ION BEAM MACHINING (IBM)

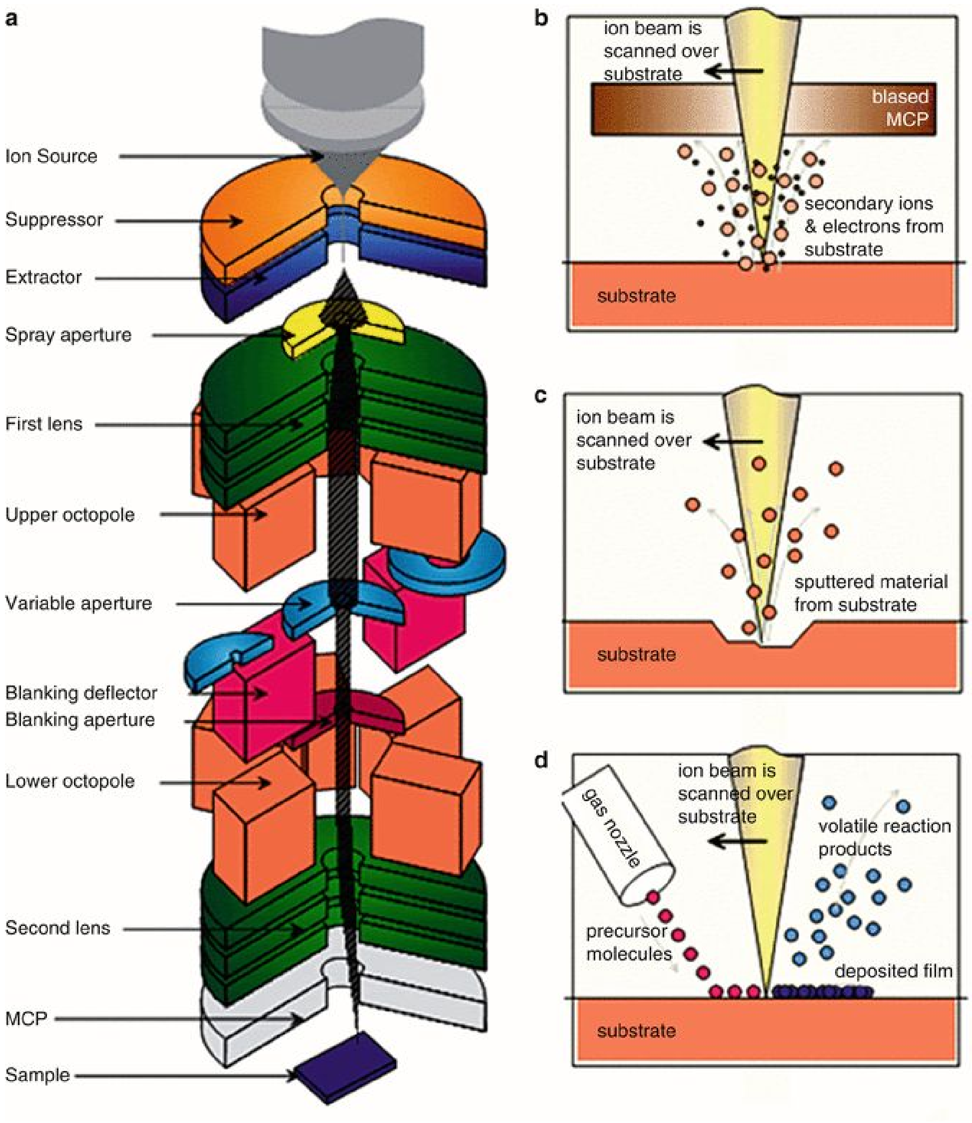
Alternative names **Ion Itching, Ion Milling, or Ion Polishing**.

Energy domain: Thermo-electric (but independent of heating; machining occurs by sputtering of ions).

Basic Introduction

The atoms are ejected from the surface by other accelerated ionized atoms hitting the surface.

- Inert gas like argon is used as ion source.
- Ions are accelerated in a vacuum by high energies.
- A stream of ions bombard the surface & dislodge material by transfer of Kinetic Energy.
- 0.1 to 10 atoms are discharged from the workpiece when an atom strikes a cluster of atoms.
    - Interatomic binding energy must be overcome.
- Classified into two main categories,
    - Large-area Ion Beam Machining (LIBM) technology
    - Focused Ion Beam Machining (FIBM) technology.



Working principle

High energy ions are impinged on the workpiece to remove atoms from it by transfer of kinetic energy.

An ion beam is a type of charged particle beam consisting of ions.

