Micro and Smart Systems
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Lecture - 08
Thin-film Materials and their Deposition

I will talk to you today about Thin Film Materials and their Deposition methods, basically for building microsystems that we have seen in the previous lectures.

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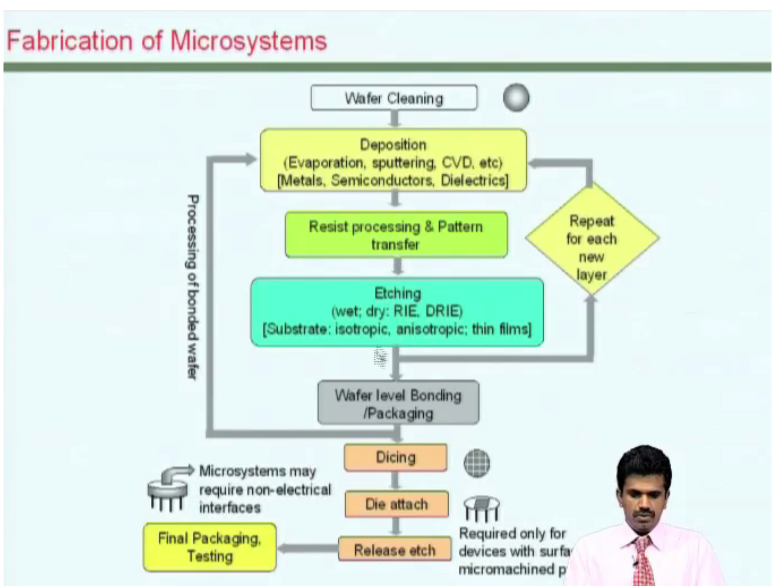

As we have seen in the previous lecture, one of the key steps in the whole chain of events that are required for fabricating microsystems is essentially deposition and this is done by various methods and various different materials can be you know fabricated by that methods that you will see in today's lecture.

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Thin films

- **Most engineering materials (usually called bulk materials) have fixed properties like electrical resistivity, optical opacity, etc.**
  - Bulk materials have fixed properties and hence their applications are limited
  - When the thickness is reduced, beyond certain limits these properties show a drastic change
  - This is called size effect and this adds flexibility in designing devices for a particular application
- **Thin film possess attractive properties and therefore can have versatile applications.**
  - Devices with thin films occupy less space
  - Their fabrication requires less materials, hence inexpensive.

Thin film are essentially you know a thinner versions of the common engineering materials that we use in various fields, and they have you know in their bulk they have properties such as electrical resistivity, optical characteristics and various other parameters that we normally look for. These properties when they are in bulk are you know reasonably fixed and you know restricted.

Whereas when comes to thin films we can actually engineer their characteristics to a certain extent by you know modifying the process by which these are deposited, and this is basically due to a size effect and when we talk about thin films essentially these are films of the order of let us say hundreds of armstrong thickness or let us say 10s to 100s of nanometre thickness.

Hence at that thickness level we are essentially talking about films that are possibly several atoms or molecules thick and hence the properties are much more predictable and also dependent on how these are assembled. One very common example that can be sighted in this context is you know like how would it look between let us say a heap of bricks or an ordered or stack, properly stacked assembly of a bricks.

If you really do that one by one layer by layer, that stack of bricks is much more you know stronger and also much more predictable characteristics, then a simple heap of bricks that if you just pour it on to a surface. So and because of that this layered thin film kind of materials have

wide range of applications in IC as well as microsystem process. Obviously, since these are thin films the you know the volume occupied by these and hence the device is made of these are much small, so they occupy less space.

And you know the overall requirements in various context in terms of materials in terms of energy required and etc. would be for less when it materials are handled as thin films.

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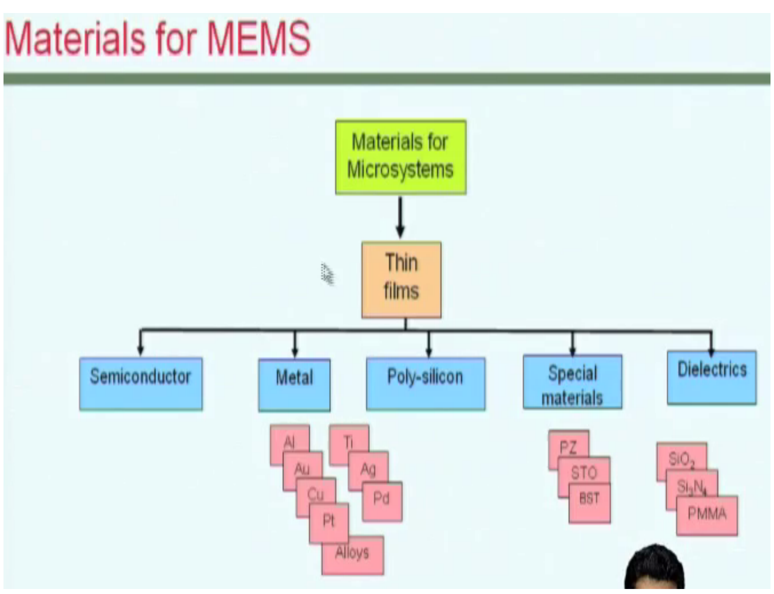

So going back to what was discussed in the previous lecture various types of thin films are used in the fabrication of MEMS and microsystems is include semiconductors, various metals and several special materials and also several dielectric materials including you know dielectrics of silicon. We also see here polysilicon and I will discuss what this is a little later in this lecture.

