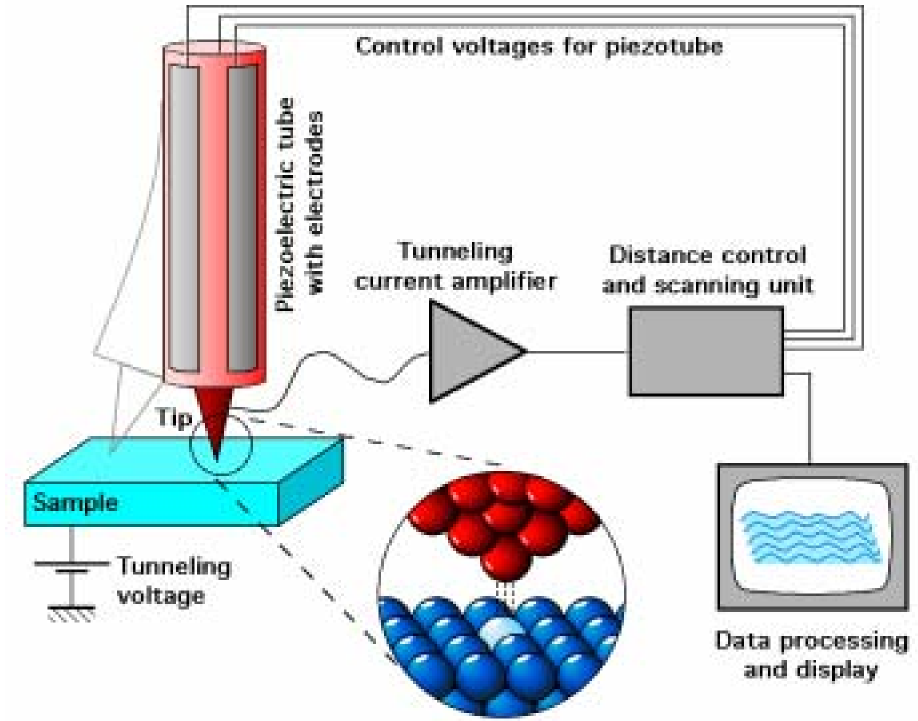
Scanning Tunneling Microscopy

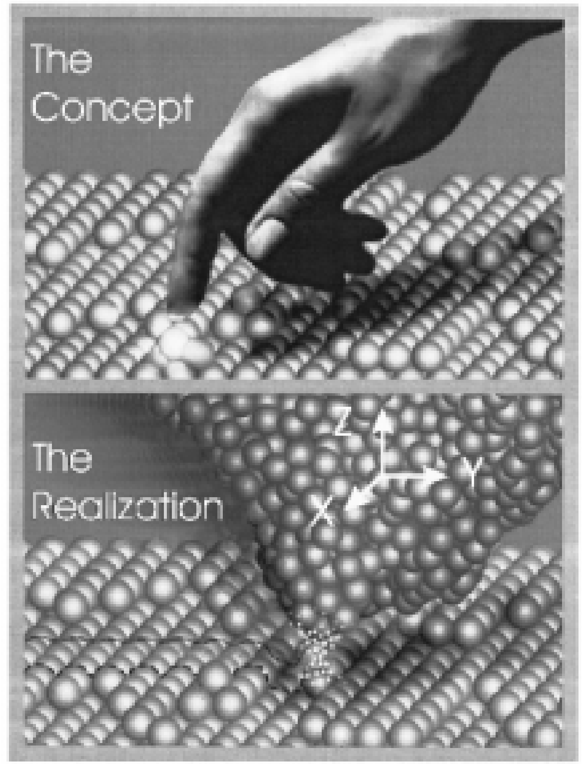


References:

1. G. Binnig, H. Rohrer, C. Gerber, and Weibel, Phys. Rev. Lett. **49**, 57 (1982); and ibid **50**, 120 (1983).

2. J. Chen, *Introduction to Scanning Tunneling Microscopy*, New York, Oxford Univ. Press (1993).

Concept: Eye and Finger

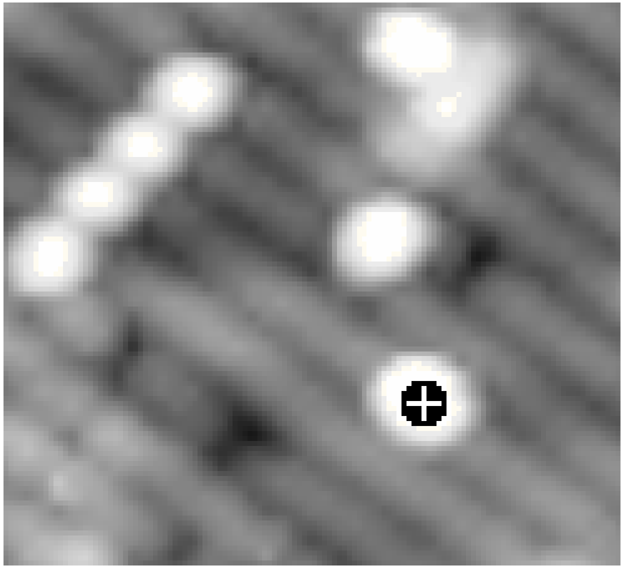


G. Binnig and and H. Rohrer, *Rev. of Mod. Phys.* **71**, S324-S330 (1999).

Atom Manipulation Involves:

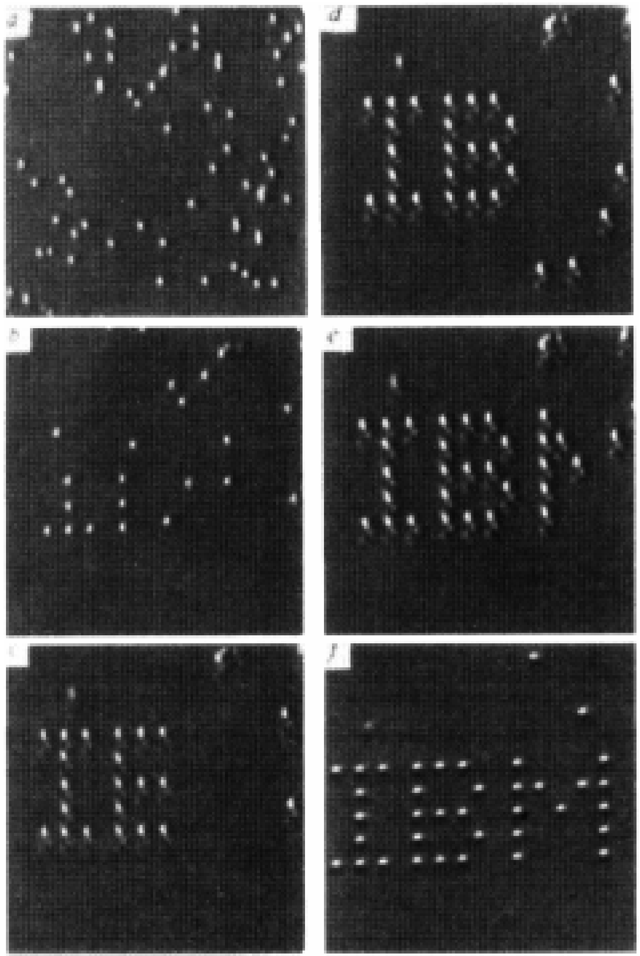
1. Positioning
2. Engaging
3. Displacing
4. Modifying

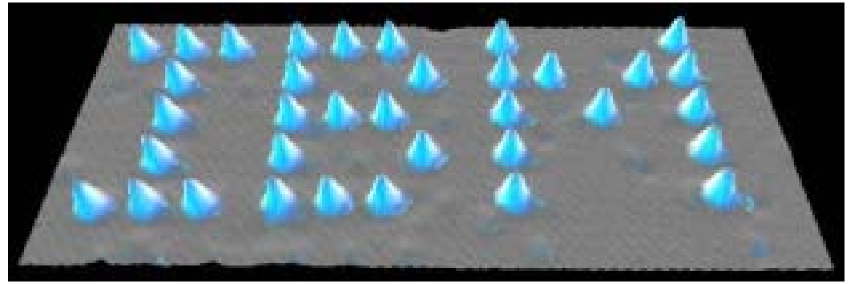
Atom Tracking



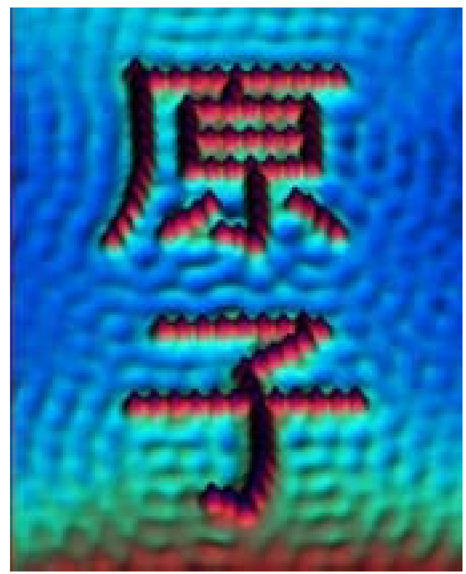
The atom tracker works by locking onto selected "bumps" (or "holes") using lateral feedback. The feedback maintains the position of the STM tip at the local maximum by continually climbing uphill. Once locked, atom-track data are acquired by reading the X, Y, and Z positions of the feedback electronics as a function of time. The motion of the surface feature is reflected in the coordinates of the atom tracker.

Atomic Manipulation with STM



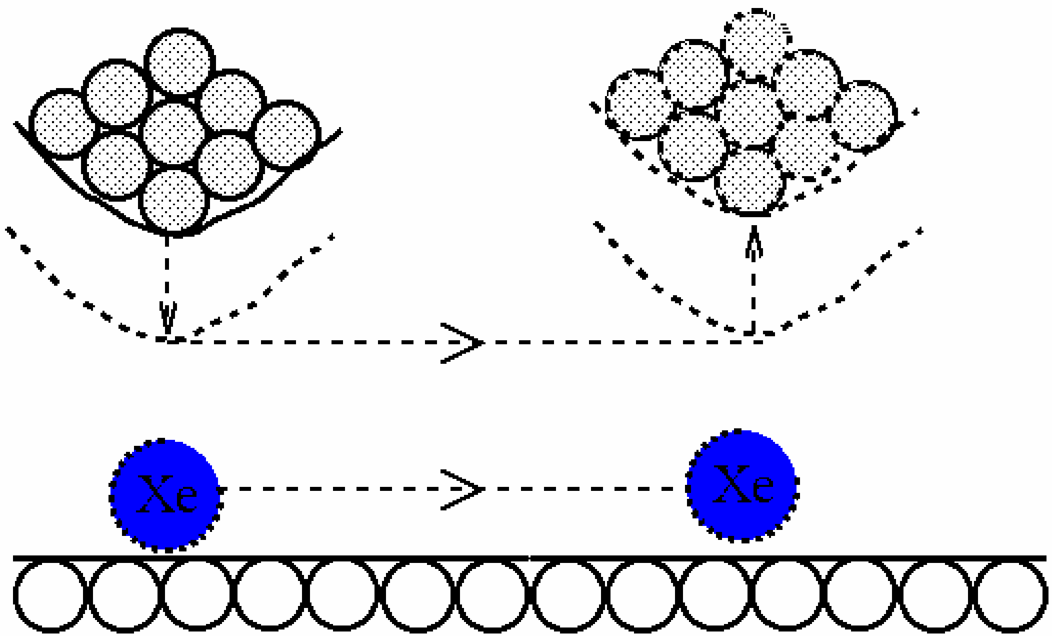


Nature **344**, 524 (1990)



