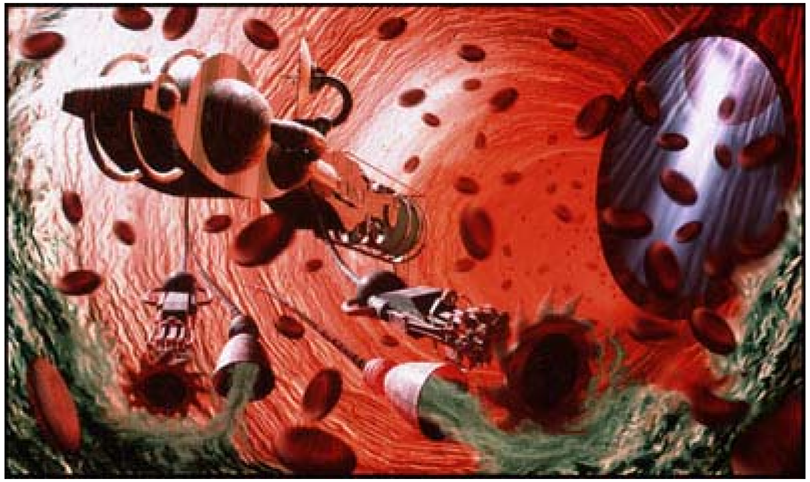
Nanorobot Construction Crews



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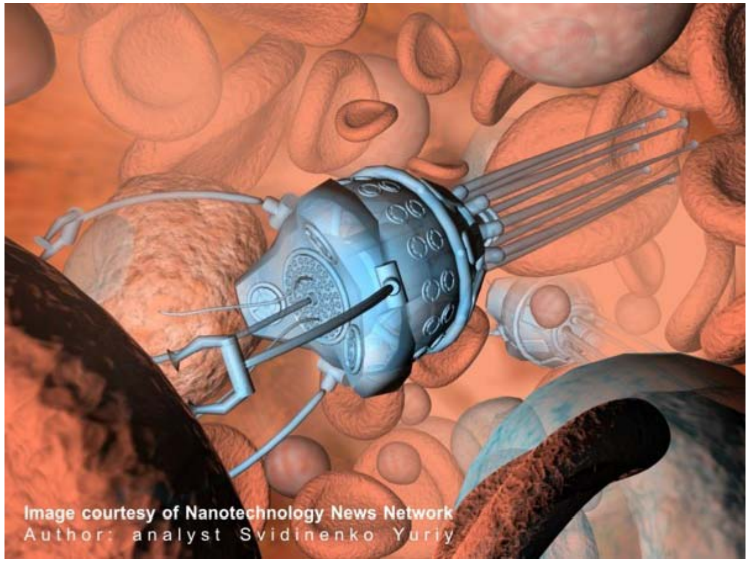
Nanorobotics

