INRF BiON

Deposition

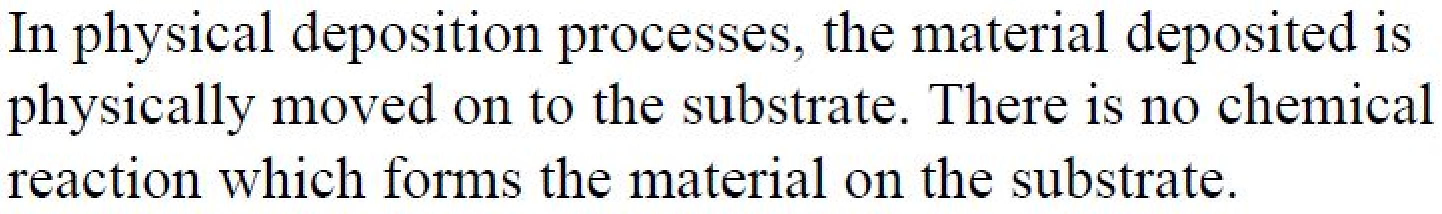
Lecture Day 2 Deposition

PVD - Physical Vapor Deposition
- E-beam Evaporation
- Thermal Evaporation (wire feed vs boat)
- Sputtering

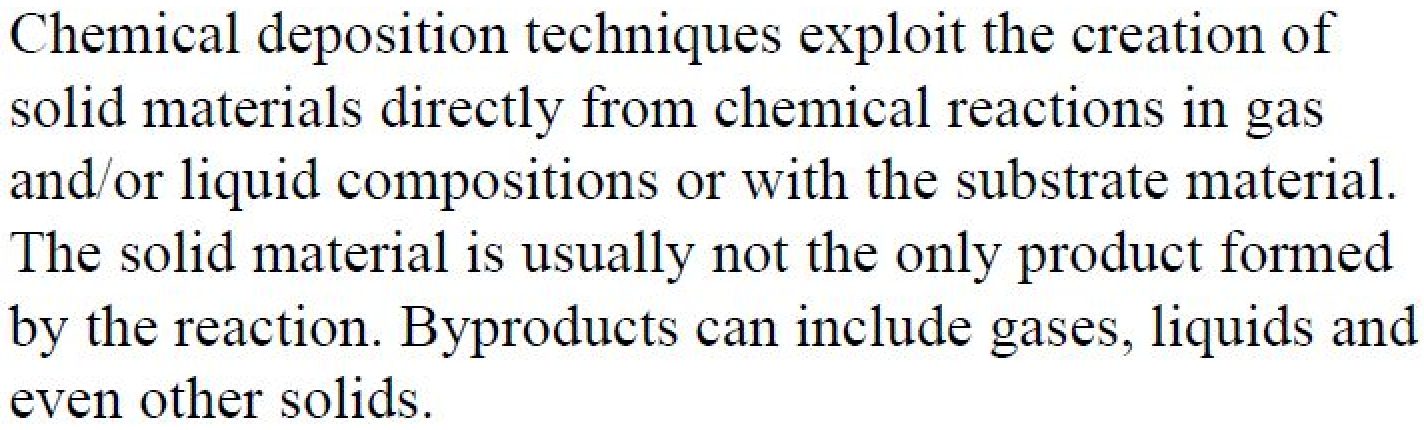
CVD - Chemical Vapor Deposition
- PECVD
- LPCVD
- MVD
- ALD
- MBE

Plating
Parylene Coating
Vacuum Systems, pumps and support equipment
Differences, Pros and Cons for depositing various materials

Physical vs. Chemical



In physical deposition processes, the material deposited is physically moved on to the substrate. There is no chemical reaction which forms the material on the substrate.



Chemical deposition techniques exploit the creation of solid materials directly from chemical reactions in gas and/or liquid compositions or with the substrate material. The solid material is usually not the only product formed by the reaction. Byproducts can include gases, liquids and even other solids.

Deposition

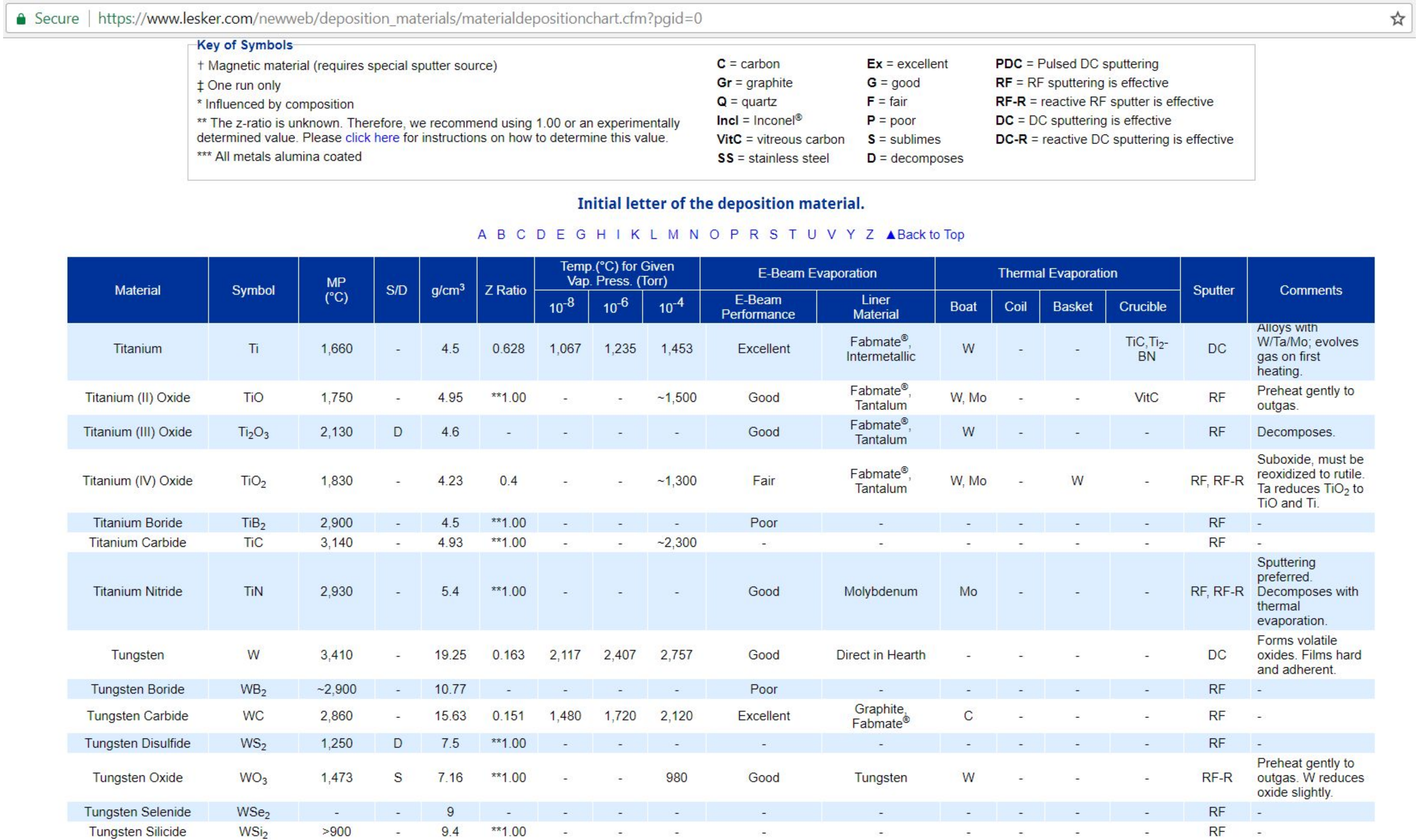
Metallization - depositing metal layers or thin films

- E-beam & Thermal Evaporation, Sputtering, Plating
- Contact layer, mask/protection layer, interface layers

Dielectric Deposition - depositing dielectric layers or thin films

-CVD, e-beam, sputtering
- insulating/capacitor layer, mask/protecting layer, interface layers

*Dielectric = an electrical insulator that can be polarized by an applied electric field.
~energy storing capacity → capacitor



Key of Symbols

† Magnetic material (requires special sputter source)
‡ One run only
* Influenced by composition
** The z-ratio is unknown. Therefore, we recommend using 1.00 or an experimentally determined value. Please click here for instructions on how to determine this value.
*** All metals alumina coated

C = carbon
Gr = graphite
Q = quartz
Incl = Inconel®
VitC = vitreous carbon
SS = stainless steel

Ex = excellent
G = good
F = fair
P = poor
S = sublimes
D = decomposes

PDC = Pulsed DC sputtering
RF = RF sputtering is effective
RF-R = reactive RF sputter is effective
DC = DC sputtering is effective
DC-R = reactive DC sputtering is effective

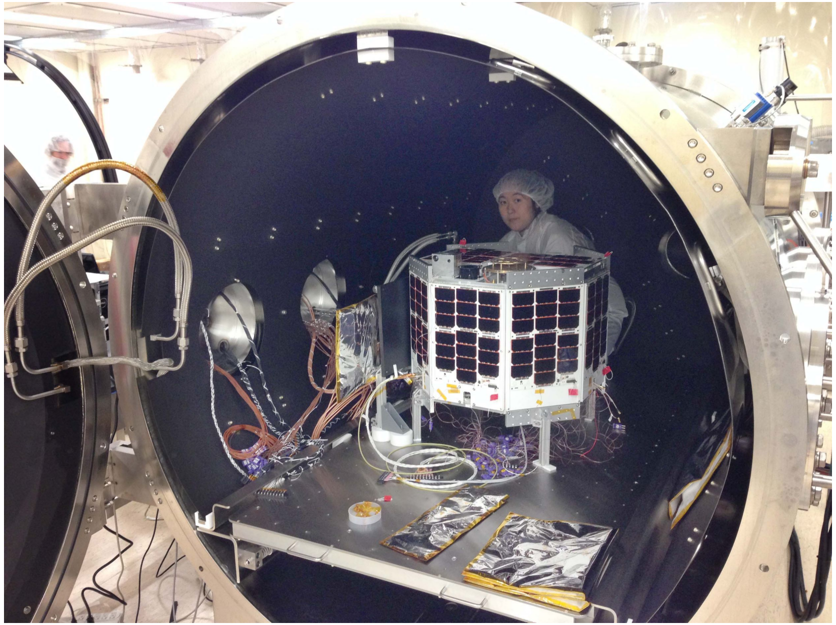
Initial letter of the deposition material.

