electrically conducting or insulating. Briefly, a cantilever is used as a force sensor in AFM to detect force between tip and sample surface (Fig.1). The cantilever is fixed at one end and its free end has a sharp tip, gently contacting the sample surface. A laser and a detector are used, forming an optical beam deflection system to detect the cantilever deflection. When the sample is being scanned the cantilever will move up and down in the direction normal to the surface [6]. In the AFM, the force between the sample and the tip is detected rather than the tunneling current to sense the proximity of the tip to the sample.

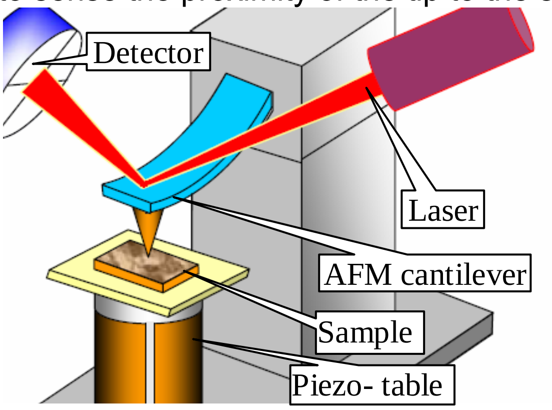

Fig.1. ***Operational principle of atomic force microscope***

The sharp tip at the end of a cantilever is brought in contact with a sample surface by moving the sample with piezoelectric scanners. The force acting on the tip causes a deflection which is measured by tunneling, capacitive, or optical detectors such as laser interferometry. The deflection can be measured to within ±0.02 nm, so for a typical lever force constant at 10 N/m a force as low as 0.2 nN (corresponding normal pressure ~200 MPa for an Si_3N_4 tip with a radius of about 50 nm against single-crystal silicon) could be detected. This operational mode is referred to as the “repulsive mode” or “contact mode”. An alternative is to use “attractive force imaging” or “noncontact imaging” in which the tip is brought in close proximity (within a few nanometers) to, and not in contact with, the sample. Although in this technique the normal pressure exerted at the interface is zero (desirable to avoid any surface deformation), it is slow and difficult to use and is rarely used outside research environments.

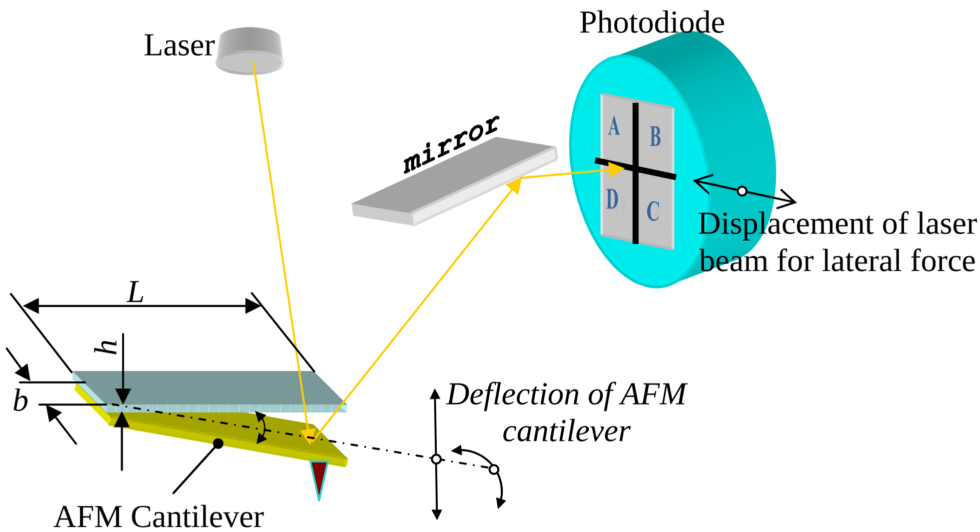

Fig.2. ***Measurement of the lateral force by AFM***

In either mode, surface topography is generated by laterally scanning the sample under the tip while simultaneously measuring the separation-dependent force or force gradient (derivative) between the tip and the surface [1]. While scanning direction is perpendicular to the long axis of the cantilever, the lateral forces between the tip and the sample results in twisting (torsion) the cantilever. This twisting is detected by the laser deflection and is often referred to as *lateral force signal* or *friction signal*. This capability of the AFM is ideal to study friction and topography [6].

