XVI IMEKO World Congress
Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

ANALYSIS OF AFFECT FACTORS OF NANO SCANNING IMAGES

L. Si, P.H. Osanna and N.M. Durakbasa
Laboratory for Nanotechnology
Department for Interchangeable Manufacturing and Industrial Metrology
Institute of Production Engineering (IFT)
Vienna University of Technology, A-1040 Vienna, Austria

Abstract: The imaging results of a group of experiments concerned with imaging two ultraprecise fabricated samples composed of Cu- and Al-alloies as well as silicon coated with C-N ion-beams in 1mm scan range, have been analysed and discussed. The sources of SPM (Scanning Probe Micoscope) artifacts and the affect factors of the SPM images are presented and investigated. It is concluded that so many scanning images looking like "atoms" topography structure obtained have been misunderstood in the world, because it is very difficult to correctly and properly in terpret so many kinds of SPM artifacts in the imaging practice applications.

Keywords: image topography, SPM artifacts, micro and nano structure; Micro and Nano Technology

1 INTRODUCTION

Currently, it is known that an ultra-precision surface topography can be obtained by using Scanning Probe Microscope (SPM). SPM is a power technique, offering the ability to gain the information that is not available in any other way, and relying on a mechanical probe for generation of magnified images [1] [2] [3].

The ideal microscope will generate a direct image map of the sample surface, such that the measurements which are made will be an exact magnification of the actual sample. Because of magnifying in three dimensions, the ideal SPM will provide measurements in all dimensions that are accurate representations of the sample surface.

All analytical techniques contain artifacts [4]. The artifacts of traditional instrument techniques become better understood and are minimized by changes to the instrumentation, methodology or by knowledgeable interpretation of data. SPM is also subject to artifacts. If these are not understood, the SPM data can not be properly in terpreted, led to many undesirable consequences, such as the inability to properly evaluate instrument performance and improper use of analytical results. The artifacts in SPM are not easy to be understood, because of resulting from very complicated sources and the sensitivity of the image results.

It is also very important that the operation performance, operator experiments and limitations of SPM instrumentation should be understood in order to properly interpret the images obtained. When artifacts are well understood, SPM data can be properly interpreted and the information can be used with confidence.

The confidence in SPM imaging results with influence of the artifacts and calibration methods of SPM instrumentation is always barrier to realize wide industrial application of SPM technology.

2 AFM AND IMAGE TOPOGRAPHIES

AFM (Atom Force Microscope) is one kind of SPM technique. AFM images are a combination of the sample surface and the probe that is used to image the micro and nano surfaces. An AFM is operable in ambient air, liquid or vacuum to solve features in three dimensions down to a fraction of an angstrom and is composed of a sensing probe, piezoelectric ceramics, a feedback electronic circuit, and a computer for generating and presenting images.

The measure principle of AFM is, that AFM uses the force sensor to measure the deflection of a cantilever. The cantilever composed of a narrow (120- or 200-µm) silicon nitride arm with integrated tip scans the surface of the sample in form of grid-pattern. The scanning process is controlled by piezoelectric ceramics (x,y) with a resolution of 0.1 angstrom. The laser beam is focused on the upper side of the cantilever through a optical system and then reflected to a four section photo detector. The amount of the motion of the cantilever can then be calculated from the difference in light intensity on the sectors. The signal of the cantilever motion will be led into the feedback loop, which controlls the third movement of the piezo in z-direction. The changes of z-position of the cantilever, which reflect the surface structure of the sample, are taken as the measuring signals and then processed for generating the image topographies.