A B C D E G H I K L M N O P R S T U V Y Z ▲Back to Top

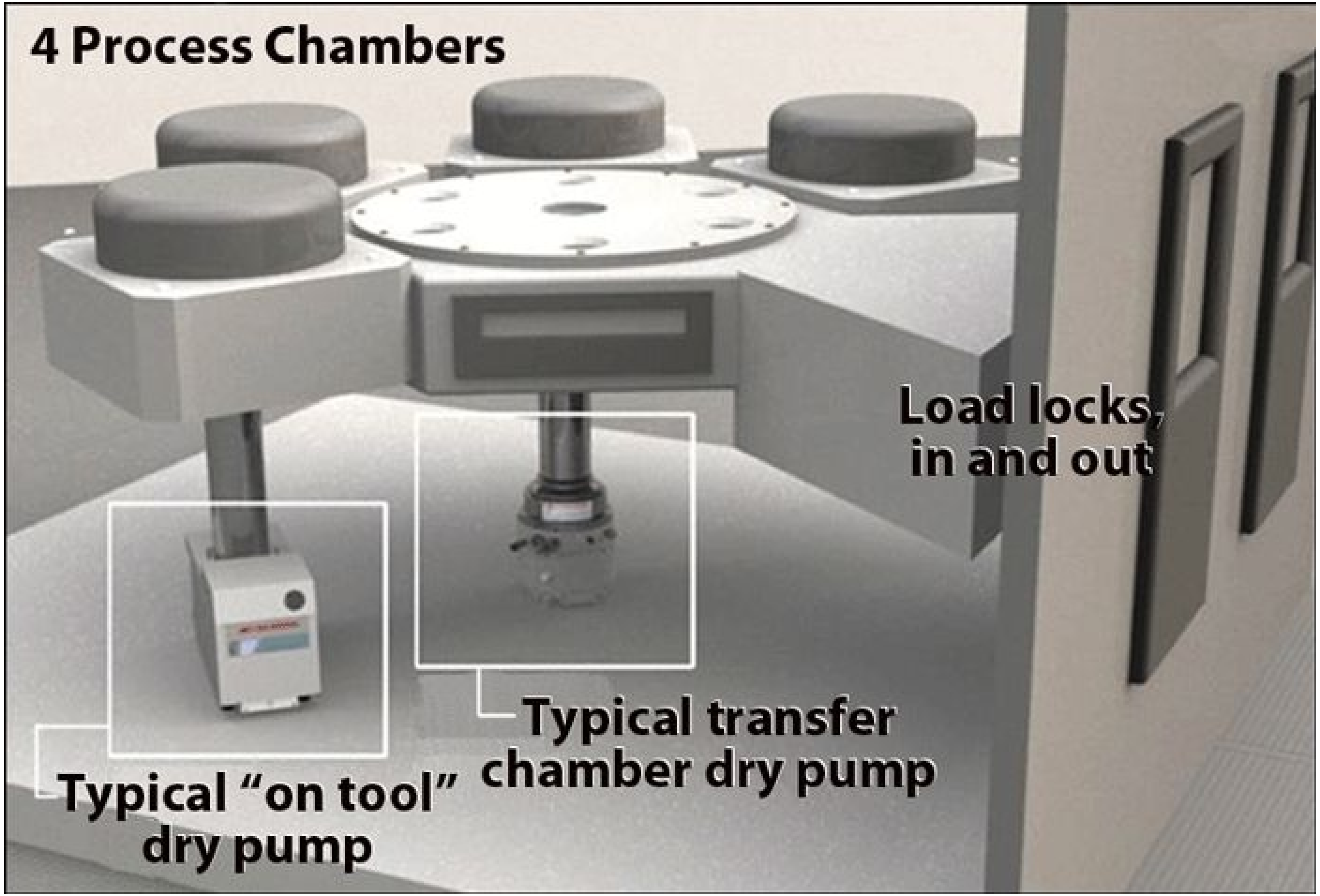
Material	Symbol	MP (°C)	S/D	g/cm^3	Z Ratio	Temp.(°C) for Given Vap. Press. (Torr)			E-Beam Evaporation		Thermal Evaporation				Sputter	Comments
						10^{-8}	10^{-6}	10^{-4}	E-Beam Performance	Liner Material	Boat	Coil	Basket	Crucible		
Titanium	Ti	1,660	-	4.5	0.628	1,067	1,235	1,453	Excellent	Fabmate®, Intermetallic	W	-	-	TiC, Ti_2-BN	DC	Alloys with W/Ta/Mo; evolves gas on first heating.
Titanium (II) Oxide	TiO	1,750	-	4.95	**1.00	-	-	~1,500	Good	Fabmate®, Tantalum	W, Mo	-	-	VitC	RF	Preheat gently to outgas.
Titanium (III) Oxide	Ti_2O_3	2,130	D	4.6	-	-	-	-	Good	Fabmate®, Tantalum	W	-	-	-	RF	Decomposes.
Titanium (IV) Oxide	TiO_2	1,830	-	4.23	0.4	-	-	~1,300	Fair	Fabmate®, Tantalum	W, Mo	-	W	-	RF, RF-R	Suboxide, must be reoxidized to rutile. Ta reduces TiO_2 to TiO and Ti.
Titanium Boride	TiB_2	2,900	-	4.5	**1.00	-	-	-	Poor	-	-	-	-	-	RF	-
Titanium Carbide	TiC	3,140	-	4.93	**1.00	-	-	~2,300	-	-	-	-	-	-	RF	-
Titanium Nitride	TiN	2,930	-	5.4	**1.00	-	-	-	Good	Molybdenum	Mo	-	-	-	RF, RF-R	Sputtering preferred. Decomposes with thermal evaporation.
Tungsten	W	3,410	-	19.25	0.163	2,117	2,407	2,757	Good	Direct in Hearth	-	-	-	-	DC	Forms volatile oxides. Films hard and adherent.
Tungsten Boride	WB_2	~2,900	-	10.77	-	-	-	-	Poor	-	-	-	-	-	RF	-
Tungsten Carbide	WC	2,860	-	15.63	0.151	1,480	1,720	2,120	Excellent	Graphite, Fabmate®	C	-	-	-	RF	-
Tungsten Disulfide	WS_2	1,250	D	7.5	**1.00	-	-	-	-	-	-	-	-	-	RF	-
Tungsten Oxide	WO_3	1,473	S	7.16	**1.00	-	-	980	Good	Tungsten	W	-	-	-	RF-R	Preheat gently to outgas. W reduces oxide slightly.
Tungsten Selenide	WSe_2	-	-	9	-	-	-	-	-	-	-	-	-	-	RF	-
Tungsten Silicide	WSi_2	>900	-	9.4	**1.00	-	-	-	-	-	-	-	-	-	RF	-

Environment of the Deposition

*Cleanroom is not enough! Must also be in vacuum!



Aluminum Deposition Only
POLARON
SAFETY CERTIFIED
SAMM NAME
EVAPORATOR 3927
OPEN
CLOSE
BACKING
ROUGHING
CURRENT
ELECTRODE VOLTAGE
EVAPORATION CONTROL
ROTARY PUMP
DIFFUSION PUMP
PENNING GAUGE
mbar/Pa
A


4 Process Chambers
Load locks, in and out
Typical transfer chamber dry pump
Typical "on tool" dry pump


ULVAC


Kurt J. Lesker
Company


Kurt J. Lesker
PVD
PROCESS EQUIPMENT
DIVISION


SPTS
SPTS

Purity of the deposited film depends on the quality of the vacuum, and on the purity of the source material.

Vacuum Science

Vacuum is space void of matter. The word stems from the Latin adjective vacuo for "vacant" or "void". An approximation to such vacuum is a region with a gaseous pressure much less than atmospheric pressure.[1] Physicists often discuss ideal test results that would occur in a perfect vacuum, which they sometimes simply call "vacuum" or free space, and use the term partial vacuum to refer to an actual imperfect vacuum as one might have in a laboratory or in space. In engineering and applied physics on the other hand, vacuum refers to any space in which the pressure is lower than atmospheric pressure.[2] The Latin term in vacuo is used to describe an object as being in what would otherwise be a vacuum.

Pressure ranges of each quality of vacuum in different units

Vacuum quality	Torr	Pa	Atmosphere
Atmospheric pressure	760	1.013×105	1
Low vacuum	760 to 25	1×105 to 3×103	9.87×10−1 to 3×10−2
Medium vacuum	25 to 1×10−3	3×103 to 1×10−1	3×10−2 to 9.87×10−7
High vacuum	1×10−3 to 1×10−9	1×10−1 to 1×10−7	9.87×10−7 to 9.87×10−13
Ultra high vacuum	1×10−9 to 1×10−12	1×10−7 to 1×10−10	9.87×10−13 to 9.87×10−16
Extremely high vacuum	< 1×10−12	< 1×10−10	< 9.87×10−16
Outer space	1×10−6 to < 1×10−17	1×10−4 to < 3×10−15	9.87×10−10 to < 2.96×10−20
Perfect vacuum	0	0	0

Atmospheric pressure is variable but standardized at 101.325 kPa (760 Torr).

Low vacuum, also called rough vacuum or coarse vacuum, is vacuum that can be achieved or measured with rudimentary equipment such as a vacuum cleaner and a liquid column manometer.

Medium vacuum is vacuum that can be achieved with a single pump, but the pressure is too low to measure with a liquid or mechanical manometer. It can be measured with a McLeod gauge, thermal gauge or a capacitive gauge.

High vacuum is vacuum where the MFP of residual gases is longer than the size of the chamber or of the object under test. High vacuum usually requires multi-stage pumping and ion gauge measurement. Some texts differentiate between high vacuum and very high vacuum.

Ultra high vacuum requires baking the chamber to remove trace gases, and other special procedures. British and German standards define ultra high vacuum as pressures below 10−6 Pa (10−8 Torr).[42][43]

Cryogenic pump · the entrainment of molecules on a cooled surface; a surface array is cooled low enough so that of arriving molecules will remain on the surface of the array after losing sufficient kinetic energy.

Turbomolecular pump – is a bladed molecular turbine that compresses gas by momentum transfer from the high speed rotating blades to the gas the gas molecules. The pump operates at rotor speeds ranging from 24,000 to 60,000 rpm and is driven by solid state power supplies or motor generators.

Ultra high vacuum – 10 x -7 > P to 10 x -10 Torr; metal gaskets are typically used for seals.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- High Vacuum Pumps

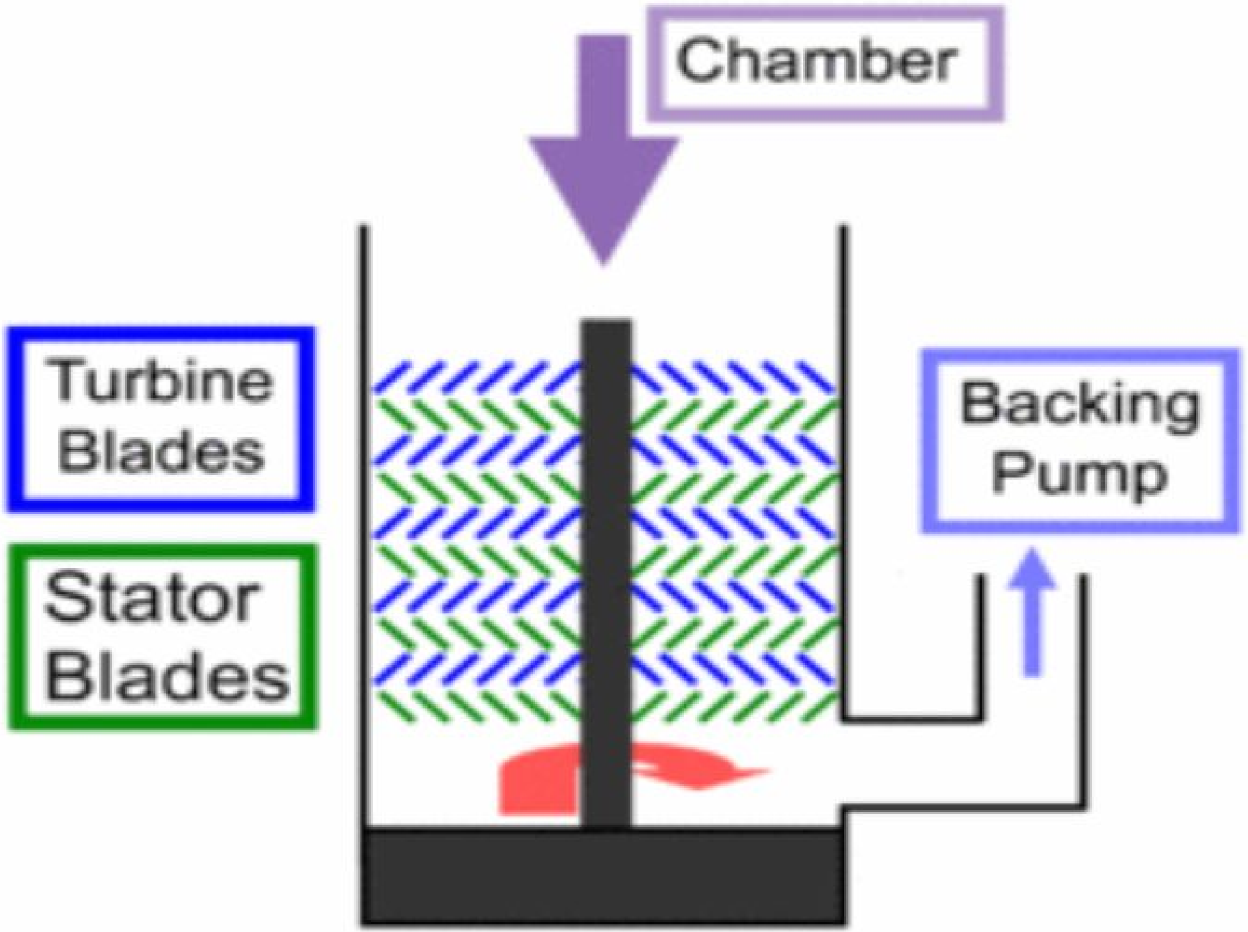
- Mechanical Pump

Turbo Pump

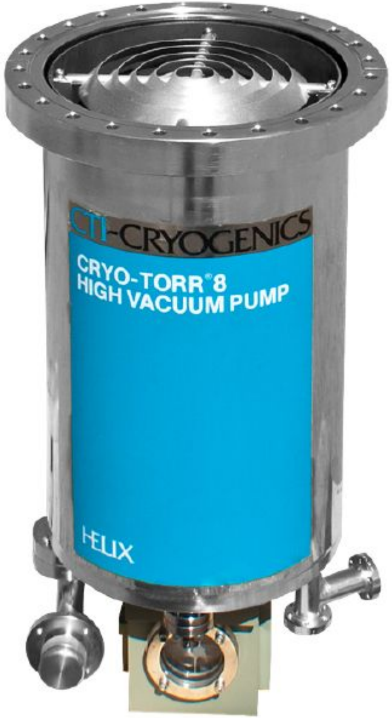
Turbo Pump

A turbomolecular pump is a type of vacuum pump, superficially similar to a turbopump, used to obtain and maintain high vacuum.[1][2] These pumps work on the principle that gas molecules can be given momentum in a desired direction by repeated collision with a moving solid surface. In a turbomolecular pump, a rapidly spinning fan rotor 'hits' gas molecules from the inlet of the pump towards the exhaust in order to create or maintain a vacuum.

