

Advanced Manufacturing Choices

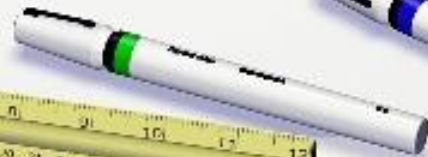


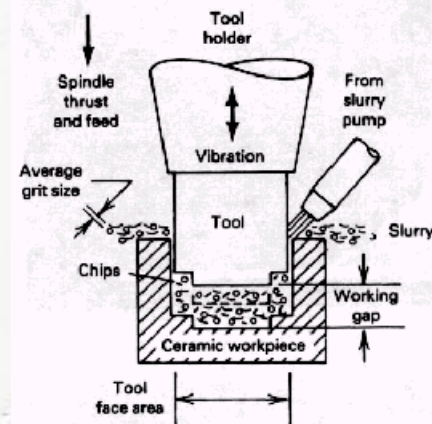
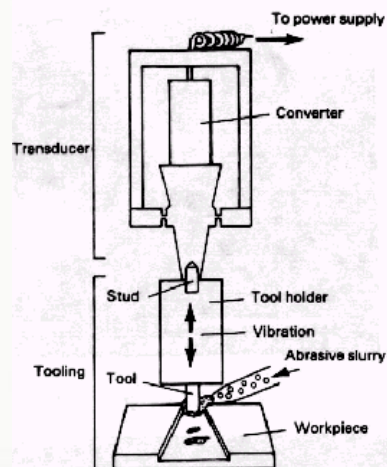


Table of Content

- Mechanical Removing Techniques
 - Ultrasonic Machining (USM)
 - Sputtering and Focused Ion Beam Milling (FIB)

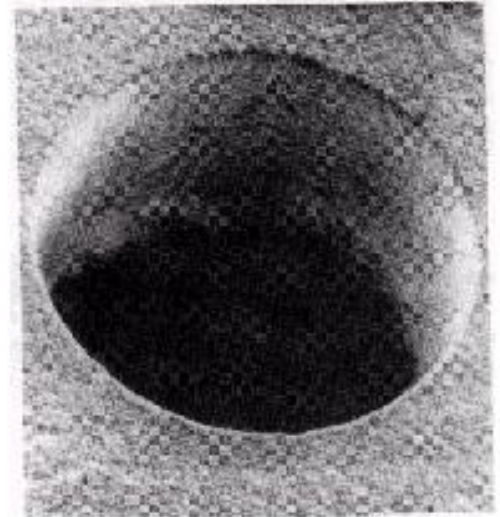
Ultrasonic Machining

- In ultrasonic machining (USM), also called ultrasonic grinding, high-frequency vibrations delivered to a tool tip, embedded in an abrasive slurry, by a booster or sonotrode, create accurate cavities of virtually any shape; that are, “negatives” of the tool.
- Since this method is non-thermal, non-electrical, and non-chemical, it produces virtually stress-free shapes even in hard and brittle work-pieces. Ultrasonic drilling is most effective for hard and brittle materials; soft materials absorb too much sound energy and make the process less efficient.



Ultrasonic Machining

- Almost any hard and brittle material, including aluminum oxides, silicon, silicon carbide, silicon nitride, glass, quartz, sapphire, ferrite, fiber optics, etc., can be ultrasonically machined.
- The tool does not exert any pressure on the work-piece (drilling without drills), and is often made from a softer material than the work-piece, say from brass, cold-rolled steel, or stainless steel and wears only slightly.
- The roots of ultrasonic technology can be traced back to research on the piezoelectric effect conducted by Pierre Curie around 1880. He found that asymmetrical crystals such as quartz and Rochelle salt (potassium sodium titrate) generate an electric charge when mechanical pressure is applied. Conversely, mechanical vibrations are obtained by applying electrical oscillations to the same crystals. Ultrasonic waves are sound waves of frequency higher than 20,000 Hz.

