Microsystem Fabrication

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Microsystems Fabrication Processes

To fabricate any solid device component, one must first select materials and adequate fabrication method.

For MEMS and microsystems components, the sizes are so small that no machine tools, e.g. lathe, milling machine, drilling press, etc. can do the job. There is simply no way one can even grip the work piece.

Consequently, radically different techniques, non-machine-tool techniques need to be used for such purpose.

Most physical-chemical processes developed for "shaping" and fabricating ICs are adopted for microsystems fabrications. This is the principal reason for using silicon and silicon compounds for most MEMS and microsystems – because these are the materials used to produce ICs.

Microfabrication
by physical-chemical processes

Traditional Manufacturing
by machine tools

Microfabrication Processes

- Photolithography
- Ion implantation
- Diffusion
- Oxidation
- Chemical vapor deposition
- Physical vapor deposition (Sputtering)
- Deposition by expitaxy
- Etching

Photolithography

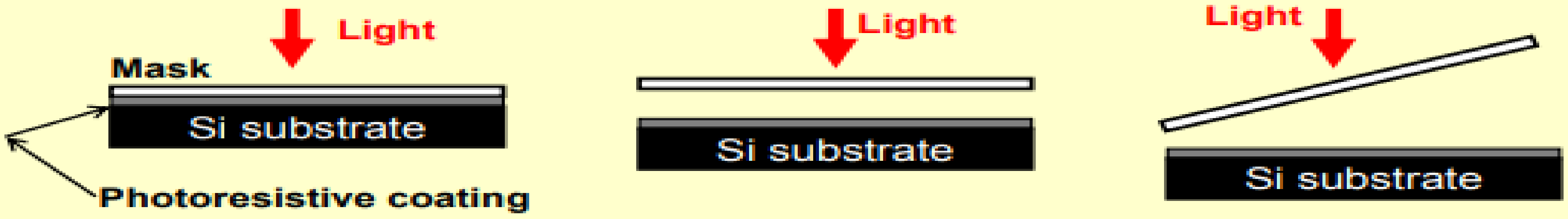
Photolithography process involves the use of an optical image and a photosensitive film to produce desired patterns on a substrate.

The "optical image" is originally in macro scale, but is photographically reduced to the micro-scale to be printed on the silicon substrates.

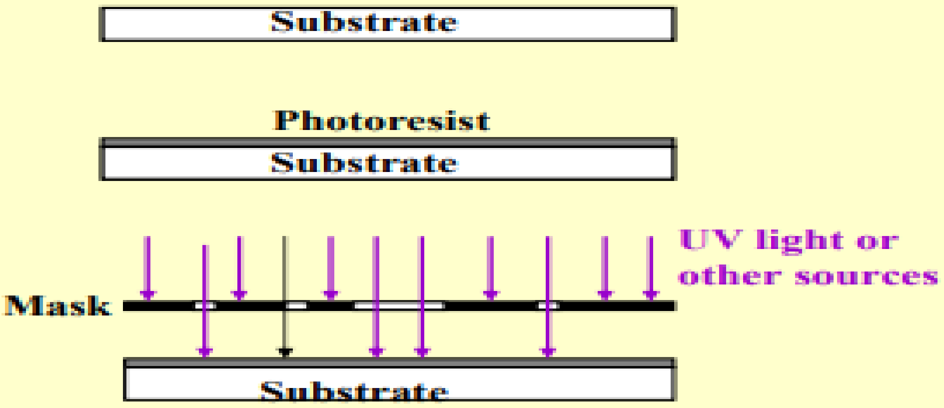
The desired patterns are first printed on light-transparent mask, usually made of quartz.