- Turbo Pumps

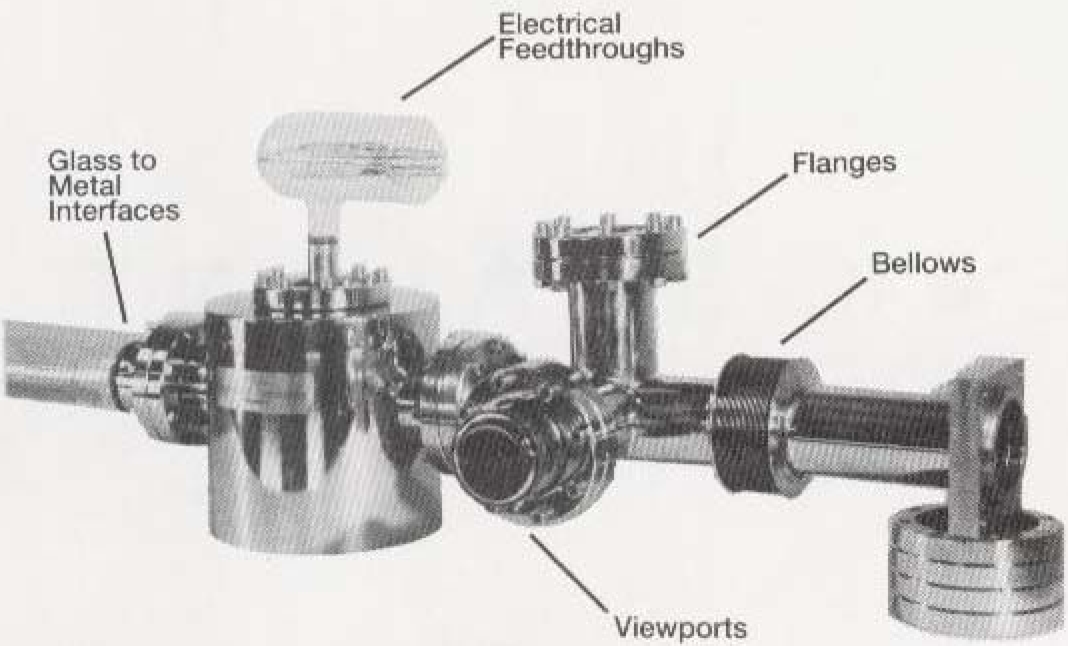


Cryo pumps


CTI-CRYOGENICS
CRYO-TORR®8
HIGH VACUUM PUMP
HELIX


CTI-CRYOGENICS

TYPICAL USES

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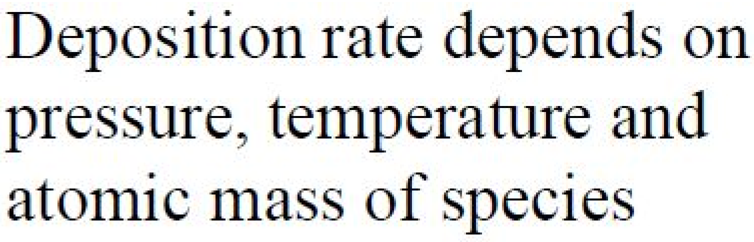
welding neck flanges
Slip On Flange
Types of
FLANGES
Threaded flange
www.piyushsteel.com
flat flanges
Blind flange

- Gas Lines
- Gas cabinets



Deposition rate depends on pressure, temperature and atomic mass of species

Evaporation is a common method of thin-film deposition. The source material is evaporated in a vacuum. The vacuum allows vapor particles to travel directly to the target object (substrate), where they condense back to a solid state. Evaporation is used in microfabrication, and to make macro-scale products such as metallized plastic film.

Any evaporation system includes a vacuum pump. It also includes an energy source that evaporates the material to be deposited. Many different energy sources exist:

- In the *thermal* method, metal material (in the form of wire, pellets, shot) is fed onto heated semimetal (ceramic) evaporators known as "boats" due to their shape. A pool of melted metal forms in the boat cavity and evaporates into a cloud above the source. Alternatively the source material is placed in a crucible, which is radiatively heated by an electric filament, or the source material may be hung from the filament itself (*filament evaporation*).
    - Molecular beam epitaxy is an advanced form of thermal evaporation.
- In the *electron-beam* method, the source is heated by an electron beam with an energy up to 15 keV.
- In *flash evaporation*, a fine wire of source material is fed continuously onto a hot ceramic bar, and evaporates on contact.
- *Resistive evaporation* is accomplished by passing a large current through a resistive wire or foil containing the material to be deposited. The heating element is often referred to as an "evaporation source". Wire type evaporation sources are made from tungsten wire and can be formed into filaments, baskets, heaters or looped shaped point sources. Boat type evaporation sources are made from tungsten, tantalum, molybdenum or ceramic type materials capable of withstanding high temperatures.

Some systems mount the substrate on an out-of-plane planetary mechanism. The mechanism rotates the substrate simultaneously around two axes, to reduce shadowing.

Evaporation involves two basic processes: a hot source material evaporates and condenses on the substrate. It resembles the familiar process by which liquid water appears on the lid of a boiling pot. However, the gaseous environment and heat source (see "Equipment" below) are different.

Evaporation takes place in a vacuum, i.e. vapors other than the source material are almost entirely removed before the process begins. In high vacuum (with a long mean free path), evaporated particles can travel directly to the deposition target without colliding with the background gas. (By contrast, in the boiling pot example, the water vapor pushes the air out of the pot before it can reach the lid.) At a typical pressure of 10^{-4} Pa, an 0.4-nm particle has a mean free path of 60 m. Hot objects in the evaporation chamber, such as heating filaments, produce unwanted vapors that limit the quality of the vacuum.

Evaporated atoms that collide with foreign particles may react with them; for instance, if aluminium is deposited in the presence of oxygen, it will form aluminium oxide. They also reduce the amount of vapor that reaches the substrate, which makes the thickness difficult to control.

Evaporated materials deposit nonuniformly if the substrate has a rough surface (as integrated circuits often do). Because the evaporated material attacks the substrate mostly from a single direction, protruding features block the evaporated material from some areas. This phenomenon is called "shadowing" or "step coverage."

When evaporation is performed in poor vacuum or close to atmospheric pressure, the resulting deposition is generally non-uniform and tends not to be a continuous or smooth film. Rather, the deposition will appear fuzzy .

Thermal evaporation uses a hot filament or boat to evaporate materials such as Cr, Ge, Au, Ni or AuGe.

E-beam evaporation allows the evaporation of a wider range of metals with higher melting points.

Physical sputtering uses ionized gases (Ar) to move material from the target to the substrate.

Dielectric films (SiO_2, Si_3N_4, Al_2O_3) can be produced from dielectric targets and RF power or else reactively sputtered in mixtures of Ar and O_2. In addition, other compounds such as TiN or TaN can be produced using Ar-N_2 mixtures and the metal target.

Sputtering provides good step coverage over topographical features in the substrate.

In addition, pre-clean sputter etching is available to ensure good contacts.

Recommend e-beam or evaporation for lift-off metals.

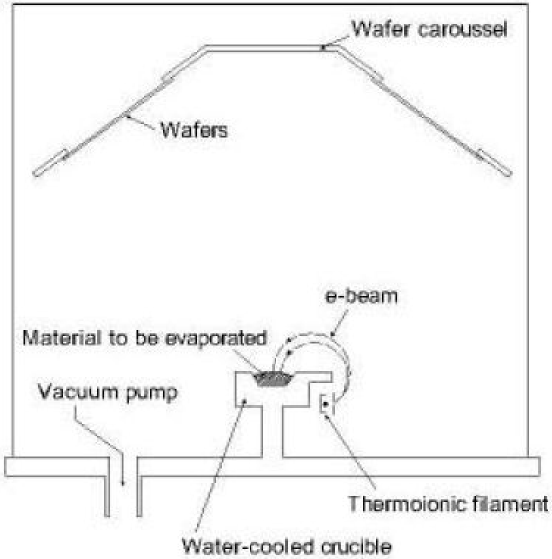
Multi-layer metal stacks use 4 hearth evaporation or sputtering

Evaporation

- Wafers placed in hemispherical cage for uniform deposition
- Step coverage is bad in evaporation -vertical etched surfaces in the wafer will not have any metal deposited on them
- To minimize these problems, rotating planetaries, And substrate heating are used.
- Two types of evaporation – thermal evaporation (heating by resistive elements or inductive heating) and E-beam evaporation

E-beam Evaporation

- In e-beam evaporation, an electron beam is aimed at the source material causing local heating and evaporation.
- Choice of evaporation method typically relates to the phase transition properties of that material (for example, aluminum is quite difficult to evaporate using resistive heating).
- Multicomponent films are usually generated by sequential deposition using separate sources.



Sputtering

GREAT 2min Sputtering description/animation by Semicore:
https://www.youtube.com/watch?v=L6ZIkmIVm6c

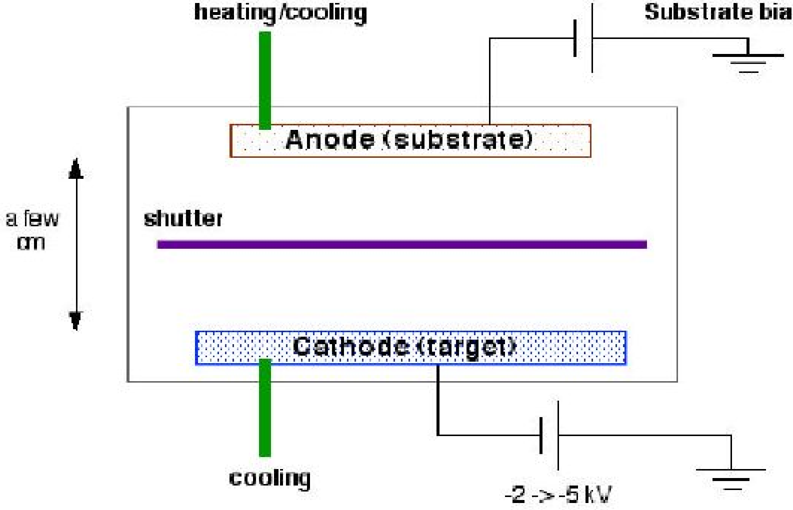
Great Animation at 1min25sec in : https://www.youtube.com/watch?v=ixx3ISj_kpg

Sputtering

- It is the primary alternative to evaporation
- It provides better step coverage than evaporation
- There is less radiation damage than in e-beam evaporation
- Stoichiometry control is better for multicomponent systems
- Material is released from the source at much lower temperature than evaporation

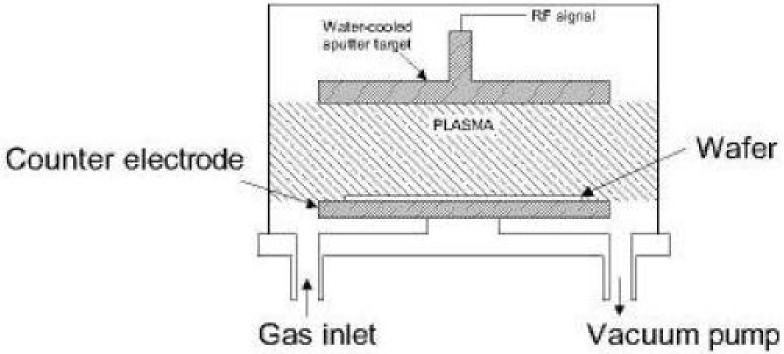
DC Sputtering

- The substrate is placed in a vacuum chamber with the source material (target), and an inert gas (such as argon) is introduced at low pressure.
- A gas plasma is struck using a DC power source, causing the gas to become ionized. The ions are accelerated towards the surface of the target, causing atoms of the source material to break off from the target in vapor form and condense on all surfaces including the substrate.



RF Sputtering

- Similar to DC sputtering, different method of creating ions
- Sputter deposition occurs when target electrode is negative
- In DC systems, positive charge builds up on cathode (target), and very high voltages are required to deposit insulators
- RF sputtering avoids charge build-up by alternating potential
- Substrate and chamber make for a very large electrode, so not too much sputtering of substrate occurs



Sputtering

- Wafer and target are kept close together to maximize collection of sputtered material
- Pressure is of the order of 0.1 Torr (mean free path of the order of 1 mm). This increases step coverage.
- Energy spread of depositing material is of the order of 10-50 eV
- Compromise between increasing the number of Ar ions, and increasing scattering of Ar ions with neutral Ar atoms. If you can increase the number of ions without increasing the number of neutrals, you can operate at lower pressures
- Particle energy and deposition rate depend strongly on sputter voltage, substrate bias and pressure

Sputtering

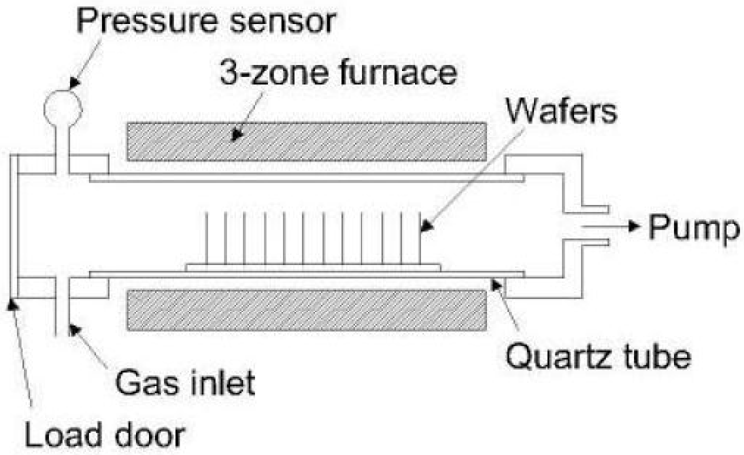
- At frequencies less than 50 kHz, electrons and ions in plasma are mobile, and both follow the switching of the anode and cathode. This is equivalent to DC sputtering of both surfaces.
- At frequencies above 50 kHz, ions (heavy) can no longer follow the switching electrons, this neutralizes positive charge build up
- Other variants of sputtering:
  - Magnetron sputtering (magnetic and electric field, put magnets behind target, higher deposition rate because electrons strike Ar atoms more frequently)
  - Ion deposited sputtering (bombard surface with different ions, requires low voltage, change in film properties because of local rearrangement of atoms)
  - Reactive sputtering (add reactive gas such as oxygen or nitrogen to chamber during deposition, good stoichiometry control, can poison target if chemical reaction rate is faster than sputter rate)
- Sputtering compared to evaporation – smaller grain size, many grain orientations, better adhesion of film

Chemical Vapor Deposition

- Substrate placed in chamber and number of gases supplied
- Reaction takes place between the source gases, product is a solid that condenses on all surfaces in the reaction chamber
- Used for many different materials (SiO_2, Si_3N_4, polysilicon, tungsten, copper, etc.)
- Can have atmospheric pressure CVD or low pressure CVD (much more common), another variant is plasma enhanced CVD.