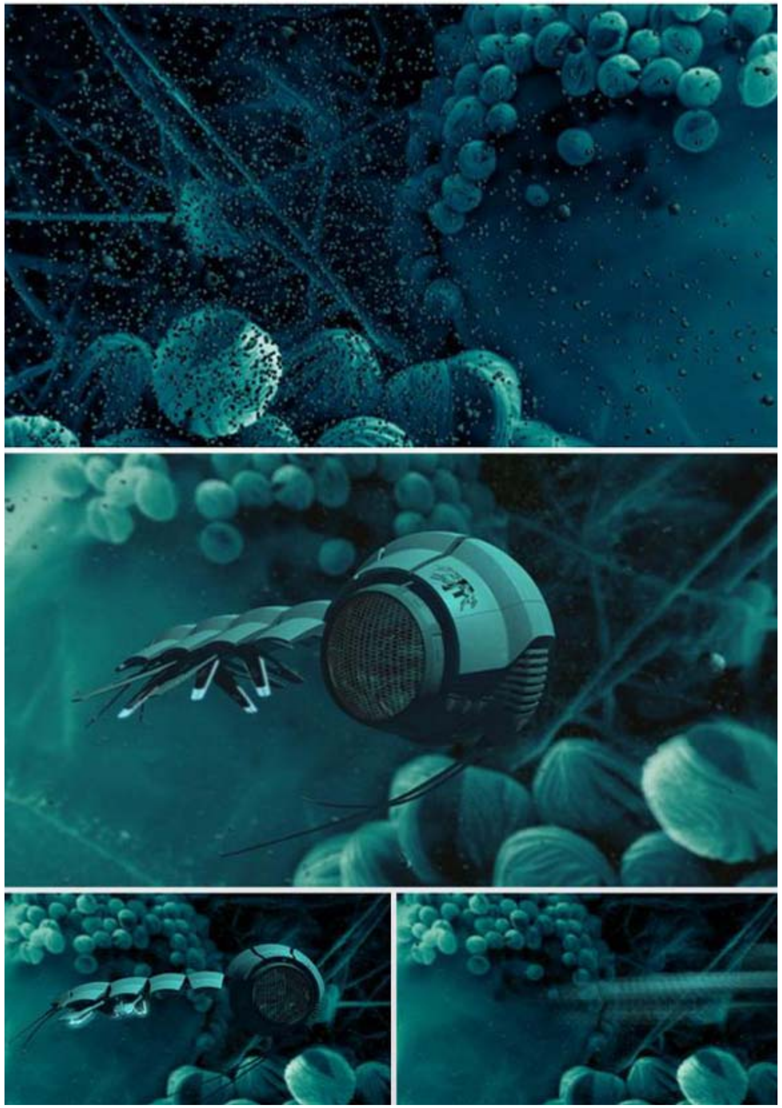


- Nanorobotics is the technology of creating machines or robots at or close to the microscopic scale of a nanometres (10^{-9} metres). More specifically, nanorobotics refers to the still largely 'hypothetical' nanotechnology engineering discipline of designing and building nanorobots.
- Nanorobots (nanobots, nanoids, nanites or nanonites) would be typically devices ranging in size from 0.1-10 micrometers and constructed of nanoscale or molecular components. As no artificial non-biological nanorobots have yet been created, they remain a 'hypothetical' concept.

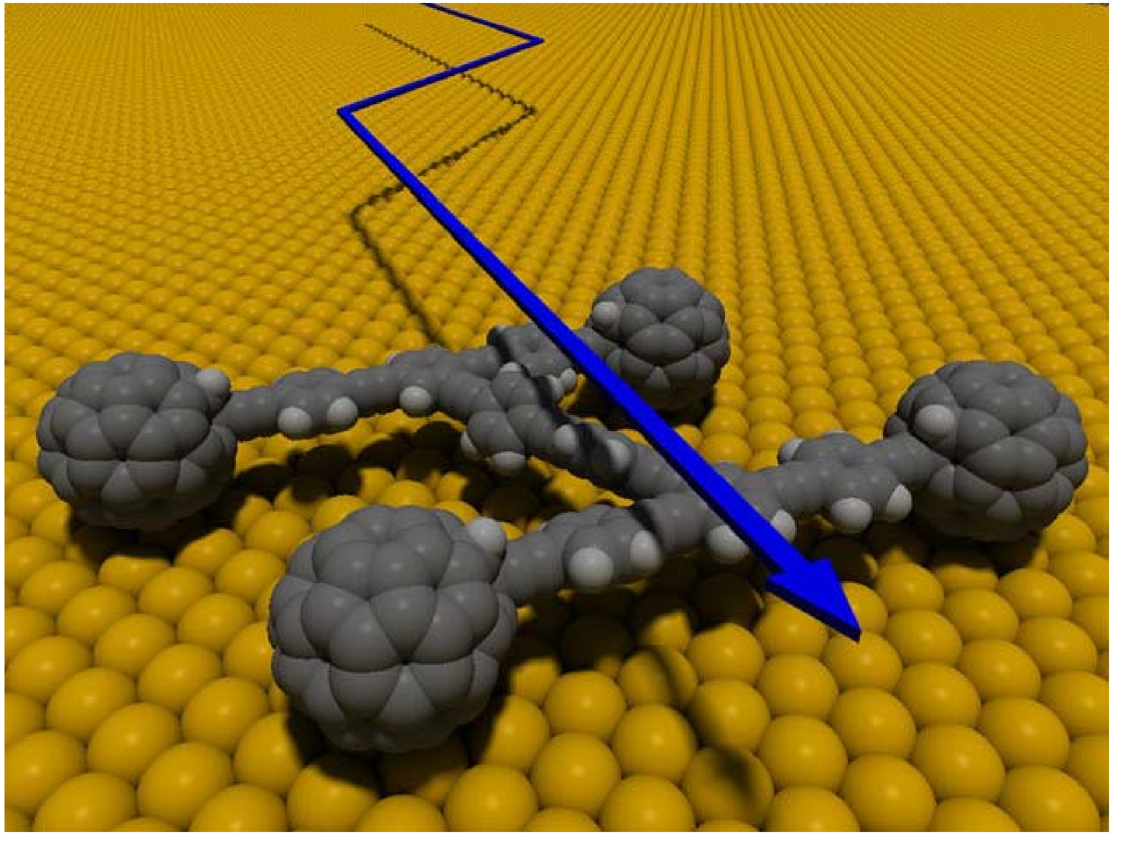
- Another definition sometimes used is a robot which allows precision interactions with nanoscale objects, or can manipulate with nanoscale resolution.
- Following this definition even a large apparatus such as an atomic force microscope can be considered a nanorobotic instrument when configured to perform nanomanipulation.
- Also, macroscale robots or microrobots which can move with nanoscale precision can also be considered nanorobots.

