STM AND NANO-MANIPULATION

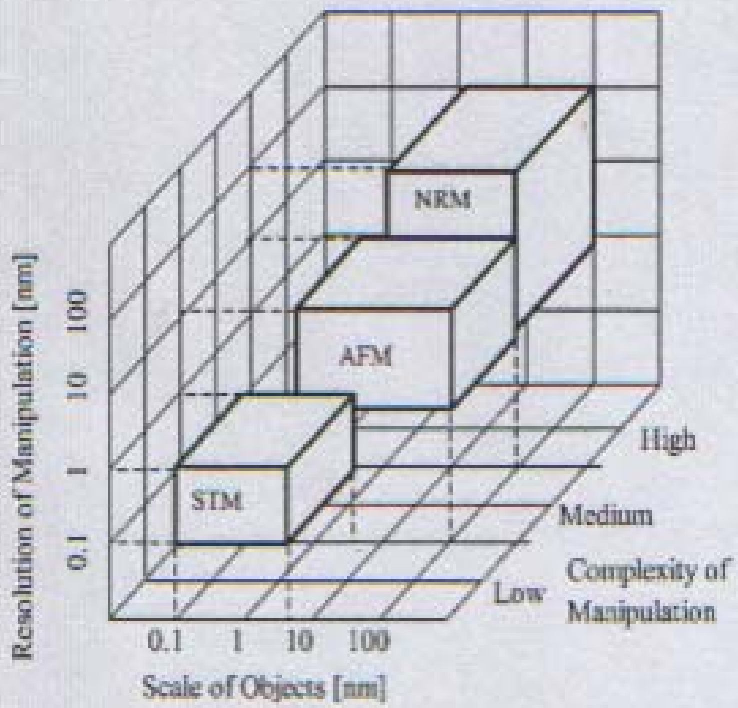
(FOCUS ON NANOMANIPULATION OF CARBON NANOTUBES AND NANOMANIPULATION USING STM)

Nano-manipulation And its Application

Positional control at the nanometer scale.

- Key enabling technology for Nanotechnology by filling the gap between the top-down and bottom up strategies.
- Nano-manipulation can be applied to scientific exploration of mesoscopic phenomena and the construction of prototype nano devices.
- Fundamental technology for property characterization of nano materials and nano devices and building of nano building blocks.

Comparison of Nanomanipulators.



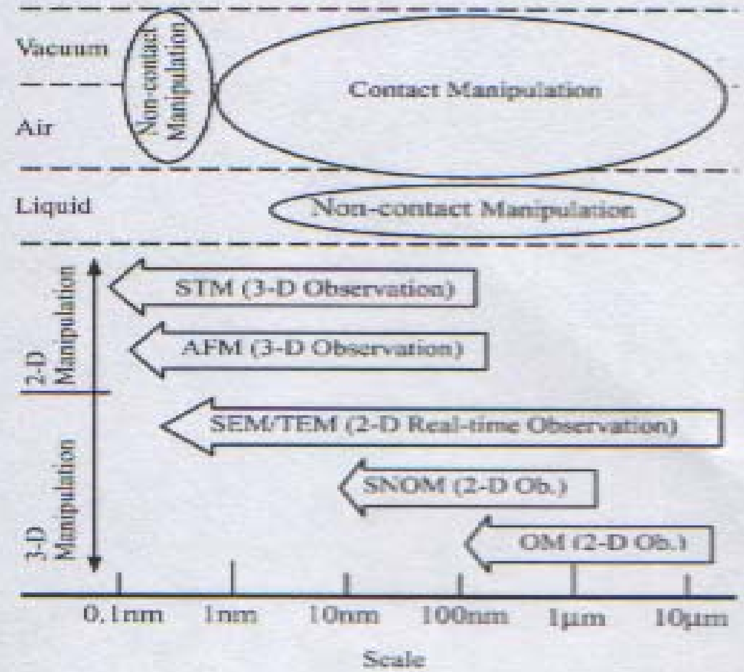


Fig. 2. Microscopes, environments, and strategies of nanomanipulations.

Strategies for nanomanipulation are determined by environment, properties and size of objects and observation method.

TECHNIQUES FOR NANOMANIPULATION USING STM.