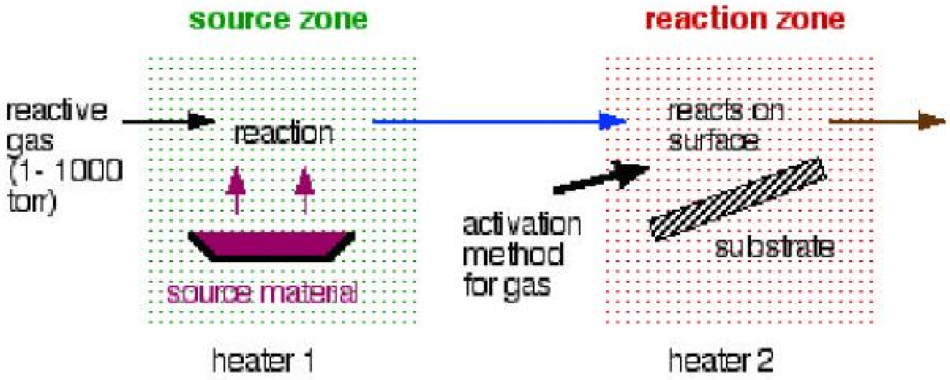
LPCVD

- Excellent uniformity of thickness and material characteristics
- High deposition temperatures (>600C) and relatively slow deposition rate
- Byproducts (gaseous) formed during processing
- LPCVD can be used to deposit films on both sides of at least 25 wafers at a time.



PECVD

- Lower temperature process (200-400C)
- Extra energy is supplied to the gas molecules by the plasma in the reactor
- Quality of films is typically inferior to LPCVD films
- PECVD systems can only deposit films on one side of up to 4 wafers at a time.



Electrochemical Deposition

- Used for metals such as copper, gold and nickel

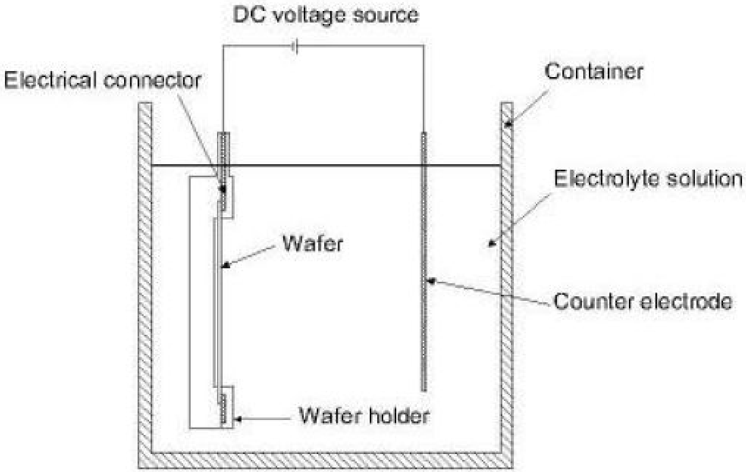
- Film thickness can be varied easily (<1micron, >100 microns)

- Control of deposition achieved by using external electric potential, it requires electrical contact to the substrate while immersed in a liquid bath

- The surface of the substrate must have an electrically conducting coating (seed layer) before deposition can be done using this method

Electrochemical Deposition

- Two methods – electroplating and electroless plating
- In the electroplating process the substrate is placed in a liquid solution (electrolyte).
- When an electrical potential is applied between a conducting area on the substrate and a counter electrode (usually platinum) in the liquid, a chemical redox process takes place resulting
- in the formation of a layer of material on the substrate and usually some gas generation at the counter electrode.



Electrochemical Deposition

- In the electroless plating process a more complex chemical solution is used

- Deposition happens spontaneously on any surface which forms a sufficiently high electrochemical potential with the solution.

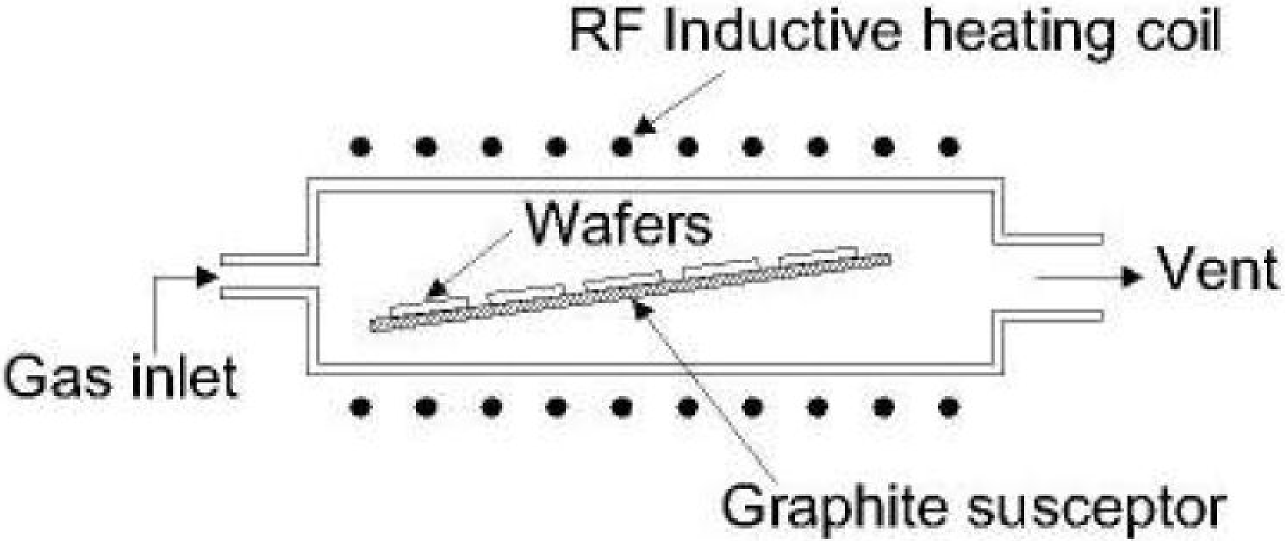
- It does not require any external electrical potential and contact to the substrate during processing.

- It is more difficult to control with regards to film thickness and uniformity.

Epitaxy

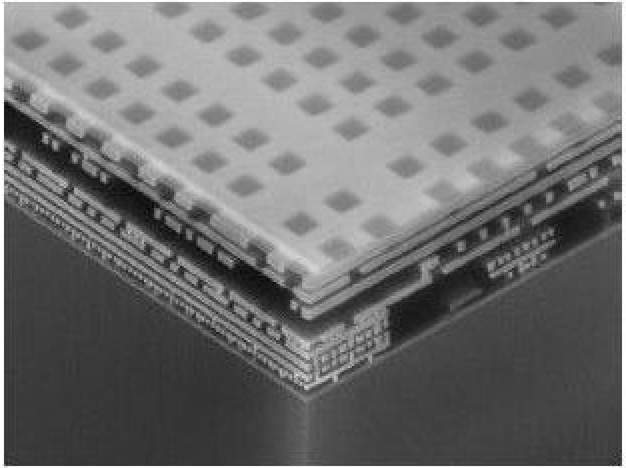
- Similar to basic CVD process
- Epitaxy is the growth of a film with a crystallographic relationship between film and substrate (same material – homoepitaxy, different materials – heteroepitaxy)
- If the substrate is a single crystal oriented in a specific direction, the film will orient the same way. A similar principle holds for amorphous and polycrystalline films.
- In vapor phase epitaxy, a number of gases are introduced into an induction heated reactor in which only the substrate is heated (to >50% of melting point of material being deposited)
- Epitaxy generally results in relatively high growth rates

Epitaxy


RF Inductive heating coil
Wafers
Gas inlet
Vent
Graphite susceptor

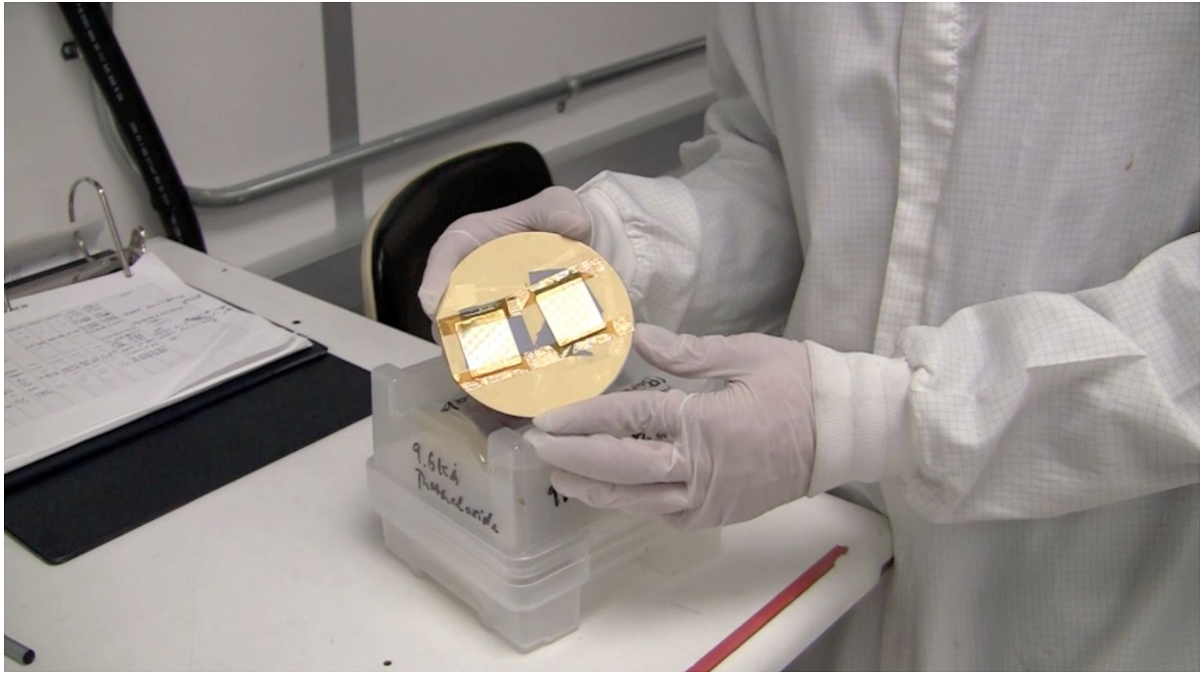
Molecular Beam Epitaxy

- Needs independently controlled thermal and/or electron beam sources for all materials and dopants.
- Evaporation at very low deposition rates
- Typically in ultra-high vacuum
- Very well controlled
- Grow films with good crystal structure
- Expensive
- Often use multiple sources to grow alloy films
- Deposition rate is so low that substrate temperature does not need to be as high



Dielectrics

Thin dielectric films are deposited using plasma enhanced chemical vapor deposition (PECVD) or remote plasma chemical vapor deposition (RPCVD) of SiO2, Si3N4 or a-Si. The source gases for the PECVD SiO2 films are 5% SiH4 in N2 plus N2O; for SixNy films source gases include 5% SiH4 in N2 plus NH3 and N2. General recipes are listed in Table A; additional recipes are available to control film stress or optical parameters or to deposit amorphous Si. The PlasmaQuest RPCDV system uses SiH4 in He plus N2O for SiO2 films and SiH4 plus NH3 for nitride films. Dielectric films can also be deposited using sputtering, reactive RF sputtering, e-beam evaporation (see metal deposition section).