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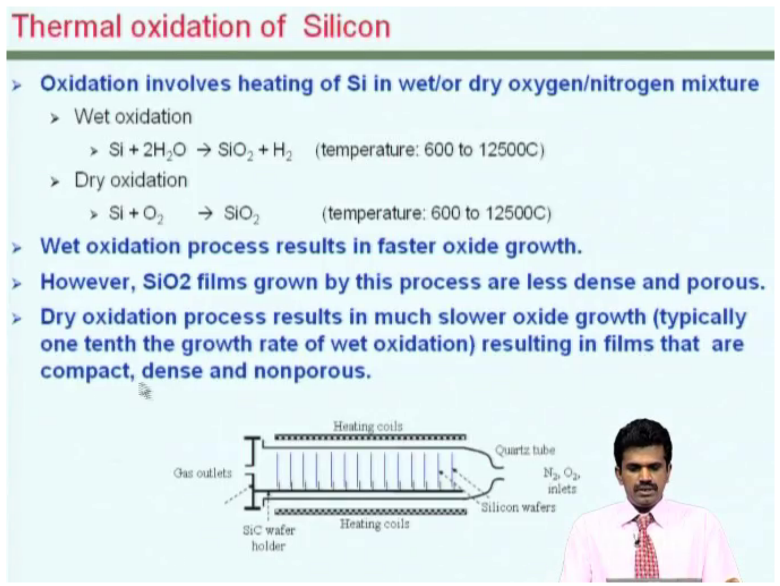

One of the easiest film that can be made on a silicon wafer is the oxide of silicon, and it can be fabricated in a simple furnace like this by processes known as oxidation and when whether there is you know steam present or not we call it wet or dry oxidation method. And the Chamber that you see here is a dry oxidation furnace in which you have gas outlets. And there is a series of wafers assembled.

And all these could be you know oxidized simultaneously using this heating coils inside outside the quartz tube where these are arranged and you will have this gas flow here. The wet oxidation process is relatively faster but the films grown by these are typically less dense and porous, so hence where the requirement is for porous films one usually goes for wet oxidation and vice versa. So dry oxidation is little slower and you know typically denser films can be formed.

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- Amount of silicon consumed is 44-46% of final oxide thickness

  $Si + O_2 \rightarrow SiO_2$

  Molecular weight: Si →28; Oxide → 60 (1g Si →2.142g oxide)
  Density: Si → 2.33; Oxide →2.24
  Volumes: (0.429cm^3 Si → 0.956cm^3 oxide)
  Thickness: 0.44μm → 1 μm oxide

- Oxidation rates depends on;
  - Crystallographic orientation of Si
    - (1 0 0) surface oxidizes 1.7 times more slowly than a (1 1 1) surface
  - Doping
  - Presence of impurities in the oxidizing gas,
  - Pressure of oxidizing gas
  - Use of plasma or photon flux
- Oxide thickness can be measured by Ellipsometer

As you could see the amount of silicon consumed for the oxidation is typically about 44 to 46% of the thickness of the final oxide that is formed, this can be obtained based on the you know by chemical equation of the formation of the oxide. How do we calculate this we basically start with the molecular weights of these materials, the ingredients and so essentially we can say that you know 28 grams of silicon would result in 60 grams of oxide.

And knowing that the densities of silicon and oxide are 2.33 and above 2.24 again this could vary in the oxide density could vary based on the approach by which it is fabricated, and based on these we could actually calculate the volume of the silicon consumed to the volume of the oxide that is formed and this could be worked, and hence we can see that about 0.44 micrometre thickness of silicon would result in a micron thick of oxide.

So this is a one good way of calculating the oxidation procedure the thickness of the material that is formed, in fact the rate of oxidation by either of those processes would depend on various factors, it depends on the crystal structure of the silicone that is whether it is (1 0 0) wafer or a (1 1 1) wafer in a previous lecture we have seen that you know the chemical characteristics of the silicon wafer depends on the crystallinity and silicon is primarily an anisotropic material.

The oxidation rate also depends on the doping and presence of various impurities in the oxidation gas and also the other parameters one can use in the process. Typically, the oxide

thickness is measured by an instrument called Ellipsometer and you know work with a standard table of colours based on how the wafer would look and you make use that determine the thickness.

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Deposition process

- Source
- Transport
- Condensation on substrate
- The nature of the film deposited depends on process parameters like substrate, deposition temperature, gaseous environment, rate of deposition etc.
- Favorable conditions are created to transfer the material from the source (*target*) to the destination (*substrate*).
  - In PVD process, this transfer takes place by a physical means such as evaporation or impact
  - In CVD process films are deposited through a chemical reaction

But oxidation is only possible in the case of silicon and only to form silicon dioxide, in general to deposit to work with thin films we need to start with the source material of the thin film and transport this source material and deposit condensate on to the substrate. So a series of process steps would be required in a general scenario when one would want to deposit a thin film onto a wafer whether it is silicon or other materials.

And obviously the nature of the film deposited would depend on various process parameters including what the substrate is, and you know the temperature pressure whatever gases that we are using and various other factors similar to that. So we can create essentially in the deposition process what we are trying to do is that we create the most favourable process conditions.

So that you know material is transferred from the source to the substrate material substrate surface in you know the most efficient manner, and so that we get the best quality films possibly with the maximum thickness possible within the minimum time, so that you know we can get some kind of you know engineering improvement over there.

There are basically 2 approaches, one is called the physical vapor deposition which is essentially the physical transfer of material from the source which is normally known as the target to the substrate. Whereas in the case of chemical process it is essentially based on the you know some kind of chemical reactions to deposit the material on to the destination which is essentially the substrate.

Normally in chemical vapor deposition we will only have you know reagents coming in mostly in the gaseous or some kind of precursor formed.