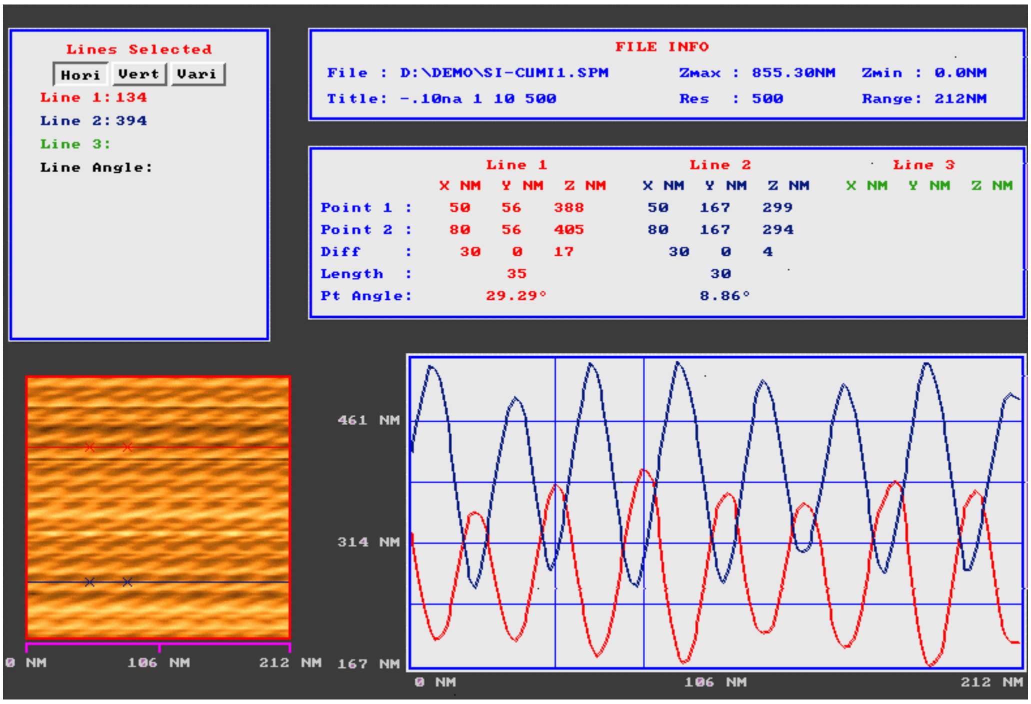

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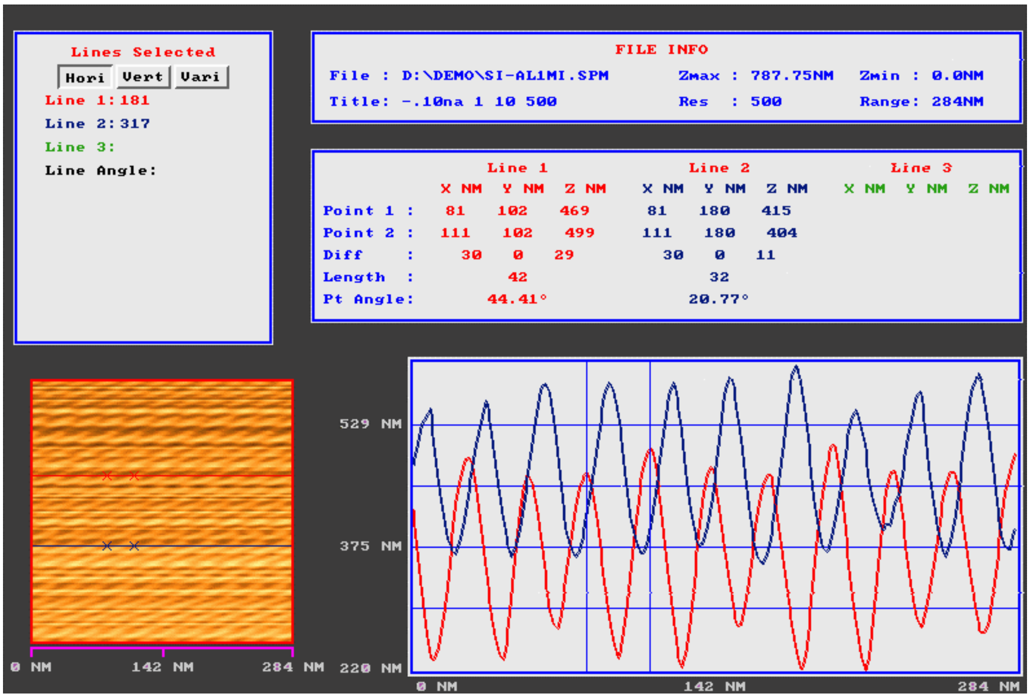
Figure 1. Surface image results of copper alloy

Hooke´s law gives the relationship between the cantilever´s motion, z, and the force required to generate the motion, F.

$$F = -kx \tag{1}$$

K is a force constant of the cantilever, and taken as 1 newton/meter.