9.6kÅ
Thermal oxide

Thermal Evaporator

Vacuum Science
Electron Beam Evaporation
Thermal Evaporation
Sputtering
Plating

Electron Evaporation, Thermal Evaporation And Sputtering are performed in vacuum system

Physical Vapor Deposition

- The two main processes are evaporation and sputtering
- Widely used for metals because it is cheap and less complex than CVD
- Step coverage of films is poor

Step coverage and conformality

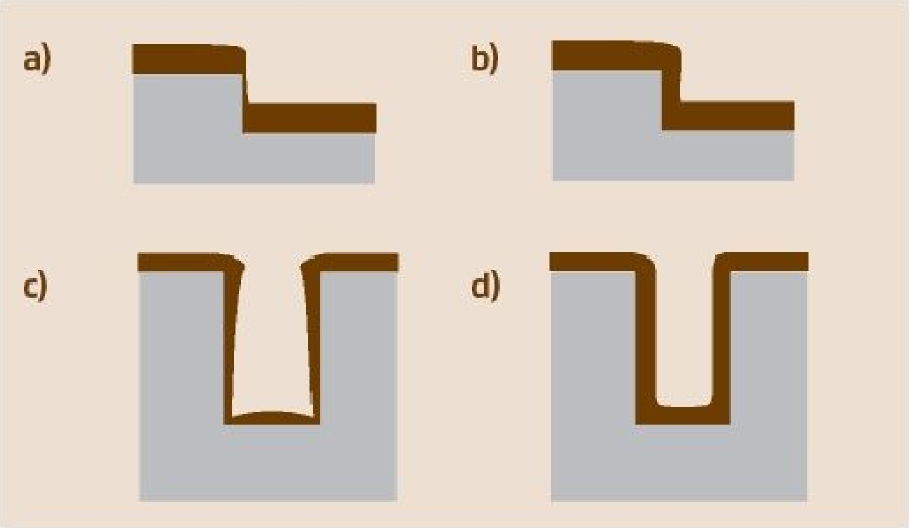
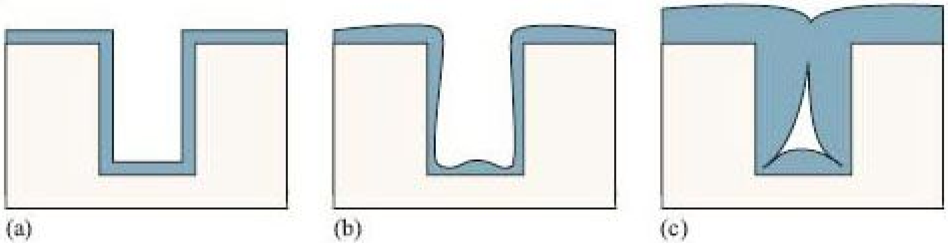
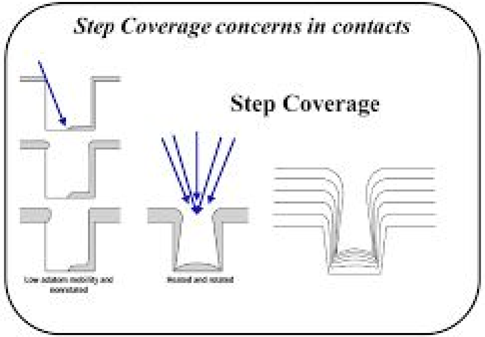


Fig. 5.3a–d Step coverage and conformality: **(a)** poor step coverage, **(b)** good step coverage, **(c)** nonconformal layer, and **(d)** conformal layer

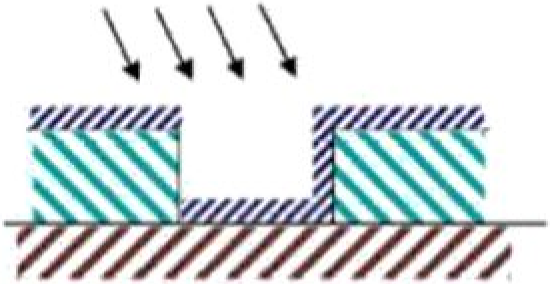
Step Coverage

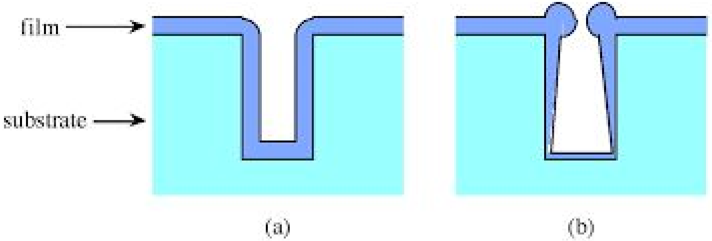
Because the evaporated material attacks the substrate mostly from a single direction, protruding features block the evaporated material from some areas. This phenomenon is called "shadowing" or "step coverage."





EE143 – Ali Javey





    - Alternatives to evaporation, such as sputtering and chemical vapor deposition, have better step coverage. This may be an advantage or disadvantage, depending on the desired result.
    - Sputtering tends to deposit material more slowly than evaporation.
    - Sputtering uses a plasma, which produces many high-speed atoms that bombard the substrate and may damage it. Evaporated atoms have a Maxwellian energy distribution, determined by the temperature of the source, which reduces the number of high-speed atoms. However, electron beams tend to produce X-rays (Bremsstrahlung) and stray electrons, each of which can also damage the substrate.

- Purity of the deposited film depends on the quality of the vacuum, and on the purity of the source material.
- At a given vacuum pressure the film purity will be higher at higher deposition rates as this minimises the relative rate of gaseous impurity inclusion.
- The thickness of the film will vary due to the geometry of the evaporation chamber. Collisions with residual gases aggravate nonuniformity of thickness.
- Wire filaments for evaporation cannot deposit thick films, because the size of the filament limits the amount of material that can be deposited. Evaporation boats and crucibles offer higher volumes for thicker coatings. Thermal evaporation offers faster evaporation rates than sputtering. Flash evaporation and other methods that use crucibles can deposit thick films.
- In order to deposit a material, the evaporation system must be able to vaporize it. This makes refractory materials such as tungsten hard to deposit by methods that do not use electron-beam heating.
- Electron-beam evaporation allows tight control of the evaporation rate. Thus, an electron-beam system with multiple beams and multiple sources can deposit a chemical compound or composite material of known composition.

Electron Beam Evaporator

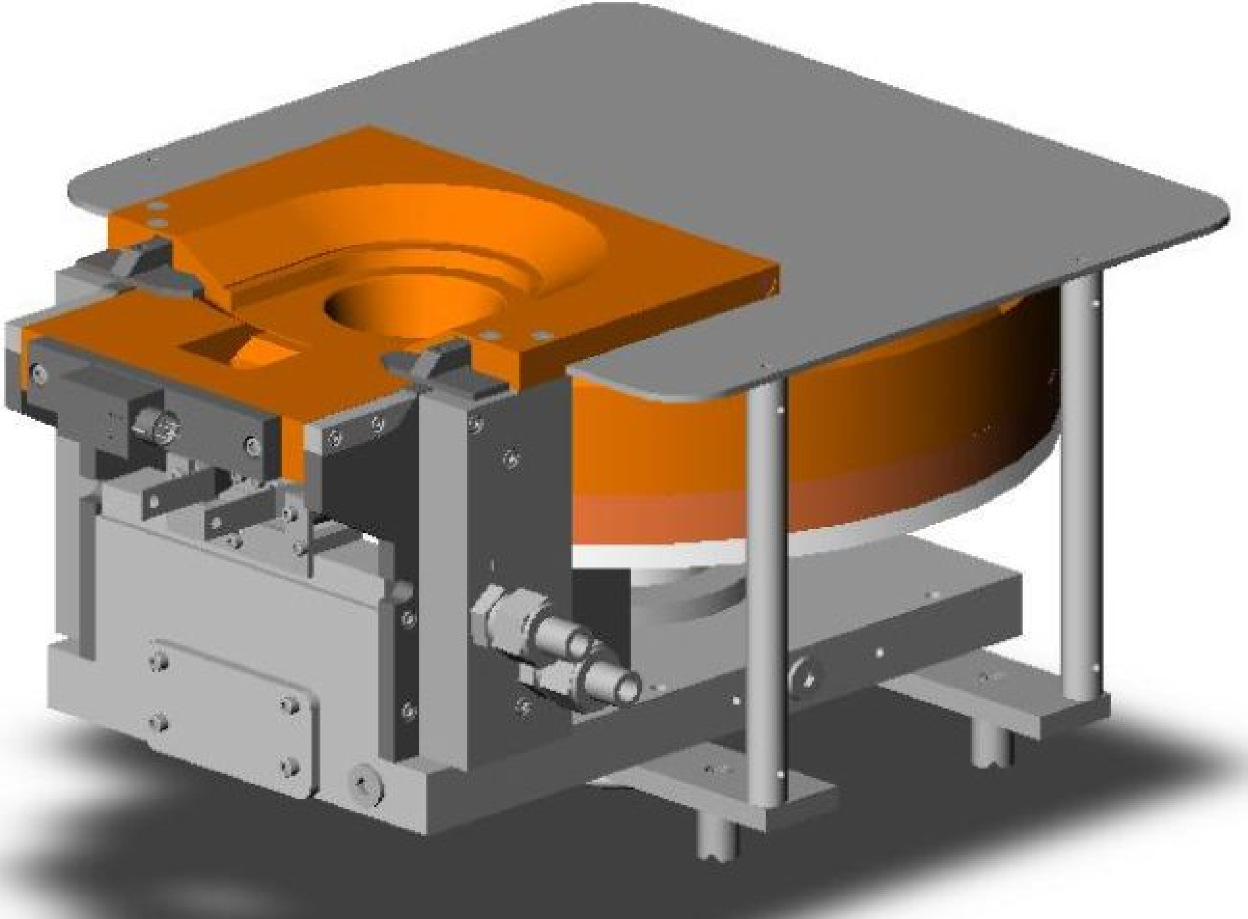
Electron Beam Evaporation

Electron Beam Evaporation is the process of depositing metal in a vacuum chamber by heating a source material up to it’s boiling point with an electron beam in a vacuum and then transfer the grains to your substrate. The electron beam causes atoms from the source material to transform in to a gaseous phase. Then the atoms precipitate into solid form coating everything in line of sight in a vacuum system.

E-Beam evaporation is a physical vapor deposition (PVD) technique whereby an intense, electron beam is generated from a filament and steered via electric and magnetic fields to strike source material (e.g. pellets of Au) and vaporize it within a vacuum environment. At some point as the source material is heated via this energy transfer its surface atoms will have sufficient energy to leave the surface. At this point they will traverse the vacuum chamber, at thermal energy (less than 1 eV), and can be used to coat a substrate positioned above the evaporating material. Average working distances are 300 mm to 1 meter.

Since thermal energy is so low, the pressure in the chamber must be below the point where the mean free path is longer than the distance between the electron beam source and the substrate. The mean free path is the average distance an atom or molecule can travel in a vacuum chamber before it collides with another particle thereby disturbing its direction to some degree. This is typically around 3.0 x 10-4


MARK 50
Evaporation



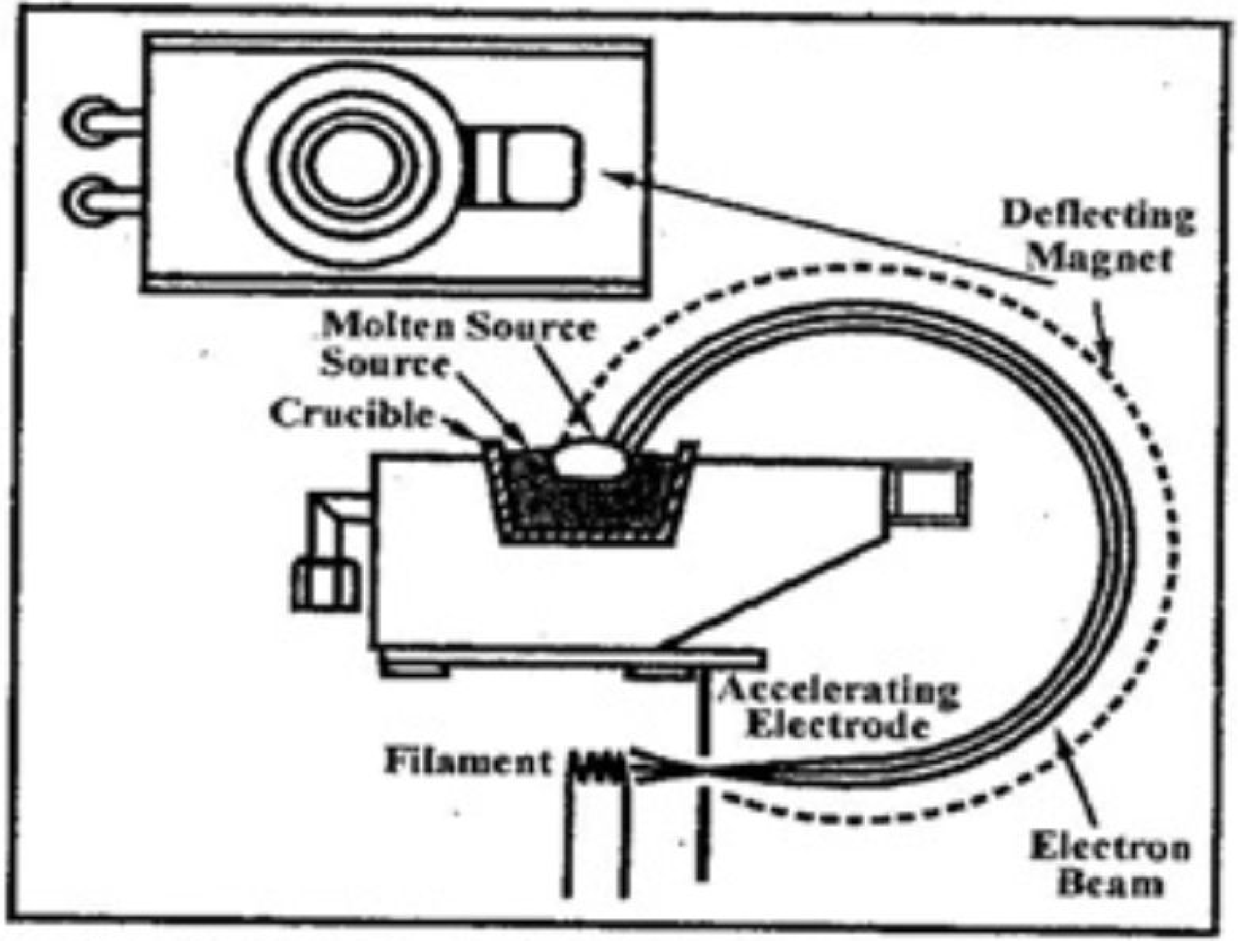
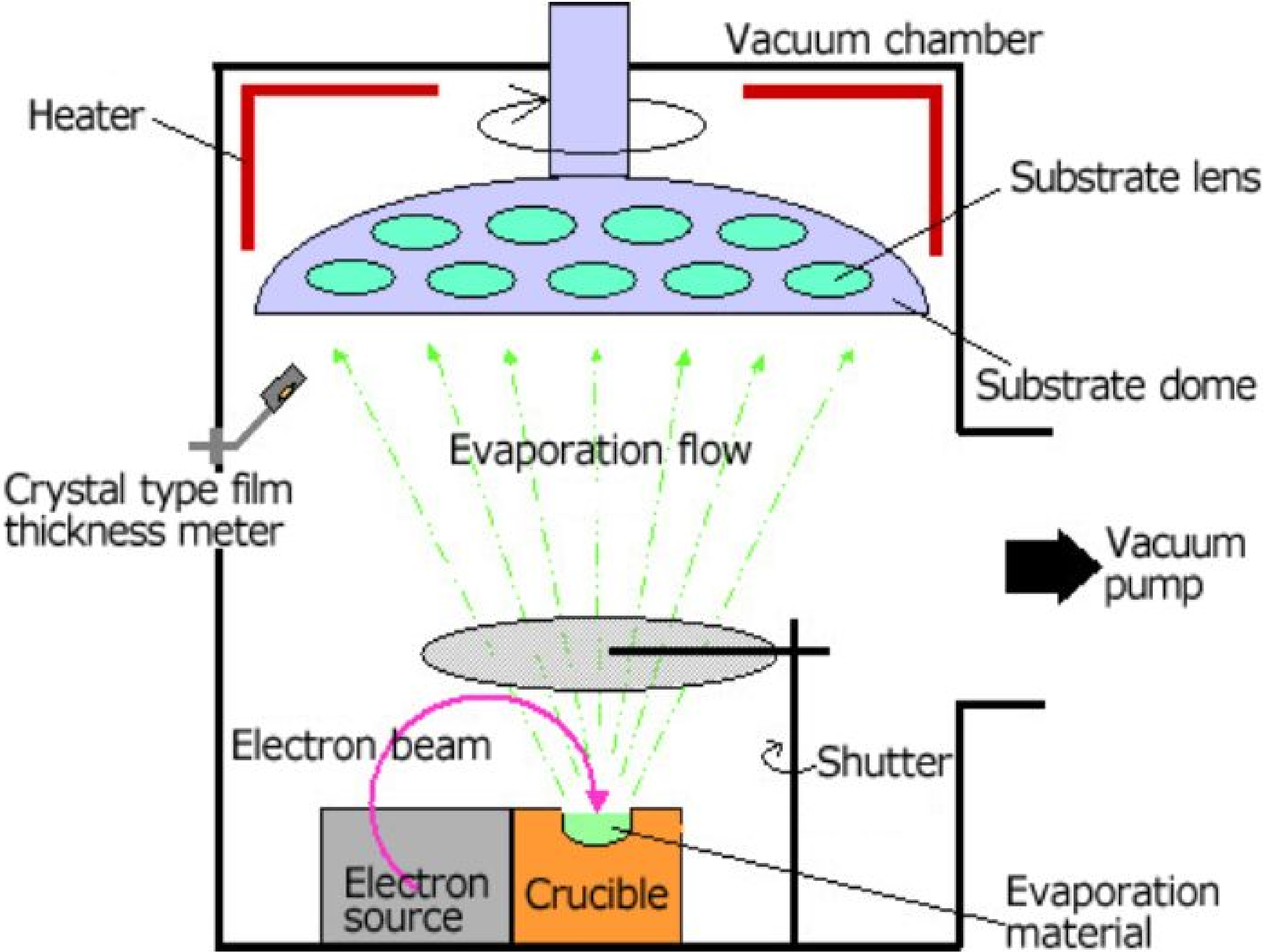