The T-1000 in *Terminator 2: Judgment Day*

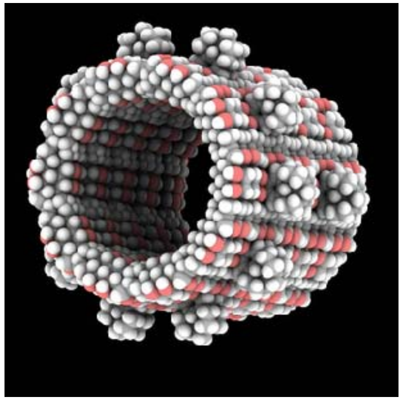
- Since nanorobots would be microscopic in size, it would probably be necessary for very large numbers of them to work together to perform microscopic and macroscopic tasks.
- These nanorobot swarms are found in many science fiction stories, such as The T-1000 in *Terminator 2: Judgment Day*, nanomachine in *Metal Gear Solid*.
- The word "nanobot" (also "nanite", "nanogene", or "nanoant") is often used to indicate this fictional context and is an informal or even pejorative term to refer to the engineering concept of nanorobots.



- An example of nanomachines would be a sensor having a switch approximately 1.5 nanometers across, capable of counting specific molecules in a chemical sample.
- The first useful applications of nanomachines, if such are ever built, might be in medical technology, where they might be used to identify cancer cells and destroy them.
- Another potential application is the detection of toxic chemicals, and the measurement of their concentrations, in the environment.

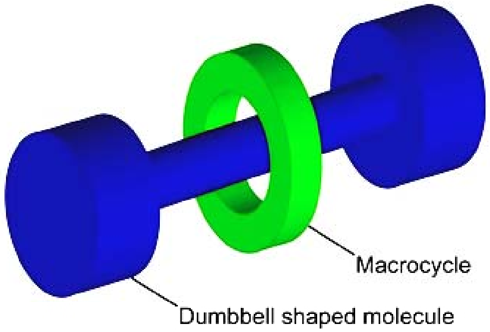


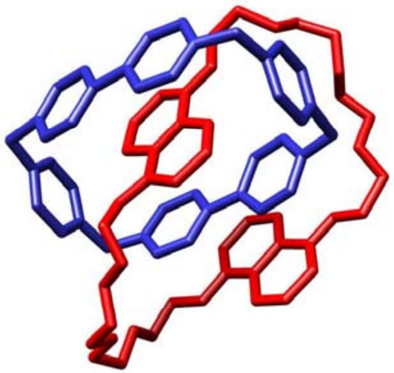
- Recently, Rice University has demonstrated **a single-molecule car** which is developed by a chemical process and includes buckyballs for wheels. It is actuated by controlling the environmental temperature and by positioning a scanning tunneling microscope tip.



- The most detailed vision of nanorobotics has been presented in the medical context of nanomedicine by Ralph Merkle: including specific design issues such as sensing, power communication, navigation, manipulation, locomotion, and onboard computation.

- The Nanofactory Collaboration, founded by Robert Freitas and Ralph Merkle in 2000, is a focused ongoing effort (involving 23 researchers from 10 organizations and 4 countries) that is developing a practical research agenda specifically aimed at developing positionally-controlled diamond mechanosynthesis and a diamondoid nanofactory that would be capable of building diamondoid medical nanorobots.