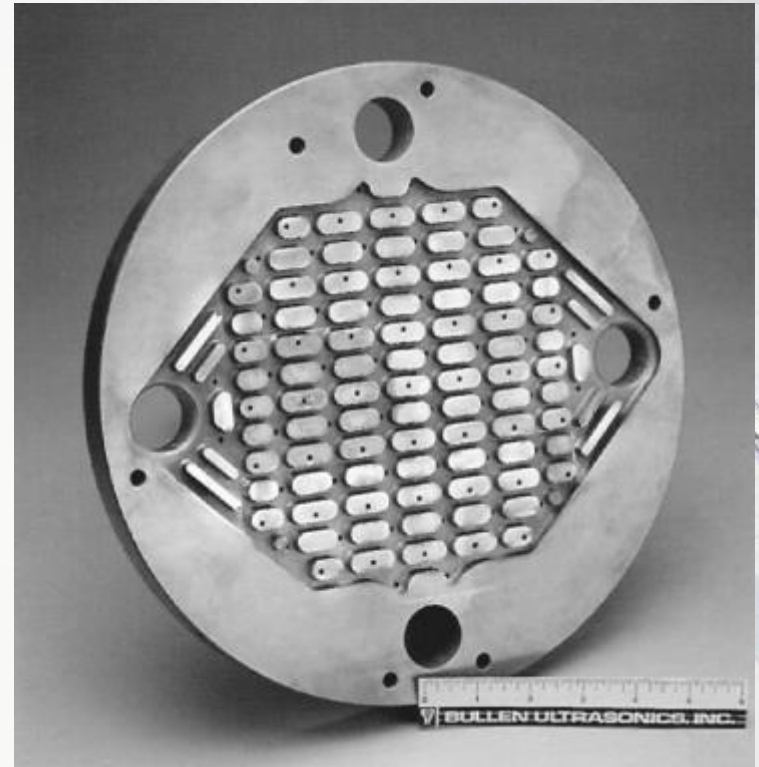


640 μ m hole by ultrasonic drill

Ultrasonic Machining

Channels and holes ultrasonically machined in a polycrystalline silicon wafer.

- The tool, typically vibrating at a low amplitude of 0.025 mm at a frequency of 20 to 100 kHz, is gradually fed into the work-piece to form a cavity corresponding to the tool shape.
- The vibration transmits a high velocity force to fine abrasive grains between the tool and the surface of the work-piece. In the process material is removed by micro-chipping or erosion with the abrasive particles.
- The grains are in a water slurry which also serves to remove debris from the cutting area. The high-frequency power supply for the magnetostrictive or piezoelectric transducer stack that drives the tool is typically rated between 0.1 and 40 kW.



Ultrasonic Machining

Coin with grooving carried out with USM

- The abrasive particles (SiC , Al_2O_3 or BC $d=8\sim 500\ \mu\text{m}$) are suspended in water or oil.
- The particle size and the vibration amplitude are usually made about the same.
- The particle size determines the roughness or surface finish and the speed of the cut.
- Material removal rates are quite low, usually less than $50\ \text{mm}^3/\text{min}$.



Ultrasonic Machining

- The mechanical properties and fracture behavior of the work-piece materials also play a large role in both roughness and cutting speed. For a given grit size of the abrasive, the resulting surface roughness depends on the ratio of the hardness (H) to the modulus of elasticity (E). As this ratio increases, the surface roughness increases.
- Higher H/E ratios also lead to higher removal rates: 4 mm³/min for carbide and 11 mm³/min for glass.



ultrasonic machining can be used to form intricate, finely detailed graphite electrodes.

Ultrasonic Machining

- Machines cost up to \$20,000, and production rates of about 2500 parts per machine per day are typical.
- If the machined part is a complex element (e.g., a fluidic element) of a size $> 1 \text{ cm}^2$ and the best material to be used is an inert, hard ceramic, this machining method might well be the most appropriate

900 watt Sonic-mill, Ultrasonic Mill







Ultrasonic Machining

Advantages and disadvantages of ultrasonic machining.