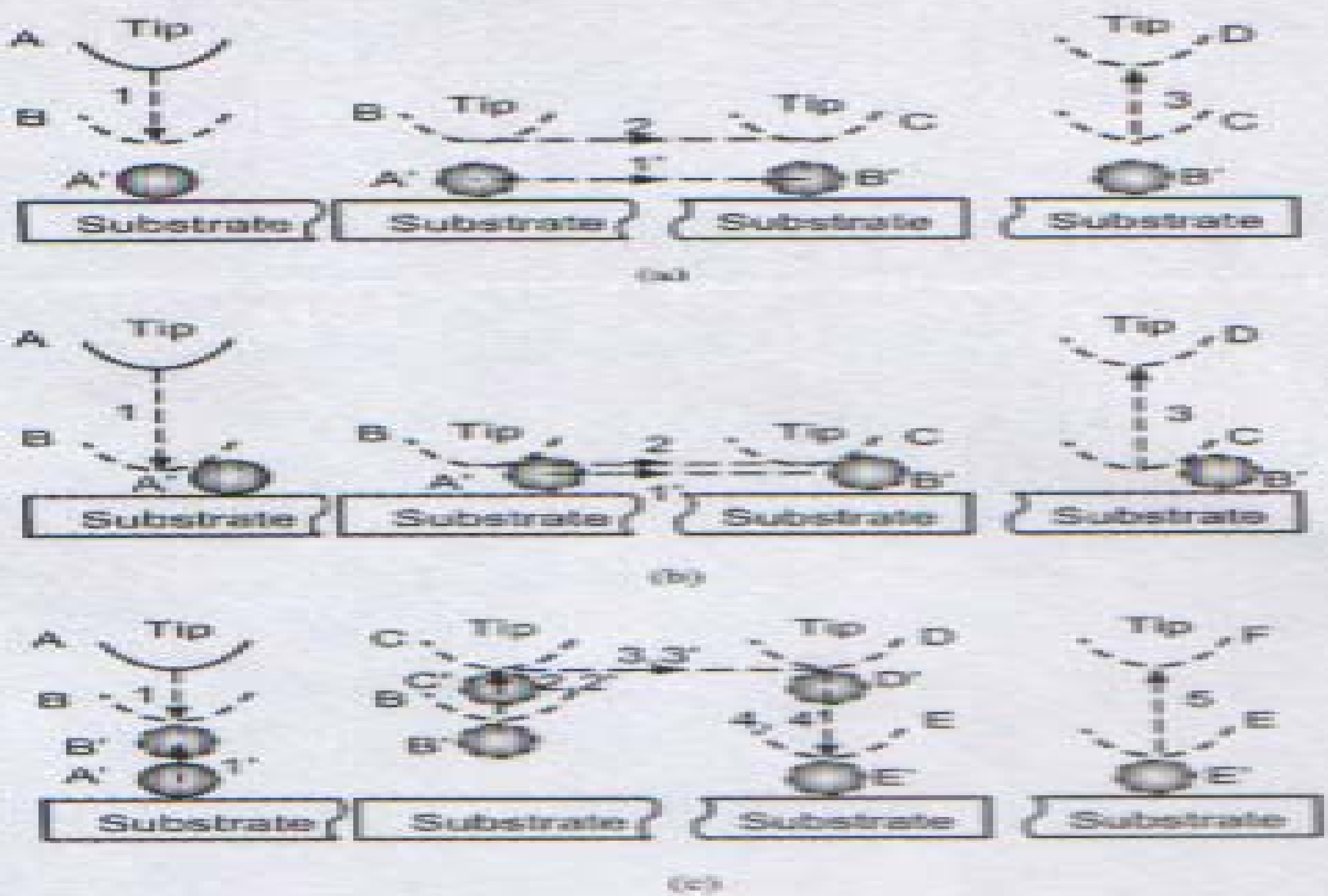


Fig. 3. Basic strategies of nanomanipulations. In the figure, A, B, C, . . . represent the positions of an end effector (e.g., a tip); A', B', C', . . . the positions of objects; 1, 2, 3, . . . the motions of the end effector; and 1', 2', 3', . . . the motions of objects. Tweezers can be used in pick-and-place to facilitate the picking up, but are generally not necessarily helpful for placing. (a) Lateral noncontact nanomanipulation (sliding). (b) Lateral contact nanomanipulation (pushing/pulling). (c) Vertical nanomanipulation (picking and placing).

1.Lateral non contact manipulation. 2.Lateral contact manipulation. 3.Vertical manipulation.

Manipulation of CNTs (Current Status)

- 2-D manipulation of CNT have been preformed using AFM.
- Manipulation of CNT in 3-D have been preformed using NRMS. The basic steps involve

1. *To pick up CNT from soot using dielectrophoresis or EBID.*
2. *Then various manipulation such as bending, buckling, stretching, breaking, bonding or aligning at a desired location can be performed.*