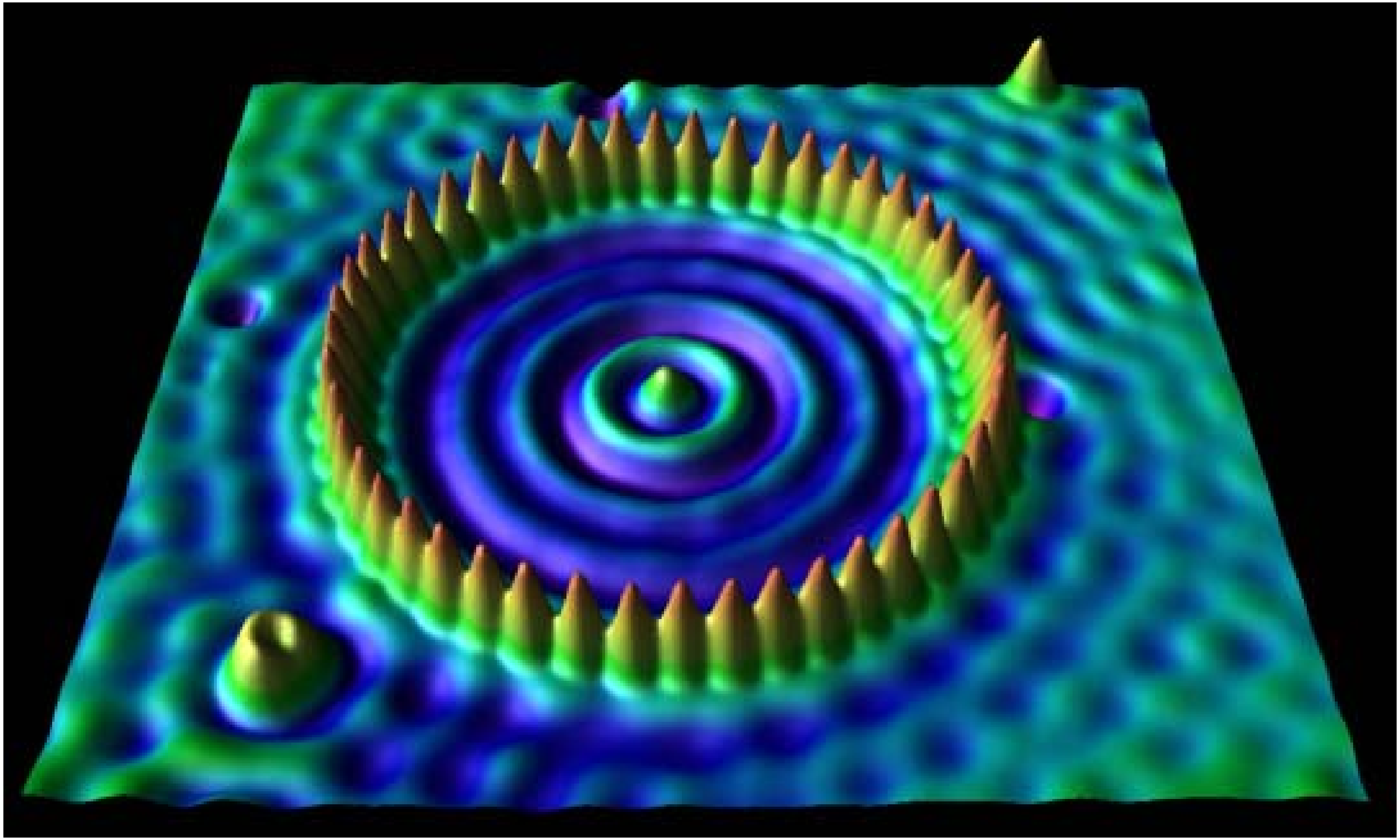
Positioning Atoms with an STM

D.M. Eigler & E.K. Schweizer Nature **344** 524 (1990)

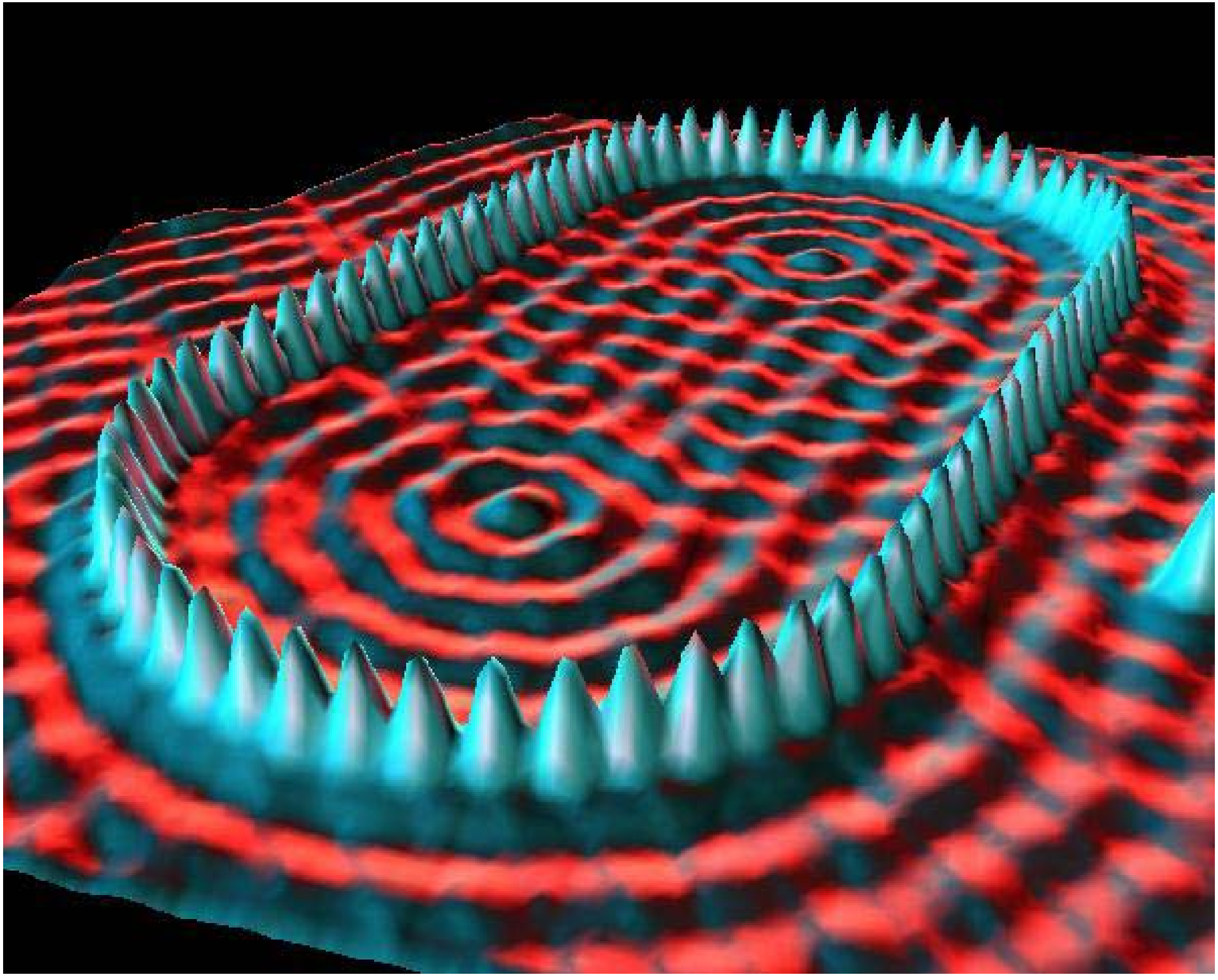


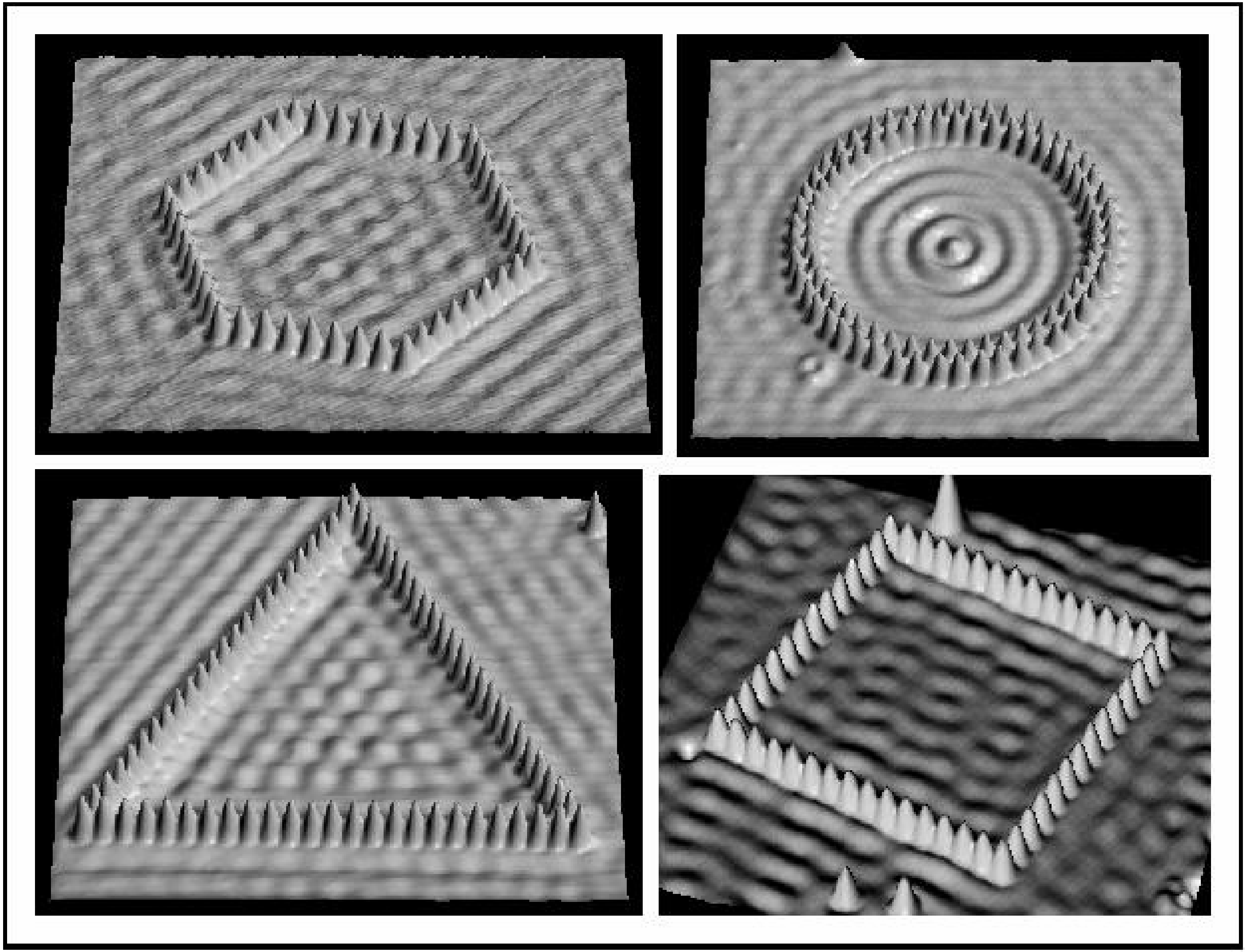
The STM tip is brought down near the atom, until the attraction is enough to hold it as the atom is dragged across the surface to a new position.

Quantum Corral

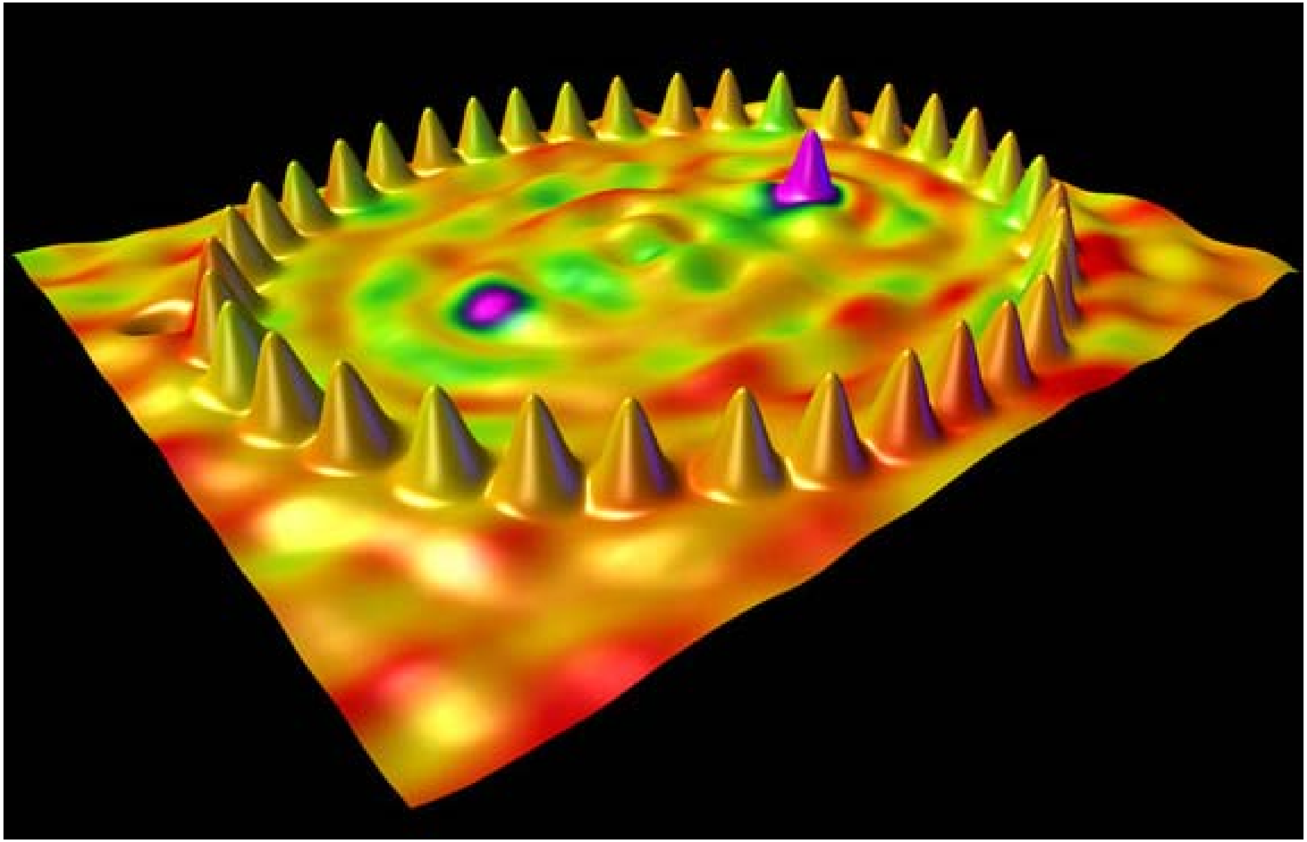


M.F. Crommie *et al.*, *Science* 262, 218 (1993).



