Manipulation of Gold Nanoparticles in Liquids Using MAC Mode Atomic Force Microscopy

Application Note

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Precise control of the structure of matter at the nanometer scale will have revolutionary implications for science and technology. Nanoelectromechanical systems (NEMS) will be extremely small and fast, and have applications that range from cell repair to ultrastrong materials. One approach for the construction of such nanostructures is assembly from molecular-sized components.

Although regular, symmetric patterns of nanoparticles can be constructed by self-assembly, many of the possible applications require asymmetric shapes. Several methods have been proposed to construct such structures. Among these, a promising strategy is the use of the scanning force microscope (SFM) as a manipulation tool to move nanoparticles and nanostructures without the restrictions imposed by the physics of self-assembly (1-5).

Until now, manipulation of nanoparticles with the SFM has been mostly limited to clearing areas on a surface, or to moving single particles sequentially to create two-dimensional patterns. By connecting individual nanoparticles (6), it may be possible to construct relatively rigid structures, "primitives", of arbitrary (planar) shapes. These structures, in turn, may serve as components for building complex NEMS.

By using organic molecules (e.g., dithiols and gold nanoparticles), scientists at the Laboratory for Molecular Robotics at USC have successfully linked these nanoparticles and manipulated them as primitives consisting of up to four particles (7). This achievement is a major breakthrough in developing a bottom-up approach for building nanostructures. The capability to perform this precise manipulation in air illustrates the potential of this approach.

Nanomanipulation in biochemical and medical areas, however, will require that most experiments be performed in a liquid environment. Atomic force microscopy (AFM) has already proven its capabilities in liquid environments. In nanomanipulation, though, only dynamic force microscopy (DFM) with an oscillating cantilever will likely satisfy the need to minimize the influence of the tip on the sample.

In the study described in this report, we used an atomic force microscope (AFM) from Agilent Technologies operated in MAC Mode to perform precise and controlled manipulation of gold nanoparticles in aqueous solutions (deionized water). The sample was prepared by depositing gold colloidal particles (EM.GC15; Ted Pella Inc.) with a diameter of 15 nm from aqueous solutions on a mica substrate that had been coated previously with a poly-L-lysine film.

Manipulation of the nanoparticles was performed by utilizing the Probe Control Software (PCS) developed in our group (3-7). This software allows the user to take single line scans by setting an "arrow" in a previously recorded dynamic mode image. The arrow determines the direction and length of the scan line and can be moved by the operator in the x- and y-direction until the displayed topography indicates that its path is centered over the particle. In order to compensate for relative position drifts, a tracking tool based on the differential height between the particle and the surface can be activated to keep the arrow aligned at the center of the particle. Two bars are positioned along the scan line within which alternative operating conditions of the AFM, and therefore the "start" and "end" points of the manipulation, can be selected. See Figure 1 and Figure 2.

Further options available with our DFM setup are the direct movement of the scanner in the z-direction (without feedback control) and the indirect movement of the scanner by changing the amplitude of the oscillation. The latter operation is carried out with feedback control and then subsequently the feedback is switched off. In case the particles and structures one wants to manipulate are strongly attached to the underlying surface, a contact mode setup is recommended. One can select either a feedback-off protocol with or

without additional direct movement of the scanner or a feedback-on protocol with indirect movement of the scanner by changing the deflection of the cantilever and therefore varying the force.

Once the tip hits the particle (with the feedback turned off), the oscillation of the cantilever breaks down and the tip climbs the particle until a particular deflection (loading force) of the cantilever occurs. At this point, the force generated by the cantilever overcomes the adhesive force between the particle and the substrate, and the particle is pushed by the AFM tip. This can be clearly observed in the line scan recorded in Figure 2. Part of the particle remains inside the feedback-off window, consistent with the above discussion.

Figure 3 shows a 500 nm x 500 nm scan of an area of the sample surface obtained with MAC Mode in deionized water. Three particles labeled 1, 2, and 3 can be observed. Utilizing the AFM tip, these particles were then pushed to new positions on the surface as recorded in Figure 4.

The ability to perform manipulation on the nanometer scale in air and in a liquid environment further illustrates the capabilities of scanning force microscopy. This not only extends previous work in controlled nanomanipulation and opens new avenues of research on the construction of complex NEMS, but also offers the possibility to perform manipulation experiments in biological and biomedical systems. Furthermore, nanomanipulation in a liquid environment enables the user to control the tip/object and object/substrate forces, which ultimately determine the success of manipulation operations. By designing automatic tools for manipulation operations in combination with multitip arrays, the SFM will become a high-throughput, programmable, nanometer-scale robot.

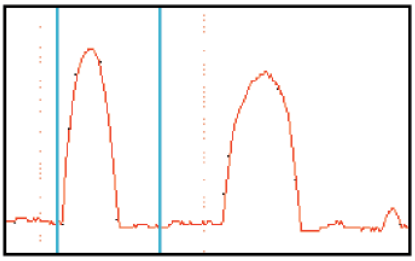


Figure 1. The initial line scan showing two particles.

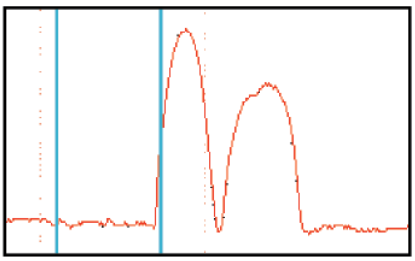
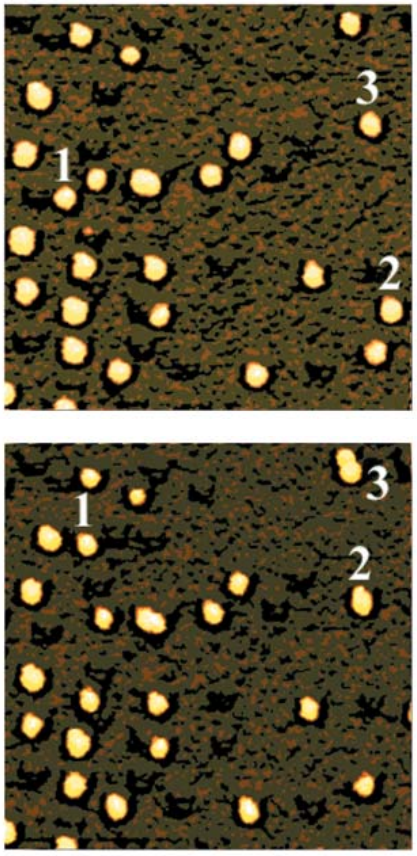


Figure 2. The line scan obtained after successfully pushing the left particle. Parameters for pushing operations were active between the two vertical bars.



Figures 3 and 4. A display of the results of pushing particles 1, 2, and 3 underwater.

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