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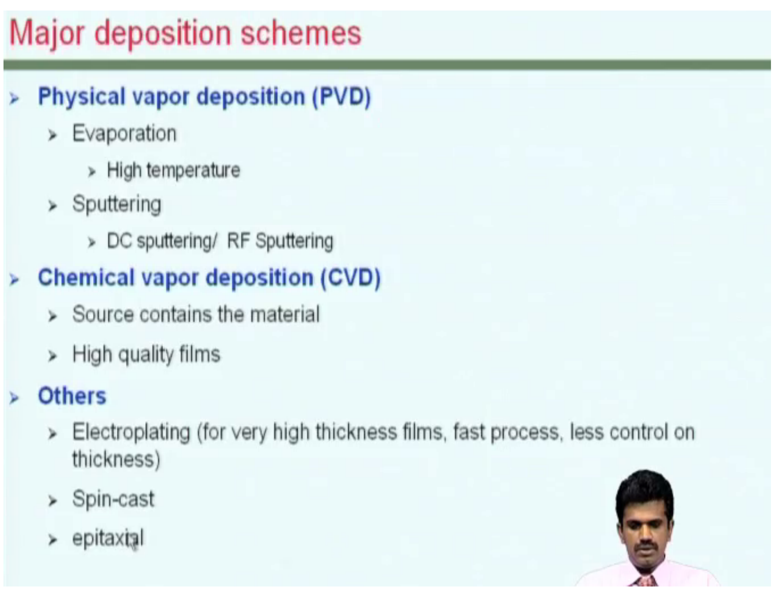

Major depositions themes therefore, are based on either they are physical vapor deposition or chemical vapor deposition. In some examples of physical vapor deposition includes the evaporation technique and what is called as sputtering technique, there are several variants of these as we will see in subsequent discussion. There is also as I mentioned chemical vapor deposition techniques which is typically used for better quality films.

There are some other methods which are used for specialized purpose for example electroplating is used when one needs really thick films of materials relatively speaking, and spin-casting or spin-coating methods are used for polymeric materials including photoresist which are require for patterning, and there are also you know epitaxial growth of semiconductors like the silicon over a surface and things like that.

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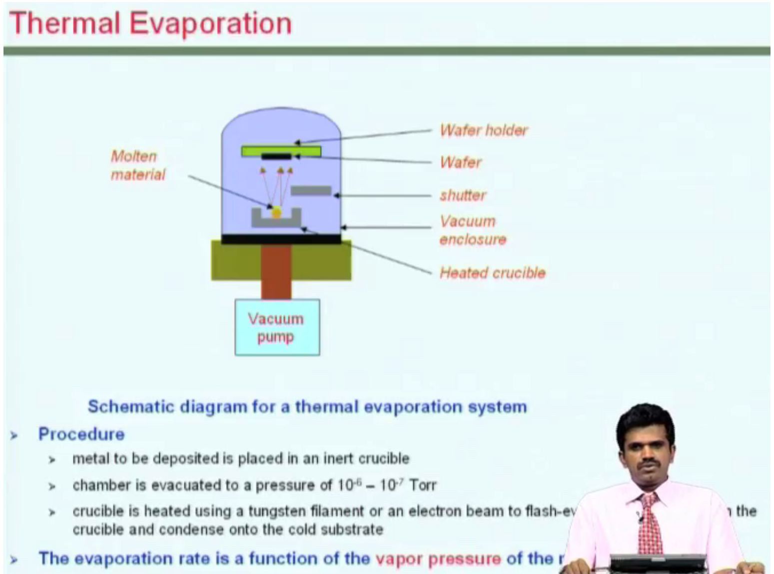

Let us first look at this example of thermal evaporation which is usually done within a chamber like this. Let us look at one of the common examples of evaporation that you would have seen in your own house one of the common example is basically you would have seen water boiling in a vessel in the kitchen and if you put a cold lid over the boiling water, you can see that the water condenses on that lid surface.

Evaporation is essentially the same thing done for engineering materials such as metals which could be melted at relatively low temperatures, hence evaporation technique is usually used for metallic materials but obviously metals cannot be melted at you know let us say 100 degrees centigrade or anything near. So one needs to be essentially reduce the pressure within the chamber.

So that you know the melting temperature required for the metal is you know relatively once again under control. So it is not too high and we need to have some kind of an arrangement to create that kind of a temperature. And so essentially the evaporation rate will therefore, be a function of the vapor pressure of the metal that is being deposited.

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Deposition by Evaporation

- Deposition rate for Al, 0.5μm/min i.e fast process,
  - no damage on substrate.

Al is the most popular interconnect material.
Resistivity: 2.65μΩcm.
Good adherance to Si/SiO_2.
Corrosion resistant, compared to Cu.
Easy to deposit / etch.
Ohmic contact is formed with Si at 450-500°C

- Source material shaped depending on the heating approach
- Methods for heating:
  - Resistive heating
    - eg in lab set ups.
    - Tungsten boat/ filament as containment structure.
    - Filament life limits thickness.(for industrial use)

One of the common example is aluminium which has the layer relatively high rate of deposition when you know deposited by evaporation, and you know relatively very good quality of film can be obtained at a good thickness by the evaporation process, and you know it stick very well with silicon substrate, and hence you will see that aluminium is used in ICs quite often. And one of the reasons it can be deposited relatively easier.

The source material you will be you know shaped whether it is in terms of filaments or springs or whether it is in terms of small pellets it all depends on what is the heating arrangement, and one of the simplest way of heating especially used in the context of let us say aluminium is resistive heating. And it is typically used in lab set up where there is a tungsten boat which is heated and this pieces of aluminium are kept over it which would melt and evaporate and getting transferred on through the substrate surface.

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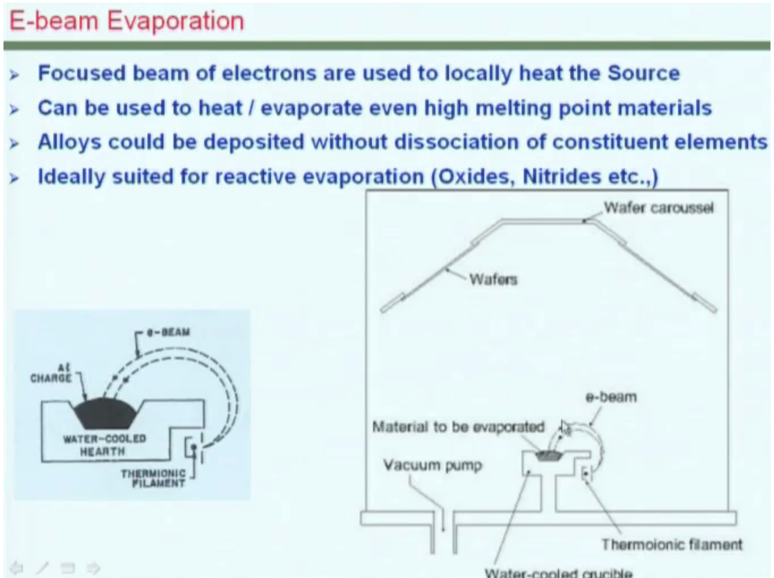

But you know most materials have much higher temperatures and cannot always be melted just by heating them, so we use other ways of energizing their atoms or molecules from the source, so that these could be displaced and transported onto the substrate surface. What you see here is an arrangement in which an electron beam is used for evaporating the source materials inside a crucible and this could be you know directed towards the wafer carousel.