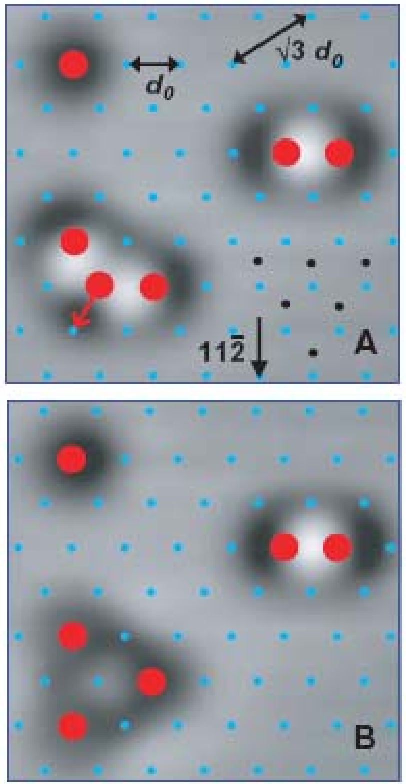


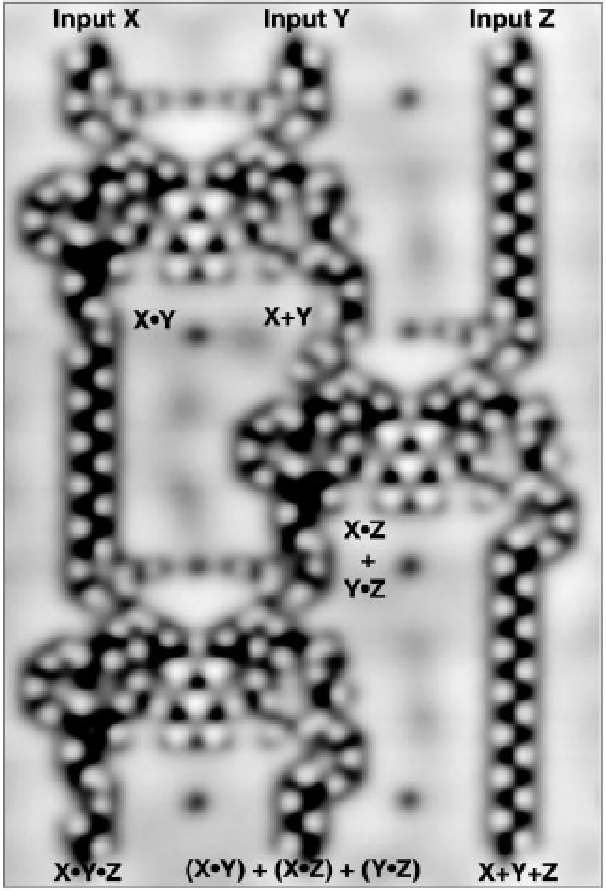
Quantum Mirage



H. C. Manoharan *et al.*, *Nature* 403, 512 (2000).

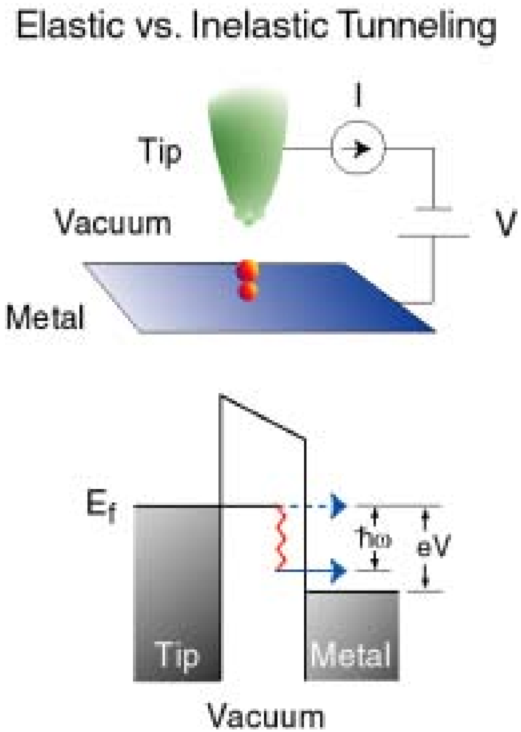
Molecule Cascades





A.J. Heinrich, C. P. Lutz, J. A. Gupta, D. M. Eigler
Science **298**, 1381 (2002)

Inelastic Tunneling



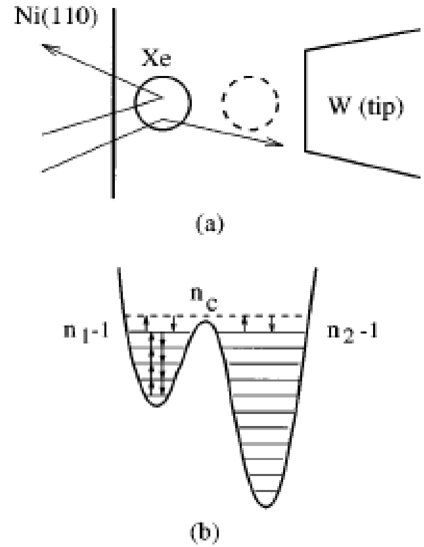
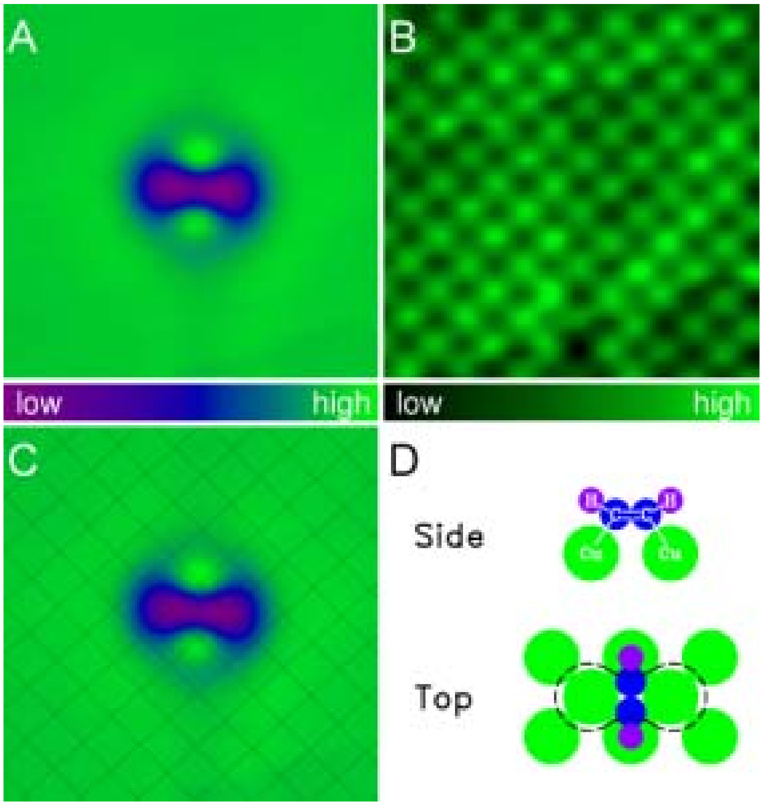
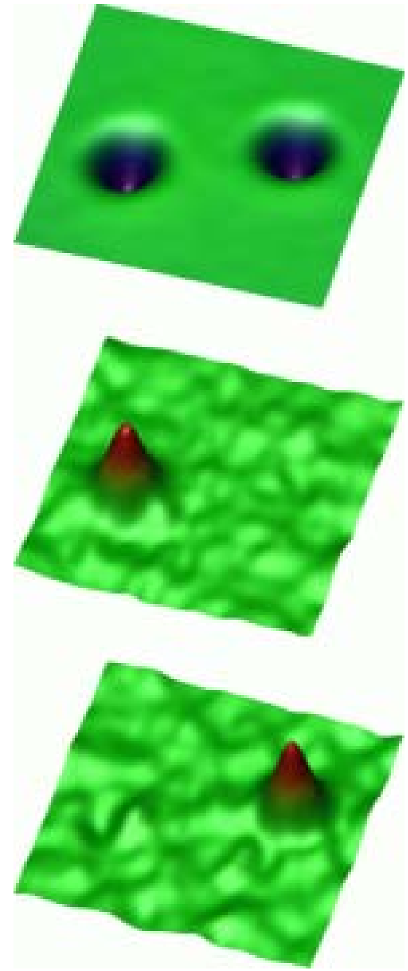


FIG. 1. (a) Schematic picture of the atomic switch. (b) Double-well model for atom transfer based on truncated harmonic oscillators. In the vibrational heating mechanism, the atom transfer results from stepwise vibrational excitation of the adsorbate-substrate bond by inelastic electron tunneling as depicted by arrows between the bound state levels of the adsorption well 1.

Single Molecule Vibrational Spectroscopy and Microscopy





B.C. Stipe, M.A. Rezaei, and W. Ho,
Science **280**, 1732-1735 (1998).

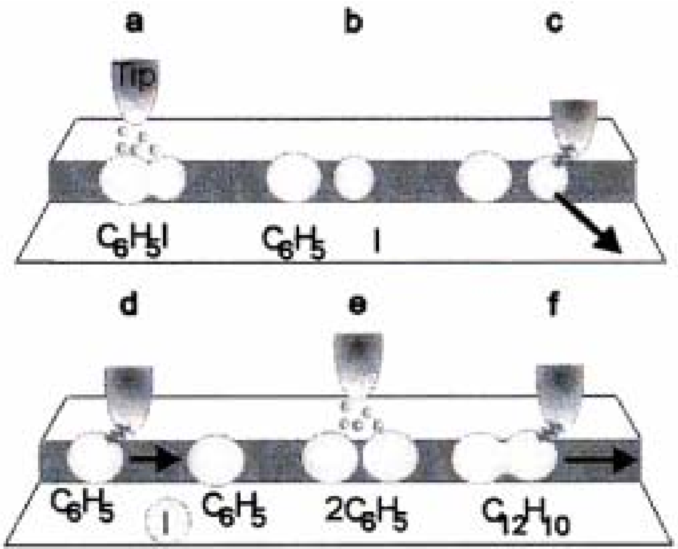
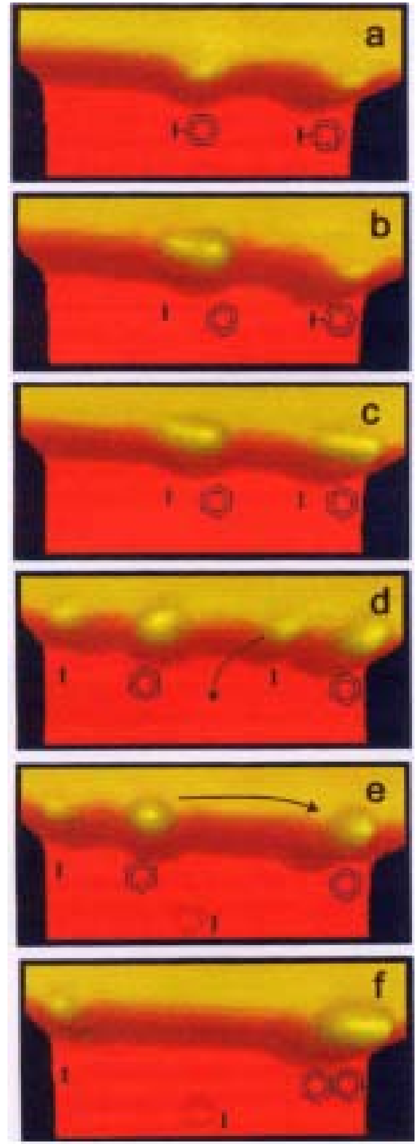
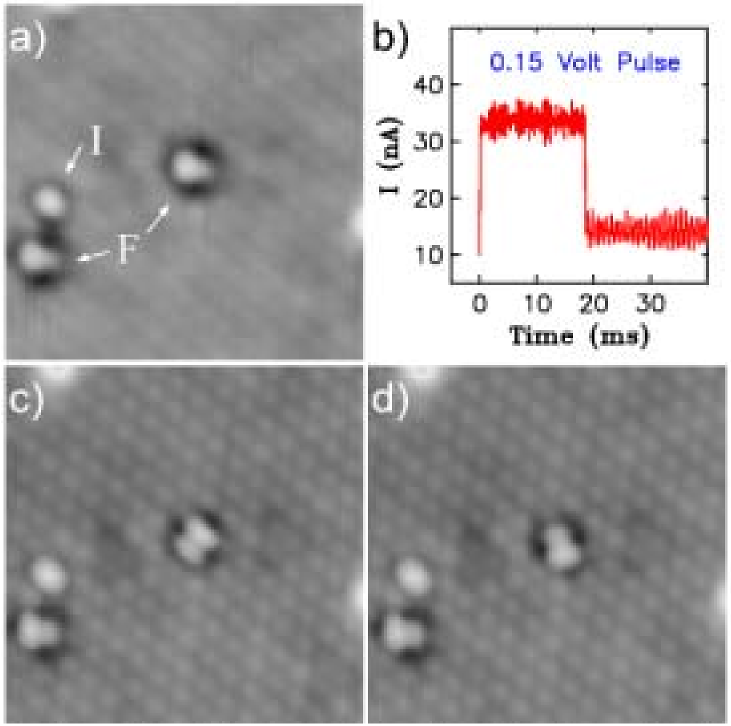


FIG. 1. Schematic illustration of the STM tip-induced synthesis steps of a biphenyl molecule. (a),(b) Electron-induced selective abstraction of iodine from iodobenzene. (c) Removal of the iodine atom to a terrace site by lateral manipulation. (d) Bringing together two phenyls by lateral manipulation. (e) Electron-induced chemical association of the phenyl couple to biphenyl. (f) Pulling the synthesized molecule by its front end with the STM tip to confirm the association.