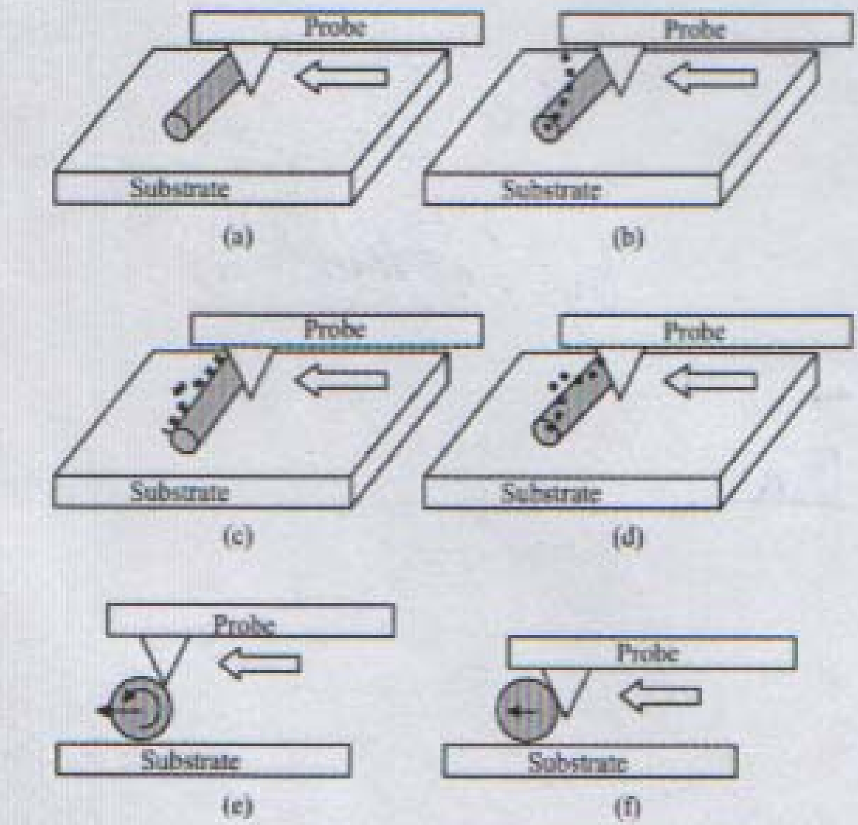
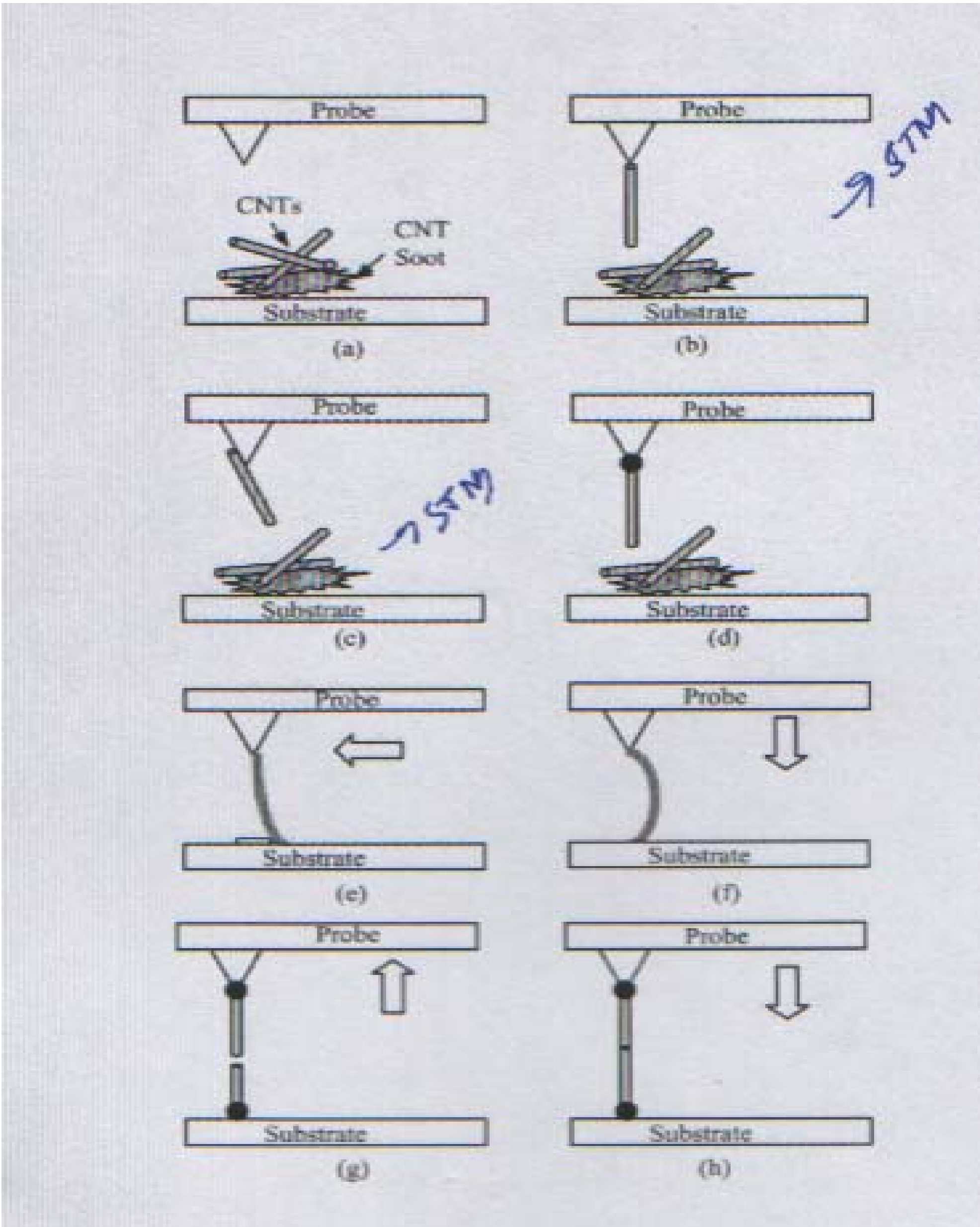


Fig. 4. Two-dimensional manipulations of CNTs. (a) Original state. (b) Bending. (c) Kinking. (d) Breaking. (e) Rolling. (f) Sliding. Starting from the original state shown in (a), pushing the tube at a different site with different force may cause the tube to deform as in (b) and (c), to break as in (d), or to move as in (e) and (f).

3-D Manipulation of CNT by NRMs



a.) Original State.

b.) Picking up with DEP force

c.) Picking up with VanderWaals force.

d.) Picking up with EBID

e.) Bending.

f.) Buckling

g.) Breaking

h.) Bonding

STM CONTROL OF CHEMICAL REACTIONS

- STM is one of the most **robust tools used for manipulation** to generate chemical reactions in the field of **nano-chemistry.**
- Tip-atom/molecule surface interactions such as **EF at tip sample junctions, tunneling electrons and tip-atom/molecule interaction forces** are deployed in a **controlled manner** to generate **chemical reaction steps such as dissociation, desorptions, diffusion and readsorption** to generate new chemical species.
- Most STM tip induced manipulation are conducted in **UHV and low temperature conditions** to keep the **substrate clean and to avoid thermally activated reactions**.

