Available online at www.sciencedirect.com
SCIENCE DIRECT®
Measurement 39 (2006) 12–15
Measurement
www.elsevier.com/locate/measurement

Distorted surface topography observed by atomic force microscopy

L.X. Li [a], R.P. Liu [a,*], Z. Xu [a], Y. Xu [a], W.K. Wang [a,b], C.Z. Fan [b]

[a] *Key Laboratory of Metastable Materials Science and Technology, Yanshan University, Qinhuangdao 066004, PR China*
[b] *Institute of Physics, Chinese Academy of Sciences, Beijing 100080, PR China*

Received 23 February 2005; accepted 17 October 2005
Available online 28 November 2005

Abstract

Topography of Au thin films deposited by magnetron sputtering technique on a silicon substrate was studied by atomic force microscopy (AFM). Distortion of the surface morphologies as a result of interaction between the film and the probe tip was observed. Some topographical morphologies that look like perfect were distorted. Thus, the reality of the topography by AFM, in some cases, needs to be re-evaluated.

Keywords: AFM; Au film; Image distortion

1. Introduction

Since its discovery [1], atomic force microscopy (AFM) has been widely used in Physics, Chemistry, biology, Materials Sciences, etc. In recent years, special applications of AFM have been found in measuring island volume [2], size [3,4], shape [5,6], patterning [7–10] and roughness [11,12] in order to study phenomena of diffusion, deposition kinetics, anodic oxidation, mechanisms of self-organization and electric conductivity etc. These studies demand that the topography must reflect the real surface morphology on atomic scale. AFM, as well as scanning tunneling microscopy and nano-indentor, has a different imaging principle from optical or electronic microscopy. AFM gains the topographical images depending on the interaction of the tip of the AFM and the surface of the sample through the relative movement of the tip upon the sample. The tip of the probe unavoidably touches or interferes the surface of sample in some cases. Consequently, changes of both the surface of the sample and the shape of the tip may occur, the result of which is that the topographical images given by the AFM may lose their reality. And sometimes the distortion of the AFM images cannot be easily noticed.

In this paper, Au films are used as examples to show some distortions of the surface topography produced by misusage of the AFM probe tip. And the mechanisms that caused the distortions are clearly presented.

* Corresponding author. Tel.: +86 335 8074723.
E-mail address: riping@ysu.edu.cn (R.P. Liu).

0263-2241/$ - see front matter
doi:10.1016/j.measurement.2005.10.005

2. Experimental

Au thin film was prepared by magnetron sputtering deposition on a silicon substrate, which was cleaned in alcohol and acetone for 10 min, respectively. The parameters used during deposition were as following: base pressure 6.0×10^{-4} Pa; Ar flow 30 sccm; working pressure 2.0 Pa; DC power 45 W; and sputtering time 16 min. The substrate was rotating during deposition to guarantee a uniform film thickness. Before deposition, the Au target was cleaned with sputtering for 10 min to remove oxides and any other contamination. Surface topographical analyses were carried out using a P47 AFM made in NT-MDT Co. of Russia. The probes used were NSG11 series tapping mode probes also from NT-MDT Co. The parameters of the probe were: elastic constant 11.5 N/m; resonance frequency 255 kHz; length 100 μm; width 35 μm; thickness 2 μm; tip radius < 10 nm; and tip angle 22°.

3. Results and discussion

Fig. 1 shows the AFM images of the Au thin film obtained by a tapping mode with a brand new probe. Homogeneous nano-particles (or islands) with the maximum height of 30 nm can be seen. Similar images were obtained repeatedly with ever-new probes. Presumably they represent the real case of the surface morphology of the prepared film.