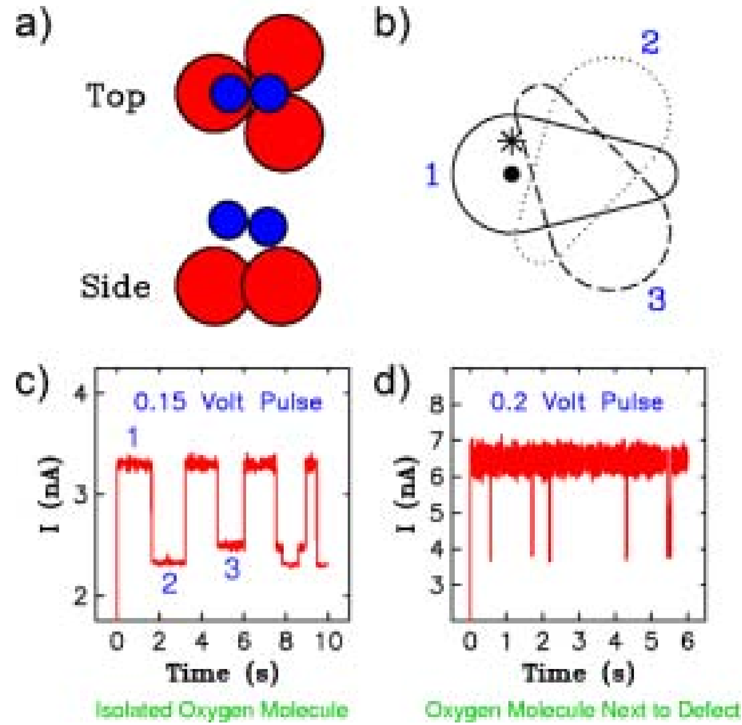


Phys. Rev. Lett. 85, 2777 (2000)

Reversible Rotation by Tunneling Electrons



Single Molecule Reversible Rotation



B. C. Stipe *et al.*,
SCIENCE 279, 1908 (1998)

(**A**) Schematic drawing showing top and side views of the fcc-site O2 molecule (black circles); Pt atoms are shown in gray. (**B**) Schematic outline of "pear" molecule shape as seen in STM images for each orientation. The solid dot is the position of maximum tip height for the first orientation; this is the tip position used for data collection. The asterisk shows an off-axis tip position displaced 0.4 Å from the solid dot. (**C**) Current during a 0.15-V pulse with the tip in the off-axis position in (B), showing three levels of current corresponding to the three orientations of the molecule. (**D**) Current during a 0.2-V pulse over a molecule next to an impurity showing a strong preference for a particular orientation.

Field Evaporation

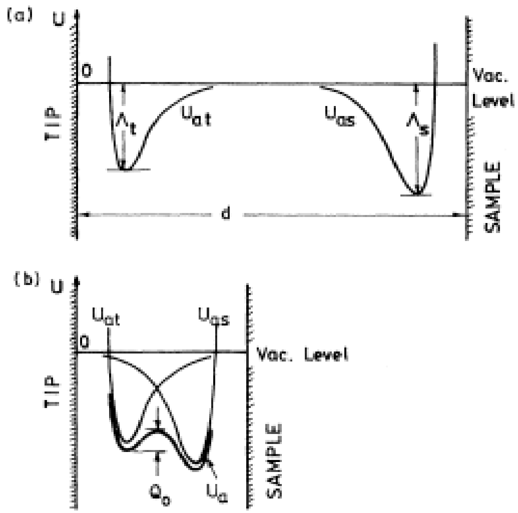
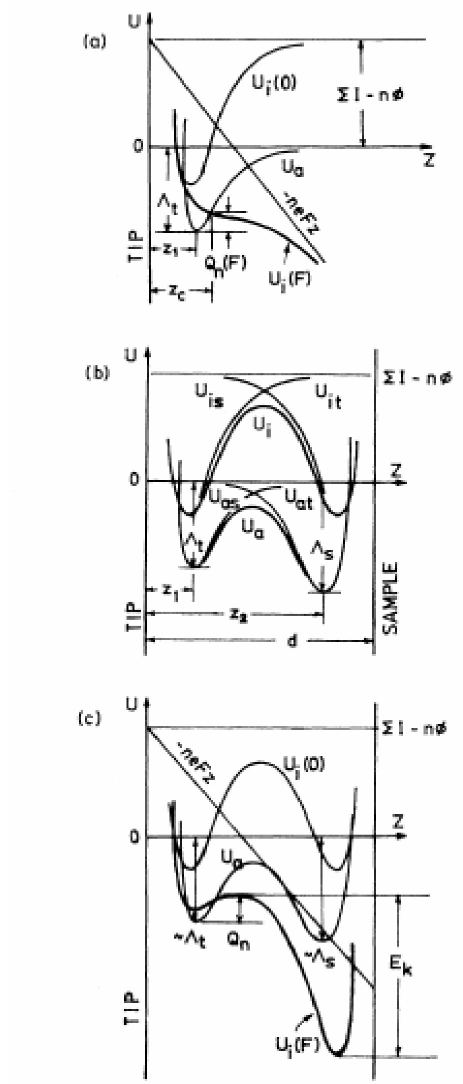
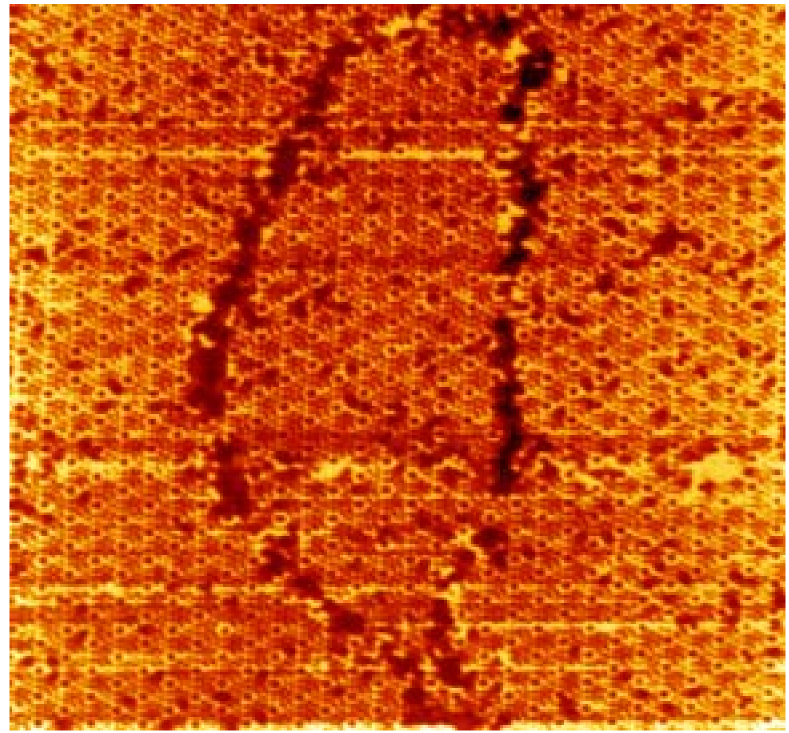


FIG. 1. When the tip to sample distance d is large, the atom-tip and atom-sample interactions U_{at} and U_{as} do not overlap significantly as shown in (a). When d is small, the two start to overlap and U_a, which is the sum of U_{at} and U_{as}, exhibits a double-well structure having a small activation barrier. The atom can either be transferred from the tip to the sample or from the sample to the tip, as shown in (b).

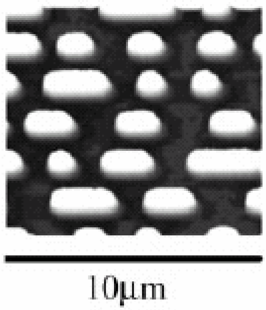


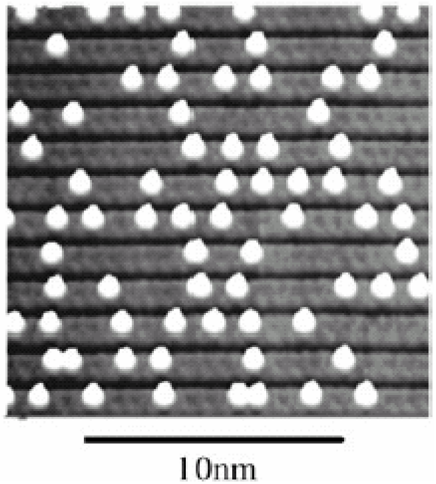



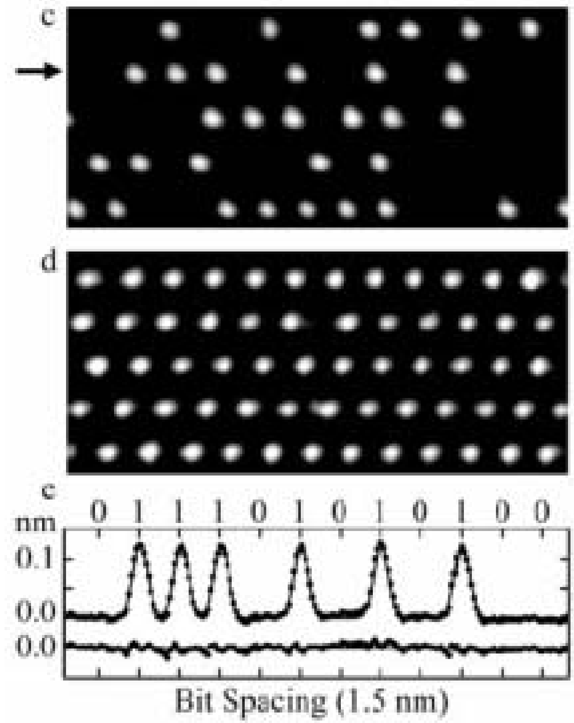
Atom Memory at Room Temperature
Au/Si(111)