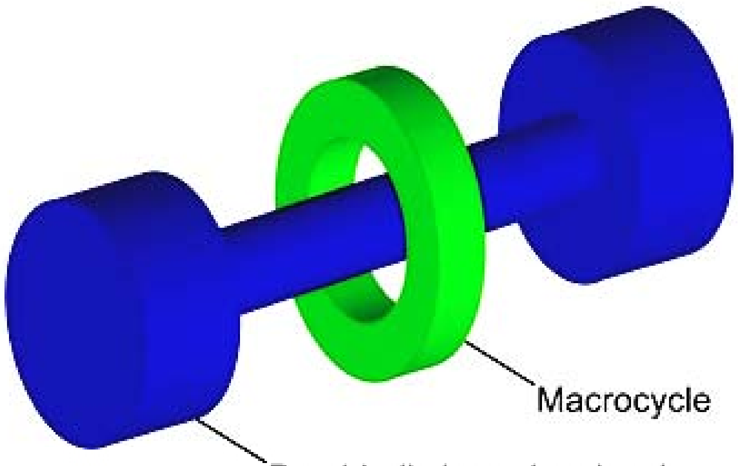




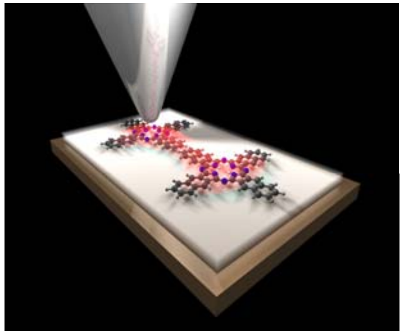
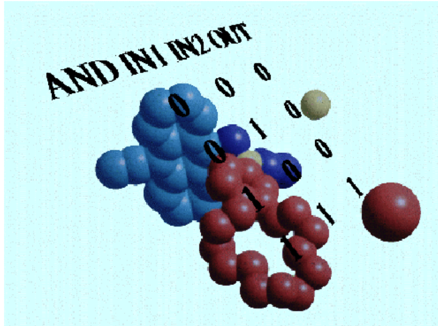
- A wide variety of rather simple molecular machines have been synthesized by chemists. They can consist of a single molecule; however, they are often constructed for mechanically-interlocked molecular architectures, such as rotaxanes and catenanes.

- **Molecular motors** are molecules that are capable of unidirectional rotation motion powered by external energy input. A number of molecular machines have been synthesized <u>powered by light or reaction with other molecules</u>.

- A molecular propeller is a molecule that can propel fluids when rotated, due to its special shape that is designed in analogy to <u>macroscopic propellers</u>. It has several molecular-scale blades attached at a certain pitch angle around the circumference of a nanoscale shaft.

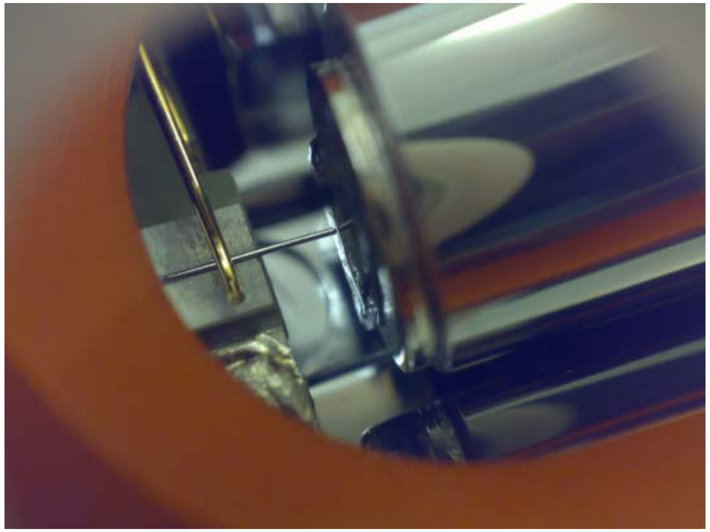


- A molecular switch is a molecule that can be reversibly shifted between two or more stable states. The molecules may be shifted between the states in response to changes in pH, light, temperature, an electrical current, microenvironment, or the presence of a ligand.
- A molecular shuttle is a molecule capable of shuttling molecules or ions from one location to another. A common molecular shuttle consists of a rotaxane where the macrocycle can move between two sites or stations along the dumbbell backbone.