Fig. 5.11 Schematic Diagram of an e-beam Evaporator System


Vacuum chamber
Heater
Substrate lens
Substrate dome
Crystal type film thickness meter
Evaporation flow
Vacuum pump
Electron beam
Shutter
Electron source
Crucible
Evaporation material

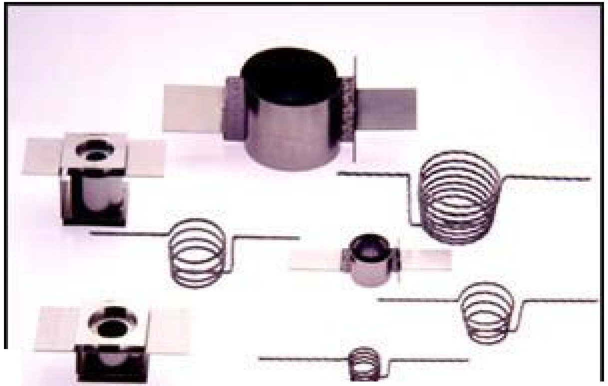
Crucibles
Liners

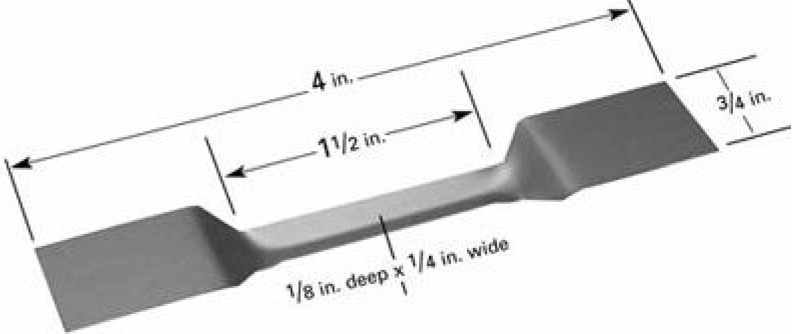
Materials of Liners
Graphite
Tungsten
Ceramic
Moly

Vendor Kurt Leskar

Thermal Evaporation

Thermal Evaporation is one of the simplest of the Physical Vapor Deposition (PVD) techniques. Basically, material is heated in a vacuum chamber until its surface atoms have sufficient energy to leave the surface. At this point they will traverse the vacuum chamber, at thermal energy (less than 1 eV), and coat a substrate positioned above the evaporating material (average working distances are 200 mm to 1 meter).




4 in.
1 1/2 in.
3/4 in.
1/8 in. deep x 1/4 in. wide

Video Presentation

Sputtering

Sputtering

Sputtering is a technique used to deposit thin films of a material onto a surface (a.k.a. "substrate"). By first creating a gaseous plasma and then accelerating the ions from this plasma into some source material (a.k.a. "target"), the source material is eroded by the arriving ions via energy transfer and is ejected in the form of neutral particles – either individual atoms, clusters of atoms or molecules. As these neutral particles are ejected they will travel in a straight line unless they come into contact with something – other particles or a nearby surface. If a "substrate" such as a Si wafer is placed in the path of these ejected particles it will be coated by a thin film of the source material.

Sputtering Video Presentation

RF DC direct, indirect Target sizes and shapes and images more and youtube videos etc

Plating

Plating is a surface covering in which a metal is deposited on a conductive surface. Plating has been done for hundreds of years; it is also critical for modern technology. Plating is used to decorate objects, for corrosion inhibition, to improve solderability, to harden, to improve wear ability, to reduce friction, to improve paint adhesion, to alter conductivity, to improve IR reflectivity, for radiation shielding, and for other purposes. Jewelry typically uses plating to give a silver or gold finish. Thin-film deposition has plated objects as small as an atom,[1] therefore plating finds uses in nanotechnology.

There are several plating methods, and many variations. In one method, a solid surface is covered with a metal sheet, and then heat and pressure are applied to fuse them (a version of this is Sheffield plate). Other plating techniques include vapor deposition under vacuum and sputter deposition. Recently, plating often refers to using liquids. Metallizing refers to coating metal on non-metallic objects.

CVD
LPCVD
ALD
PEALD
MVD

Chemical vapor deposition (CVD) is a chemical process used to produce high quality, high-performance, solid materials. The process is often used in the semiconductor industry to produce thin films. In typical CVD, the wafer (substrate) is exposed to one or more volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit. Frequently, volatile by-products are also produced, which are removed by gas flow through the reaction chamber.

Dielectric film deposition processes are used to form some of the most difficult-to-produce insulating features in a semiconductor device, including those used in the latest transistors and 3D structures. For some applications, these films need to conform tightly around intricate structures. Other applications require exceptionally smooth films since slight imperfections are multiplied greatly in subsequent layers.

As feature dimensions in advanced semiconductors continue to shrink, a number of critical process steps rely on the deposition of exceptionally high-quality dielectric films – films that meet exacting thickness; feature coverage; and stress, electrical, and mechanical requirements. PECVD and ALD technologies are often used for these processes.

Chemical Vapor Deposition

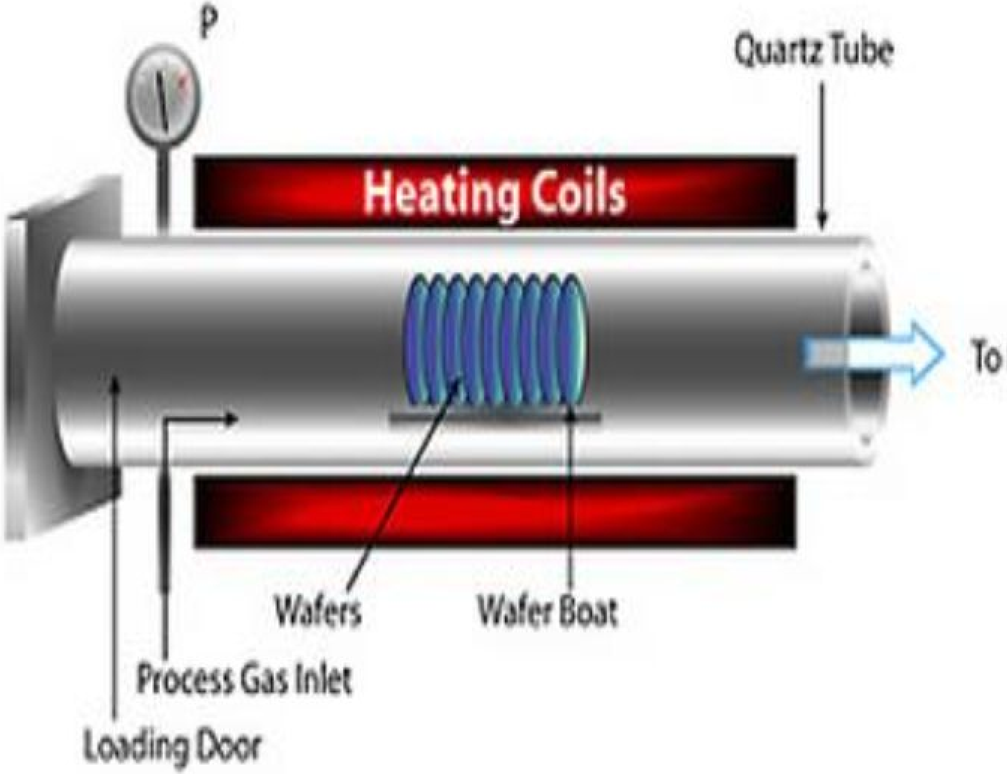
Chemical vapor deposition (CVD) is a chemical process used to produce high quality, high-performance, solid materials. The process is often used in the semiconductor industry to produce thin films. In typical CVD, the wafer (substrate) is exposed to one or more volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit.

LPCVD is a process used in the manufacturing of the deposition of thin films on semiconductors usually ranging from a few nanometers to many micrometers. LPCVD is used to deposit a wide range of possible film compositions with good conformal step coverage. These films include a variety of materials including polysilicon for gate contacts, thick oxides used for isolation, doped oxides for global planarization, nitrides and other dielectrics. LPCVD is similar to other types of CVD in that it is a process where a gaseous species reacts on a solid surface or wafer and the reaction that occurs produces a solid phase material. Each and every CVD process has the same four steps that must happen. First, the reacting gaseous species must be transported to the surface. Second, the gaseous species must absorb into the surface of the wafer. Third, the heterogeneous surface reaction produces reaction products.[1] Finally the gaseous reactants need to be removed from the surface.

The low pressure distinguishes LPCVD from other CVD processes: atmospheric pressure CVD, of course, is CVD performed without pressurization or depressurization. The main reason for using LPCVD instead of APCVD is the ratio of the mass transport velocity and the velocity of reaction on the surface. During APCVD the ratio is close to one as the two velocities are of the same order of magnitude. The velocity of the mass transport depends mainly on the reactant concentration, diffusion, and thickness of the border layer. When the pressure is lowered during LPCVD, the diffusion of the gas decreases proportionally to the reciprocal of the pressure. The pressure for LPCVD is usually around 10–1000 Pa while standard atmospheric pressure is 101,325 Pa. If the pressure is lowered from atmospheric pressure to about 100 Pa the diffusion will decrease by almost 1000. This means that the velocity of mass transport will decrease meaning the substrates can approach more closely and the deposited films show better uniformity and homogeneity.[2] So there is less dependence on the resulting layer on mass transport velocity.

The LPCVD process has a quartz tube placed in a spiral heater that starts with tube pressure at very low pressure around 0.1 Pa. The tube is then heated to the desired temperature and the gaseous species ("working gas") is inserted into the tube at the pressure predetermined between 10-1000 Pa. This working gas consists of dilution gas and the reactive gas that will react with the substrate and create a solid phase material on the substrate. After the working gas enters the tube it spreads out around the hot substrates that are already in the tube at the same temperature. The substrate temperature is extremely important and influences what reactions take place. This working gas reacts with the substrates and forms the solid phase material and the excess material is pumped out of the tube.