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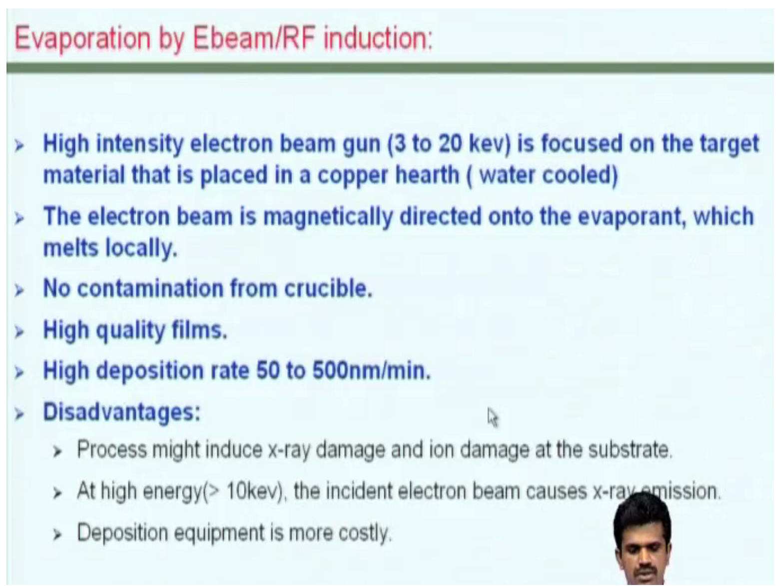

It is also possible by you know RF induction by to generate such beams which could essentially displace these atoms from essentially the source material inside the crucible and these approaches would result in relatively better quality films compared to the simple heating based approaches, and have reasonably good deposition rates. But you know because this includes

energy transfer from one beam to another there could be potentially beam damages happening in the devices on the substrate.

And hence you know one has to you know basically choose the kind of approaches that would be regarding in particular context. And obviously the system required for such deposition could be more expensive than the previous.

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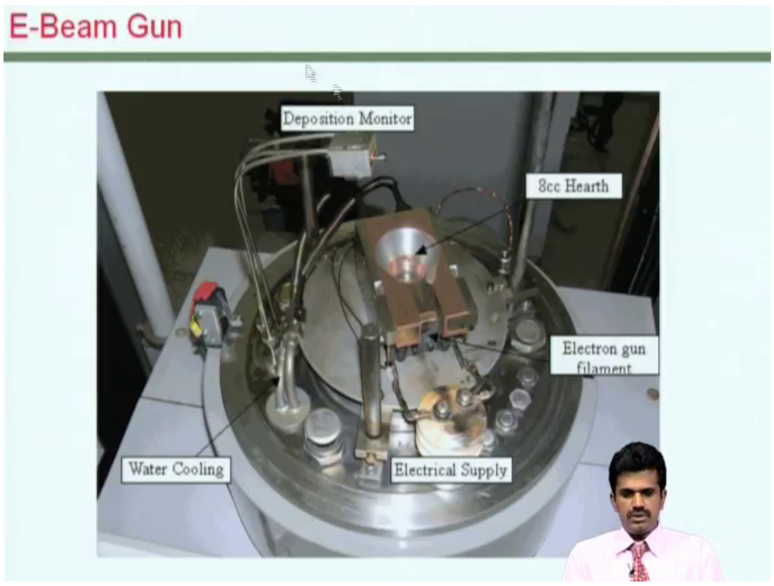

And what you see here is an image of an opened out chamber in which this electron beam gun can be seen very clearly.

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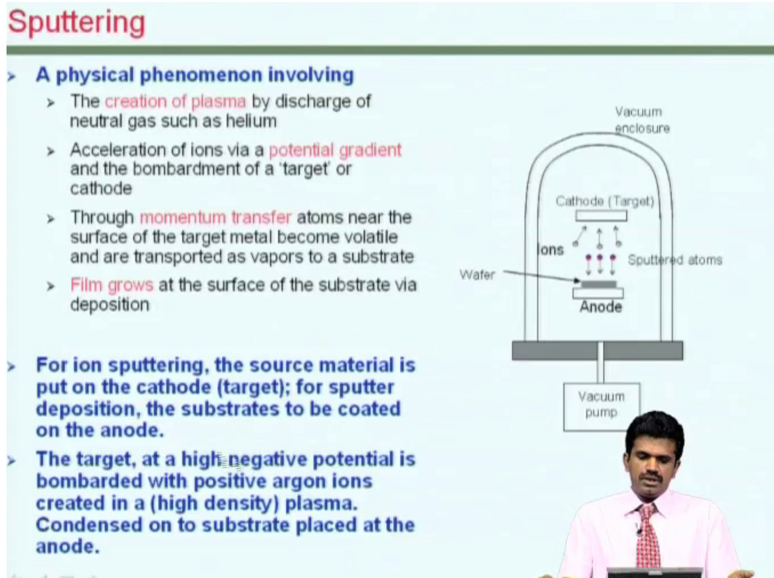

The second physical method that listed there is sputtering, so this is once again a physical phenomenon of transporting and in this case it is done by creating a plasma and the ions created by this plasma are attracted towards the positive ions are attracted towards a cathode and the source material is kept at the cathode and these ions when they bombard the target, the atoms from there are sputtered out and we keep the wafer at the anode.

So that the displaced atoms sputtered atoms are coming out from the target material will go and attach onto the wafer at the anode, so the film is essentially grows on the wafer once again to create this plasma one would require a low pressure and hence this is done in a vacuum enclosure. So the source material is at the target and in the substrate for sputter deposition is kept at the anode.