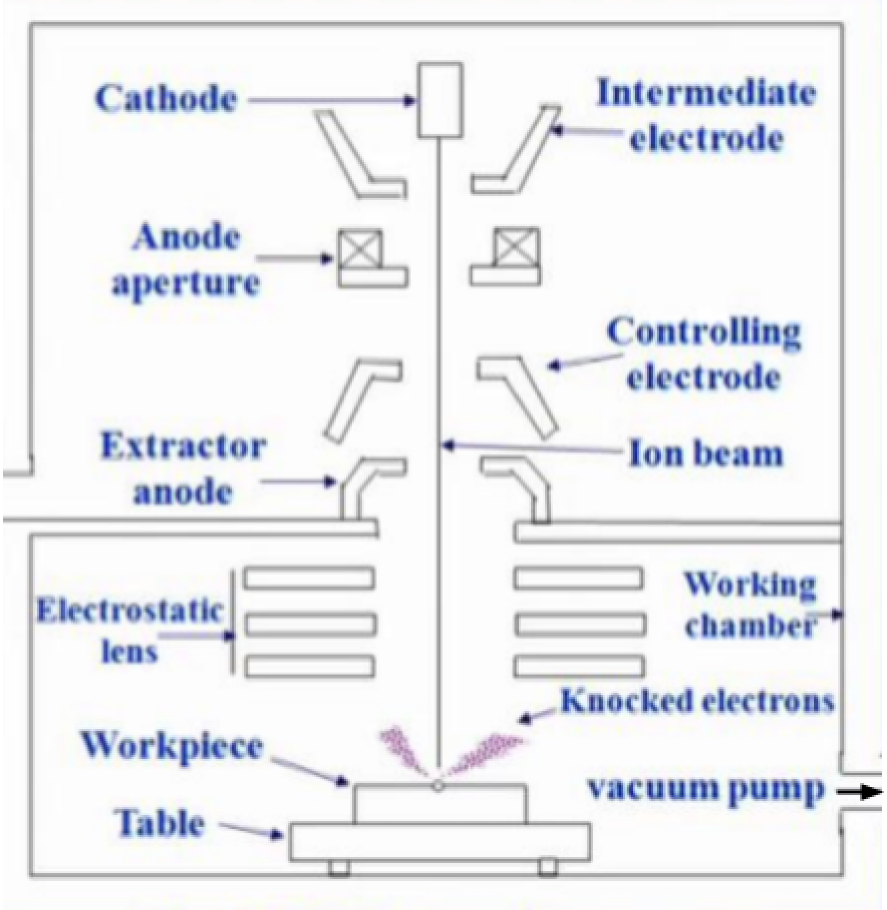
- Useful in electronics manufacturing (principally ion implantation) & other industries.
- A variety of ion beam sources exist, some derived from the mercury vapor thrusters developed by NASA in the 1960s.

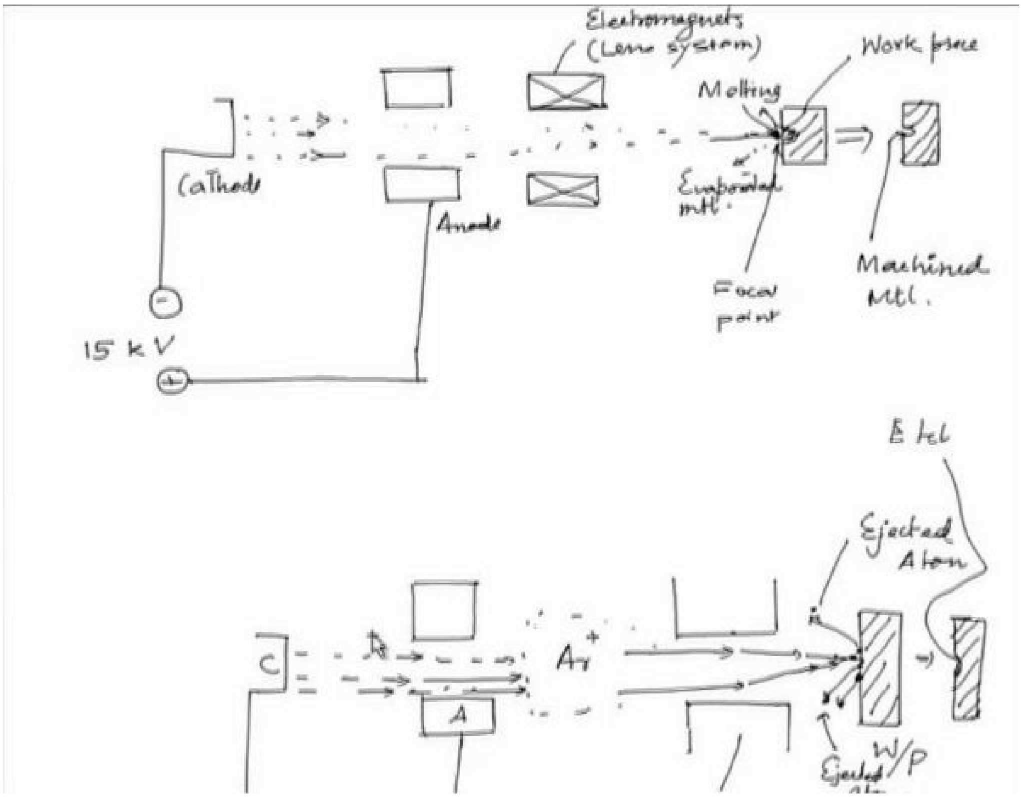
Ion beam application, etching, or sputtering, is a technique conceptually similar to sandblasting, but using individual atoms in an ion beam to ablate a target.