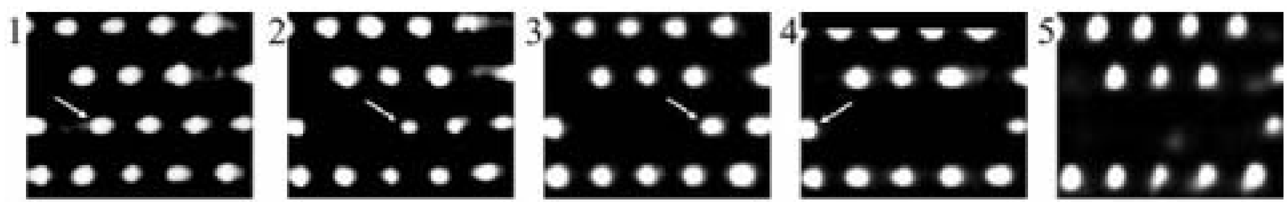
Nanotechnology **13** (2002) 499–502

CD-ROM







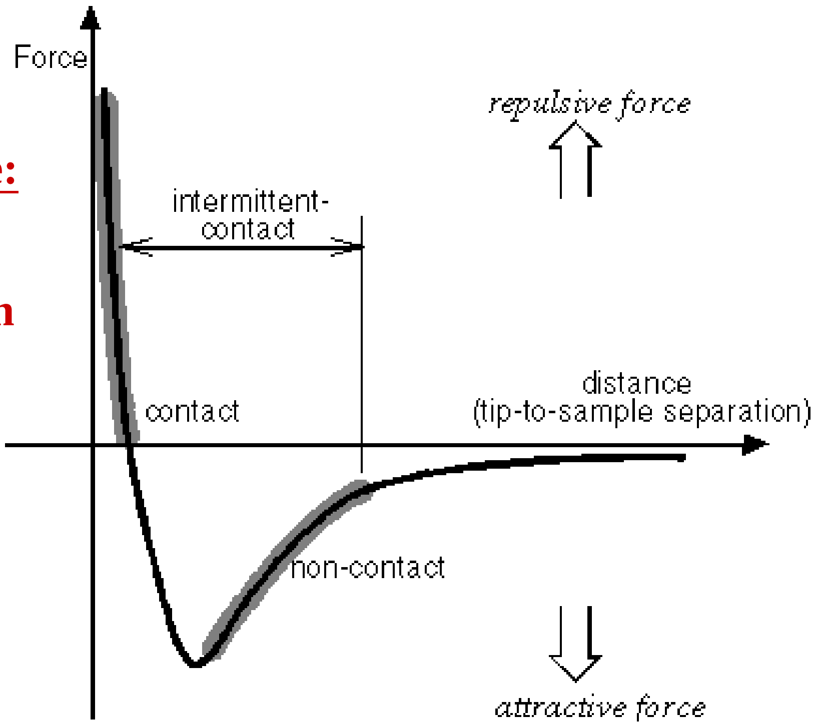


Interaction between the probe and sample

Short-range:

1) Bonding

2) Repulsion



Long-range:

1) Van der Waal

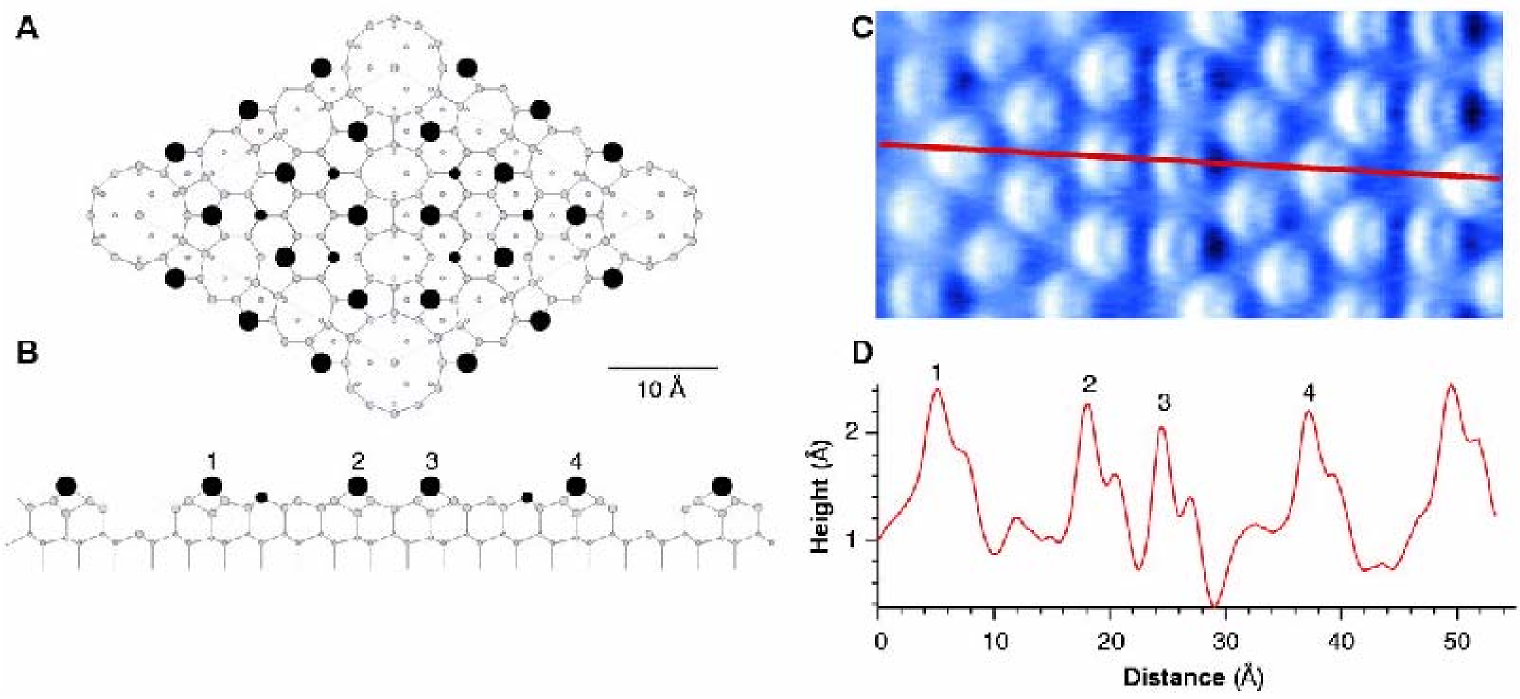
2) Capillary

3) Magnetic

4) Electrostatic

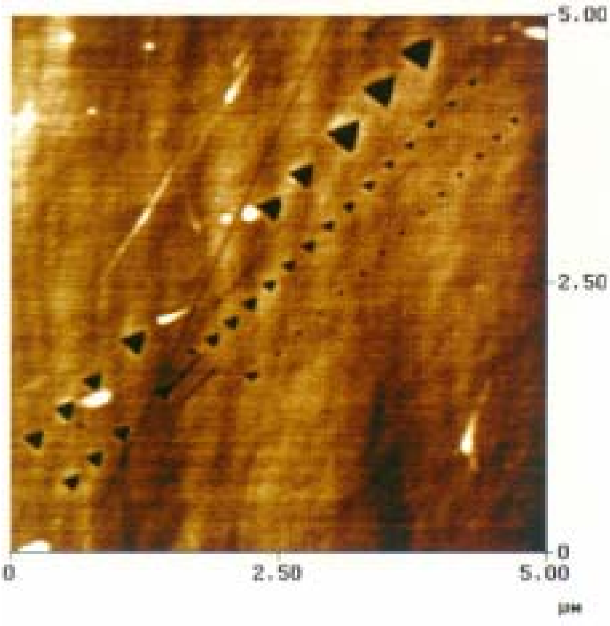
Lennard-Jones potential $\phi(r) = - A/r^6 + B/r^{12}$

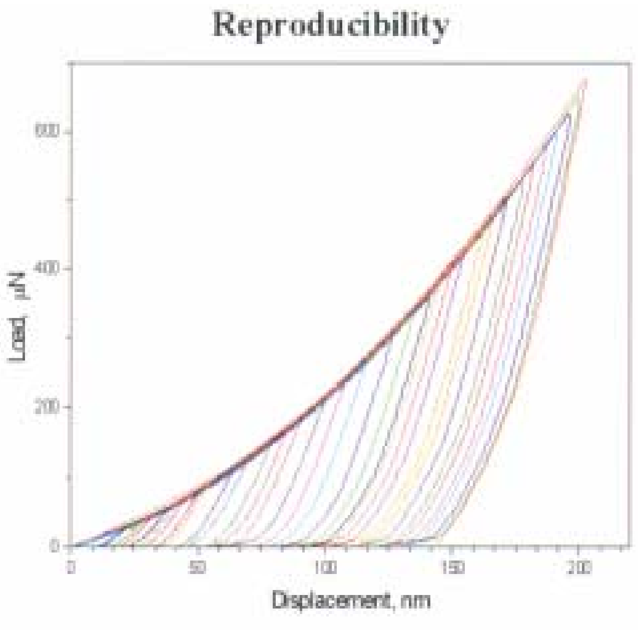
Atomic Image of Si(111)-(7×7) Taken with AFM



F.J. Giessibl *et al*., Science <u>289</u>, 422 (2000)

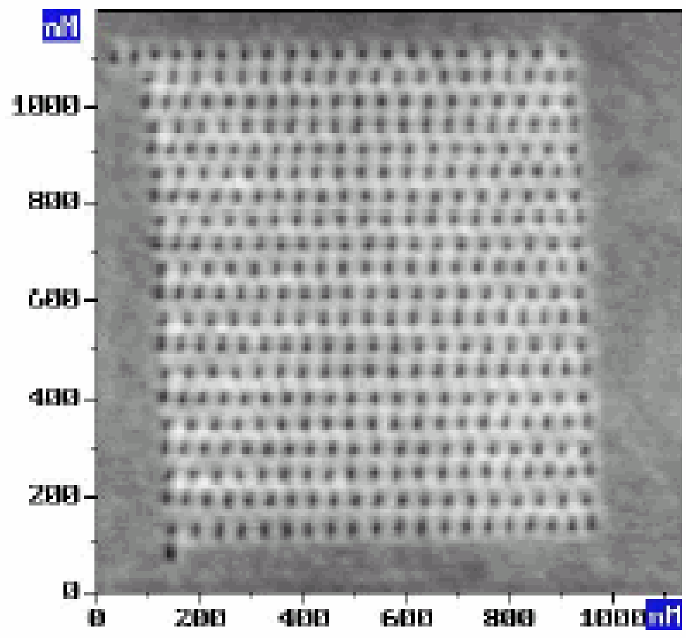
Measurement of Mechanical Properties



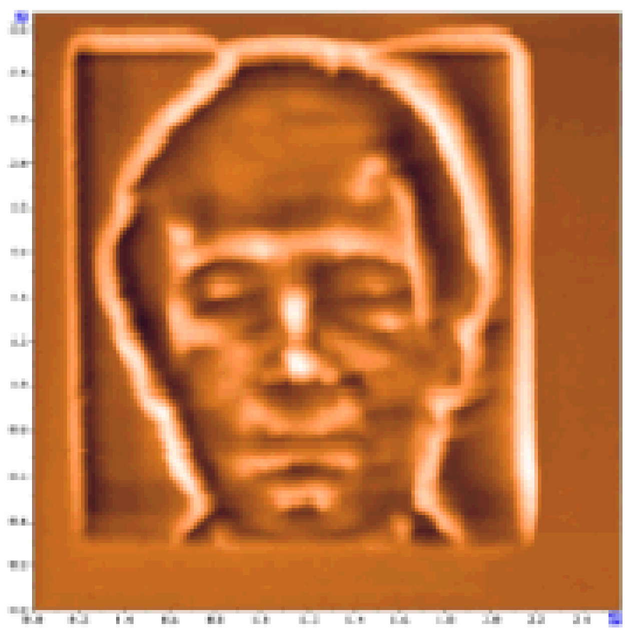


1. The load-displacement curves provide a “mechanical fingerprint” of material’s response to deformation, from which parameters such as hardness and young’s modulus of elasticity can be determined.
2. In measuring the mechanical properties of thin coated system, the size of contact impression should be kept small relative to the film thickness.