So the target as I mentioned is at a high negative potential and the ions that are there in the plasma argon is typically used as it is an inert gas and this can be used for the displacement and the displaced atoms as I said condensed onto the wafer.

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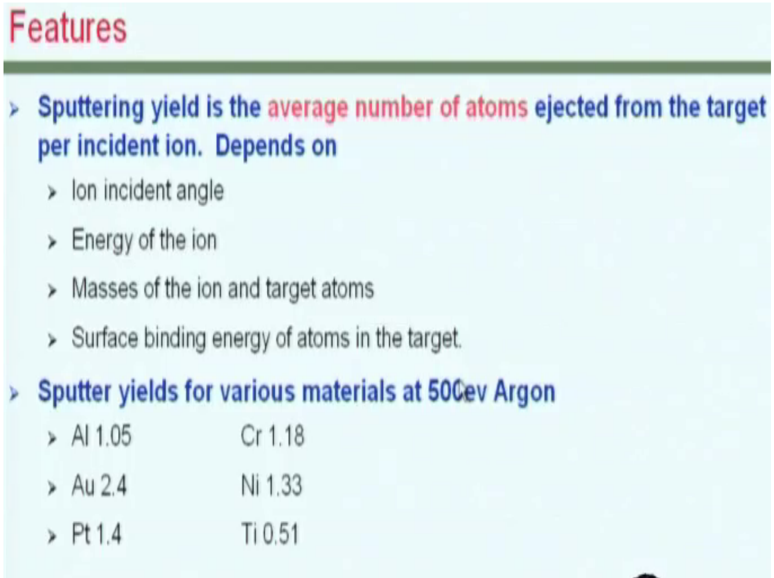

There is a terminology called sputtering yield which is essentially the average number of atoms ejected from the target which is kept at the cathode and that will depend on the incidence angle for the ions, the energy of the ion, the mass of the ion and the target atom and the surface binding

energy of atoms in the target. And hence it would vary depending on the target material and as you could see from the list below with a standard let us say plasma creation environment.

The number or the average number of atoms displaced would vary let us say from 0.51 in the case of Titanium to 2.4 in the case of Gold in this list that you see here.

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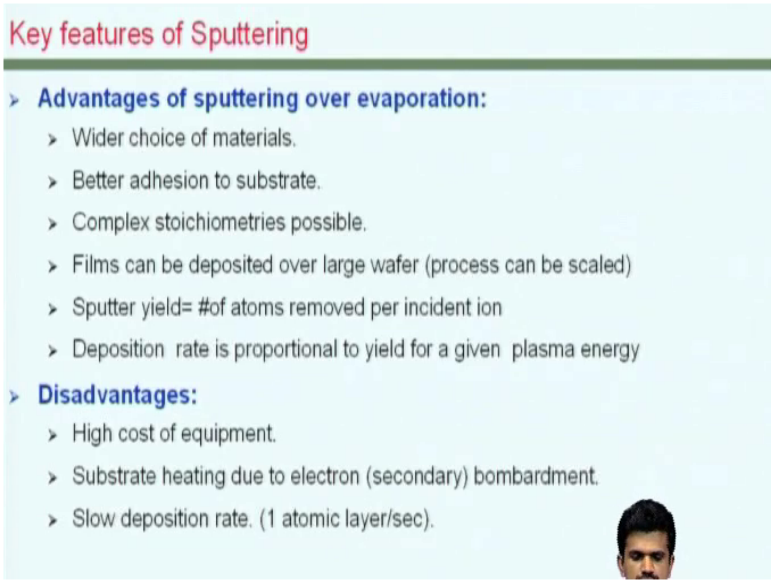

The basic features of sputtering includes you know the wide choice of materials, because in the case of evaporation if you recall you could only have materials which have relatively low melting points. And since the sputtering is done usually at a lower rate they have better adhesion characteristics and there are ways in which one can engineer the sputtering to have complex stoichiometric you know make films.

The films can be deposited over a larger area by sputtering and hence compared to evaporation sputtering process is more popular more widely used when one would want to require over you know a larger wafers especially in industrial facilities. The deposition yield as I mentioned is proportional to various factors that we have seen in the previous thing. Disadvantages includes the high cost of equipment.

And you know sometimes there are substrate heating happening due to the secondary bombardment, and obviously as I mentioned the deposition rate is relatively slow.

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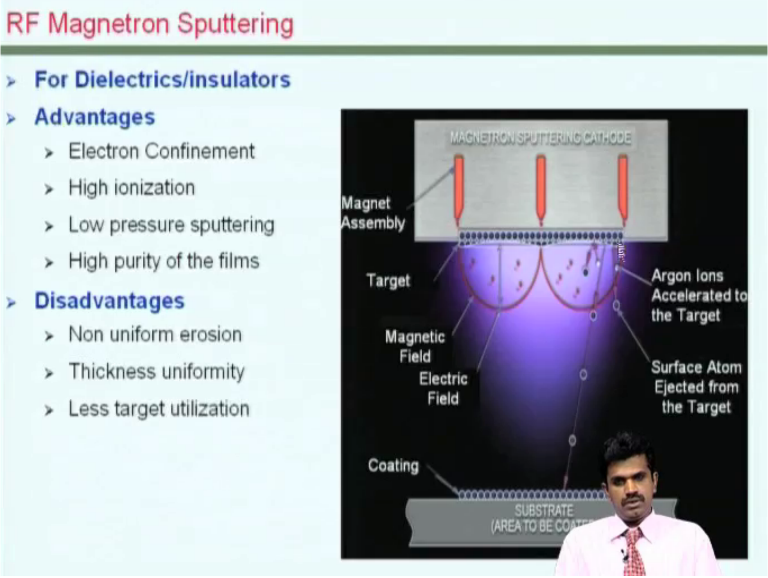

The essentially 2 types of sputtering depending on how one creates the plasma, can create a plasma with DC for conducting materials such as metals we create an RF Magnetron based plasma for dielectrics or insulating materials, and that has better control especially for you know depositing dielectric materials, and once again this is also very popular you know large area films especially for industrial applications.