Advantages	Disadvantages
Machining of any material regardless of conductivity	Low material removal rate
Precision machining of brittle hard materials	Tool wears fast
Does not produce electric, thermal or chemical defects at the surface	Machining area and depth are quite restricted
Can drill circular or non-circular holes in very hard materials	
Less stress because of its non-thermal nature	



Sputtering

- Talking about sputtering we usually mean the usage of the phenomena which are going on at the surface of solids (target) exposed in vacuum under the directed flow of atomic particles - ions or neutrals. Ions are extracted from gas discharge plasma as a spatially restricted beam and accelerated by the electric field to the required energies.
- Usually for the purposes of sputtering we use the energy band from about 100 eV to 5000 eV (for ion implantation, energies up to a few tens keV may be used) (see figure on next slide).
- What happens when ions with energy 0,1 - 5 keV bombard the surface of the solid target? (The velocities of ions with such energies in vacuum may be about a few tens thousand meters per second!). They can knock out atoms from the work-piece.

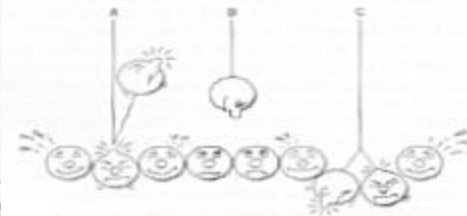


FIGURE 1 Ions at normal incidence onto a surface.

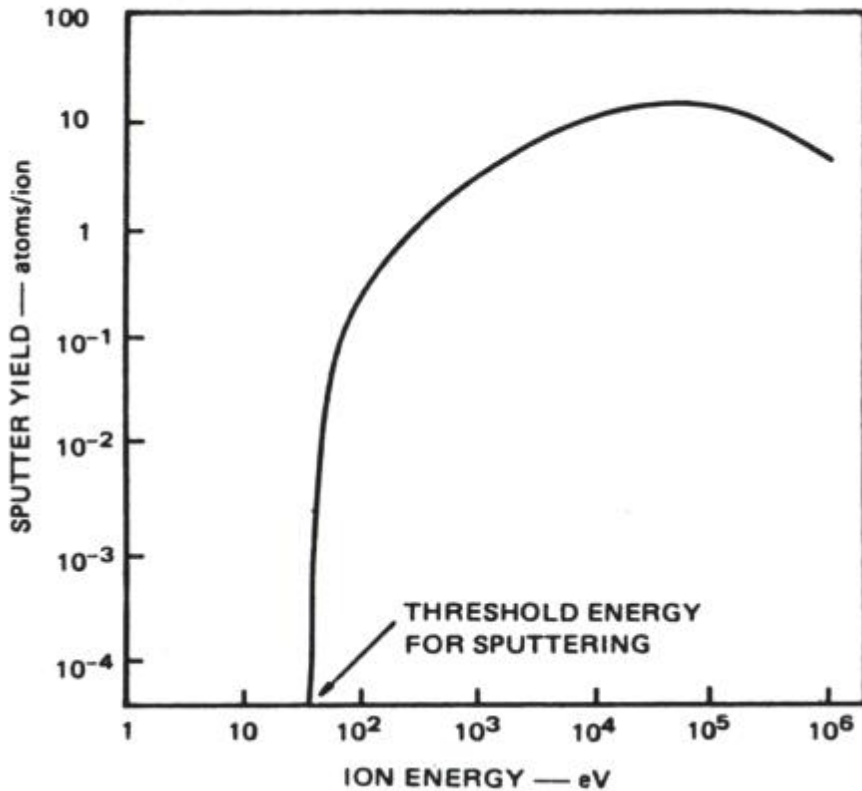
Energy Requirements Associated with Various Physical Processes.