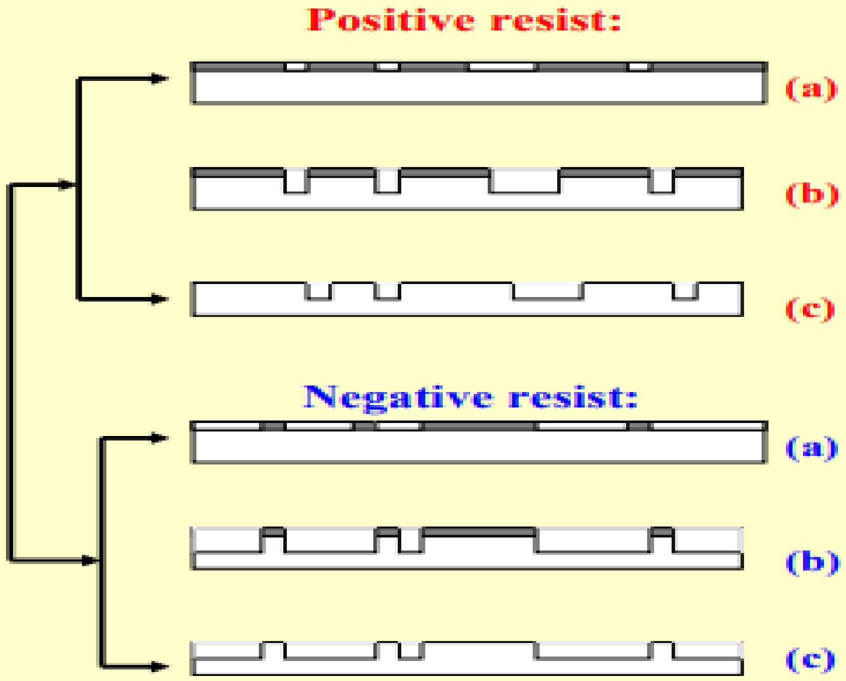
The mask is then placed above the top-face of a silicon substrate coated with thin film of photoresistive materials.

The mask can be in contact with the photoresistave material, or placed with a gap, or inclined to the substrate surface:



Photolithography



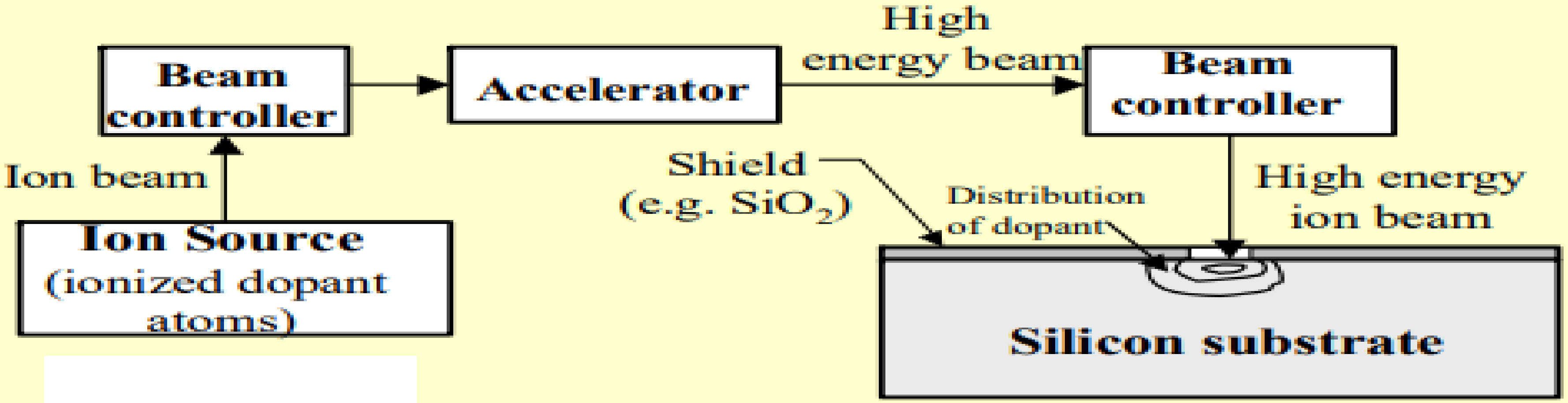


Processes:

(a) Development
(b) Etching
(c) Photoresist removal

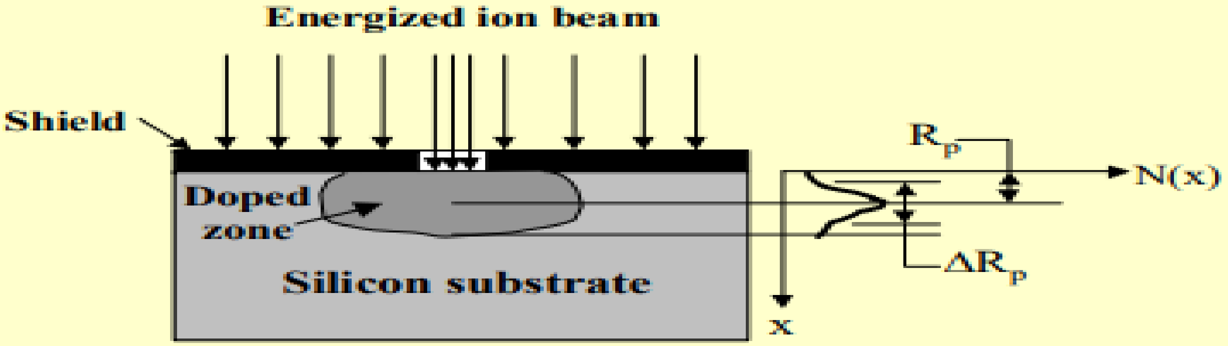
Ion Implantation

- It is physical process used to dope silicon substrates.
- It involves "forcing" free charge-carrying ionized atoms of B, P of As into silicon crystals.
- These ions associated with sufficiently high kinetic energy will be penetrated into the silicon substrate.
- Physical process is illustrated as follows:



Ion Implantation

Density distribution in depth

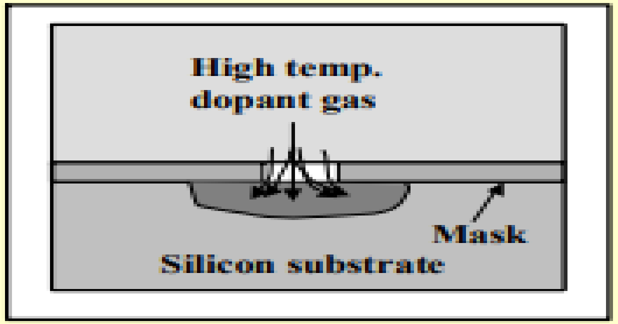


$$N(x) = \frac{Q}{\sqrt{2\pi}\Delta R_p} \exp\left[\frac{-(x-R_p)^2}{2\Delta R_p{}^2}\right]$$

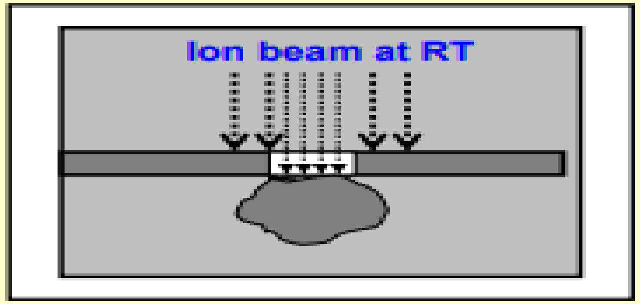
where R_p = projected range in μm,
ΔR_p = scatter or "straggle" in μm, and
Q = dose of ion beam (atoms/cm²)

Diffusion

- Diffusion is another common technique for doping silicon substrates.
- Unlike ion implantation, diffusion takes place at high temperature.
- Diffusion is a chemical process.
- The profile of the spread of dopant in silicon by diffusion is different from that by ion implantation:



Dopant profile by Diffusion



Dopant profile by ion implantation

Oxidation

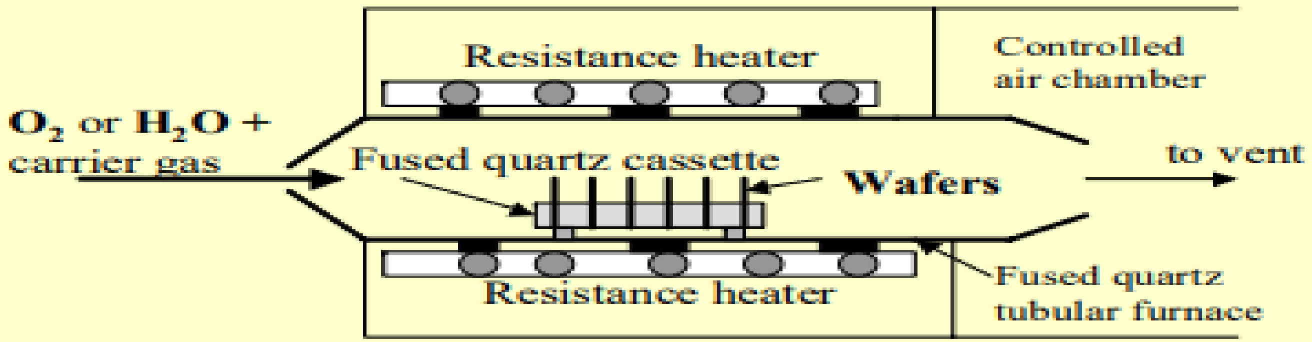
SiO_2 is an important element in MEMS and microsystems. Major application of SiO_2 layers or films are:

(1) To be used as thermal insulation media
(2) To be used as dielectric layers for electrical insulation

- SiO_2 can be produced over the surface of silicon substrates either by:
  (1) Chemical vapor deposition (CVD), or
  (2) Growing SiO_2 with dry O_2 in the air, or wet steam by the following two chemical reactions at high temperature:

$$Si \text{ (solid)} + O_2 \text{ (gas)} \rightarrow SiO_2 \text{ (solid)}$$

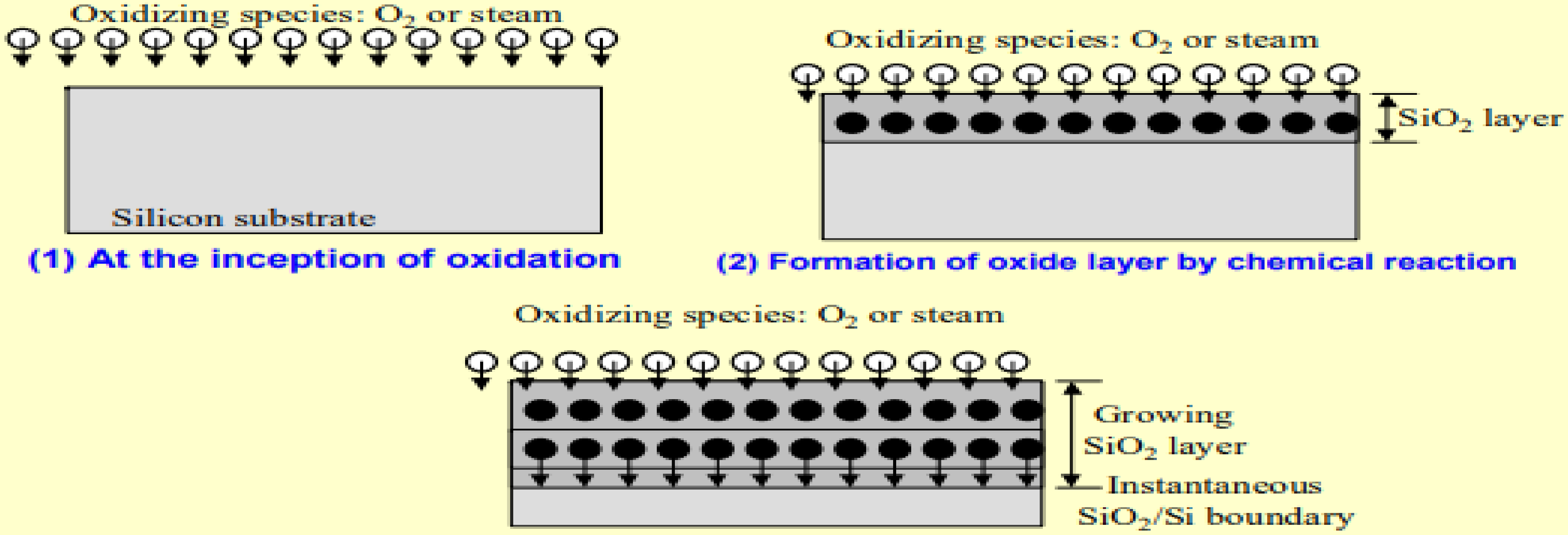
$$Si \text{ (solid)} + 2H_2O \text{ (steam)} \rightarrow SiO_2 \text{ (solid)} + 2H_2 \text{ (gas)}$$