There are challenges in creating uniform films and you know a proper utilization of the source which is essentially the target material for the films.

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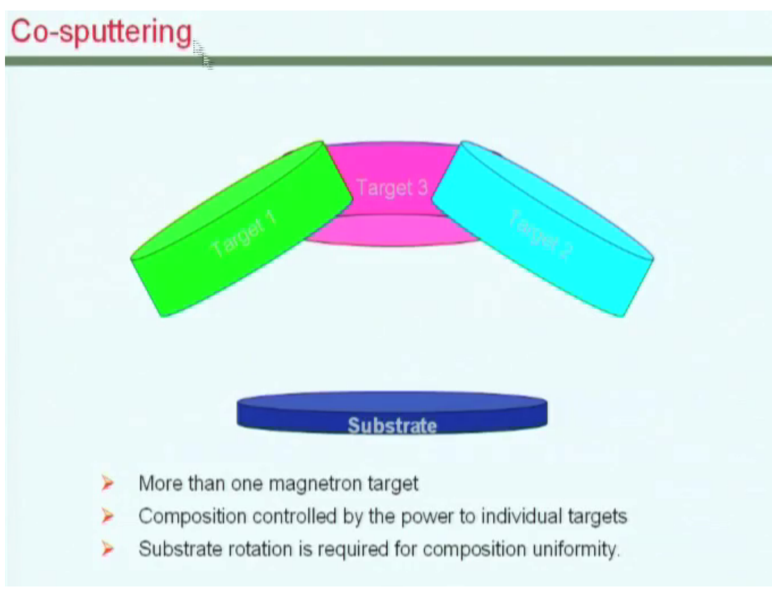

In this approach it is also possible to do a Co-sputtering with multiple targets, so when we need a composite film it is also possible you know locate these targets appropriately, so that we can have a Co-sputtered film which will be based on the various materials that are provided with individual targets, so that is one key advantage of using sputtering.

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Comparison: Evaporation & Sputtering

	Evaporation	Sputtering
Rate	1000 atomic layer/sec (thickness control is difficult)	1 atomic layer/sec (thickness control possible)
Choice of material	Limited (to those with low melting point)	Almost unlimited
Purity	Better	Possibility of incorporating impurity
Alloy composition	Little or no control	Can be tightly controlled
Changes in source material	Easy	Expensive
Decomposition of material	High	Low
Adhesion	Often poor	Very good

If you look at a basic comparison between evaporation and sputtering techniques the one that would stand out includes the low rate of deposition of sputtering, and the you know unlimited choice of materials that are there in sputtering, and relatively sputtering gives better purity films, and can be used for again alloy kind of materials, but obviously it is more expensive and the results in films that are of typically better quality than evaporation.

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Deposition Methods for some metals

Metal	Melting point (°C)	Methods of deposition
Aluminium	659	Thermal evaporation
Silver	957	Thermal evaporation
Gold	1067	Thermal evaporation/sputtering
Copper	1083	Thermal evaporation/sputtering
Palladium	1552	Electron beam/sputtering
Platinum	1769	Electron beam/sputtering
Titanium	1677	Electron beam/sputtering
Nickel	1453	Electron beam/evaporation
Chromium	1887	Electron beam/sputtering
Tungsten	3377	Electron beam/sputtering

And you know we looked at how various materials in this case metals could be deposited, we can look at them from the point of view of their melting points under standard conditions, and as you could see aluminium having relatively lower melting point can be deposited using thermal evaporation techniques, and materials having higher melting points would require other ways of melting or the sputtering kind of approaches for their deposition.

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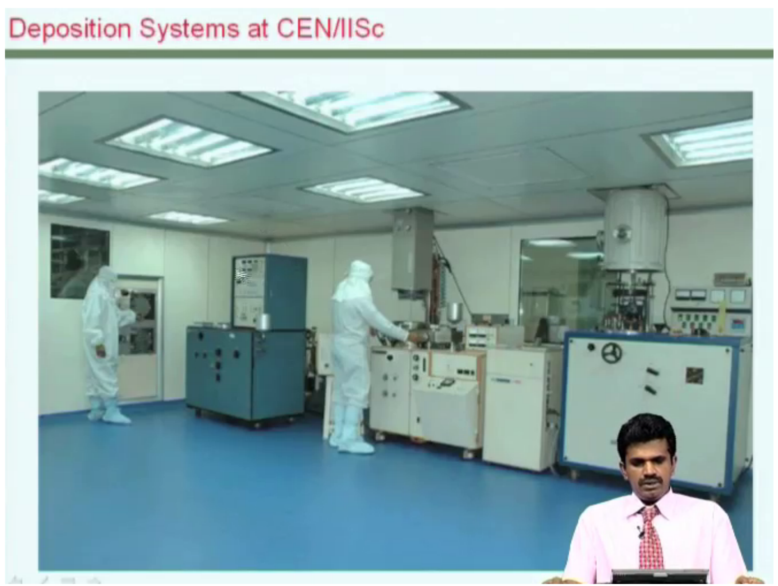

What you see here is set of deposition equipment that are available at IISc where you know we can use sputtering or evaporation kind of techniques for depositing various films.

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Laser Ablation

- **Uses LASER radiation to erode a target, and deposit the eroded material onto a substrate.**
  - The energy of the laser is absorbed by the upper surface of the target resulting in an extreme temperature flash, evaporating a small amount of material.
  - Usually pulsed laser is used.
- **Material displaced is deposited onto the substrate without decomposition.**
- **The method is highly preferred when complex stoichiometries are required.**
  - Thin film keeps the same atomic ratio as the target material.

HEATER
LASER BEAM
SUBSTRATE
PLUME
VACUUM CHAMBER
TARGET
O_2

Another approach for depositing even better quality films is based on laser, as in the case of sputtering that you have seen previously instead of using an ion beam what we use here is a laser beam, and as you may know lasers can be used to you know like melt materials because of the high energy of laser and these melted material can be you know arranged to be transported onto the substrate.