Ion Energy (eV)

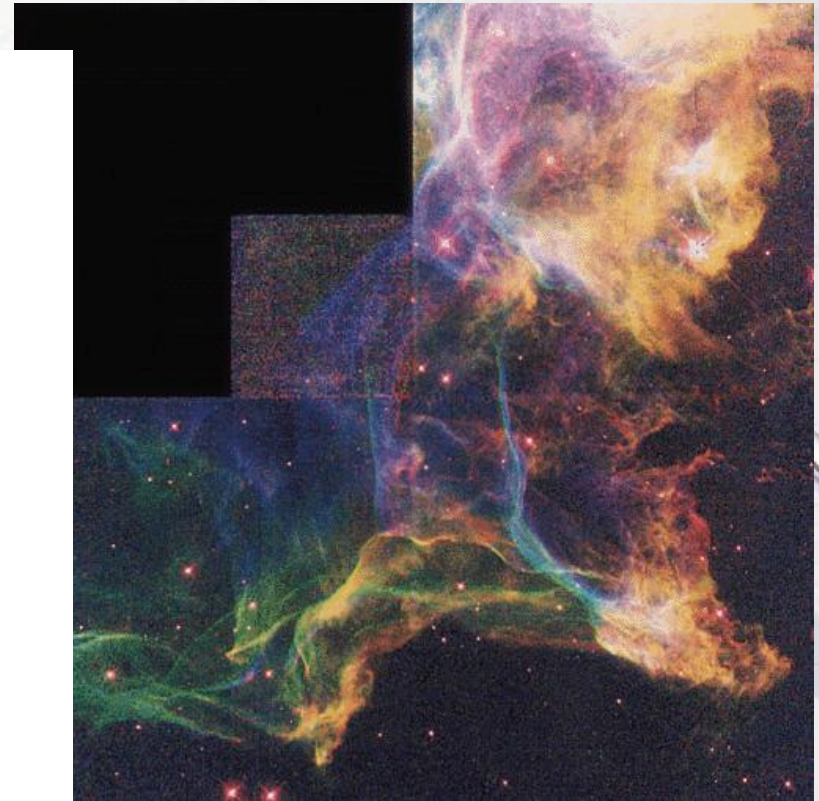
<3
4-10
10-5000
10K-20 K

Reaction

Physical adsorption
Some surface sputtering
Sputtering
Implantation

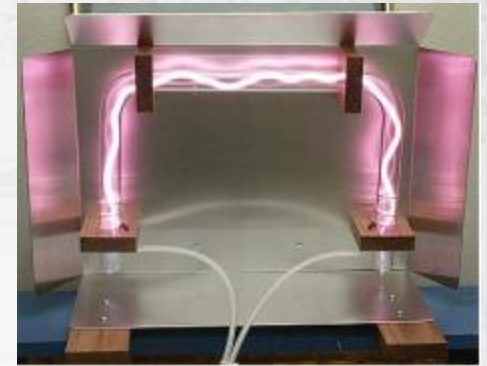


Sputtering



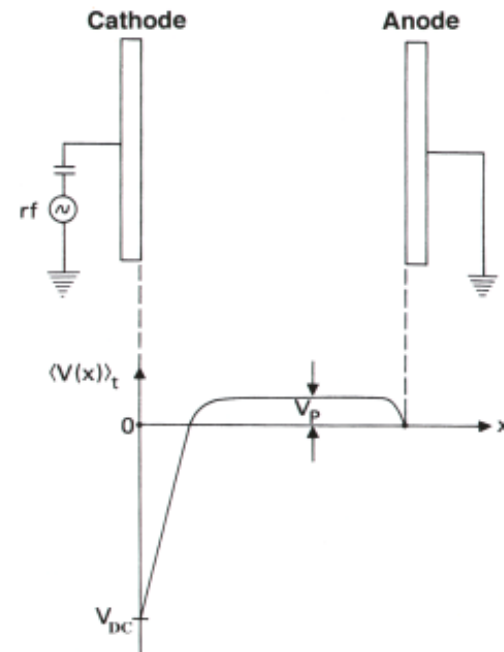
Sputtering

- The simplest plasma reactor consists of opposed parallel plate electrodes in a chamber maintainable at low pressure, typically in the order of 1 mbar.
- The electrical potentials established in the reaction chamber, filled with an inert gas such as argon at a reduced pressure, determine the energy of ions and electrons striking the surfaces immersed in the discharge.
- Apply 1.5 kV between them. With the electrodes separated by 15 cm this results in a 100 V/cm field. Electrical breakdown (rapid ionization of a medium following the application of an over-voltage) of the argon gas in this reactor will occur when electrons, accelerated in the existing field, transfer an amount of kinetic energy greater than the argon ionization potential (i.e., 15.7 eV) to the argon neutrals. Elastic collisions deplete very little of the electron's energy and do not significantly influence the molecules because of the great mass difference between electrons and gas molecules.



Sputtering