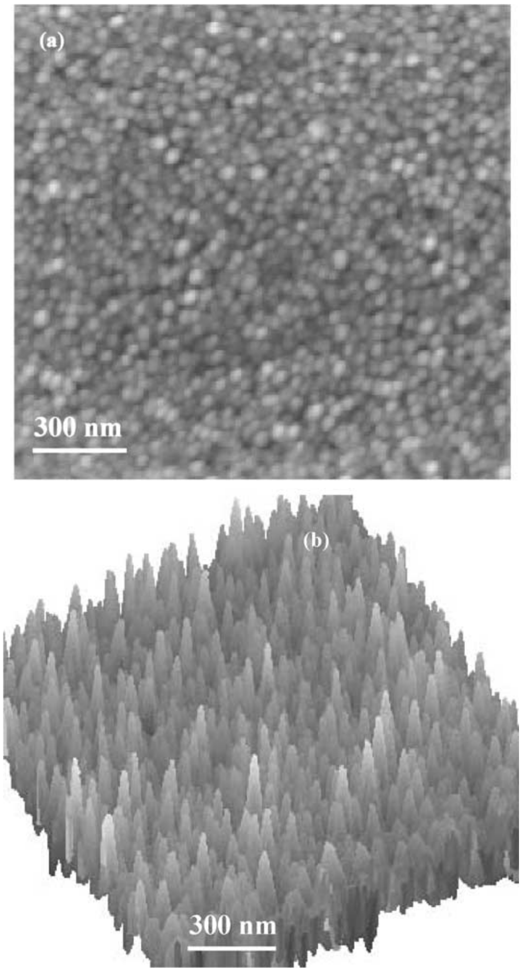

Fig. 1. AFM images of Au film scanned by a tapping mode with brand new probe: (a) top view, (b) three-dimensional view.

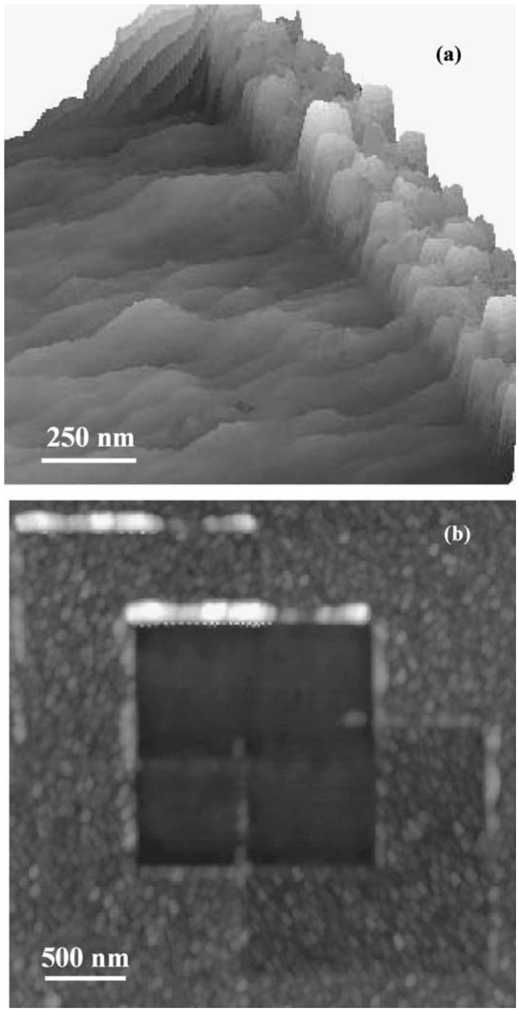

Fig. 2. AFM images of Au film scanned by a contact mode: (a) three-dimensional view of the scanned area, (b) top view of the scanned area, but with a decreased magnification.

Then the AFM was switched to a contact mode with the same probe as in the tapping mode to scan the Au film. After contact scanning, the AFM was switched back to the tapping mode to obtain the image of the contact-scanned area, as shown in Fig. 2. Since the film is softer than the probe, deformation or changing of the surface morphology was unavoidable when contact-scanning mode was used. From Fig. 2a, it can be found that the small islands observed in Fig. 1 were flattened and the surface of the film was scratched with a clear stacking of Au at the end of contact scanning. By increasing the area observed, a wider view of the deformed area was obtained, as shown in Fig. 2b. A scratched square in the observed sample area was obtained.

Using the same probe, which had been used as a contact-scanning probe, to observe with a tapping mode the area that had not been exposed to contact scanning, a special image was often obtained as shown in Fig. 3a, which was different from that of Fig. 1a. It can be found that the islands were elongated along the scanning direction in this case. Obviously this is an illusive or distorted image in comparison with Fig. 1a. Considering the history of the probe that it was used as a contact probe, a tiny piece of Au was possibly stuck to the probe, which enlarged the size of the tip in the scanning direction. This kind of tip was naturally making the islands be elongated in the scanning direction, as illustrated in Fig. 3b. If the stuck Au enlarges the size of the tip along the direction with an angle to the scanning direction, e.g. 45° as shown in Fig. 4a, images of the islands will be elongated in the direction of 45° relative to the scanning direction, as shown in Fig. 4b.