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Range: 284NM

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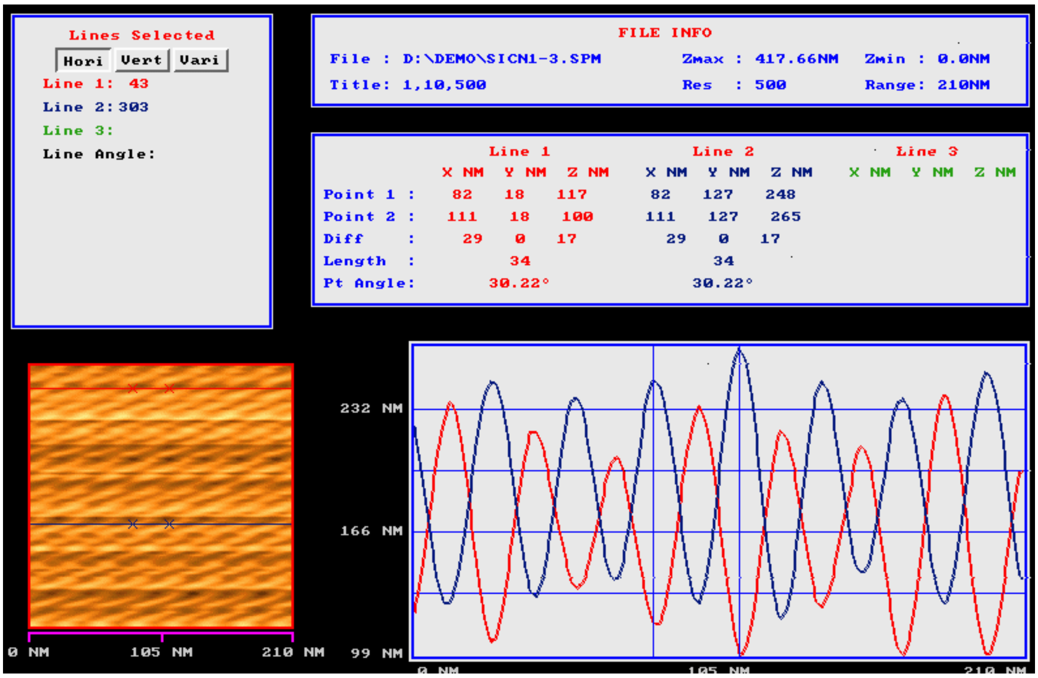
Point 2 :	111	102	499	111	180	404			
Diff :	30	0	29	30	0	11			
Length :		42			32				
Pt Angle:		44.41°			20.77°				

Figure 2. Surface image results of aluminium alloy

The image topographies of the ultraprecise milled surfaces of Al- and Cu-alloies generated by using a diamond milling tool on the air-bearing precise milling machine as well as silicon coated with C-N ion-beams were obtained and analyzed by means of AFM.

The samples used, which are made from OFHC-copper and AlMgSi 13 separately, are from company KUGLER GmbH Germany. Parameters of the samples are: diameter Ø48mm, height 8mm, surface roughness <10nm, Rt < 100nm on the surfaces.

Figure 1 to figure 4 are the image topographies and their analytical image results of the surfaces.



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Point 2 :	111	18	100	111	127	265			
Diff :	29	0	17	29	0	17			
Length :	34			34					
Pt Angle:	30.22°			30.22°					

Figure 3. Surface image results of silicon (C-N-coated)

3 ARTIFACTS

Any measurement that results in an image differing from the actual sample surface is an artifact [4] [5]. Artifacts are a part of any microscope technique. SPM artifacts can come from many sources. These artifacts are ranged over probe artifacts, scanner and piezoelectric ceramic artifacts, artifacts resulting from instrument mechanical and electronic design, artifacts resulting from data manipulation and artifacts created by SPM samples.

As mentioned above, artifacts in SPM images can result from probe, such as probe/cantilever artifacts, probe geometry, step/concave feature distortions, convex feature distortions, probe asymmetry, probe flexing, cantilever backlash, probe reproducibility, contamination, double tips, and probe/sample angle.

The scanner and piezoelectric ceramic artifacts can come from the scanner material characters and the mechanical construction of SPM scanners, such as non-linearity, drift, creep, hysteresis, bowing, and dynamic range artifacts of the piezoelectric ceramics.

Artifacts resulting from instrument mechanical and electronic design are from for example, vibration between the SPM probe and sample, thermal stability of the stage, optimization of the feedback control loop, instrument noise from the SPM power supply. Vibration resulting from instrument mechanical and electronic design is also a main factor resulting in SPM artifacts. When vibration occurs between the sample and the SPM probe, they can produce difficulty in achieving stable feedback and artifacts in images. Images which appear to look like „atoms“ have actually been due solely to vibration [4] [6]. These artifacts can appear as oscillations at the vibation frequency.

Data manipulation artifacts come from enhancement techniques of SPM images, such as tilt and level correction, band pass filtering, fast Fourier Transform, smoothing algorithms, shading and independent x, y, and z magnification.

Artifacts created by SPM samples are from, such as contamination of the sample, sample curvature, softness of the sample, probe/sample adhesion, particles on the sample surface and features deeper than the probe length.