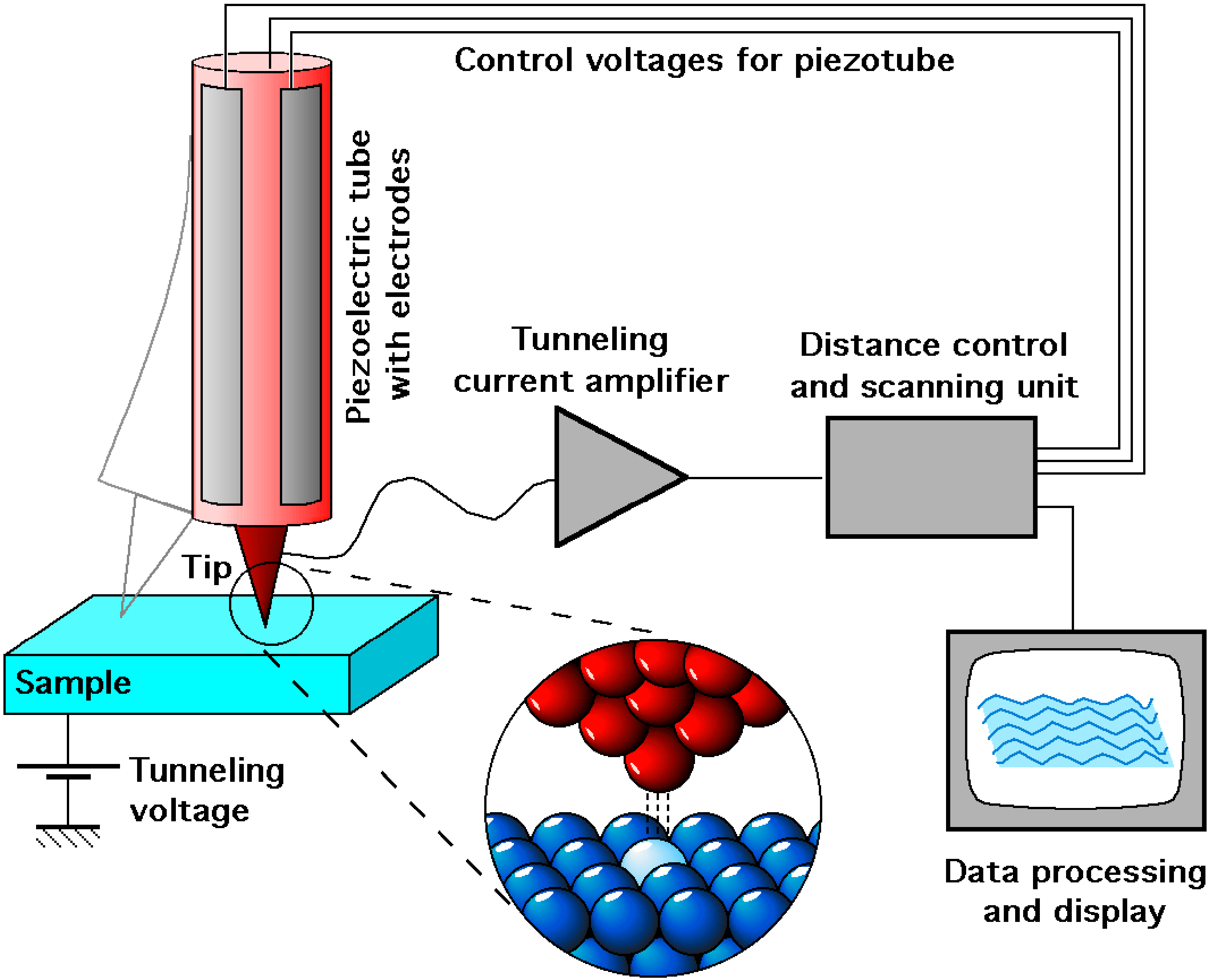
 

- Molecular tweezers are host molecules capable of holding guests between two arms. The open cavity of the molecular tweezers binds guests using non-covalent bonding including hydrogen bonding, metal coordination, hydrophobic forces, van der Waals forces, π-π interactions, and/or electrostatic effects.
- A molecular sensor is a molecule that interacts with an analyte to produce a detectable change. Molecular sensors combine molecular recognition with some form of reporter, so the presence of the guest can be observed.
- A molecular logic gate is a molecule that performs a logical operation on one or more logic inputs and produces a single logic output. Unlike a molecular sensor, the molecular logic gate will only output when a particular combination of inputs are present.

Scanning tunneling microscope (STM)



- The STM is based on the concept of quantum tunneling. When a conducting tip is brought very near to a metallic or semi-conducting surface, a bias between the two can allow electrons to tunnel through the vacuum between them. For low voltages, this tunneling current is a function of the local density of states (LDOS) at the Fermi level of the sample. Variations in current as the probe passes over the surface are translated into an image. STM can be a challenging technique, as it requires extremely clean surfaces and sharp tips.