Nanolithography of Tapping-Mode AFM

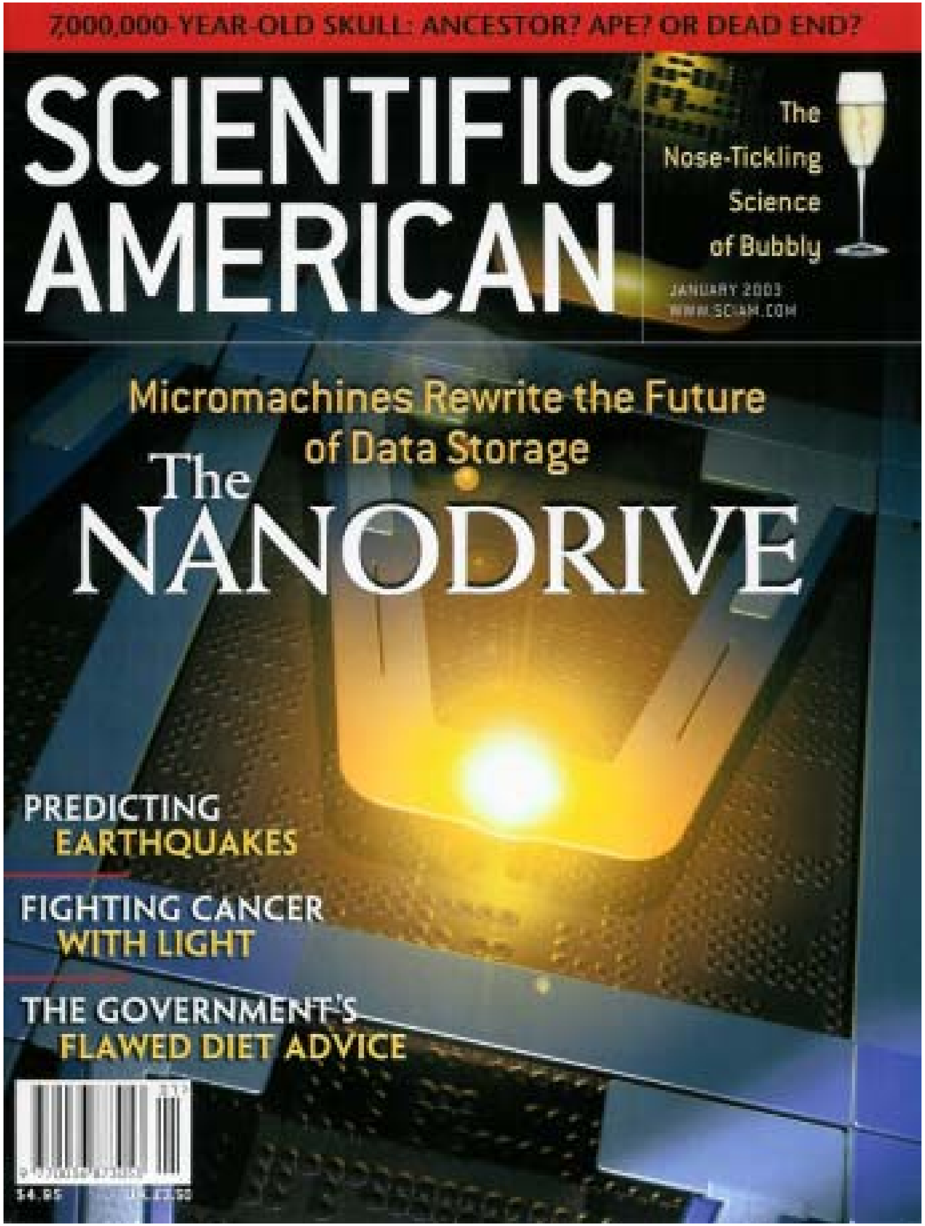


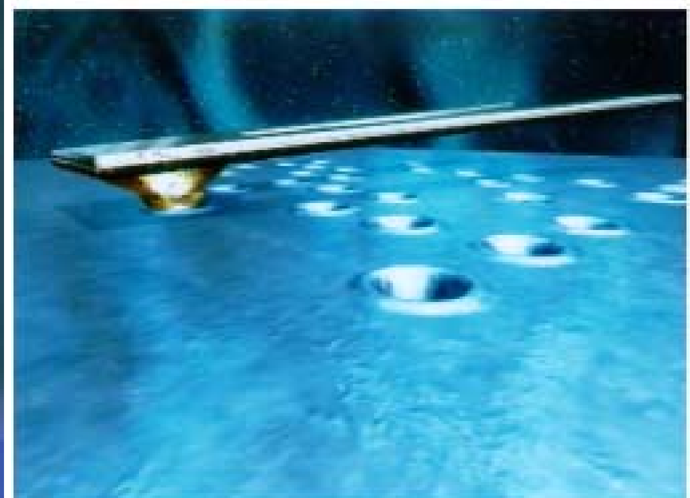
(1.2 μm× 1.2 μm)

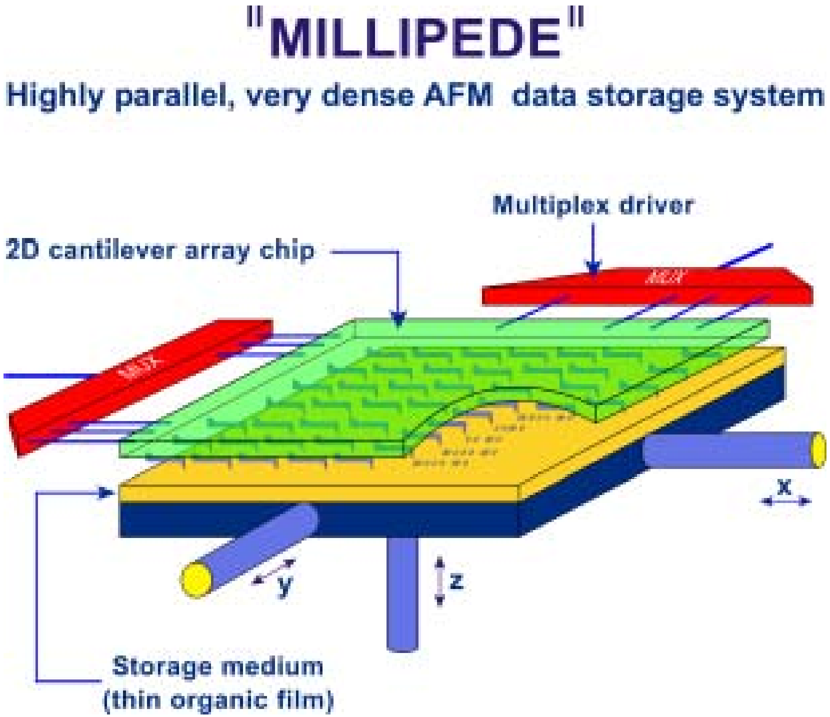


(2.5 μm× 2.5 μm)

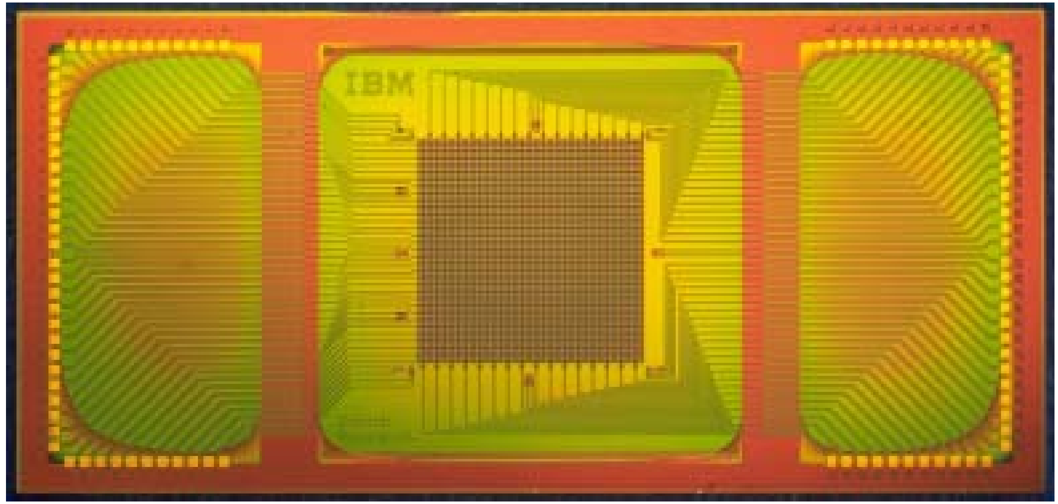
Image of polycarbonate film on silicon surface


7,000,000-YEAR-OLD SKULL: ANCESTOR? APE? OR DEAD END?
SCIENTIFIC AMERICAN
The Nose-Tickling Science of Bubbly
JANUARY 2003
WWW.SCIAM.COM
Micromachines Rewrite the Future of Data Storage
The NANODRIVE
PREDICTING EARTHQUAKES
FIGHTING CANCER WITH LIGHT
THE GOVERNMENT'S FLAWED DIET ADVICE

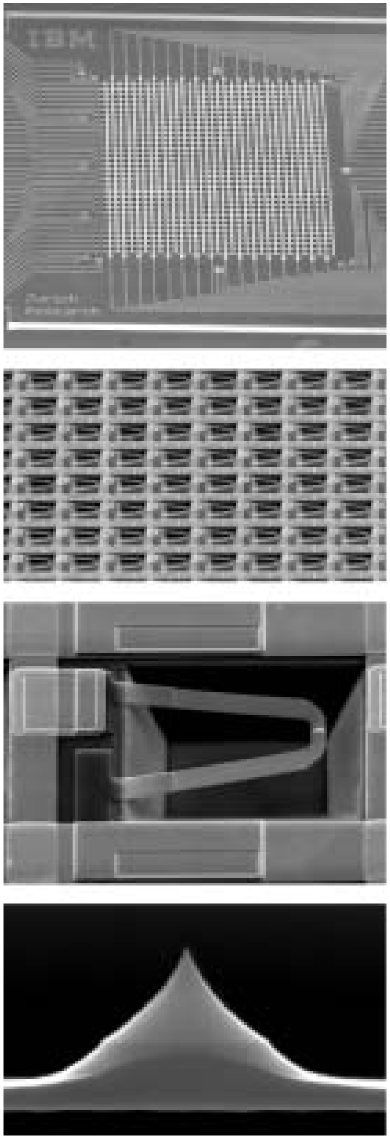




The Millipede concept: for operation of the device, the storage medium - a thin film of organic material (yellow) deposited on a silicon "table" - is brought into contact with the array of silicon tips (green) and moved in x- and y-direction for reading and writing. Multiplex drivers (red) allow addressing of each tip individually.

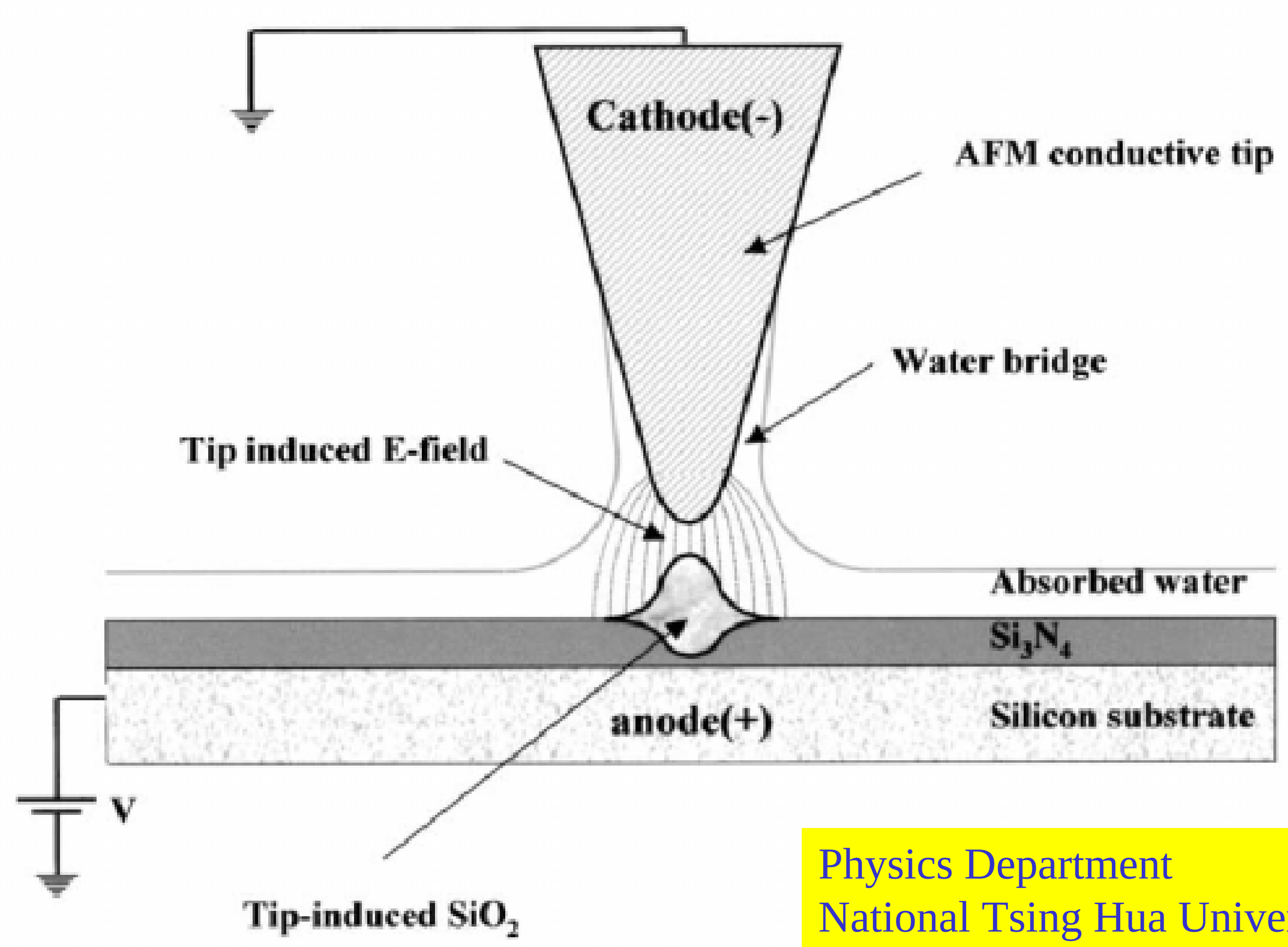


The Millipede chip: the image shows the electrical wiring for addressing the 1,024 tips etched out in a square of 3mm by 3mm (center). The chip's size is 7 mm by 14 mm.