And one of the methods is essentially based on what is called pulsed laser that is typically called pulse laser deposition or pulsed laser ablation techniques. The material is you know deposited onto the substrate actually without decomposition, so it is does not basically change its properties in this method. So once again this is also useful when you know complex stoichiometric properties are required for the films, and we have a target material with the same stoichiometric this can be transported from the target to the substrate by the pulse laser ablation techniques.

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Pulsed Laser Ablation deposition (PLD)

- **Used for high quality thin films,**
  - e.g., superconducting materials such as $YBa_2Cu_3O_{7-y}$
  - short-wavelength lasers such as the KrF or XeCl excimer laser in a non-equilibrium process.
- **Ease of operation and reproducibility.**
- **Films do not require post-deposition annealing**
- **Processing variables**
  - laser energy,
  - laser pulse repetition rate,
  - substrate temperature
  - oxygen background pressure.

As I mentioned one of the common method is called PLD and it is can be used for high quality thin films of materials such as superconducting materials, and so the main advantage in this case is that it is relatively easier to you know reproduce films based on this, and the films deposited by these techniques do not require post deposition annealing which is typically required in the case of the previous techniques that physical vapor deposition techniques that you have seen here.

Obviously, the laser characteristics and some of the other environment parameters determine the deposition rate by this approach.

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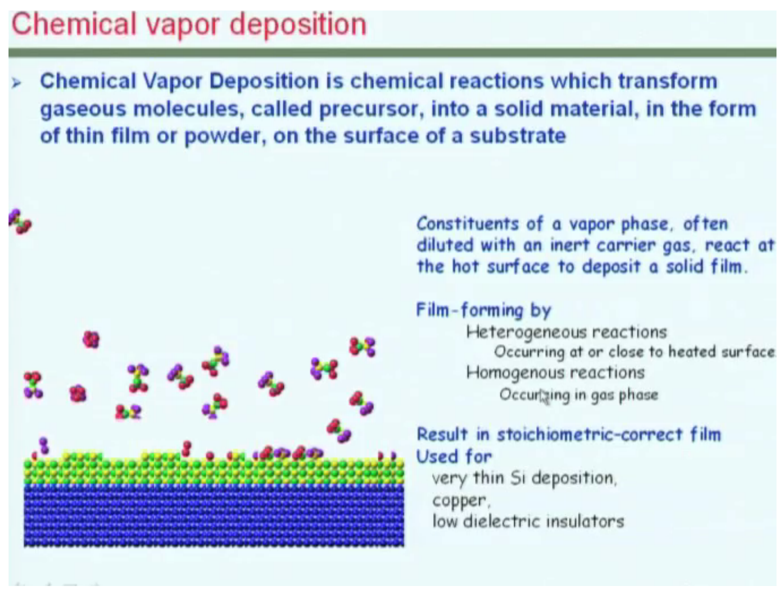

The next deposition approach that we want to discuss is based on chemical vapor deposition, so in this case a chemical reaction would happen which would transform the incoming gaseous molecules which are typically called precursor, and we make them you know after the reaction the precipitate of the chemical reaction would be made to stick onto the surface. So in this case there are no real target, it is essentially incoming is the gaseous form.

And we need to make appropriate reactions to happen, so that the films formed by either a heterogeneous or a homogeneous chemical reaction to be you know formed onto the surface, and various materials could be performed on to the substrate materials at a wide range of environmental conditions by the chemical deposition schemes.

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- **Common thin films deposited by CVD are**
  - Polysilicon   Silicon oxide
  - Silicon Nitride   Tungsten
  - Titanium   Tantalum
  - Nitrides of W & Ti & Ta   Copper
  - Low permittivity dielectric insulators
- **Parameters that significantly influence the rate of chemical vapour deposition are:**
  - temperature
  - pressure of carrier gas
  - velocity of gas flow
  - distance along the direction of gas flow

Films include the silicon compounds, metals and also various other dielectric insulators. The process parameters include the temperature, the pressure and the flow of the gas and the distance on within the chamber and the direction on which these are incident on to the surface.

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Process in CVD

- Mass transport of reactant (and diluent gases) in the bulk gases flow region from the reactor inlet to the deposition zone.
- Gas phase reactions leading to film precursors and by-products.
- Mass transport of film pre-cursors and reactants to the growth surface.
- Adsorption of film precursors and reactants on the growth surface.
- Surface reactions of adatoms occurring selectively on the heated surface.
- Surface migration of film formers to the growth sites.
- Incorporation of film constituents into the growing film.
- Desorption of by-products of the surface reaction.
- Mass transport of by-products in the bulk gas flow region away from the deposition zone towards the reactor exit

This is essentially the mass transport of reactants that would you know result in the formation of the precipitate, these are formed usually by gaseous phase reaction from the precursors, and as I mentioned the there is a mass transport from this precursor on to the growth surface, there is some kind of adsorption happening there, so that that you know the films would stick to the surface.

There are surface reaction and surface migrations where the films forms continuously onto the surface. And the by-products are inducing out of the surface, so that you know a good quality film can be formed, this by-products are taken out from the chamber.

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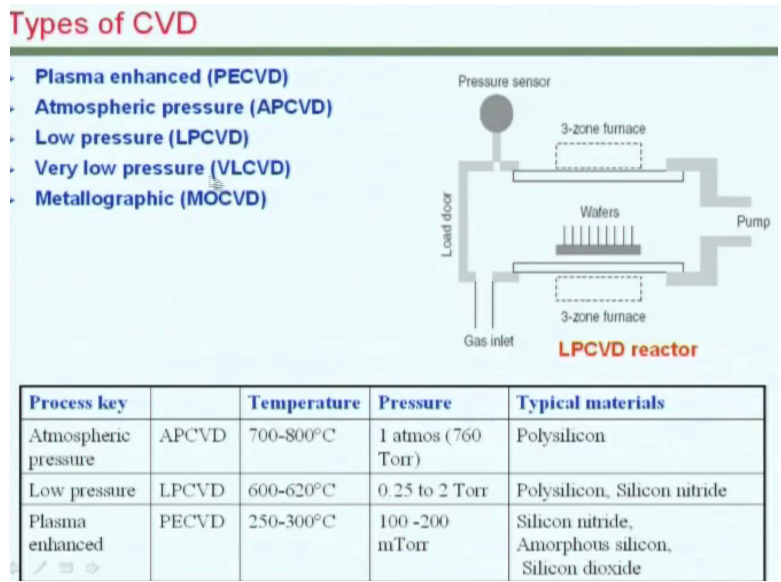

