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Experimental manipulation of gold nano-particles by Atomic Force Microscope and investigating effect of various working parameters

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Abstract. Due to involvement of various fields of engineering and bio researchers in nano projects and their need in achieving certain layout of nano-particles (NPs) in many research studies, considerable attention is paid to nanomanipulation nowadays. The present experimental study employs Atomic Force Microscope (AFM) in order to push gold nano-particles on a highly flat mica surface. A silicon probe in contact mode is used to both image and manipulate nano-particles and Topo and L-R images have been obtained to show the successes of manipulation when proper conditions are fulfilled. The effect of AFM parameters such as applied force, scanning speed and number of pixels of image on nanomanipulation efficiency is investigated. Moreover, the tip is moved along a special path which can be set by software to study manipulation of nano-particles aggregates. Finally, possible applications of nanomanipulation in nano-mechanics, nano-electronics, nano-materials and bio-technology are reported and further experimental research works on nanomanipulation are proposed.

Introduction

Nanotechnology, which aims at the ideal miniaturization of devices and machines down to atomic and molecular scale, has become a strategic topic with a promising future in high technology for the forthcoming century [1]. By the precise control of atoms, molecules, or nanoscale objects, new sensors and man-made materials, micromachines, organic integrated computers, microscale intelligence system and communication tools would be possible within the near future [2].

Nanomanipulation has a great impact on nanometer scale expertise. By manipulation of nanoscale objects (nano-objects), we mean using external force for positioning or assembling objects in two (2-D) or three (3-D) dimensions by twisting, bending, picking-and-placing, or pushing and pulling them. Three main modes are used in atomic force microscopy, i.e., non-contact (NC) mode, contact mode and intermittent tapping mode [3, 4]. Nanomanipulation is seen as a complex 3-D problem because mechanical and chemical properties of substrates, probing tools and nano-objects (especially 'particles') are combined, different results are expected depending on the environmental and operating conditions. Therefore numerous methods exist for the manipulation of nanostructures which can be classified into two categories as non-contact and contact manipulation systems. In the former, laser trapping (optical tweezers), electrostatic or magnetic field forces are utilized [5]. Paollicelli et al. [6] manipulated gold nano-particles deposited on highly oriented pyrolitic graphite using AFM in tapping mode. NPs were selectively moved as a function of their size varying from 24 up to 42 nm in diameter and the energy detachment threshold of NPs was estimated accordingly. Sitti and coworkers [7] have also manipulated nanoscale latex particles positioned on Si substrates with an accuracy of about 30 nm whilst Mougin et al. [8] manipulated as-synthesized and functionalized gold nanoparticles on silicon substrates with dynamic AFM. In this paper the sensitivity of parameters like scan velocity and tip range has been investigated.

Experimental work

To perform manipulation, gold nano-particles with a mean particle size of 15 nm, which are synthesized by actinobacteria mediated synthesis method [9], is placed on a highly flat mica surface. Imaging and manipulating is performed by ARA-AFM, an Iranian made AFM (manufactured by Ara-Research Company in Tehran) in contact mode. Fig. 1 shows the ARA-AFM setup. All experiments are conducted in air and room temperature and the CSC17 silicon probe from Mikromasch Company is employed. The probe characteristics are summarized in Table 1.

Fig. 1. Atomic Force Microscope made in Iran, modeled ARA-AFM, used in nanomanipulation.

Table 1. The CSC17 probe characteristics which is used for imaging and manipulating

Probe	Tip radius (nm)	Tip material	Typical force constant (N/m)	Typical resonance frequency (kHz)
CSC17	< 10	Silicon	0.15	12

In contact mode, when the tip is brought into proximity of the sample surface, forces acting between the tip and the sample lead to deflection of the cantilever according to the Hooke's law (Eq. 1).