Artificial Diffusion of Single Atom Molecule

- Creates an artificial diffusion process along the surface
- Approach the tip toward a target atom/molecule at its initial location to increase the tip-atom/molecule interaction force.
- Scan the tip along a desired path until it reaches a predetermined destination
- Atom/molecule moves along with the tip.
- Tip is retracted back to the normal imaging height.
- Atom/molecule left behind on the surface.

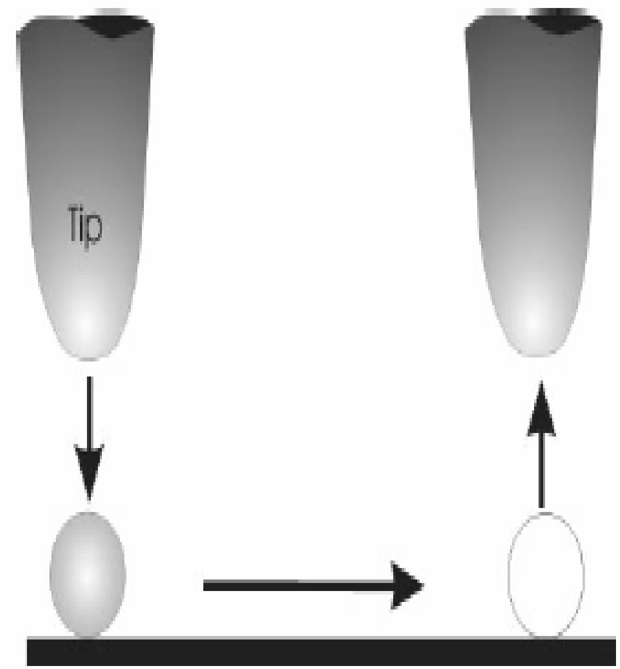
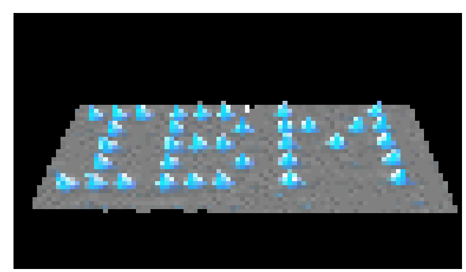
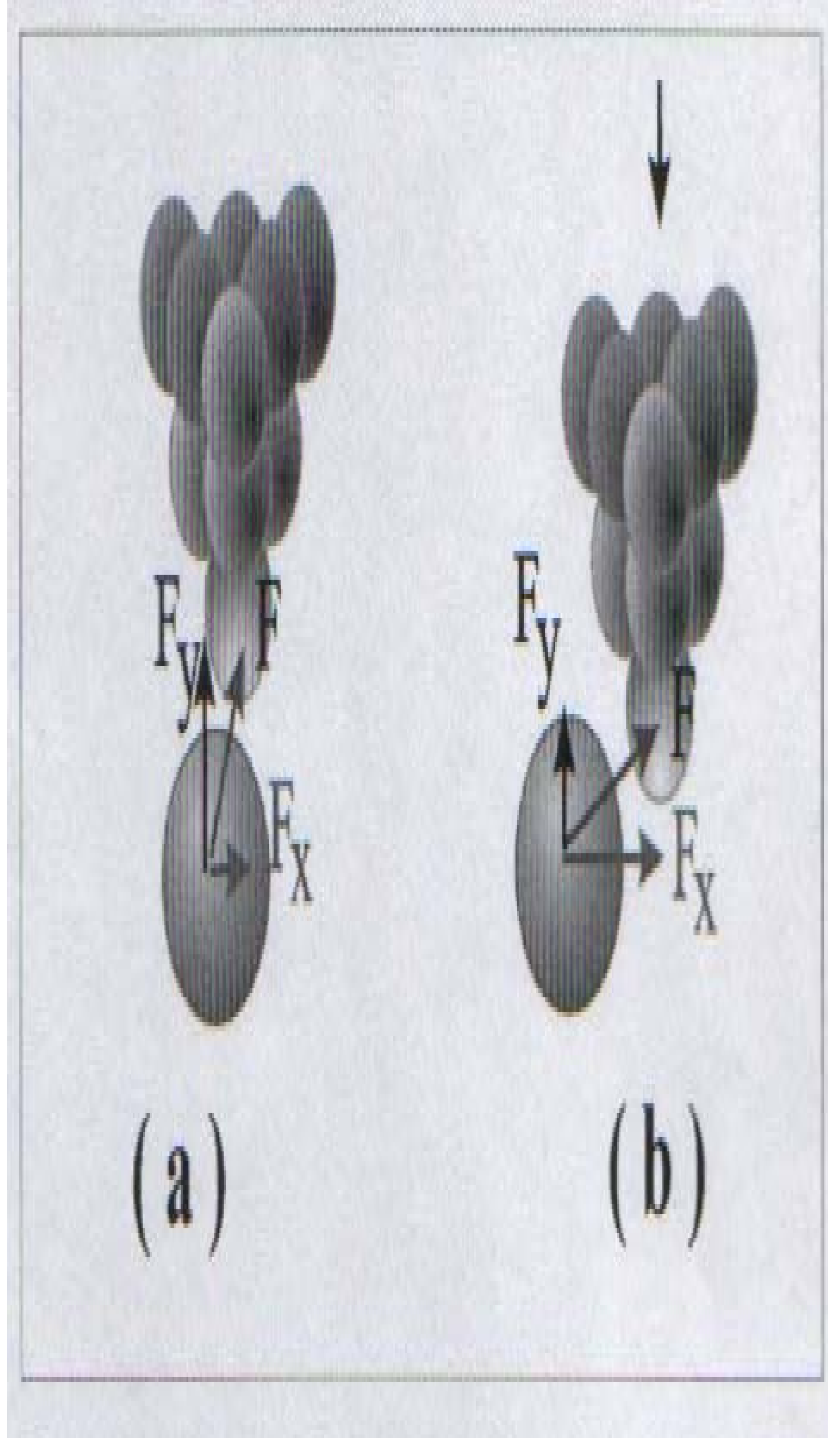