Oxidation

Principle of thermal oxidation:

It is a combined <u>continuous</u> physical diffusion and chemical reactions



(3) Growth of oxide layer with diffusion and chemical reactions

Chemical Vapor Deposition

- Chemical vapor deposition (CVD) is the most important process in microfabrication.
- It is used extensively for producing thin films by depositing many different kind of foreign materials over the surface of silicon substrates, or over other thin films that have already been deposited to the silicon substrate.
- Materials for CVD may include:
  (a) Metals: Al, Ag, Au, W, Cu, Pt and Sn.
  (b) Organic materials: Al_2O_3, polysilicon, SiO_2, Si_3N_4, piezoelectric ZnO, SMA TiNi, etc.
- There are three (3) available CVD processes in microfabrication:
  (a) APCVD: (Atmospheric-pressure CVD);
  (b) LPCVD (Low-pressure CVD), and
  (c) PECVD (Plasma-enhanced CVD).
- CVD usually takes place at elevated temperatures and in vacuum in high class clean rooms.

Chemical Vapor Deposition

Working principle of CVD:

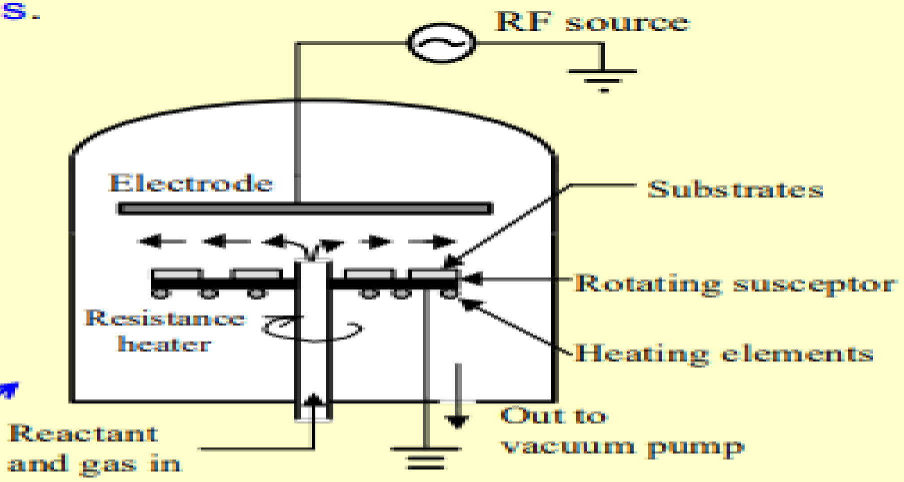
- CVD involves the flow of a gas containing diffused reactants (normally in vapor form) over the hot substrate surface
- The gas that carries the reactants is called "*carrier gas*"
- The "diffused" reactants are foreign material that needed to be deposited on the substrate surface
- The carrier gas and the reactant flow over the hot substrate surface, the energy supplied by the surface temperature provokes chemical reactions of the reactants that form films during and after the reactions
- The by-products of the chemical reactions are then let to the vent
- Various types of CVD reactors are built to perform the CVD processes

Chemical Vapor Deposition

Enhanced CVD -

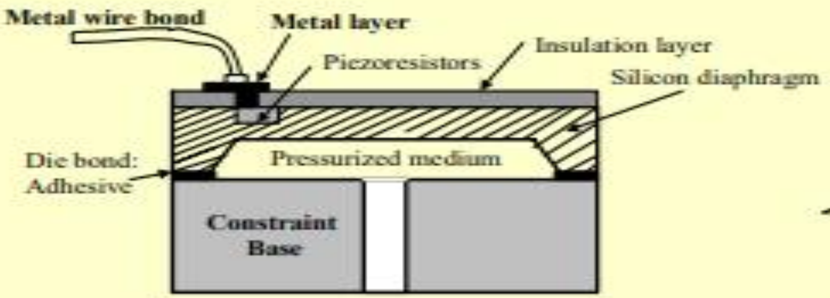
Plasma Enhanced CVD (PECVD)