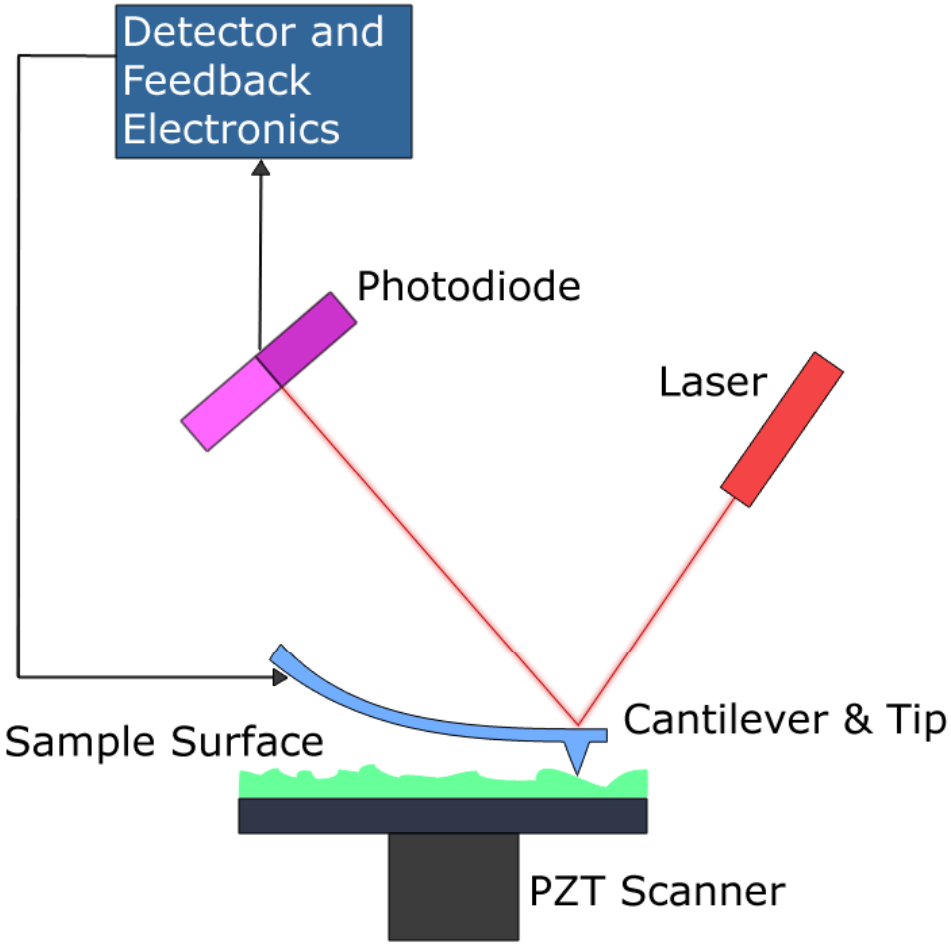


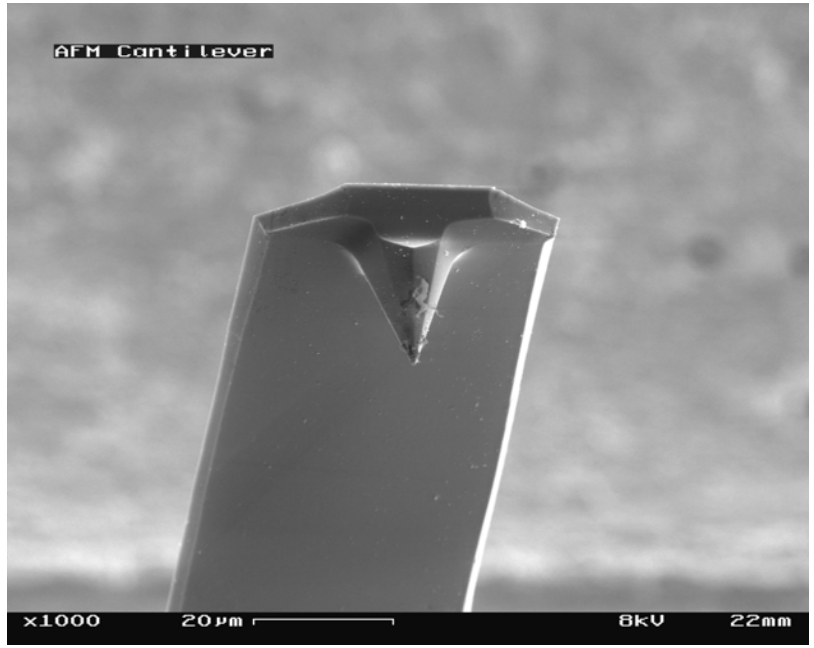
Control voltages for piezotube
Piezoelectric tube with electrodes
Tunneling current amplifier
Distance control and scanning unit
Tip
Sample
Tunneling voltage
Data processing and display

Atomic force microscope (AFM)