Reactive ion etching is an important extension that uses chemical reactivity to enhance the physical sputtering effect.

Equipment

- Ion source: to produce ion beam of suitable intensity.
  - Heated tungsten filament acts as cathode & accelerates electrons
  - Voltage about 1kV is used.
- Extra intermediate electrodes is used for increasing electron emission.
- An anode accelerates / attracts electrons.
- A magnetic field produced between the cathode & the anode makes the electrons spiral.
- These interact with argon atoms in the plasma source to produce the ions.
- The produced ions are extracted from the plasma & directed towards workpiece.
- Electrostatic lens / Controlling electrodes are used to guide the ion beam.
- The atoms will be dislodged due to transfer of Kinetic Energy of the ions.
  - Thermal effect has no role to play.
- The workpiece surface is masked wherever no material removal is intended.
  - Material removal occurs only at unmasked surface.
  - The workpiece is mounted on a water cooled table.
- A vacuum pump is used to create high vacuum.





Process Description

In a typical use in semiconductor manufacturing,

- a mask can selectively expose a layer of photoresist on a substrate made of a semiconductor material such as a silicon dioxide or gallium arsenide wafer.
- The wafer is developed, & for a positive photoresist, the exposed portions are removed in a chemical process.
- The result is a pattern left on the surface areas of the wafer that had been masked from exposure.
- The wafer is then placed in a vacuum chamber, & exposed to the ion beam.
- The impact of the ions erodes the target, abrading away the areas not covered by the photoresist.

Process Parameters

- Sputtering coefficient: Number of atoms dislodged by each bombarded ion.
    - It's a function of:
        - Kinetic Energy of ions
            - 1^{st} increases & later falls off.
            - Reason: High energy ions penetrate workpiece without dislodging workpiece atoms.
        - atomic weight of incident ion (directly proportional).
        - angle of incidence (directly proportional).
            - Grazing incidence gives highest yield.
        - workpiece material.
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Performance Characteristics

- Practical etching rates - about 2000 Å/min or $2x10^{-4}$ mm/min
    - Varies for different materials &
        - Tungsten etches at half the rate of Aluminium.
    - external means to cool the workpiece.
- Machining of small dimensions as 10 to 100 nanometer are possible
- accuracy levels of plus minus 1 percent
- repeatability of plus minus 1 percent have been reported.
- Smoothening to a surface finish of less than 1 micrometer can be obtained.
- Depth to width ratios up to is to 1.

Advantages

- Almost any material can be machined.
- No chemical reagents or etchants required.
- No residue.
- Resolution is only limited by that of the mask.
- No undercutting as in chemical etching.
- Etching rates are easily controllable.

Disadvantages

- Relatively expensive.
- Slow etching rates.
- Thermal or radiation damage may occur in some cases.

Applications

- Micro/Nanofabrication of electronic components like

    - computer memories
    - figuring optical surfaces
- Fabrication of fine wire dies in refractory materials.
- Smoothening of laser mirrors
- Production of closely packed, textured cones in copper, nickel, stainless steel, gold & silver.
- Atomically clean surfaces used in adhesion of gold films to silicon & aluminum oxide substrates.
- Removing surface oxide layers by using higher ion energies.
- Milling a line width of 0.2 micrometer used in fabrication of bubble memory devices
- Reducing the thickness of thin films without affecting the surface finish
    - Silicon samples with thickness 10 to 15 micrometer have been reported, using argon ions impinging at normal incidence by MC Geough in the year 1988.
- Using two opposing beams, samples for transmission electron microscopy can be produced.
    - This is a very critical application as the sample preparation for transmission electron microscope is a critical job, which needs very thin samples to be prepared.
    - Polishing & shaping of optical surfaces by direct sputtering of performs in glass, silica & diamond can be performed using patterning masks.
- Materials: glass, alumina, quartz crystals, silica, agates, orcelains, cermets, mixtures of quartz, asbestos, numerous metals & oxides including rare earth metals.
- Extremely valuable in etching surfaces of specimens prior to study of microstructure.
    - Reason: It reveals microstructure without altering surface.
    - Resulting surface is suitable for both optical & electron microscope.
- Etching multilayered structures (i.e. forming terminals) without risk of incompatibility.
- Deposition of thin film of material in IBM / Electronic industries process.
    - Material to be deposited is made anode.
    - Argon or other rare inert gas used under low pressure.
    - Gaseous ions bombard cathode, sputtering its material on the substrate.
    - Depositions are used on razor blades as well.

Extra points:

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