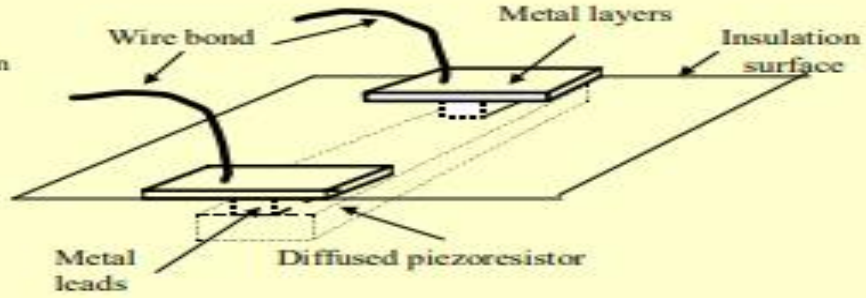
- Both APCVD and LPCVD operate at **elevated temperatures**, which often damage the silicon substrates..
- High substrate surface temperature is required to provide sufficient energy for diffusion and chemical reactions.
- The operating temperatures may be avoided if alternative form of energy supply can be found.
- CVD using **plasmas** generated from high energy **RF (radio-frequency) sources** is one of such alternative methods.
- This popular deposition method is called "Plasma Enhanced CVD" or **PECVD**.
- A typical PECVD reactor is shown:



Sputtering

- Sputtering is a form of **Physical Vapor Deposition**.
- It is used to deposit thin **metal films** in the order of 100 A (1A = 10^{-10} m) onto the substrate surface.
- Metal films are used as electrical circuit terminals as illustrated below:

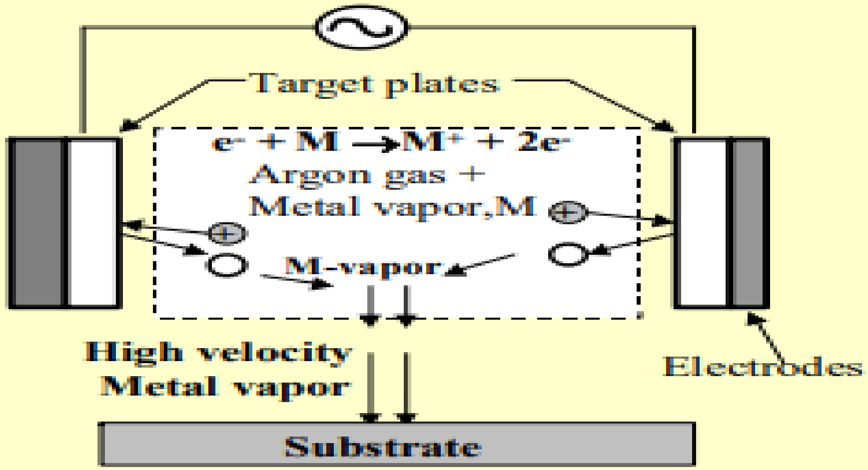




- Sputtering process is carried out with plasmas under very low pressure in **high vacuum** up to 5×10^{-7} torr and at **room temperature**.
- No chemical reaction is involved in the deposition process.

Sputtering -

- **Metal vapor** is created by the plasma generated by the high energy RF sources, such as the one illustrated below.



- Inert **Argon gas** is used as the carrier gas for metal vapor.
- The metal vapor forms the metal films after condensation of the substrate surface.

Etching

- MEMS and microsystems consist of components of 3-dimensional geometry.
- There are two ways to create 3-dimensional geometry:
  - by **adding** materials at the desired locations of the substrates using vapor deposition techniques, or
  - by **removing** substrate material at desired locations using the etiching methods.
- There are two types of etching techniques:
  - **Wet etching** involving the use of strong chemical solvents (**etchants**), or
  - **Dry etching** using high energy **plasmas**.
- In either etching processes, **masks** made of strong-resisting materials are used to protect the parts of substrate from etching.
- Both etching methods will be presented in detail in the subsequent chapter on Micromanufacturing.

Thank you