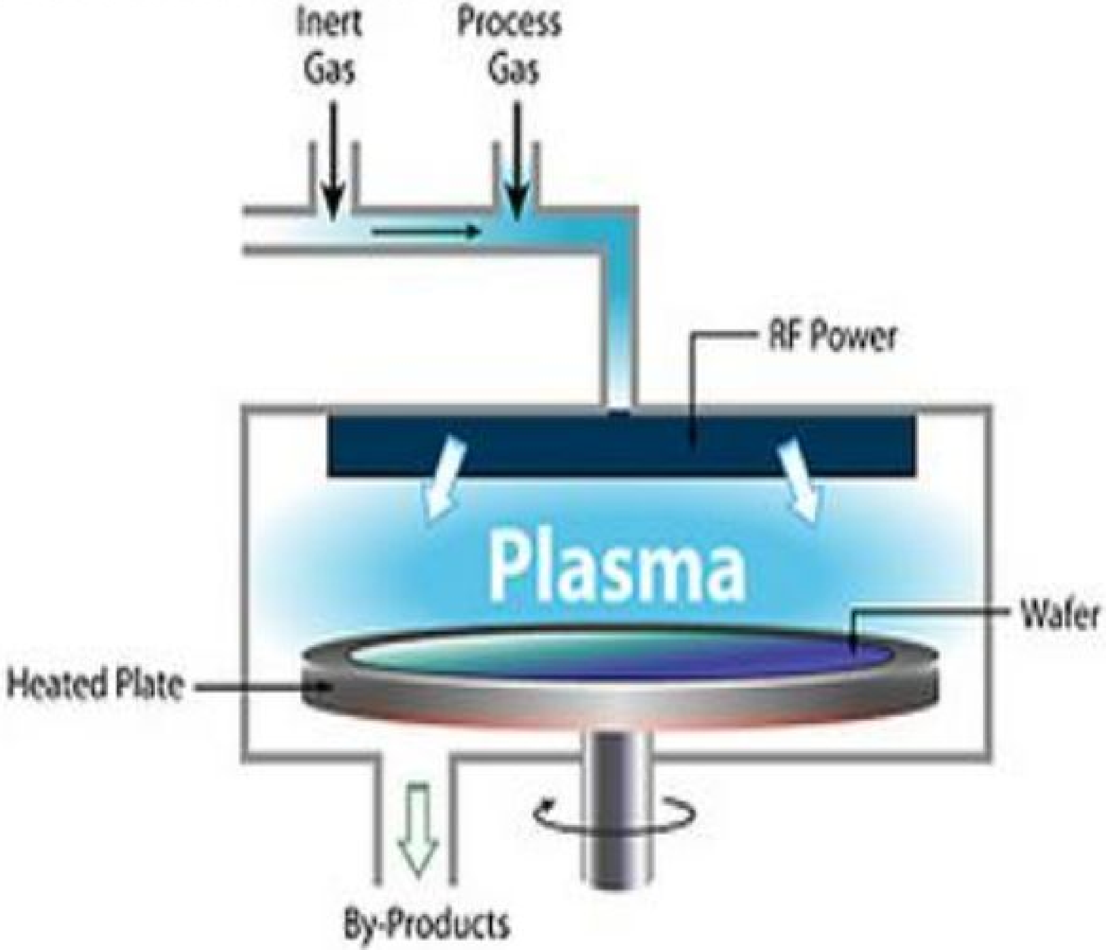
LPCVD System



LPCVD is most successfully applied in deposition of polysilicon thin films. These films are used for gate contact and short interconnect lines. This is done using compounds like SiH4 in the temperature range 600-660oC. Other thin films include undoped and doped oxides that use compounds like Dichlorosilane at 900 °C and Tetraethoxysilane at 700 °C for undoped oxides that will leave SiO2 and other by-products. Doped oxides include PSG (phosphorosilicate glass) at 950-1100 °C and BPSG (Borophosphorosilicate glass) 850-950 °C which are useful for smooth interconnects. Figure 2 below shows an example of LPCVD of phosphorous. LPCVD can also be used for nitrides that are used for encapsulation. This is done by adding compounds like Silane at 700-900 °C.

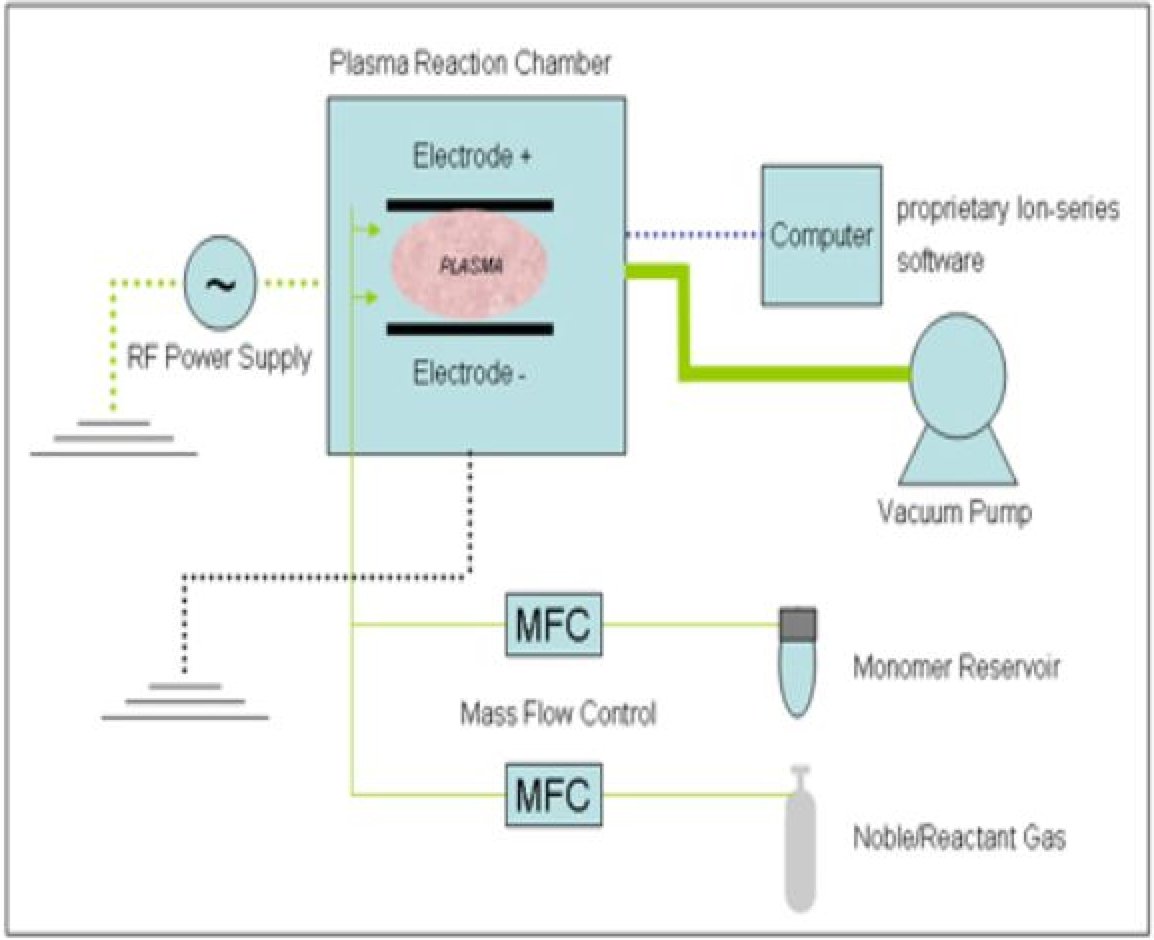
Plasma-Enhanced Chemical Vapor Deposition: PECVD is a fabrication method for depositing thin films on a wafer. PECVD is used to deposit SiO_2, Si_3N_4 (Si_xN_y), $Si_xO_yN_z$ and amorphous Si films. In this method of CVD, plasma is added in the deposition chamber with reactive gases to create the desired solid surface on the substrate. Plasma is a partially ionized gas with high free electron content (about 50%). Plasmas are divided into two groups; cold (also called non-thermal) and thermal. In thermal plasmas, electrons and particles in the gas are at the same temperature; however, in cold plasmas the electrons have a much higher temperature than the neutral particles and ions. Therefore, cold plasmas can utilize the energy of the electrons by changing just the pressure. This allows a PECVD system to operate at low temperatures (between 100 and 400 degree Celsius). The energy from the electrons in cold thermal plasmas is useful in PECVD. When the mean free path is large and the system size is small, the free electrons won't exchange energy with ions before they collide with other outside objects. The energy from the electrons is then used to dissociate the reactive gas in order to form the solid film on the substrate. In order to excite and sustain excitation state, a voltage must be applied to the plasma. The voltage is usually applied using an RF signal between two electrodes. PECVD systems must contain two electrodes (in a parallel plate configuration), plasma gas, and reactive gas in a chamber. To begin the PECVD process, a wafer is placed on the bottom electrode and reactive gas with the deposition elements is introduced into the chamber. Plasma is then introduced into the chamber between the two electrodes, and voltage is applied to excite the plasma. The excited state plasma then bombards the reactive gas causing dissociation. This dissociation deposits the desired element onto the wafer.

Plasma Enhanced CVD System



Advantages of PECVD include the low temperature, higher film density for higher dielectric and more compression, and ease of cleaning the chamber. Disadvantages include the expense of the equipment and the stress of plasma bombardment. Batch size is also small: PECVD can only deposit the film on one side of 1-4 wafers while LPCVD can deposit films on both sides of at least 25 wafers.[5]

(PECVD) Plasma Enhanced Chemical Vapor Deposition



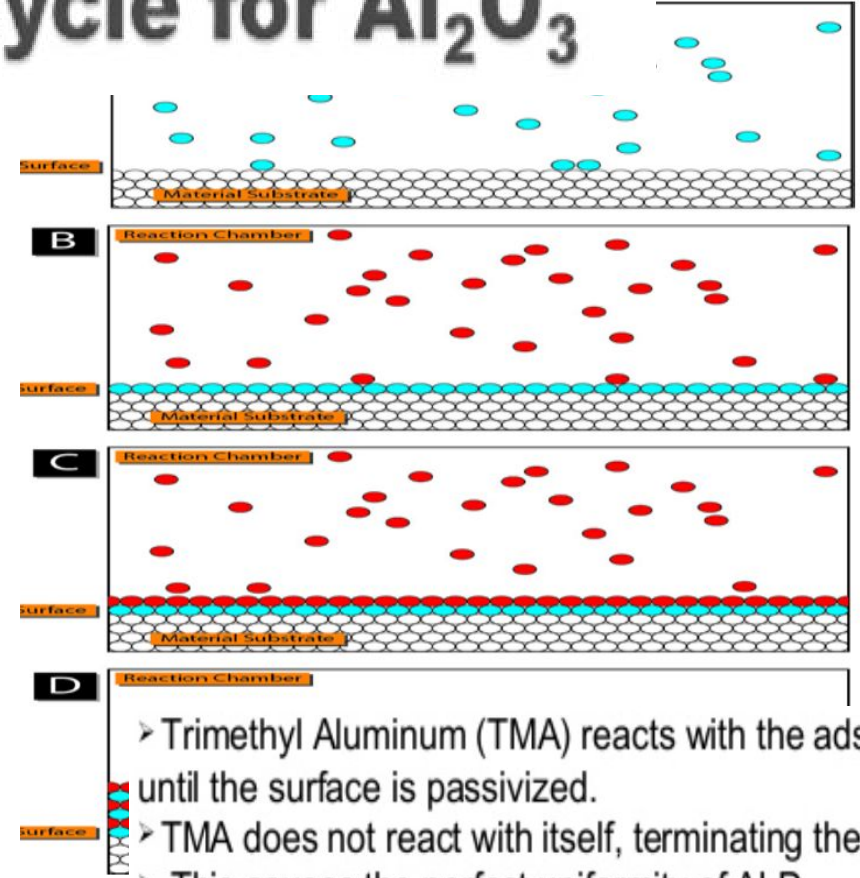
Atomic Layer Deposition ALD)

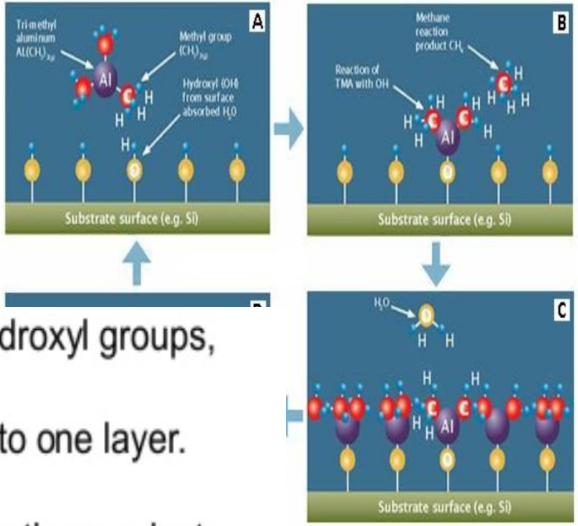
Atomic Layer Deposition (ALD) is a thin film deposition method in which a film is grown on a substrate by exposing its surface to alternate gaseous species (typically referred to as precursors). In contrast to chemical vapor deposition, the precursors are never present simultaneously in the reactor, but they are inserted as a series of sequential, non-overlapping pulses. In each of these pulses the precursor molecules react with the surface in a self-limiting way, so that the reaction terminates once all the reactive sites on the surface are consumed. Consequently, the maximum amount of material deposited on the surface after a single exposure to all of the precursors (a so-called ALD cycle) is determined by the nature of the precursor-surface interaction.[1] By varying the number of cycles it is possible to grow materials uniformly and with high precision on arbitrarily complex and large substrates.