With a repeatedly used probe, another distorted image was obtained as shown in Fig. 5. The islands are now showing dome-like shapes, not as that shown in Fig. 1b, which is thought to be the real

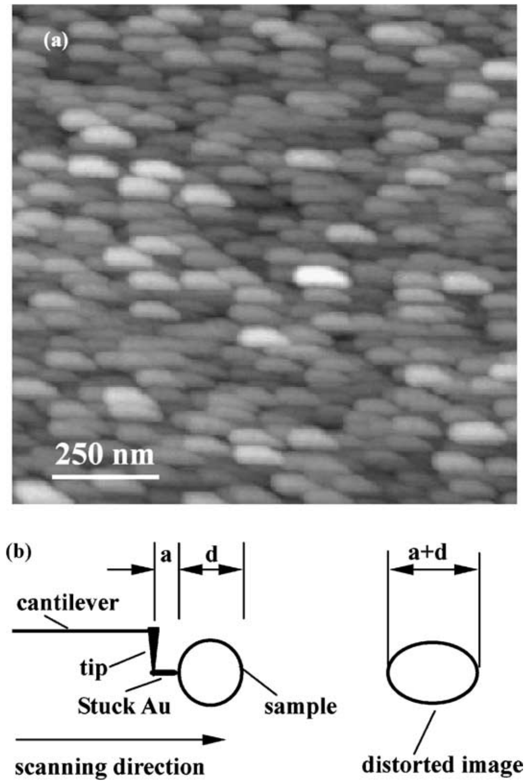

Fig. 3. AFM images of Au film scanned by a tapping mode with the probe which had been used to scan the surface of the film with a contact mode. A tiny piece of Au was stuck to the tip with an increasing of the tip size in the scanning direction. (a) Top view, (b) illustrating how the distorted image formed.

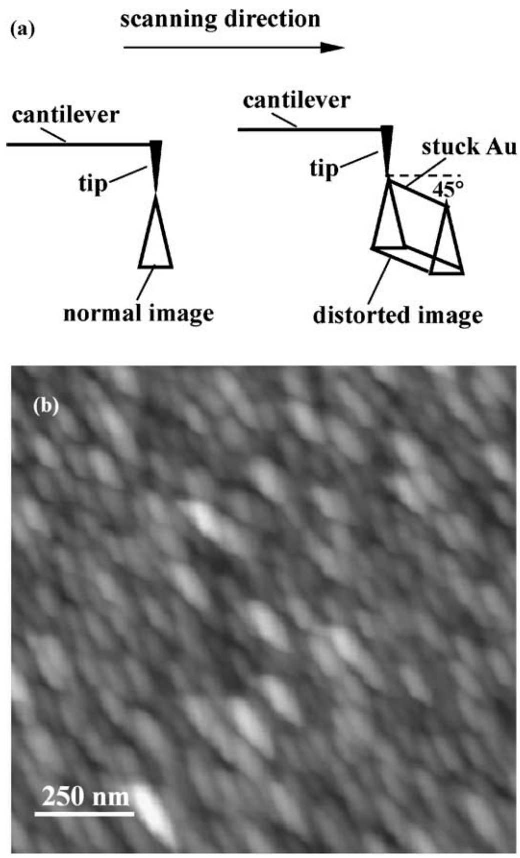

Fig. 4. AFM images of Au film scanned by a tapping mode with the probe which had been used to scan the surface of the film with a contact mode. A tiny piece of Au was stuck to the tip with an increasing of the tip size in the direction 45° to the scanning direction. (a) Illustrating how a distorted image formed, (b) top view.