The scanning process of nano surfaces by using AFM is also often influenced by several kinds of external factors, especially by environmental influences like vibrations, sound, air flow, changes of temperature etc., They appear also as distortion of images or errors of measurements of the microstructures.

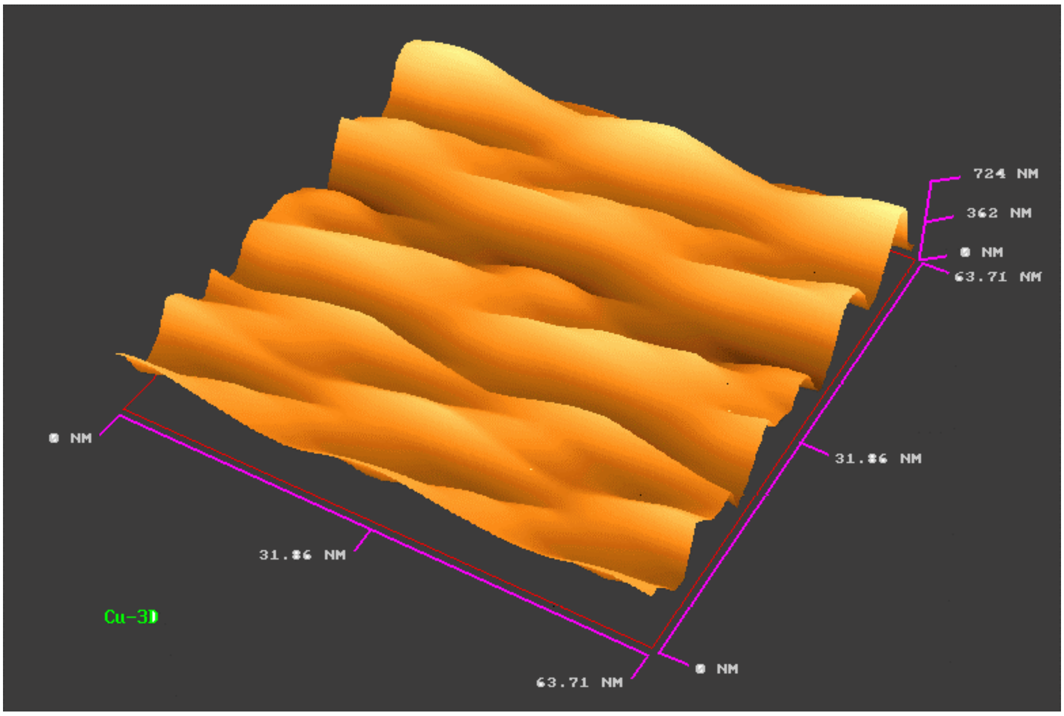

Figure 4. 3-D image topographie of the sample surface of the copper alloy - „atoms“ structure

4 ANALYSIS OF AFFECT FACTORS OF NANO SCANNING IMAGES

The imaging results of a group of experiments that deal with imaging two ultraprecise milled samples composed of Cu- and Al-alloies, and Silicon coated with C-N ion-beams in 1µm scan range, using scanner which has a maximum scan range of 150µm on AFM that has been installed on an anti-vibration worktable in a precise measuring laboratory, in which the temperature is maintained constant 20±0.1°C, have been achieved and will be discussed as following. The base of the Laboratory was also made for anti-vibration. The scanning head and scanning stage of the AFM are masked in a glass-plastic mask without the influence of air flow. Therefore, it is desirable to image micro- and nanostructures of ultraprecise machined surfaces by using AFM. The influence from the external factors in this case can be ignored.

For the all samples, the same experiment processes were taken, and the scanning range is always 1µm, and other scan parameters are also same.

By means of the analysis of the image results, an interesting phenomenon that the image topographies obtained from different samples with the scanning parameters selected in a certain area are just like the same one - “atoms” structure, being independent of the surface states, manufacturing techniques and materials of the samples, appears. Images which appear to look like „atoms“ have actually been due to the artifacts mentioned above in chapter 3, especially due to that the resolution of sanners and the control system of the sanners are not high enough, and due mainly to the vibration resulting from instrument mechanical and electronic design, e.g. the vibration of the sanning movement between the scanner - the tip of the probe and the sample, because these artifacts in SPM images can appear as oscillations at the vibration frequency through analysis of the image topographies obtained. This can be determinated by varying the scan speed, range and rotation, and observing the resulting change in the image. The frequency of the vibration has been obtained through the investigation. It is about 350 Hz.

The influence grade of the vibration is dependent of the scanning frequency and size of the scanning area. If the vibration between the probe and sample appears, it is very difficult to get the stable feedback and the artifacts also appear in the image results. The operator experiences are also very important for the adjustment of the scanning parameters and the nano instrumentations.