3. MEASUREMENTS OF FRICTION COEFFICIENT OF MICROCOMPONENTS

The coefficient of friction is estimated by the measurement of frictional force between two surfaces. It is an index of friction behavior of two materials being in contact and relative motion. Analysis of tribological characteristics of thermal microcomponents by using the lateral force module of atomic force microscope (AFM) is performing. The AFM cantilever used for measurement the friction forces is the NSC15/Si3N4/Cr-AuBS15.

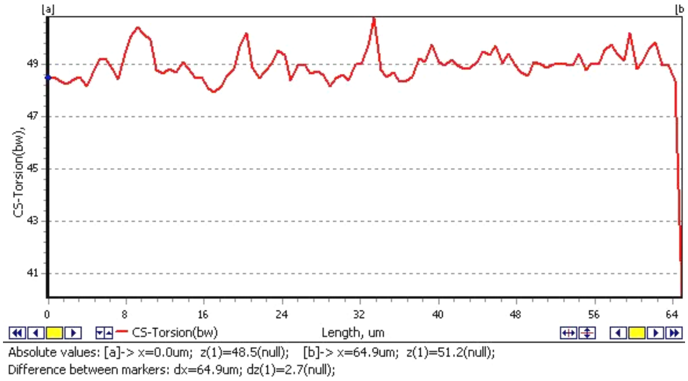

Fig.3. Variation of torsion deflection of AFM cantilever for scanning of gold material

For the measurement of the friction force, the lateral force profiles at forward and backward motions were identified (Fig.3). By use the deflection *dz* of AFM cantilever gives by the torsion map (Fig.3) the friction force can be calculated as:

$$F_f = \frac{dz \cdot r \cdot G \cdot h^3 \cdot b}{l^2 \cdot s} \qquad \textbf{(1)}$$

where *dz* is the deflection of AFM cantilever [nm], *r* – the radius of tip of AFM cantilever, *G* – shear modulus of the cantilever material, *l* – length of cantilever, *t* – thickness of AFM cantilever, *b* – width of AFM cantilever, *s* - height of tip of AFM cantilever.
At known normal force, by the use of AFM software, the friction coefficient 0.22 was calculated for a gold microstructure and the p-type silicon tip of the AFM cantilever.

4. CONCLUSIONS

There is the possibility to measurement the friction coefficient and wear at micro/nano-scale by use of atomic force microscope (AFM). The accuracy of the results depends by the initial calibration of AFM device and by the quality of AFM cantilever. For measurement the friction coefficient of soft materials a special AFM cantilever with ball as tip has to be use.

REFERENCES

[1] Bhushan, B., (1999), *Handbook of Micro/Nano Tribology*, CRC Press, Boca Raton
[2] Bhushan, B., (1999), *Wear and Mechanical Characterization on Micro to Pico-scale using Atomic Force Microscope*, International Materials Review, Vol. 44
[3] Bhushan, B., (1994), *Atomic-scale Friction Measurements using Atomic Force Microscopy*, Journal of Tribology, Vol. 116,
[4] Gitis, N., (2004), *Tribometrological Studies In Bioengineering*, International Congress and Exposition on Experimental and Applied Mechanics, California
[5] Neale, N., (2001)*The Tribology Handbook*-second edition, Elsevier
[6] Pustan, M., Rymuza, Z., (2007), *Mechanical and Tribological Characterization of MEMS Structures*, Risoprint, Cluj-Napoca
[7] Stochowiak, W., Batchelor, W., (2005), *Engineering Tribology* - third edition, Elsevier