- Inelastic collisions on the other hand, excite the molecules of the gas or ionize them by completely removing an electron. Such energetic inelastic collisions may thus generate a second free electron and a positive ion for each successful strike. Both free electrons reenergize, creating an avalanche of ions and electrons that results in a gas breakdown emitting a characteristic beautiful blue glow (in the case of Argon; for air or nitrogen a pink color is due to excited nitrogen molecules).



Sputtering

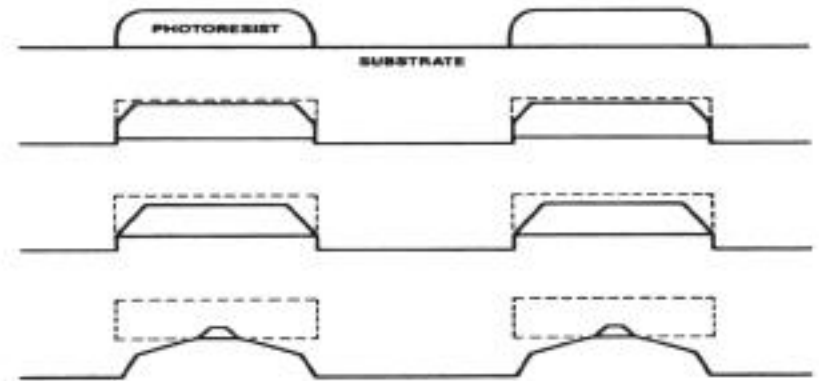
- The main production process in the argon plasmas we study is electron impact ionisation of a ground state atom. This is simply a collision between an electron and a neutral atom which results in a positive ion and two electrons. Plasmas used in important industrial applications are created in vacuum chambers by the application of electrical energy to a gas at low pressure. The plasma is in a "steady state" when the production rate of charged particles is the same as the loss rate. At low pressures, charged particles are lost mainly by diffusion through the gas to the chamber walls.



Sputtersphere 822

Sputtering

- Faceting: angle of preferential etching
- Ditching (trenching): sometimes caused by faceting
- Redeposition: rotational stage might reduce this effect.