$$F = K\,x \tag{1}$$

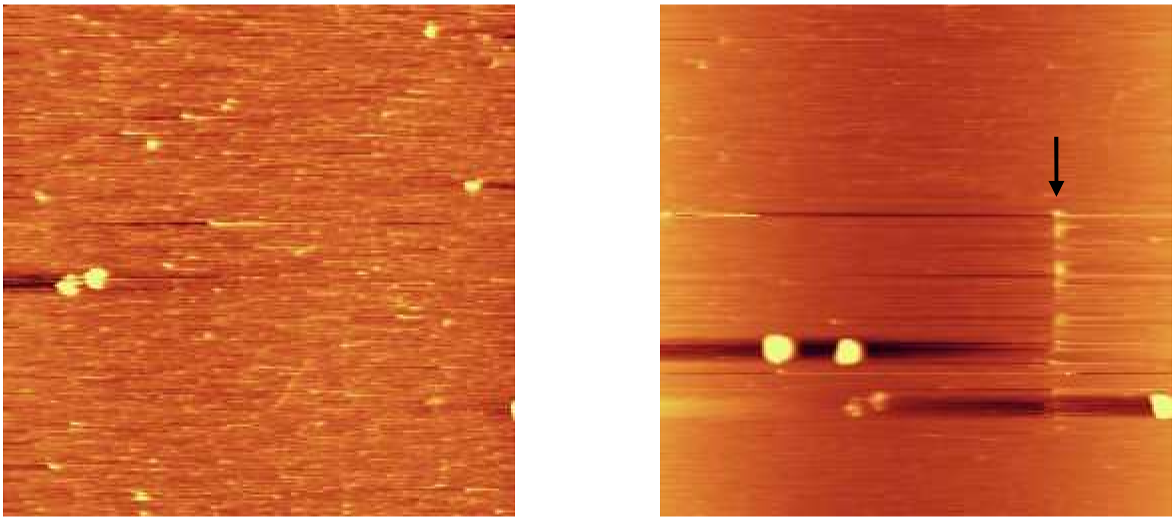
Also, relation between cantilever deflection (mV) and tip-sample interaction force (nN) is obtained from force spectroscopy analysis by ARA-AFM. The results show 1 mV deflection of cantilever is proportional to 0.15 nN of force.

The force value is adjusted to 7.5 nN for imaging, while 15 nN is chosen to manipulate the nano-particles. Moreover, in order to study the effect of force value on manipulation, the force is varied from 30 to 45 nN. Scanning speed and number of pixels of images is normally chosen 1 lines/second and 256, respectively. Topo and L-R images are obtained to investigate nano-particles distribution. L-R image is a result of Lateral Force Microscopy (LFM).

Results and Discussion

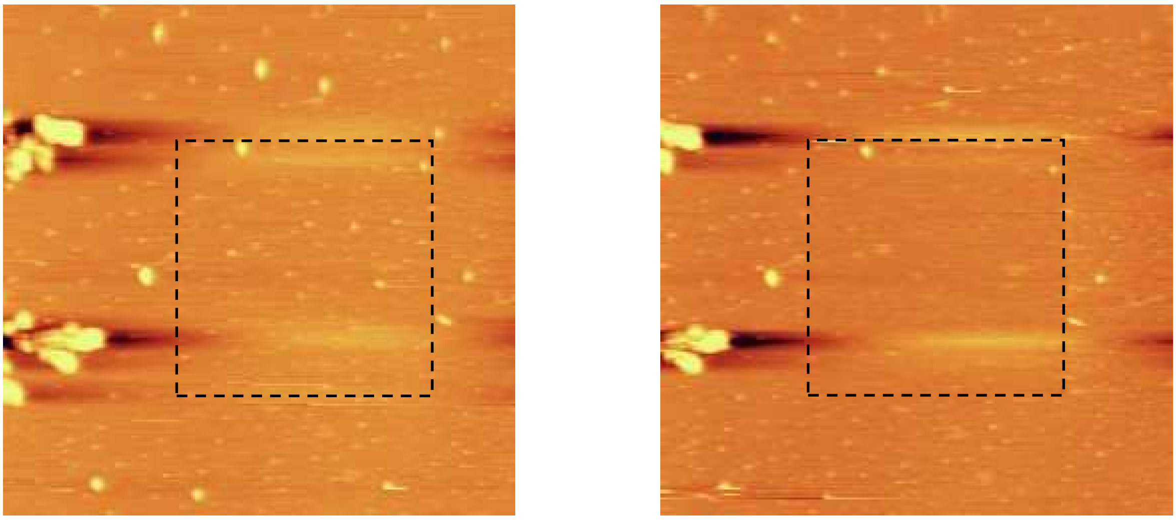
Topo images of gold nano-particles before and after manipulation are shown in Fig. 2. As it is mentioned, in the first step, imaging of nano-particles are obtained with a force of 7.5 nN in 10×10 µm frame (Fig. 2-a). For manipulation, the 5×5 µm frame with a force of 15 nN scanning is performed. Another 10×10 μm image is obtained and shown in Fig. 2-b. As is seen in Fig. 2-b, the nano-particles are pushed across the scan direction and aligned in the other direction i.e. perpendicular to the scan direction.