ALD is considered one deposition method with great potential for producing very thin, conformal films with control of the thickness and composition of the films possible at the atomic level. A major driving force for the recent interest is the prospective seen for ALD in scaling down microelectronic devices according to Moore's law. ALD is an active field of research, with hundreds of different processes published in the scientific literature,[1][2] though some of them exhibit behaviors that depart from that of an ideal ALD process.[1]

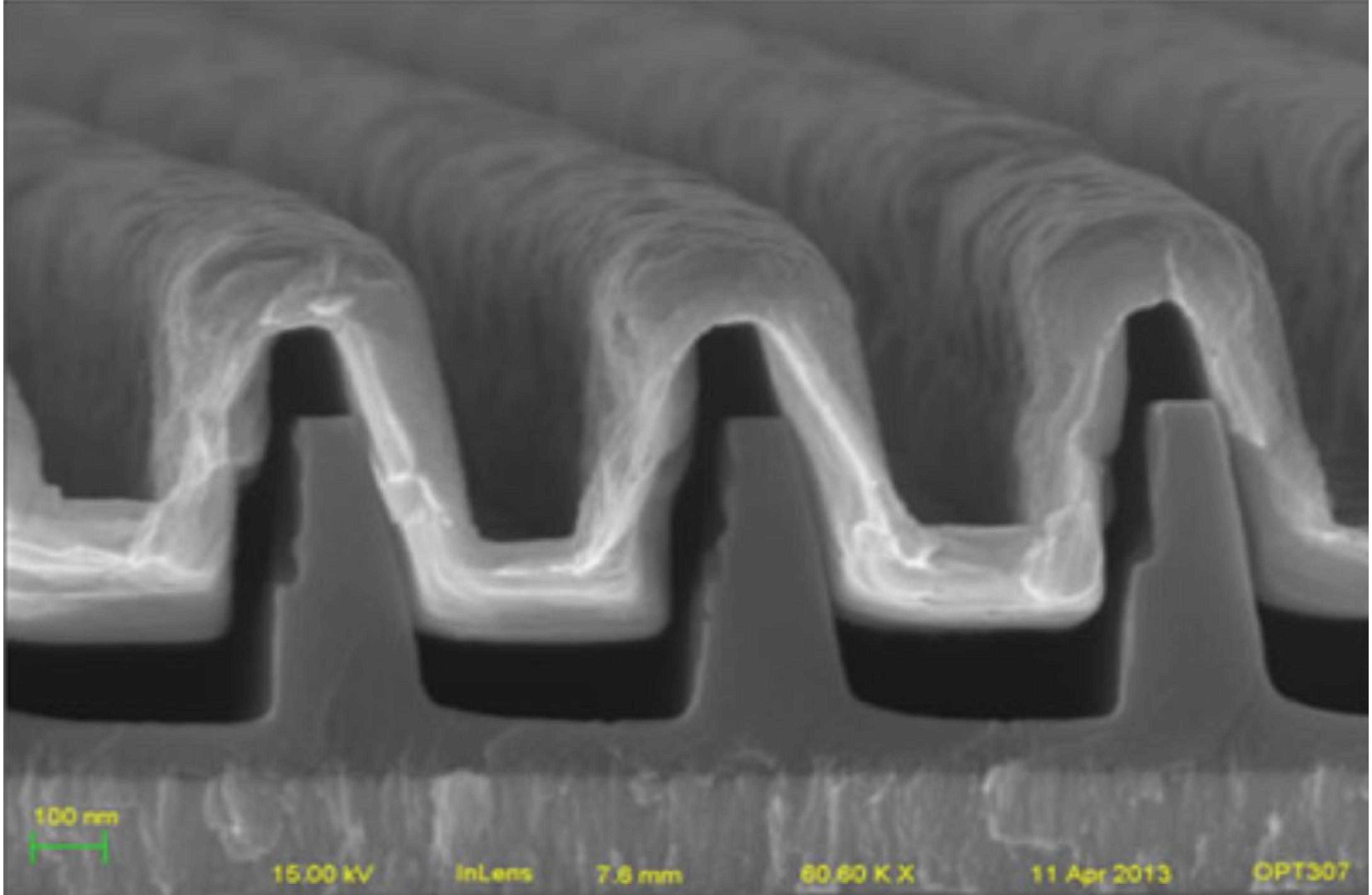
ALD is an important technique to deposit very thin films of a variety of materials. This CVD technique utilizes self-limiting surface chemistry along with the appropriate source gases to generate mono-layer films. The process sequences are computer controlled to enable repeated steps and the fabrication of thicker layers. One example is the use of trimethylaluminum (TMA) plus water vapor (H2O) to grow Al2O3 dielectrics. Extensive ALD development has been done in recent years by the semiconductor industry to develop thin high-K gate dielectric layers. Surface cleans and treatments are an important part of ALD film depositions. A wide array of materials have been developed for ALD applications; see the following references for more information.

ALD Cycle for Al_2O_3





- Trimethyl Aluminum (TMA) reacts with the adsorbed hydroxyl groups, until the surface is passivized.
- TMA does not react with itself, terminating the reaction to one layer.
- This causes the perfect uniformity of ALD.
- The excess TMA is pumped away with the methane reaction product.


100 nm
15.00 kV
InLens
7.6 mm
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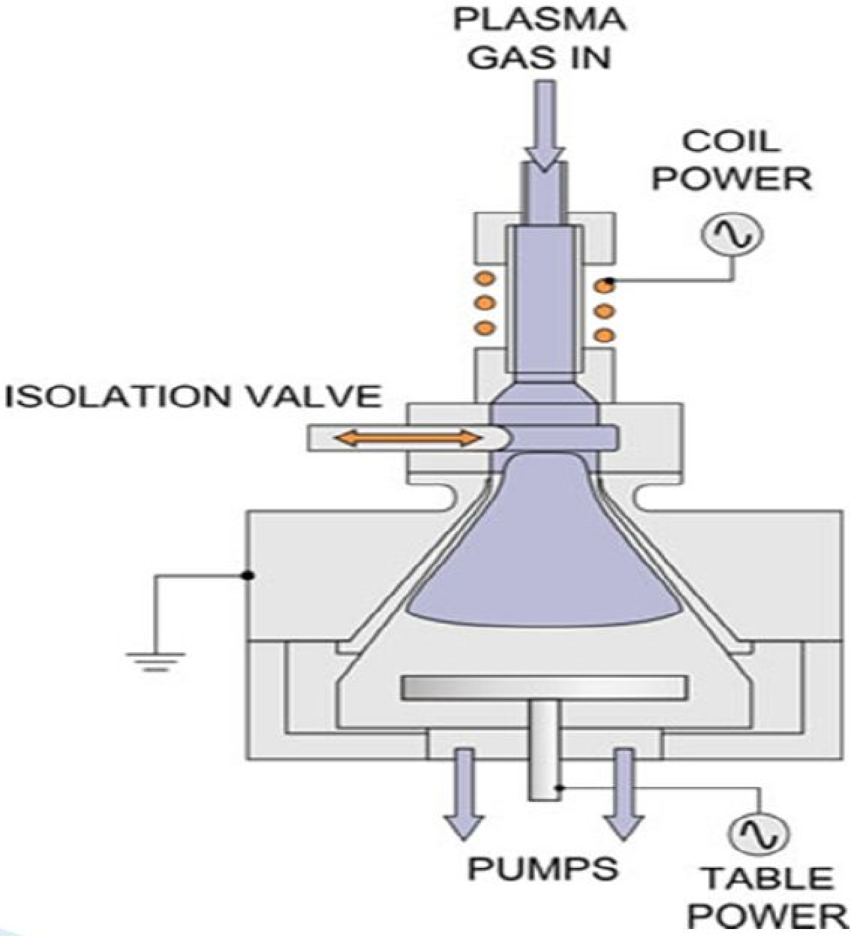
OPT307

PEALD

The key to Plasma Enhanced Atomic Layer Deposition (PEALD) is to remove passivating hydrogen atoms without the use of a thermal spike. Our approach is to break the remaining Si–H bonds using energy from Ar plasma, while decreasing the substrate temperature to within the thermal budget of front–end chip processing. Plasma is a mixture of ions, electrons, excited atoms and neutral atoms. Argon ions and excited atoms (metastable atoms) have 15.75 eV and >10.55 eV potential energies, respectively. Therefore, these argon plasma species have sufficient energies to break Si–H bonds (3–4 V), even if the substrate temperature is below 550. Once the plasma has chemically activated the surface, the next monolayer of precursor can be introduced, completing the ALD cycle.

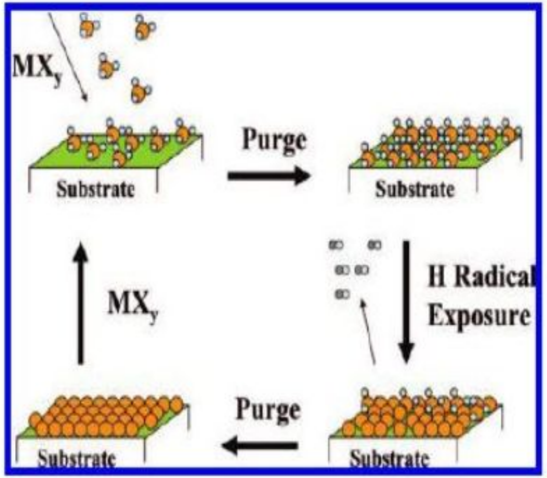
PEALD

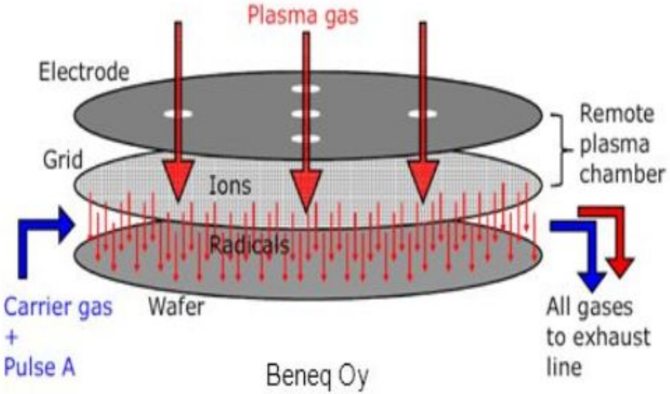


Plasma Enhanced ALD (PEALD)

PEALD is a useful extenstion of thermal ALD adding additional capabilties:

- Low temperatures and higher deposition rates (eg. SiO_2)
- Enhanced film quality and tunability
- It has good film adhesion than thermal ALD (Creation of more active sites)
- Enhances reaction chemistry for specific films
- Cycle time can be lowered (easy switch on and off of plasma)
- It helps in the deposition of single elements (eg. Noble metals like Pt, Cu..)





Beneq Oy

MVD

MVD process technology deposits ultra-thin films by vapor deposition at low temperatures on a broad spectrum of substrates. It’s the only deposition technology of its kind. A highly flexible system that can run both ALD-like and CVD-like processes, the platforms feature optional integrated plasma generation for substrate conditioning. MVD platforms allow for the use of up to four precursors, and can process multiple wafers or other three-dimensional objects in a single batch. It delivers extremely high conformality on aggressive aspect ratios of up to 2000:1.

Sputtering Process Trend for typical metals and films

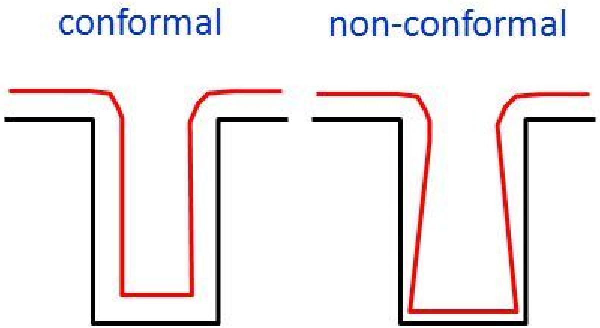
	Base Pressure	Sputtering Pressure	Power	Substrate RF Bias
Deposition Rate	⇔	⇧ | ⇩ Below~3mT Above~8mT	⬆	⇩
Stress (+ tensile, - compressive)	⇔	⬆	⬇	⬇
Step Coverage/ Sidewall coverage	⇔	⇧	2nd order effect depending on geometry	⇧ Can cause re-dep onto sidewalls thru collisions
Resistivity	⬆	⇧	2nd order effect with substrate or target heating on some films	2nd order effect with some films by changing density or stress

Legend

- ⬆ Strong increase in response
- ⬇ Strong decrease in response
- ⇧ Slight increase in response
- ⇩ Slight decrease in response
- ⇔ Typically no response

Thin film deposition: key performance indices

- Deposition rate
- Film uniformity
- Film conformality: step coverage (e.g. evaporation has worst step coverage)
- Electrical properties: resistivity, dielectric characteristics, breakdown voltage, …
- Mechanical properties: residual stress, adhesion, yield strength, …
- Optical properties: transparency, refractive index, …



Poor step coverage is good for liftoff.
Conformal film is good for electrical connection…

ECE 730: Fabrication in the nanoscale: principles, technology and applications
Instructor: Bo Cui, ECE, University of Waterloo; http://ece.uwaterloo.ca/~bcui/
Textbook: Nanofabrication: principles, capabilities and limits, by Zheng Cui