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The Method of Spherical Surface Roughness Measurement

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Abstract

The spherical surface is measured by means of Atomic Force Microscope (AFM) on nanometer scale. In order to evaluate the surface quality of this kind of three dimensional measurement, the following parameters are suggested: R_a,R_q,R_y and T_p. Some questions related to this choice are discussed in this paper.

Keywords: Surface roughness measurement, Spherical surface, Atomic force microscope

1. Introduction

The spherical surface plays an important role in precision engineering. They are used in precision machines and instruments. People usually use interferometers and contact (stylus) instruments to measure the spherical surface roughness. The interferometer is non contact, but when the corrugation of the surface is less than 0.05um, it is difficult to evaluate it because the interface fringes are almost straight lines. (L C Leonard ,1998,p.433). The stylus can get several parameters by means of a computer. But it is a contact method. The limit of this method mainly depends on the radius of the scanning tip. For example, the instrument Tallest has the minimum radius of 0.1um.Besides,it is almost impossible for these two methods to operate with small balls due to their reduced diameter(3mm).Both methods are limited because they give line profiles.(Takahiko,2003,p,452-455).

Since Scanning Tunneling Microscope (STM) and Atomic Force Microscope (AFM) were invented, they have shown great potential in the measurement of the surface structure on nm scale. They have soon applied to precision engineering. Nigeria et al. used STM to measure the surface roughness of a “0” class block gauge. (Garcia, 1985, p.566).

Here we report on the results we have obtained by using an AFM to measure the spherical surface. We operated the AFM in the repulsive mode with a small force of $<5x10^{-8}$N,which is more than two orders of magnitude lower than the force applied by the stylus instrument.AFM gives three-dimensional images and it can get nm resolution.

An important point is how to specify quantitatively the surface structure. For one dimensional measurement, there are international standards and various national standards. But for 3-dimensional measurement there are no formal documents that can be used. Here we propose four parameters: the arithmetical mean deviation of the profiles R_a , the root-mean-square deviation of the surface R_q, the maximum height of the surface R_y, and bearing area ratio T_p.

2. Experiments

We installed an AFM (Schnenberger, 1989,p.3131. Huang, 1991, p.1323-1328) based on a polarized laser interferometer. A tungsten tip was glued onto a commercial silicon wafer. The tip was made by direct-current (dc) etching (3V) of 0.1mm polycrystalline W wire. We measured the tips by Scanning Electron Micron Microscope (SEM).The radii of these tips were about 10nm.The force constant of the cantilever was about 12N/m. The frequency of 1.2 kHz.

We used the precision spherical surface which its diameter is 3mm.Because the system was sensitive to optical, mechanical, air and thermal fluctuation; we designed our system with cylindrical symmetry structure. We used materials which had small thermal expansion. The optical parts were fixed directly on a granite plate, and also the acoustic noise. The granite plate was suspended with soft springs. Finally we got an output of the signal sensitivity of 20mV/λ, the noise was about 5mV, and the thermal drift 0.05 λ/sec.

Usually we use the repulsive force mode. The constant force is about 5×10^{-8}N.The scanning frequency is 1-5Hz.Here we show two images of different measuring range.Fig.1 shows the three dimensional and top view representations of a 3μm×3μm area.Fig.2 shows the same data for size 1μm×1μm taken on a different area of the same sphere surface.

3. Parameters of 3-diamensional profiles

The data obtained by AFM can be processed to give a 3-D representation of the surface. Although this representation can be sometimes self-evident, it is important to give quantitative information from the image. For that purpose and to give the non periodic character of the surface, we suggest that four parameters be used: the arithmetical mean deviation R_a, the root-mean-square deviation R_q ,the maximum height R_y and the profile bearing area ratio T_p. The reference plane is the least squares mean plane. We use the same terminologies and the same symbols as those in ISO 4287/1-1984 and ISO 468-1982, in order that people can understand and use them easily conveniently.

The arithmetical mean deviation Ra id defined as

$$R_a = \frac{1}{N_x} \bullet \frac{1}{N_y} \sum_{i}^{N_x} \sum_{j}^{N_y} \left| Z_{ij} \right| \tag{1}$$

Here N_x: sampling points in X direction

N_y: sampling points in Y direction

Z_{ij}: height with respect to the least squares mean plane

The root-mean-square value Rq is defined as

$$R_q = \left\{ \frac{1}{N_x} \bullet \frac{1}{N_y} \sum_{i}^{N_x} \sum_{j}^{N_y} Z_{ij}^{\ 2} \right\}^{1/2} \tag{2}$$

Here N_x,N_y,Z_{ij} are the same as in(1).

The maximum height Ry is defined as

$$R_y = R_p + R_m \tag{3}$$

Here R_p is the distance between the highest point of the profiles and the reference planer is the distance between the lowest point of the profiles and the reference plane.

The profile bearing area ratio T_p is defined as

$$Tp = \frac{\eta_p}{S} \tag{4}$$

Here η_p is the sum of the section areas obtained by cutting the profile peaks with a plane parallel to the reference plane. S is the area of scanning. From this we can get the curve of the profile bearing area ratio representing the relationship between the value of the profile bearing area ratio and the section level.

In our experiment, in 3μm×3μm area ,Ra=4.1nm,Rq=5.2nm,Ry=34nm.The values for the 1μm×1μm image are Ra=4.1nm,Rq=4.9nm,Ry=25nm,The curves of bearing area ratio are shown in Fig.3.

4. Discussions

From our experiment, it is clear the AFM is a potential tool to measure an ultra-precise surface. Not only can conductiv3 sample be measured but also the non conductive one. Along with the development of science and technology, the requirements of specifying 3-dimensional high quality surface with nanometer scale are placed on the order of the day. The standardization of the parameters and values for the specification of 3-dimensional surface is absolutely necessary.