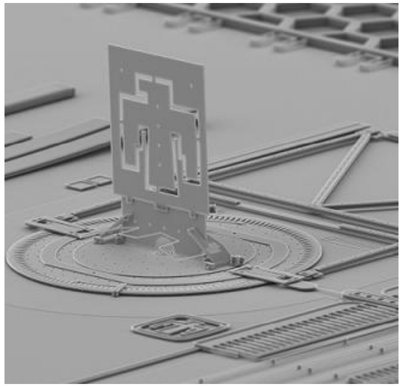
- The **atomic force microscope** (AFM) is a very high-resolution type of scanning probe microscope, with resolution of fractions of a nanometer, more than 1000 times better than the optical diffraction limit.
- The precursor to the AFM, the scanning tunneling microscope, was developed by Gerd Binnig and Heinrich Rohrer in the early 1980s, a development that earned them the Nobel Prize for Physics in 1986. Binnig, Quate and Gerber invented the first AFM in 1986.
- The AFM is one of the foremost tools for imaging, measuring and manipulating matter at the nanoscale. The term 'microscope' in the name is actually a misnomer because it implies looking, while in fact the information is gathered by "feeling" the surface with a mechanical probe. Piezoelectric elements that facilitate tiny but accurate and precise movements on (electronic) command enable the very precise scanning.

- The AFM consists of a microscale cantilever with a sharp tip (probe) at its end that is used to scan the specimen surface. The cantilever is typically silicon or silicon nitride with a tip radius of curvature on the order of nanometers.
- When the tip is brought into proximity of a sample surface, forces between the tip and the sample lead to a deflection of the cantilever according to Hooke's law.
- Depending on the situation, forces that are measured in AFM include mechanical contact force, Van der Waals forces, capillary forces, chemical bonding, electrostatic forces, magnetic forces (see Magnetic force microscope (MFM)), Casimir forces, solvation forces etc.
- As well as force, additional quantities may simultaneously be measured through the use of specialized types of probe.



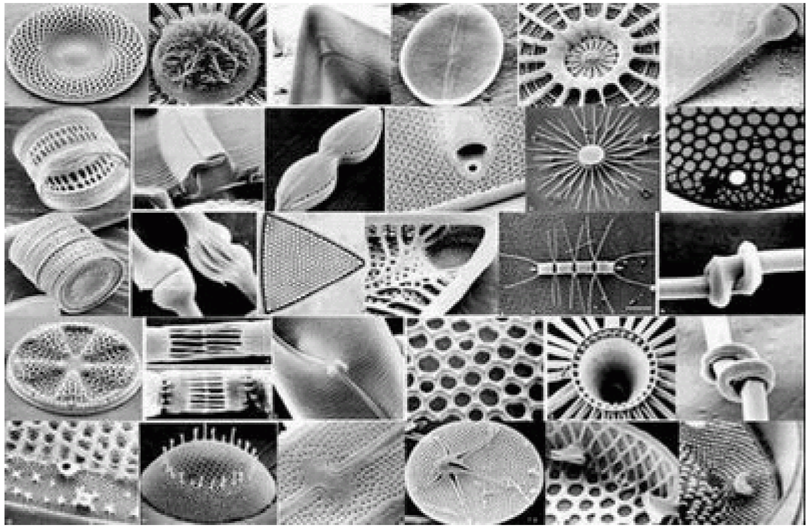


- Typically, the deflection is measured using a laser spot reflected from the top of the cantilever into an array of photodiodes. Using a Wheatstone bridge, strain in the AFM cantilever due to deflection can be measured.