Figure 2 STM lateral manipulation procedure.

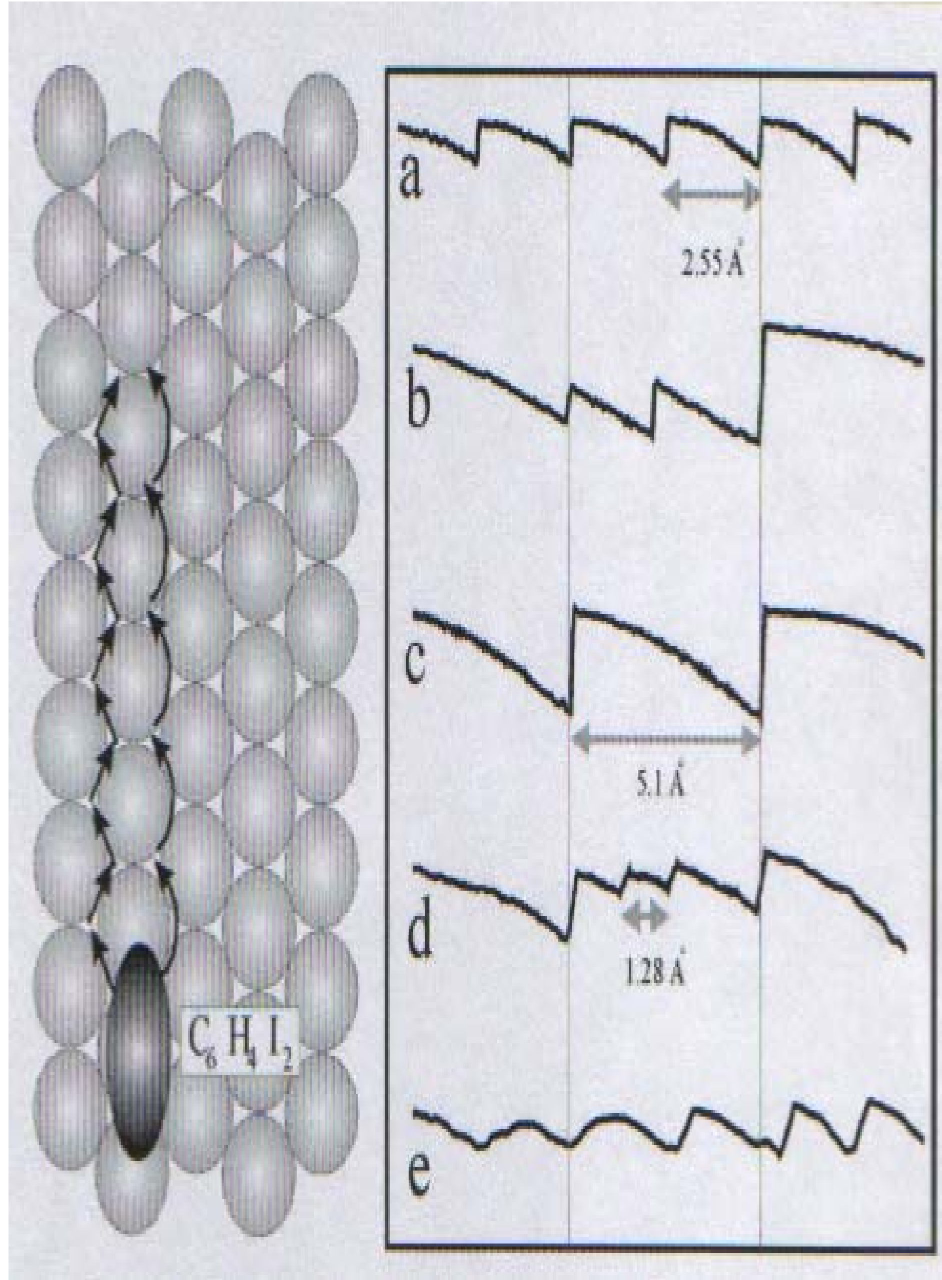


- As tip moves down slope of the contour the lateral component F_x increases.
- Increase in F_x causes the molecule to overcome the surface potential barrier and hop into the next absorption site.
- This hopping causes the tip to retract abruptly producing the tip height to increase.
- This is known as “stick-slip” movement regime.