From the point of the view of metrology, the important and more difficulty thing is to calibrate the instrument and to estimate the uncertainty of the measuring method. There is a lot of work to be done. Some people (Li Y Z,1989,p.15) suggest using diffraction grating to calibrate μm scale range and using lattice constant to calibrate nanometer scale image. This is feasible at the present time. Maybe it is necessary to find some standard material which is very stable and suitable for calibrating the 3-dimensional measurements.

In this paper, we have not mentioned the terminology “sampling area”. It is not the question that the values of R_a,R_q,R_y and T_p are not dependent on the “sampling area”. In fact, like the “sampling length” in ISO 4287/1-1984 and ISO 468-1982,this is very important. The question is that because we performed few experiments we can not determine how big the “sampling area” is reasonable. At the moment, we suggest considering the “sampling area” as being equal to the scanning area. So it is clear that when someone mention the value of R_a,R_q,R_y or T_p of 3-dimensional profiles, he must point out the value of the scanning area.

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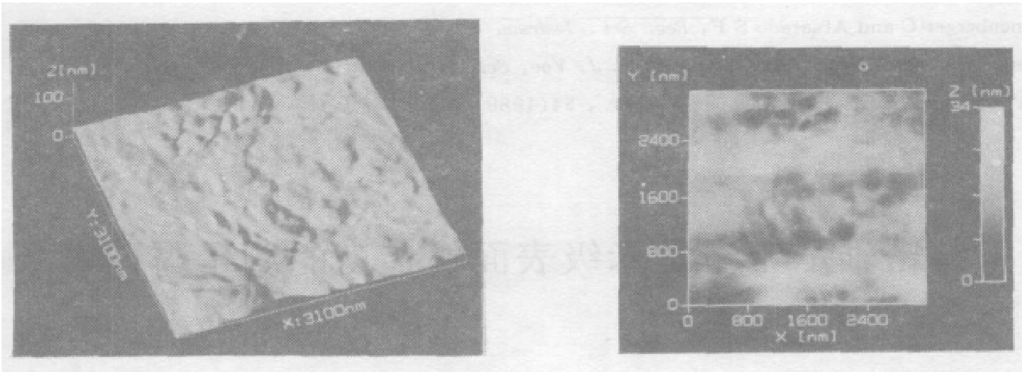

Figure 1a shows a 3-dimensional representation of a sphere surface of 3mm .

Fig 1b is the top view.

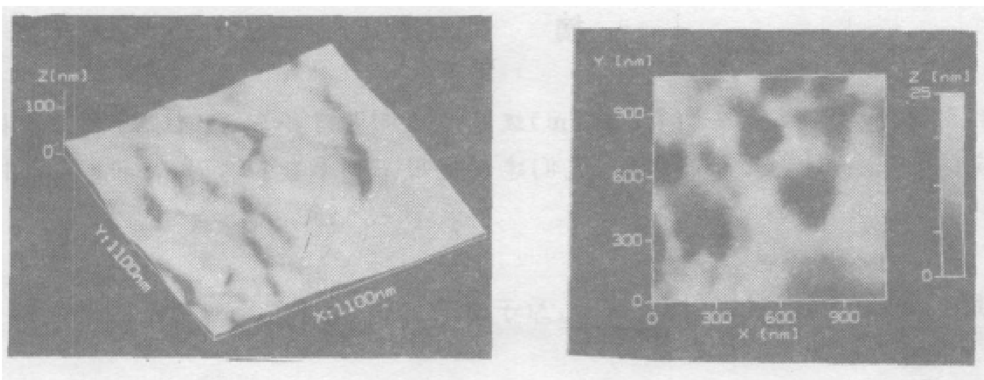

Figure 2a and 2b show a smaller area of a different place in the same sphere surface as in Figure 1.

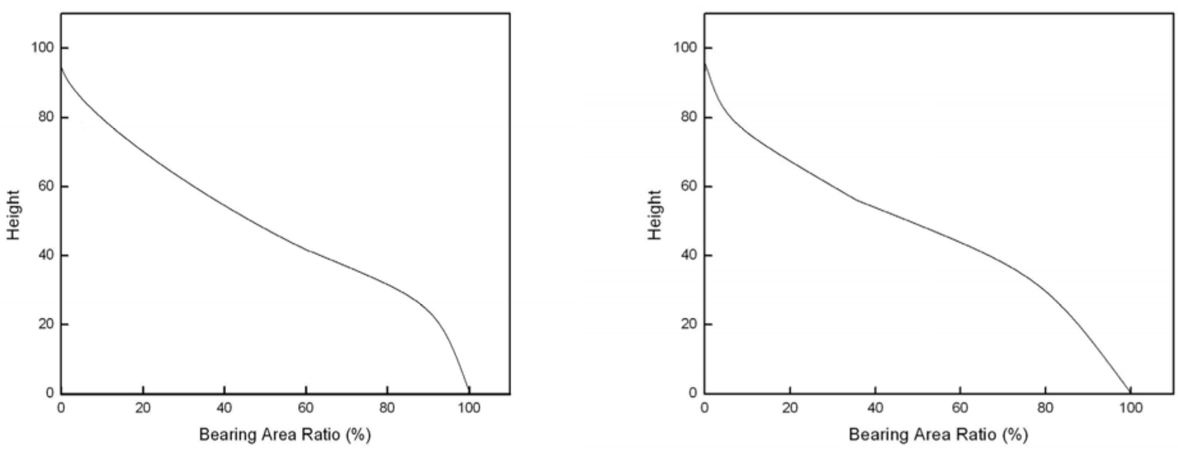

Figure 3a and 3b show the curves of bearing area ratio corresponding respectively to the regions depicted in Figures 1 and 2.