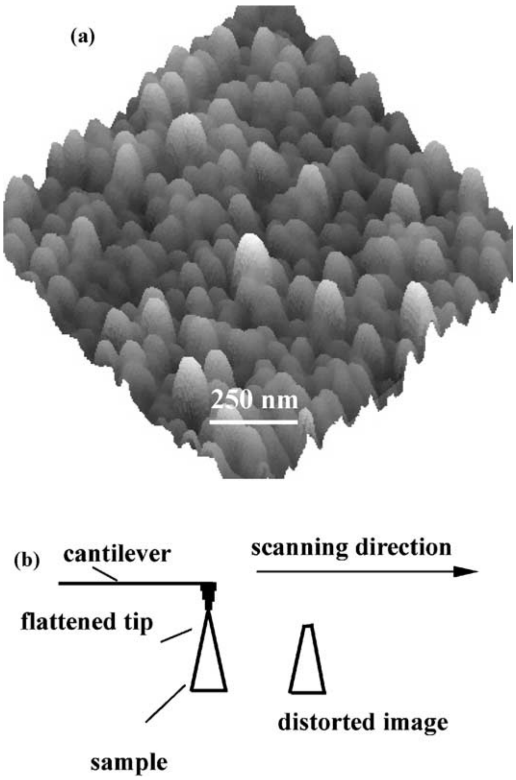

Fig. 5. Dome-like islands on the Au film, a distorted AFM image because of a flattened tip: (a) three-dimensional view, (b) illustrating how the distorted image formed.

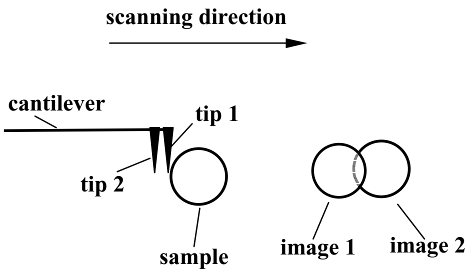

Fig. 6. Multi-tip effect on formation of duplicated images.

case. The reason is that the probe was used too many times that it was flattened or rounded at the tip, not as sharp as before. With a blunt tip, dome-like shape of the islands is possible, as illustrated in Fig. 5b.

Another kind of distorted AFM image is that produced by the so-called multi-tip effect. Sometimes the tip is contaminated with the sample material, and consequently, several new tips are formed by accident. Scanning with a multi-tip probe, duplicated images will be formed. Fig. 6 illustrates the case with two tips. Carefully checking Fig. 2b, one can find three square images along the diagonal line from the top-left corner to the bottom-right corner of Fig. 2b. The centric square is much clearer than the other two. This is actually a multi-tip effect on imaging of AFM.

4. Conclusion

The reality or quality of AFM images depends greatly on operation, tip state, the hardness of sample surface, etc. In some cases, images that look perfect may be distorted ones. The state of the probe tip, for example, has been shown to have great influence on the AFM images. Flattening and contamination of the tips must be avoided in order to obtain real images of the sample surfaces.

Acknowledgements

The authors acknowledge financial support from NSFC (Grant No. 50325103) and Hebei Provincial Funds (Grant No. 2001116/503278).

References

[1] G. Binnig, C.F. Quate, C. Gerber, Phys. Rev. Lett. 56 (1986) 930.
[2] M. Floyd, Y. Zhang, K.P. Driver, et al., Appl. Phys. Lett. 82 (2003) 9.
[3] Z. Zhong, J. Stangl, F. Schaffler, G. Bauer, Appl. Phys. Lett. 83 (2003) 18.
[4] Y. Zhang, M. Floyd, K.P. Driver, et al., Appl. Phys. Lett. 80 (2002) 19.
[5] C.J. Huang, Y.H. Zuo, D.Z. Li, et al., Appl. Phys. Lett. 78 (2001) 24.
[6] G. Palasantzas, S.A. Koch, De Hosson, Appl. Phys. Lett. 81 (2002) 6.
[7] M. Lazzarino, S. Heun, B. Ressel, et al., Appl. Phys. Lett. 81 (2002) 15.
[8] V. Bouchiat, M. Faucher, T. Fournier, et al., Microelectron. Eng. 61–62 (2002) 517.
[9] G. Capellini, M. De Seta, C. Spinella, et al., Appl. Phys. Lett. 82 (2003) 11.
[10] W.-c. Moon, T. Yoshinobu, H. Iwasaki, et al., Ultramicroscopy 119–123 (2000) 82.
[11] H. Huang, H.L. Wei, C.H. Woo, et al., Appl. Phys. Lett. 82 (2003) 24.
[12] Wu. Tang, K. Xu, P. Wang, et al., Microelectron. Eng. 66 (2003) 445–450.