Fig. 3 shows similar process in another position of mica with a smaller frame size of 8×8 μm. The number of nano-particles is seen to decrease in the selected area of 4×4 μm after manipulation.



(a) (b)

Fig. 2. The Topo images (10×10 μm) of gold nano-particles: a) before and b) after manipulation.



(a) (b)

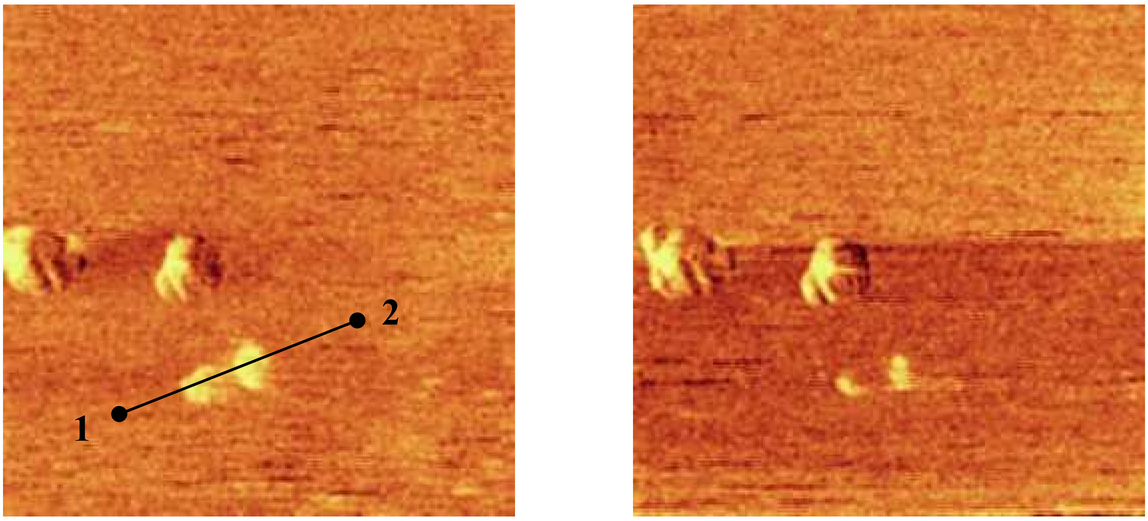
Fig. 3. The Topo images (8×8 μm) of gold nano-particles: a) before and b) after manipulation.

To study the effect of AFM parameters on manipulation, an area of 4×4 μm is scanned with various force, speed and number of pixel values. Subsequently, the number of nano-particles is counted for each image. As a rule, as this number gets lower, the success of perform manipulation is higher. The results are shown in Table 2. Increasing force and speed result in increasing mobility of nano-particles and success of manipulation while the number of pixels has a negligible effect.

Adhesion of gold nano-particles results in aggregation of particles to mica surface. This means that in these cases, higher values of force is required to reach manipulation. Fig. 4-a shows L-R image of large aggregates which does not manipulate with normal manipulation conditions mentioned previously in the present report. To manipulate such aggregate, first the tip conducts to point 1, the force is set at 45 nN and tip moves to point 2 along a drawn line. This process is repeated 10 times and finally image of Fig. 4-b is obtained. As shown, the nano-particles of these aggregates are separated and go out of this frame.

Table 2. The number of gold nano-particles in selected area of 4×4 μm scanned with different AFM parameters

Image number	Applied force (nN)	Scanning speed (lines/second)	Number of pixels	Number of gold nano-particles
1	15	1	256	150
2	15	3	256	130
3	15	3	512	129
4	30	1	256	110



(a) (b)

Fig. 4. The L-R images (5×5 μm) of gold nano-particles aggregates: a) before and b) after manipulation.

Conclusion

Atomic Force Microscope (AFM) is employed to manipulate gold nano-particles on a mica base in contact mode. The sample images show that gold nano-particles are pushed successfully across the scan direction and aligned in the direction perpendicular to scan lines. Experiments show that higher force and speed result in increasing mobility of the nano-particles and higher efficiency of manipulation while number of pixels has a negligible effect. Finally the aggregates of nano-particles are separated after manipulation in a certain line.

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