Scanning images of the nano surfaces using probe on AFM is often influenced with several kinds of causes as mentioned in the chapter 3. They are environmental influences like ambient vibrations, sound, air flow, changes of temperature etc., noise from sensor (scanner) devices, geometry of scanning probes, and scanning movement itself, etc.. Measurement errors due to scanning movement are caused by non-linearity and hysteresis of commonly used piezoelectric-translators. They appear as distortion of images or errors of measurements of the microstructures.

If the feedback control loop is not properly optimized, oscillations or other undesired effects may result. These can cause the SPM image to show waves, noise, or other artifacts. Noise from the SPM power supply will cause noise on the voltages applied to the piezoelectric ceramics.

The techniques that are used to enhance SPM images may also distort the data and lead to misinterpretation. Tilt and level correction, band pass filtering; Fast Fourier Transform (FFT), smoothing algorithms and shading, which can be helpful in enhancing SPM images, can also introduce artifacts.

Sample contamination and curvature can also result in artifacts, particularly if combined with sample tilt. Softness, probe/sample adhesion, particles on the sample surface and features deeper than the probe length can create the artifacts. If a feature is imaged, such as a pit, which is deeper than the probe tip is long, the cantilever will strike the edge of the feature. The resulting image will be a combination of the actual sample surface and the shape of the cantilever.

An understanding of the interaction between probes and samples is important, in order to properly evaluate SPM images. Obtaining reproducible tips is currently a major challenge, especially since good tips often become dull or dirty after 1 day or less of imaging.

The scan range of considerable software manipulation is possible, making poor raw data appear to be of high quality. This does not mean that the data are an accurate representation of the sample surface, however, and must be interpreted with caution. A knowledge of the image rendering techniques used and access to the raw data collected are essential for analyst to interpret SPM data with confidence and present quality images.

The artifacts and errors can be reduced in several ways: by tubular corrections or, by used of position sensors and interpolation between nominal values and actual sizes or, by a priori high precision positioning, that is positioning of piezo-translators in a closed loop control. Use of closed loop controlled piezo-translators allows to reduce non-linearity, depending on performance of positioning sensors and control circuits This requires the compromise between decreasing scanning speed and increasing positioning accuarcy. In order to obtain the image topographies with atom resolution by using AFM, the artifacts mentioned in the chapter 3 must be avoided and properly interpreted.

5 CONCLUSIONS

In this paper, the sources of SPM artifacts and the affect factors of the SPM images are presented and investigated. The imaging results obtained have been analyzed and discussed, and the frequency of the vibration from sensor devices and scanning movement are investigated..

It has been concluded that so many scanning images looking like “atoms” topography structure obtained have been misunderstood in the world, because it is very difficult to correctly and properly interpret so many kinds of SPM artifacts in the imaging practice applications. Therefore, it is very important to control the vibration between the sample and the SPM probe, e.g. to improve the design and manufacturing technology of new types of the scanners and the nano instrumentations to enhance the wide industrial application of SPM technology.

For the future development of the SPM instrumentation, the characters of the piezoelectric ceramics, such as hysteresis, creep and thermal drift must be perfectly avoided or compensated, and the all artifacts mentioned above and the influences of the environment, e.g. the influence of the temperature, the air flow and the vibration have to be minimized and be understood, the images obtained must be properly interpreted.

The confidence in SPM imaging results with influence of the artifacts and calibration methods of SPM instrumentation are always barriers to realize wide industrial application of SPM technology.

In order to obtain the image topographies with atom resolution by using AFM, the resolution and the stability of the piezoelectric ceramics, the vibration of the scanning movement between the probe and sample und the geometry of the probe as well as the operator experiences play a very important role.

Today the scanning probe methodology is still partially under developing phase of the measuring technology. It is sure that AFM is a powerful instrumentation for nano surface measurement in the future. But the confidence in SPM images, limitation of the calibration methode for AFM and the stability of the scanning results are always the barrier to realise the fully industrial applications of SPM technology.

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AUTHORS: Univ. Prof. Dr. P. Herbert OSANNA, Dipl.-Ing. L. SI and Ass. Prof. Dr. Numan M. DURAKBASA, Department of Interchangeable Manufacturing and Industrial Metrology of the Institute of Production Engineering, Vienna University of Technology, Karlsplatz 13/3113, A-1040 Vienna, Austria, Phone Int.: ++431 58801 31140, Fax Int.: ++431 58801 31196
E-mail: osanna@mail.ift.tuwien.ac.at