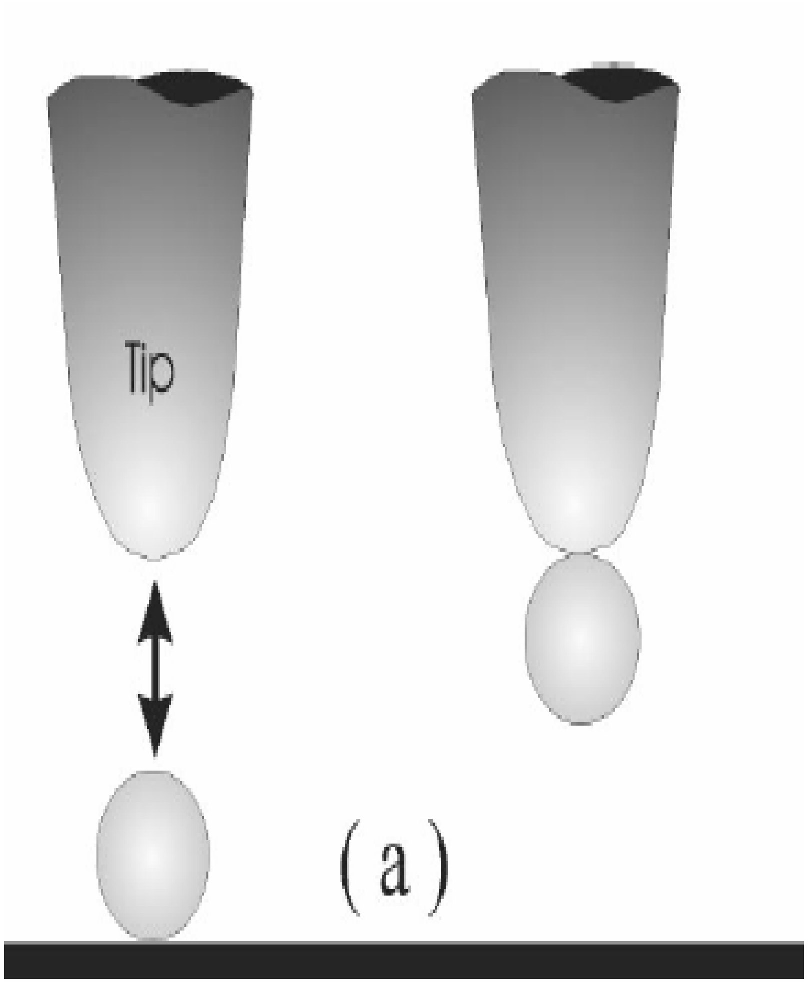


Manipulation of Diidobenze Molecule on Cu Substrate

- The surface is scanned at a very close tip-sample distance.
- The tip height signal indicates a sliding motion where molecule moves cont. with the tip.
- The reduction in tip-molecule interaction induces double site hopping.