A



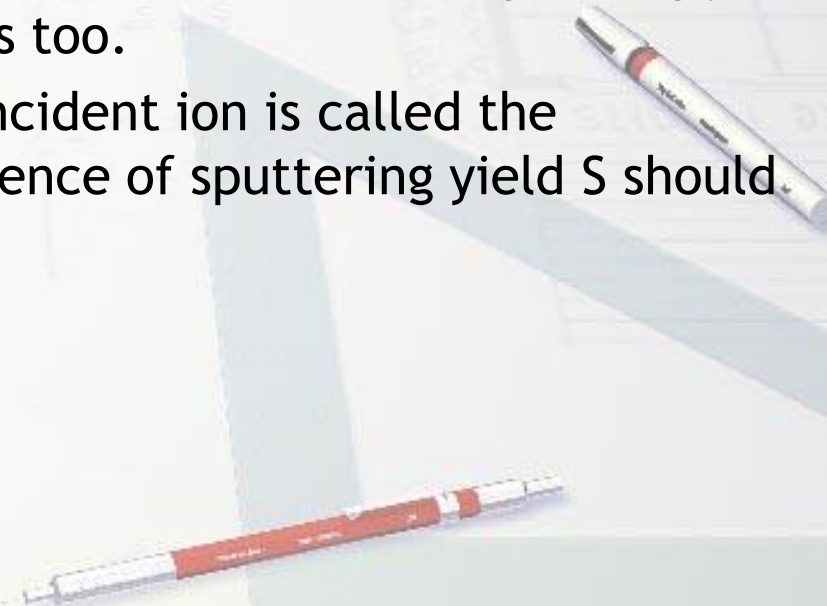
B



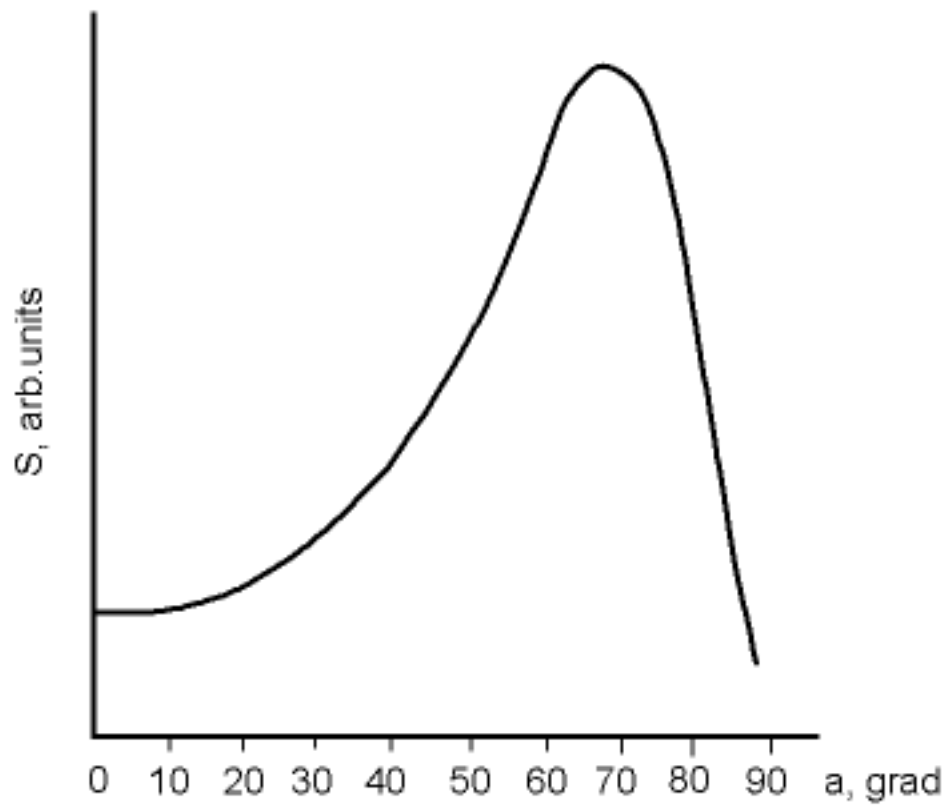
C



Sputtering

- In case the direction of momentum propagation in the target (work-piece) changes : (a) the depths of the disturbed zone changes and (b) the surface zone where the atoms are sputtered from changes.
 - It can be shown that the number of sputtered atoms will increase when the angle becomes larger than 0° . But when the angle becomes close to 90° , ions start practically to slide along the surface and the energy and momentum transferred to the target's atoms decrease. Correspondingly the number of sputtered atoms decreases too.
 - The number of atoms sputtered by one incident ion is called the "sputtering yield". So the angular dependence of sputtering yield S should be like shown below.
- 