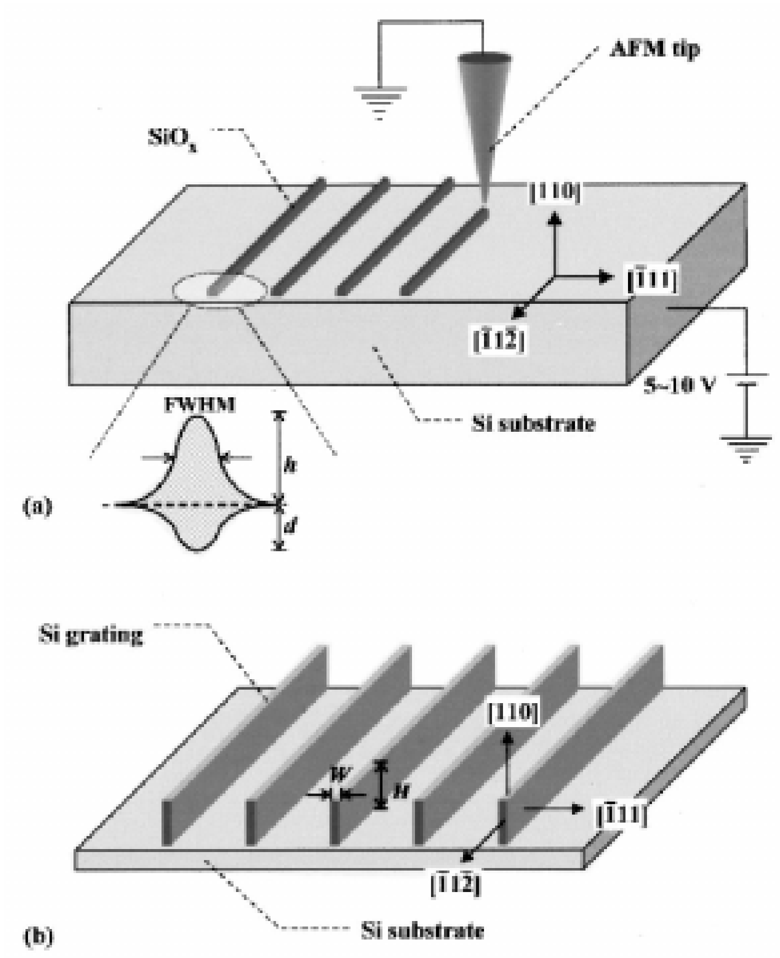


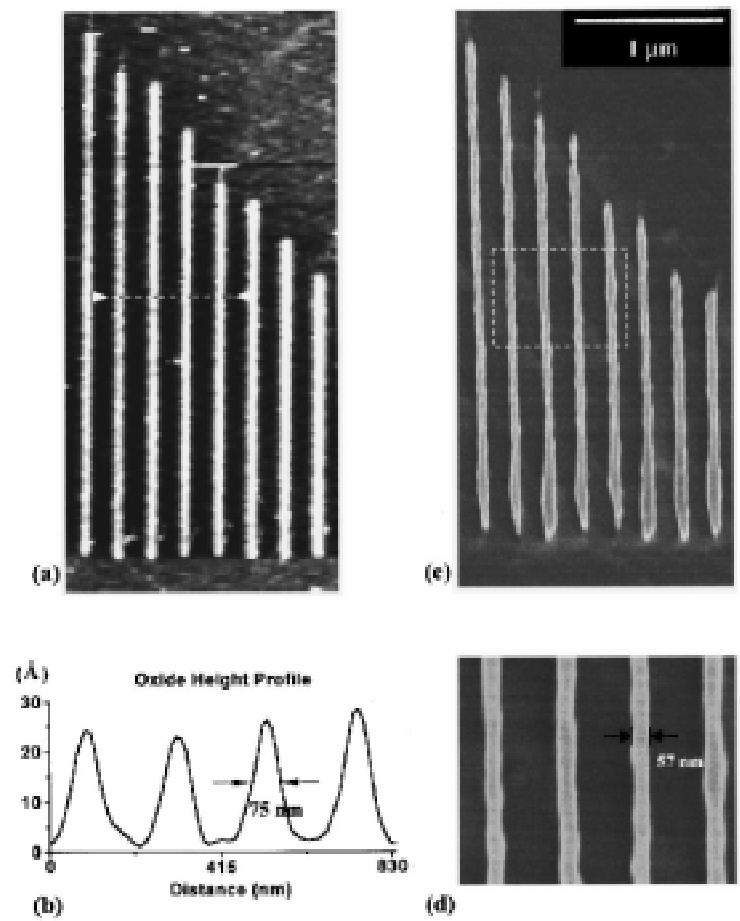
Millipede cantilevers and tips: electron microscope views of the 3 mm by 3 mm cantilever array (top), of an array section of 64 cantilevers (upper center), an individual cantilever (lower center), and an individual tip (bottom) positioned at the free end of the cantilever which is 70 micrometers (thousands of a millimeter) long, 10 micrometers wide, and 0.5 micrometers thick. The tip is less than 2 micrometers high and the radius at its apex smaller than 20 nanometers (millionths of a millimeter).

Nano-Lithography with an AFM Tip

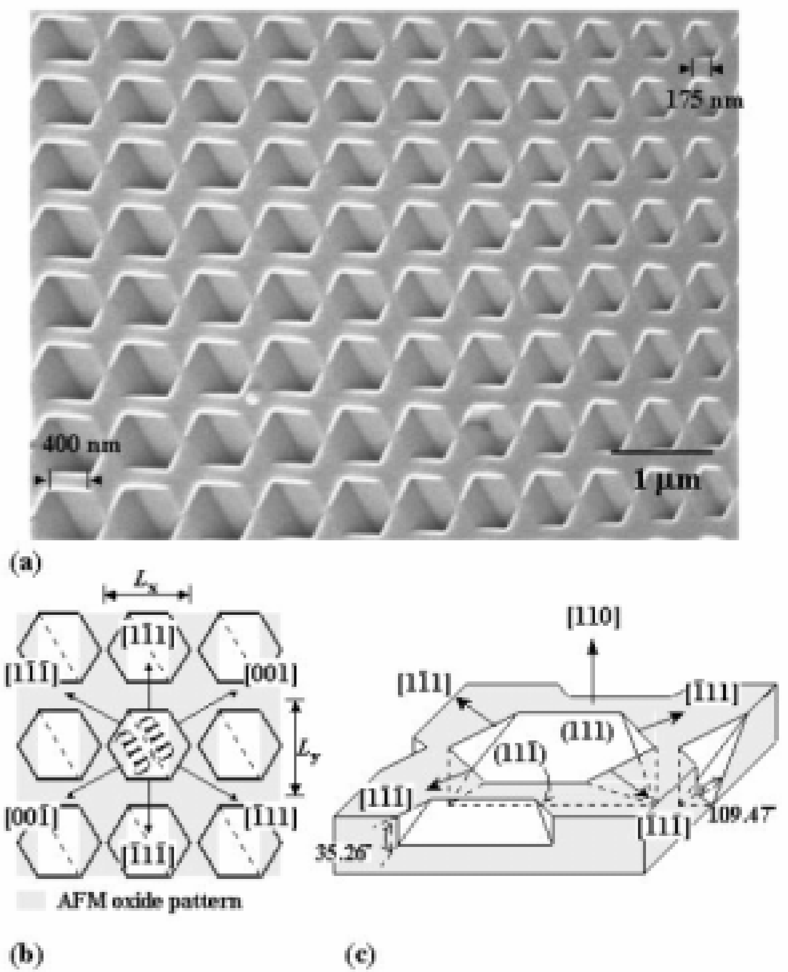


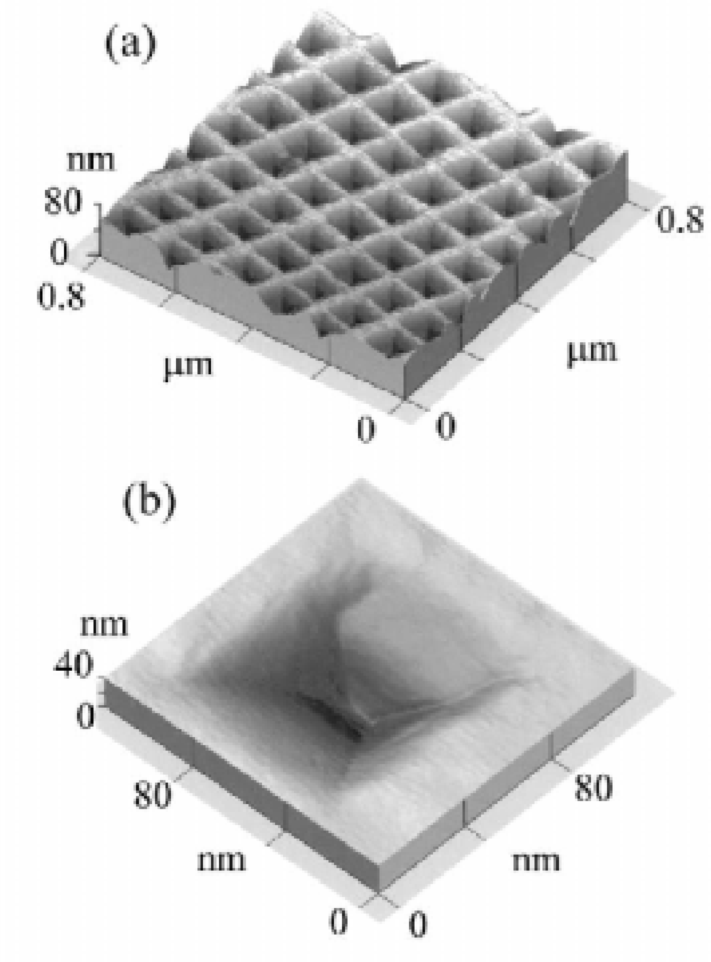
Physics Department
National Tsing Hua University



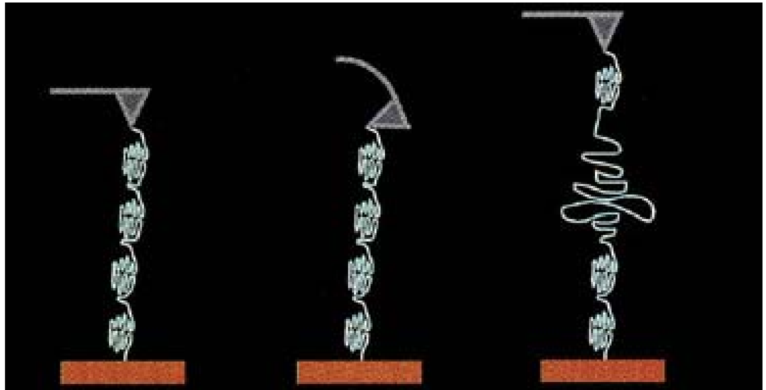


F.S.-S. Chien *et al*., APL 75, 2429 (1999)

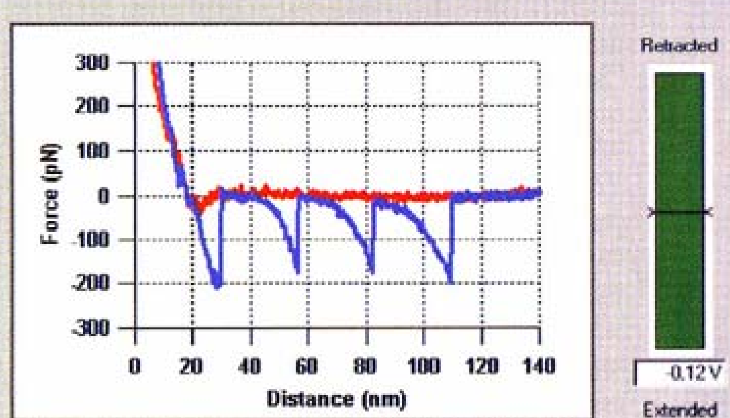




果尚志 , Physics Dept., National Tsing Hua University



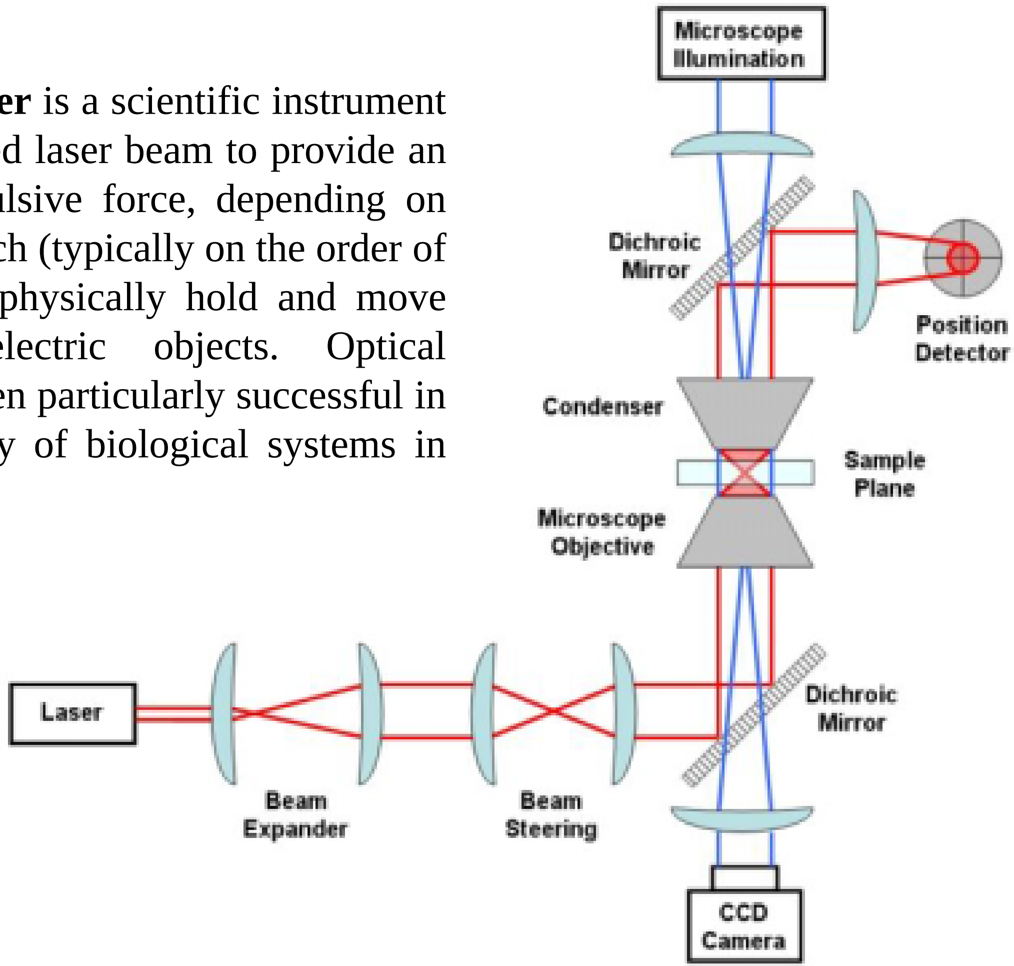
Force measurement of an unfolding complex molecule.