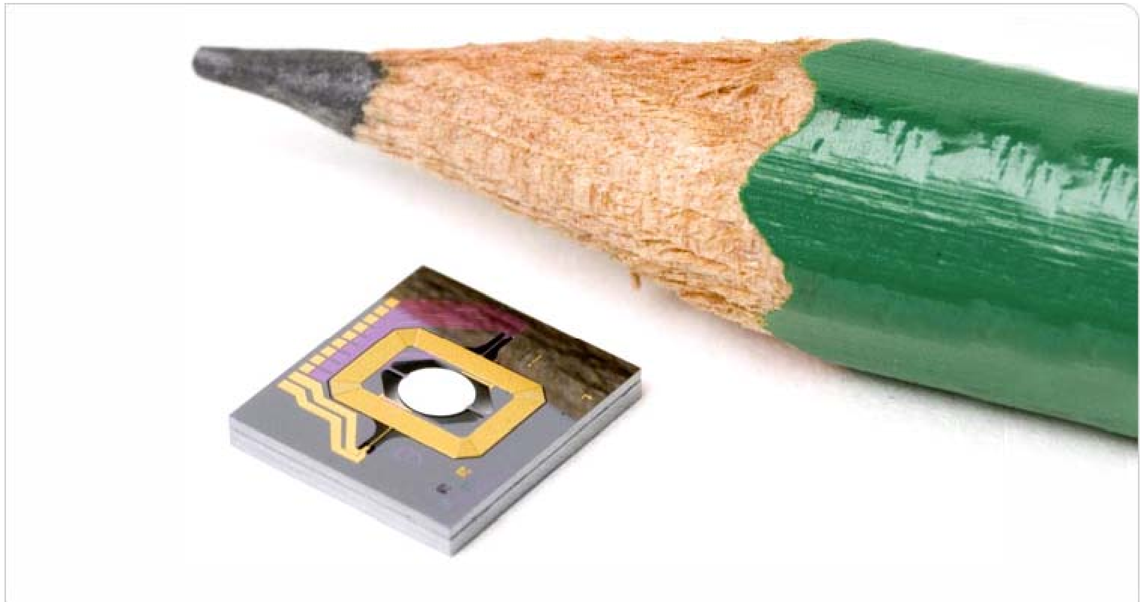


- If the tip were scanned at a constant height, there would be a risk that the tip would collide with the surface, causing damage. Hence, in most cases a feedback mechanism is employed to adjust the tip-to-sample distance to maintain a constant force between the tip and the sample.
- Traditionally, the sample is mounted on a piezoelectric tube, that can move the sample in the *z* direction for maintaining a constant force, and the *x* and *y* directions for scanning the sample.
- Alternatively a 'tripod' configuration of three piezo crystals may be employed, with each responsible for scanning in the x,y and z directions.

MicroElectroMechanical System(MEMS)



- **Microelectromechanical systems** (**MEMS**) is the technology of the very small, and merges at the nano-scale into nanoelectromechanical systems (NEMS).
- MEMS are made up of components between 1 to 100 micrometers in size (i.e. 0.001 to 0.1 mm) and MEMS devices generally range in size from a 20 micrometers (20 millionth of a meter) to a millimeter.
- They usually consist of a central unit that processes data, the microprocessor and several components that interact with the outside such as microsensors.



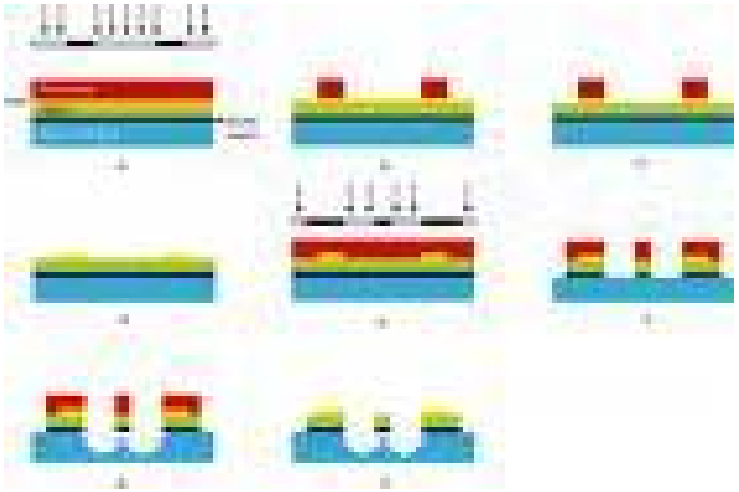
- The potential of very small machines was appreciated long before the technology existed that could make them— Feynman's famous 1959 lecture There's Plenty of Room at the Bottom.
- MEMS became practical once they could be fabricated using modified semiconductor fabrication technologies, normally used to make electronics.
- These include molding and plating, wet etching and dry etching, electro discharge machining, and other technologies capable of manufacturing very small devices.

Microelectromechanical systems processes

- **Photolithography**

- Lithography in MEMS is the transfer of a pattern to a photosensitive material by selective exposure to a radiation source such as light.
- A photosensitive material is a material that experiences a change in its physical properties when exposed to a radiation source. If a photosensitive material is selectively exposed to radiation (e.g. by masking some of the radiation) the pattern of the radiation on the material is transferred to the material exposed, as the properties of the exposed and unexposed regions differs.
- This exposed region can then be removed or treated providing a mask for the underlying substrate. Photolithography is typically used with metal or other thin film deposition, wet and dry etching.

Microelectromechanical systems processes



- **Etching processes**

There are two basic categories of etching processes: wet and dry etching. In the former, the material is dissolved when immersed in a chemical solution. In the latter, the material is sputtered or dissolved using reactive ions or a vapor phase etchant.