Sputtering



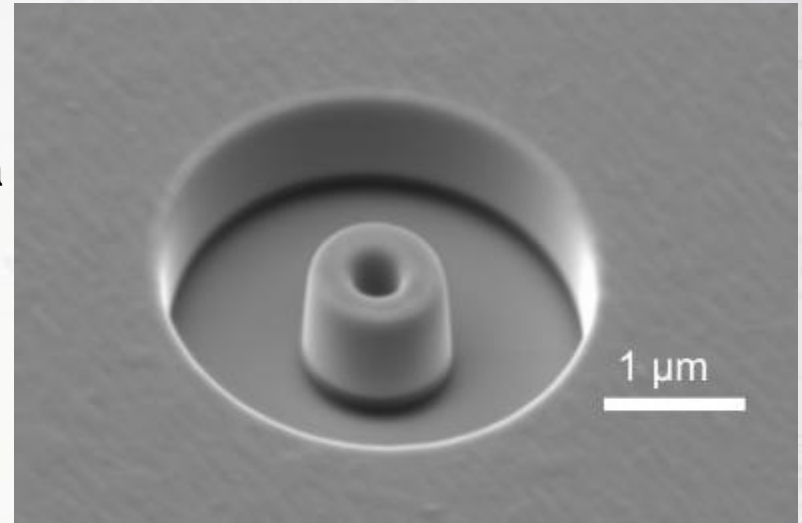


Focused Ion Beam Milling (FIB)

- Focused ion beam, also known as FIB, is a technique used particularly in the semiconductor and materials science fields for site-specific analysis, deposition, and ablation of materials.
- The FIB is a scientific instrument that resembles a scanning electron microscope. However, while the SEM uses a focused beam of electrons to image the sample in the chamber, a FIB instead uses a focused beam of ions.
- Gallium ions are accelerated to an energy of 5-50 keV (kiloelectronvolts), and then focused onto the sample by electrostatic lenses. A modern FIB can deliver tens of nanoamps of current to a sample and can image the sample with a spot size on the order of a few nanometers.

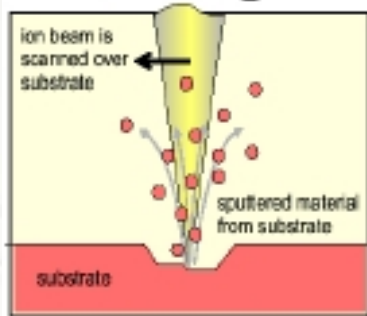
Focused Ion Beam Milling (FIB)

- Because of the sputtering capability, the FIB is used as a micro-machining tool, to modify or machine materials at the micro- and nanoscale. FIB micro machining has become a broad field of its own, but nano machining with FIB is a field that still needs developing.
- The common smallest beam size is 4-6 nm. FIB tools are designed to etch or machine surfaces, an ideal FIB might machine away one atom layer without any disruption of the atoms in the next layer, or any residual disruptions above the surface.

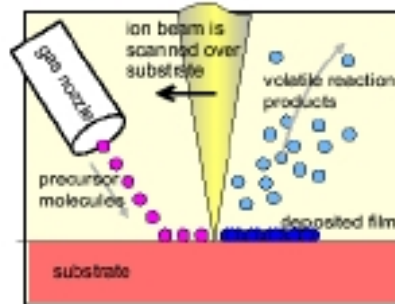


Focused Ion Beam Milling (FIB)

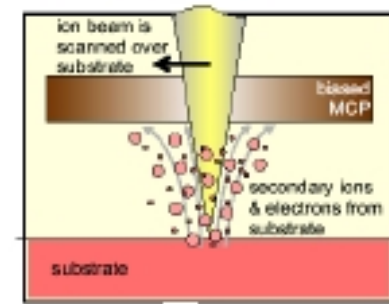
Milling



Deposition



Imaging, doping



<http://www.youtube.com/watch?v=VV90xM3QTcM>