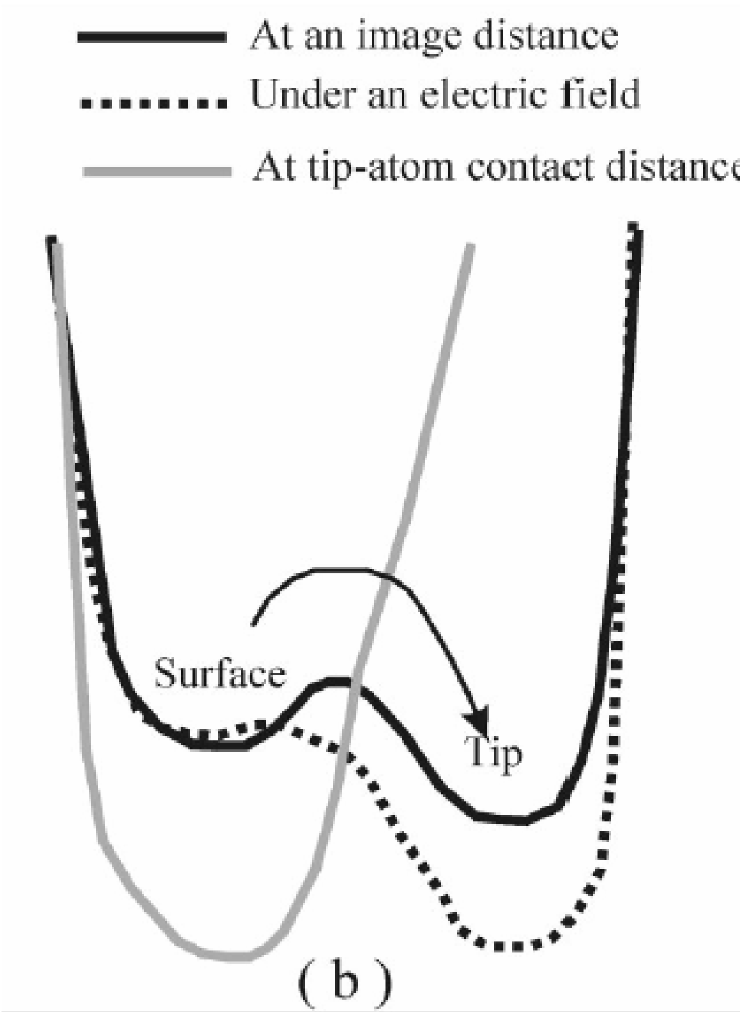


VERTICAL MANIPULATION



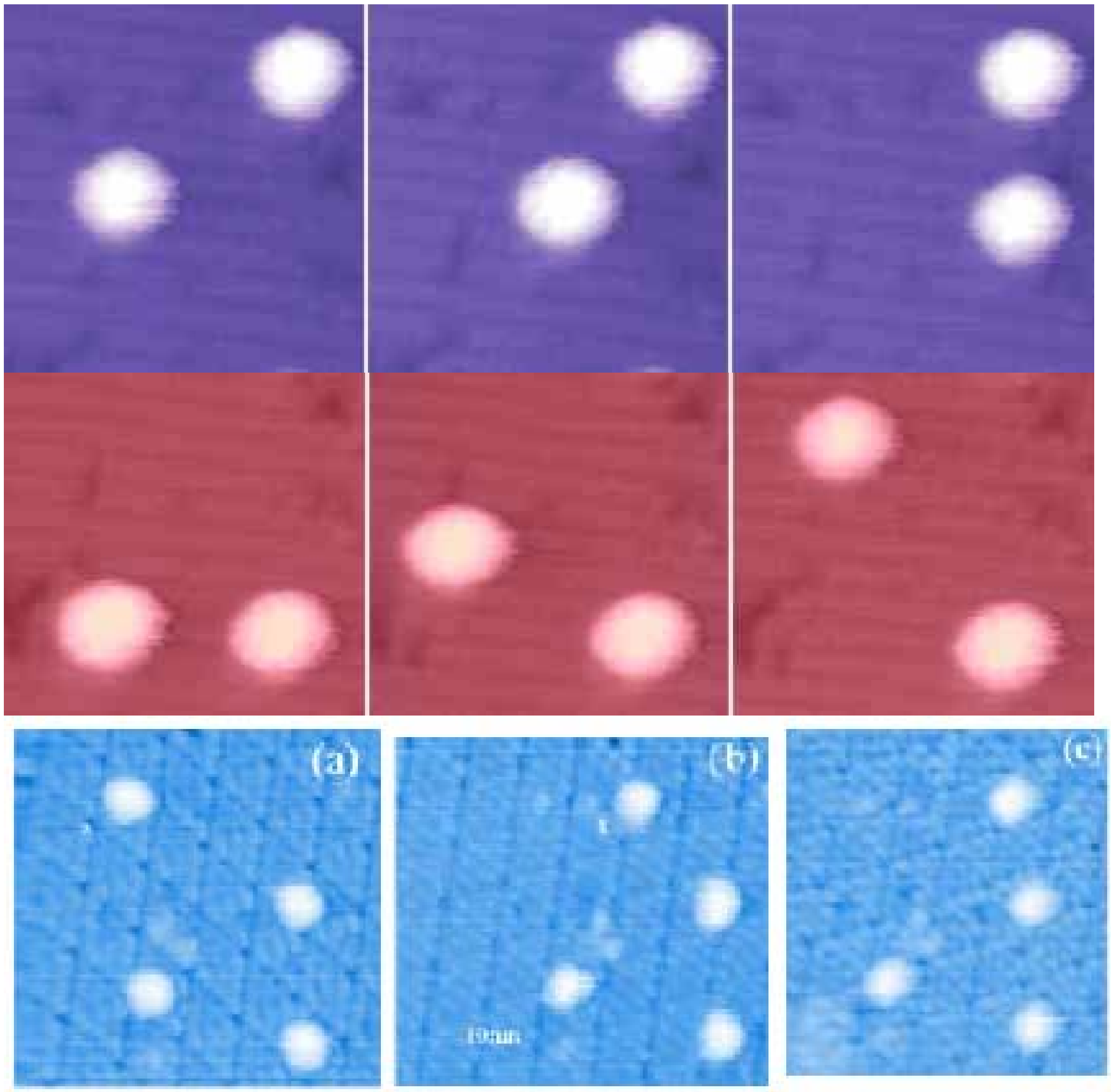
- This process involves the transfer of single atoms or molecules between the tip and substrate and vice versa
- The atom/molecule transfer process can be realized by using an electric field between the tip and sample, by exciting with inelastic tunneling electrons, or by making mechanical contact between the tip and the atom/molecule.
- Transfer mechanism can be explained by using a model of a double potential well.

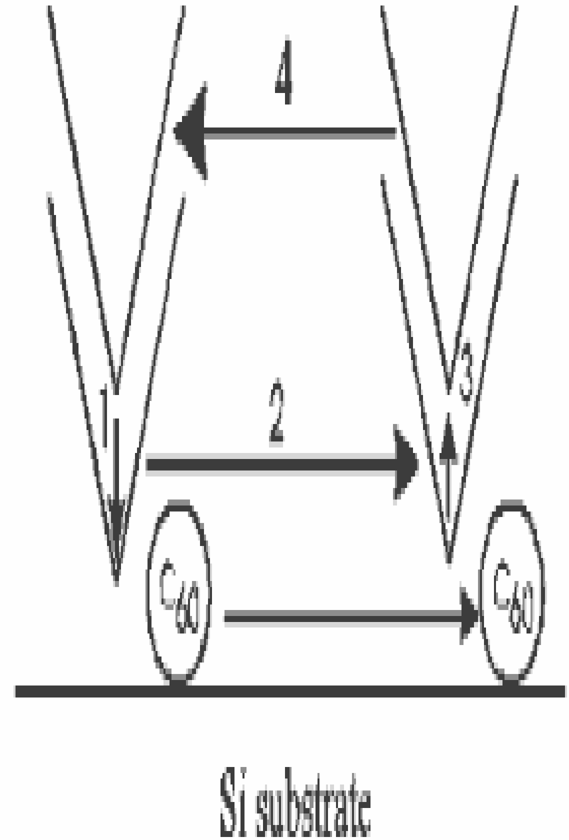
DOUBLE POTENTIAL WELL MODEL.