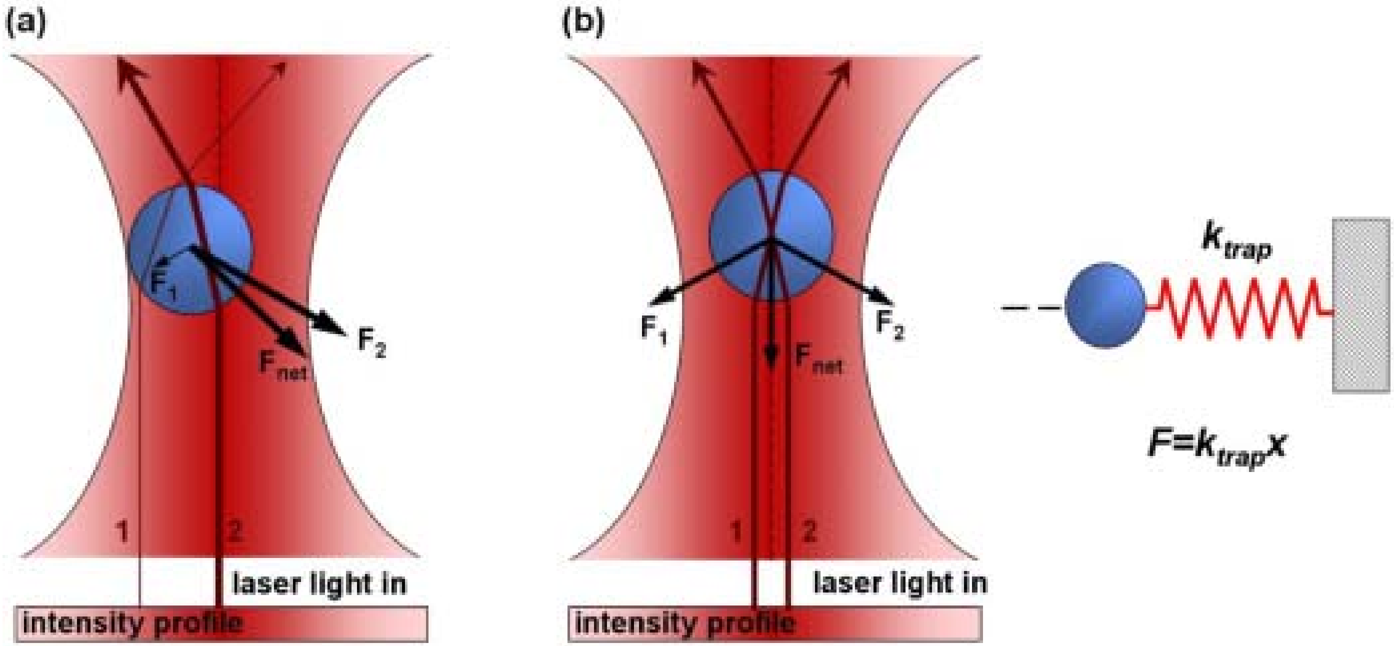
Advanced graphical user interface shows titin muscle molecule force curve.

Setup for an Optical Tweezer

An **optical tweezer** is a scientific instrument that uses a focused laser beam to provide an attractive or repulsive force, depending on the index mismatch (typically on the order of piconewtons) to physically hold and move microscopic dielectric objects. Optical tweezers have been particularly successful in studying a variety of biological systems in recent years.

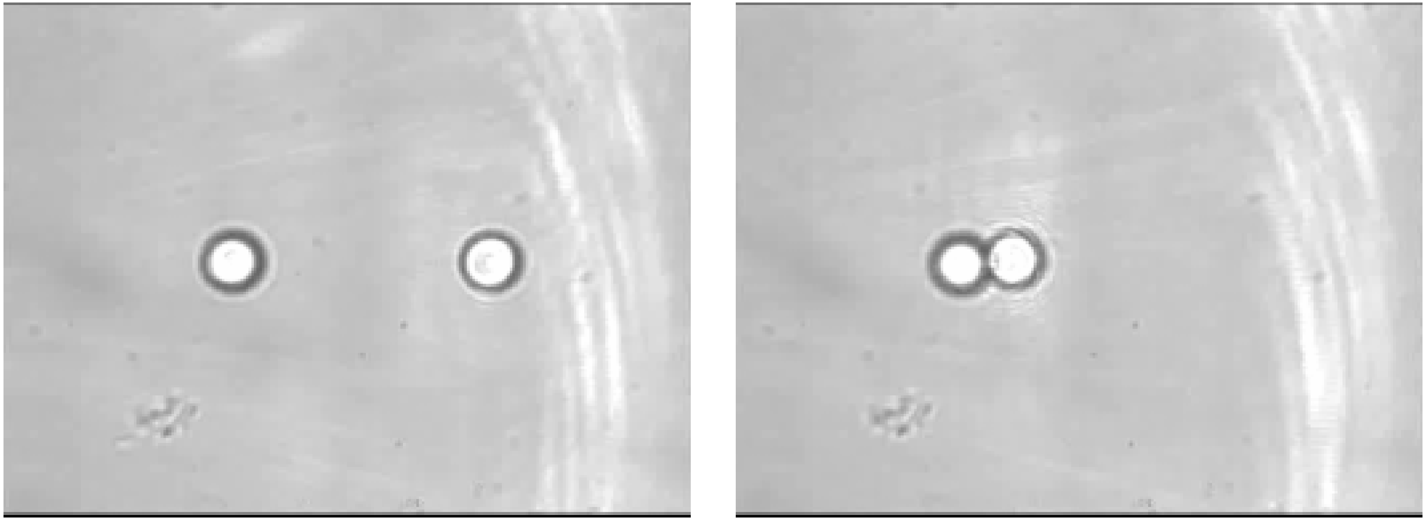


Working Principles of Optical Tweezer



A particle encountering the laser beam will be pushed towards the center of the beam, if the particle's index of refraction is higher than that of the surrounding medium. In a ray optics picture we realize how light is deflected in the particle, resulting in a gradient force that pushes the particle vertically to the propagation of the laser beam, towards the largest intensity of light (the middle of the laser beam). By focusing the light, the gradient force pushes the particle backwards as well. If this force overcomes the propagation force of the laser beam, the particle is trapped.

Optical Tweezer on a Plastic Bead



Magnetic Tweezer

A *Magnetic Tweezer* is a scientific instrument for exerting and measuring forces on magnetic particles using a magnetic field gradient. Typical applications are single-molecule micromanipulation, rheology of soft matter, and studies of force-regulated processes in living cells. Forces are typically on the order of pico- to nanonewtons. Due to their simple architecture, magnetic tweezers are one of the most popular and widespread biophysical techniques.

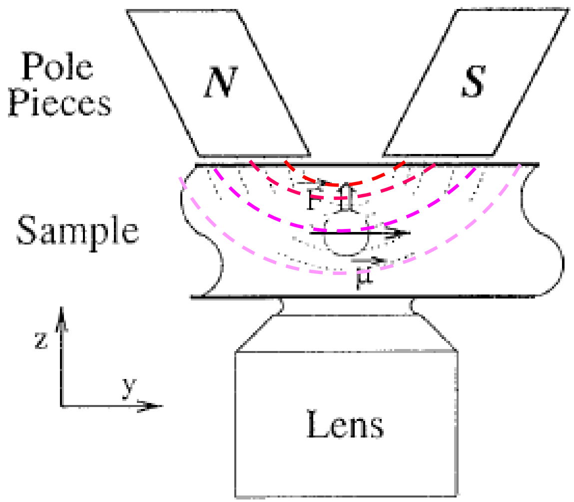
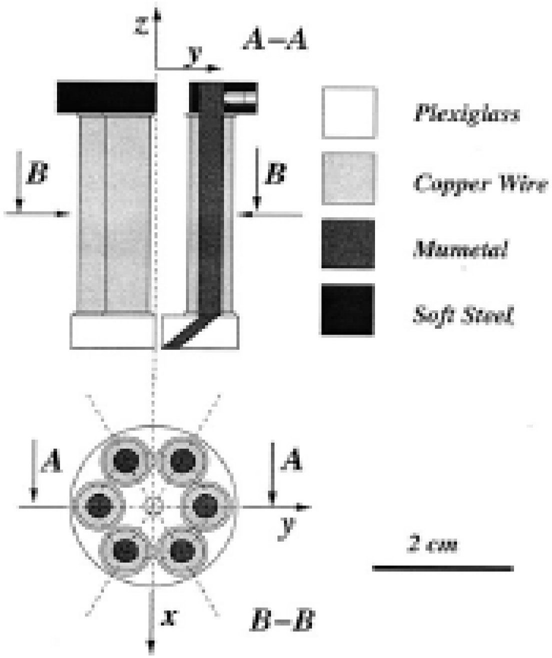
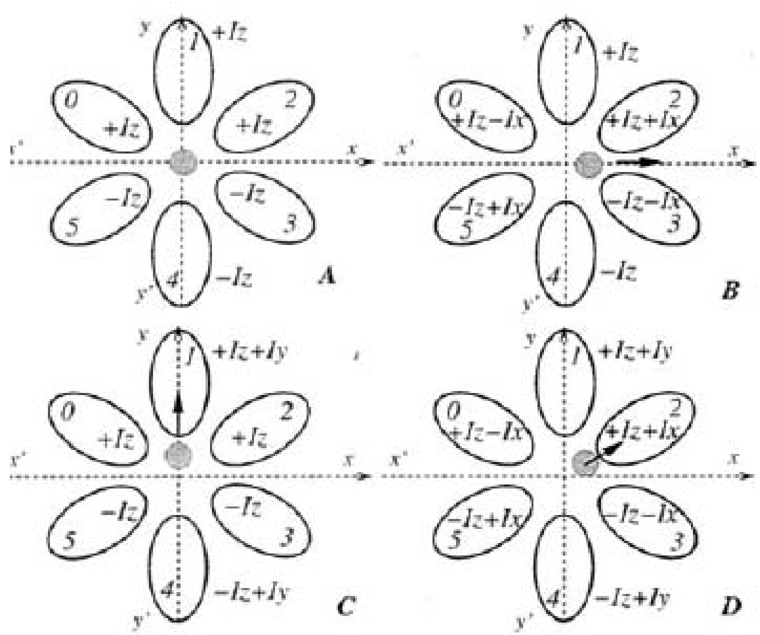


FIGURE 3 Coils and pole pieces produce a horizontal magnetic field in the middle of the sample. The magnetic moment $\vec{\mu}$ of the bead aligns with the field lines and the vertical magnetic field gradient exerts a force $\vec{F}$ that raises the super-paramagnetic object.

$$\mathbf{F} = \nabla(\mathbf{m} \cdot \mathbf{H})$$

Working Principles of Magnetic Tweezer





ɟURE 4 Schematic representation of the principles governing the ɩd displacement (top view of the sample). (*A*, *B*, and *C*) Three different current configurations are used to move the magnetic particle along *z*, *x*, and *y*. (*D*) More complicated displacements can be reached by linear combination of the basic settings. Note that, in this figure, all the currents (I_x, I_y, and I_z) are positive.