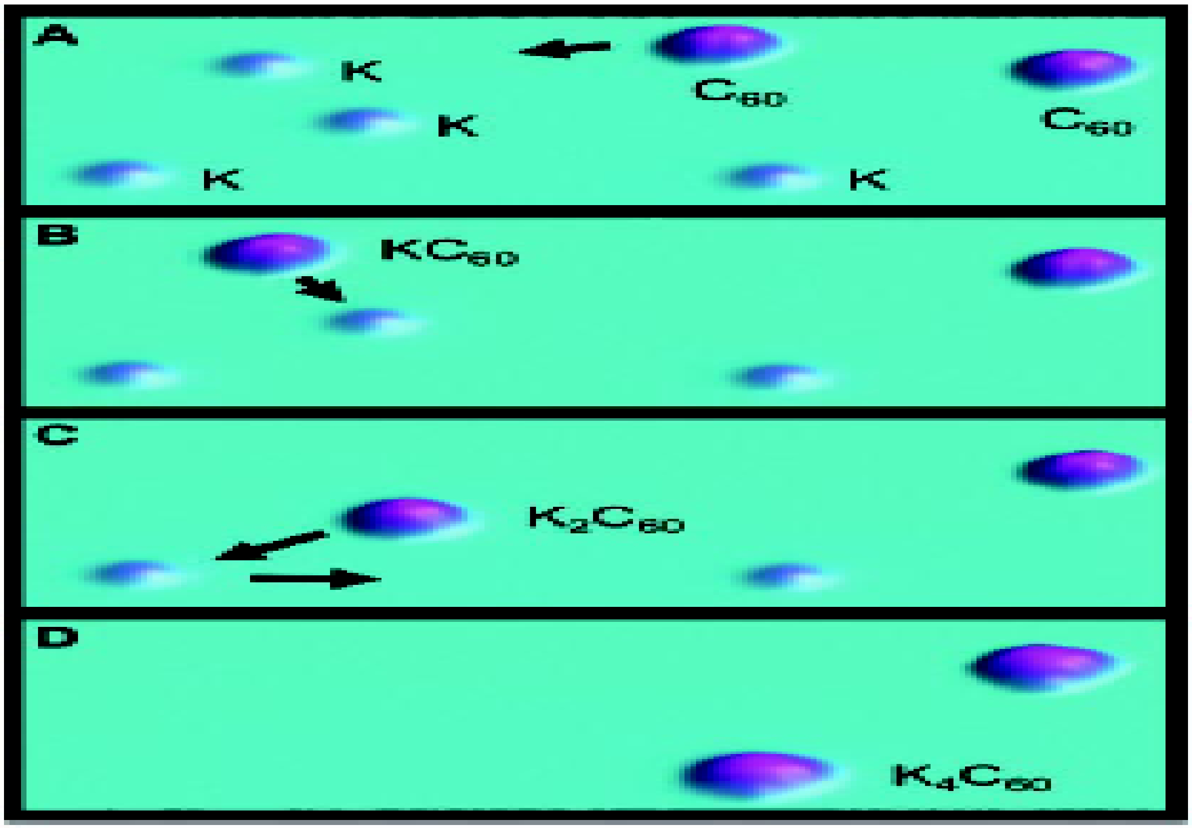
- At an imaging distance, the atom/molecule has two possible stable positions, one at the surface and one at the tip apex.
- Each position is represented by a potential well, and the two potential wells are more or less equal in shape, separated by a barrier
- If the tip is stopped above the atom at the same distance and an electric field is applied, then the shape of the double potential well changes
- The barrier between the two wells reduces, and the potential well at the tip apex has a much lower energy level
- The atom now can easily transfer to the tip.
- By applying a reverse polarity bias, the minimum potential well can be changed to the surface side.
- The atom can then transfer back to the surface.

STM induced manipulation of Buckyballs (C_{60})-(Mechanical contact)





STM Controlled Atomic Doping of Single C60 Molecule



NONCONTACT MANIPULATION USING STM

Manipulator	Object	Substrate	Temp.	Environment	Strategy of Manipulation	Result /Application
STM	Xe atom	Metal Ni(110)	4K	UHV	Van der Waals force	Logo "IBM"
STM	Fe atom	Cu(111)	4K	UHV	Van der Waals force	Quantum corrals: wave-particle nature
STM	Cs	GaAs(110) InSb(110)	RT	UHV	Electric-field-induced electrostatic force	RT bonding dissociation
STM	Si	Si(111)-(7x7)	RT	UHV	Chemical interaction and electrostatic force	Bonding the tip to selected atom
STM	$B_{10}H_{14}$	Si(111)	RT	UHV	Tunneling current induced local heating	Molecule dissociation
STM	H	H-terminated Si(100)	RT	UHV	Inelastic tunneling caused vibration	Atom/molecule adsorption
STM	C_{60}	Step Cu(111)	RT	UHV	Repulsive pushing	Abacus: monoatomic step of molecules
STM	CO-Fe, Fe(CO)-CO	Ag(110)	13K	UHV	Electric-field-induced electrostatic force	Synthesis of molecules