Process key		Temperature	Pressure	Typical materials
Atmospheric pressure	APCVD	700-800°C	1 atmos (760 Torr)	Polysilicon
Low pressure	LPCVD	600-620°C	0.25 to 2 Torr	Polysilicon, Silicon nitride
Plasma enhanced	PECVD	250-300°C	100 -200 mTorr	Silicon nitride, Amorphous silicon, Silicon dioxide

So one you know typical situation in which the films are formed on multiple wafers is shown here, we how to control the pressure inside the chamber temperature and various parameters. And there are various types of CVD based on how we enable these chemical reactions to happen, there are techniques in which we use plasma inside the chamber and which is usually at lower temperature, there are also methods in which lower pressures are used.

There is specialized methods using metal organic materials are used for depositing metallic films onto this, and if you see typical range of temperature the order would include PECVD which is plasma enhanced chemical vapor deposition which is usually done at lower temperature than the other methods. And as you could see various materials could be deposited using these approaches, and are typically used relatively better quality films are required thinner films are required for various applications of microsystems and integrated circuits.

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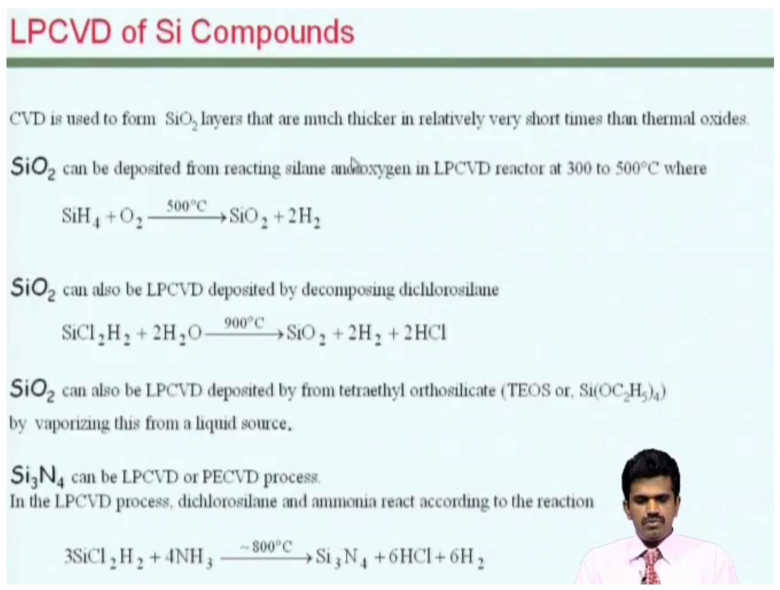

CVD is based on chemical reactions for example to form silicon dioxide one would start with silane and oxygen and we can make the chemical reaction happened at the LPCVD reactor at 500 degree centigrade for the formation of silicon dioxide. There also other source materials that could be used for realizing silicon dioxide. Similarly, silicon nitride can also formed either by LPCVD or PECVD and based on you know various other factors and typically the temperatures are 800 degree centigrade for LPCVD of silicon nitride.

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LPCVD for Polysilicon

- Carried out at low pressure (200mTorr to 1000mTorr) by pyroletic decomposition of silane (SiH_4). in the temperature range 500-625°C

$$SiH_4 \rightarrow Si + 2H_2$$

- Most common low-pressure processes used for polysilicon
- Pressures between 0.2 and 1.0 Torr using 100% silane.
- PolySi deposition rate is approximately 10nm /minute at 620°C Maximum LPCVD Poly Si thickness is generally restricted to 2μm (2000 nm).
- Amorphous Si when deposited below 580°C and deposition rate is very low (2nm/min at 550°C)
- LPCVD poly Si is compatible with VLSI Technology

It is also possible to deposit silicon layers on to a wafer by using LPCVD, the usually LPCVD is used in this particular context by the way, and at a pressure ranges from 0.2 to you know 1.0 Torr is used for this and the deposition rate is typically 10 nanometer per minute at above 600 degree centigrade, but if the temperature is lower what is formed is usually amorphous silicon. Now the question is what is really you know this polysilicon and why is it typically used in IC fabrication and in many VLSI kind of devices.

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Polysilicon

- Polysilicon comprises of small crystallites of single crystal silicon, separated by grain boundaries.
- Polysilicon is often used as a **structural material** in MEMS.
- This is also used in MEMS and microelectronics for electrode formation and as a **conductor or high-value resistor**, depending on its doping level (must be highly doped to increase conductivity).
- When doped, resistivity 500-525μΩcm
- Polysilicon is commonly used for MOSFET Gate electrode:
- Poly can form ohmic contact with Si.
- Easy to pattern

As you could see polysilicon is essentially what is called the polycrystalline silicon, so it is not a single crystal silicon that will be formed by this approach, if you recall when we talked about substrate silicon wafer is essentially a single crystal silicon, so from one point to another

anywhere on this wafer the silicon atoms are at a fixed distance which is a multiple of the lattice constant of the wafer.

But in the case of polysilicon what you will see is in locally it consists of crystallite small small crystallites but there are grain boundaries, and beyond which the lattice is not continuous and hence it is not a single crystal silicon, but it is a very good structural material for MEMS and most of the properties of polysilicon especially in the context of MEMS are very similar to that of silicon and it can be doped to you know various levels of conductivity.

And hence it can be used as an electrode material as well and hence it has multiple roles in many microsystems, the resistivity could be you know as high as above you know 500 micro ohms centimeter, and as I mentioned it could be used as gate electrodes and typically used in CMOS technologies, it also can form an ohmic contact with the silicon, and hence it is easy to pattern to and it is widely used as the electrode material.

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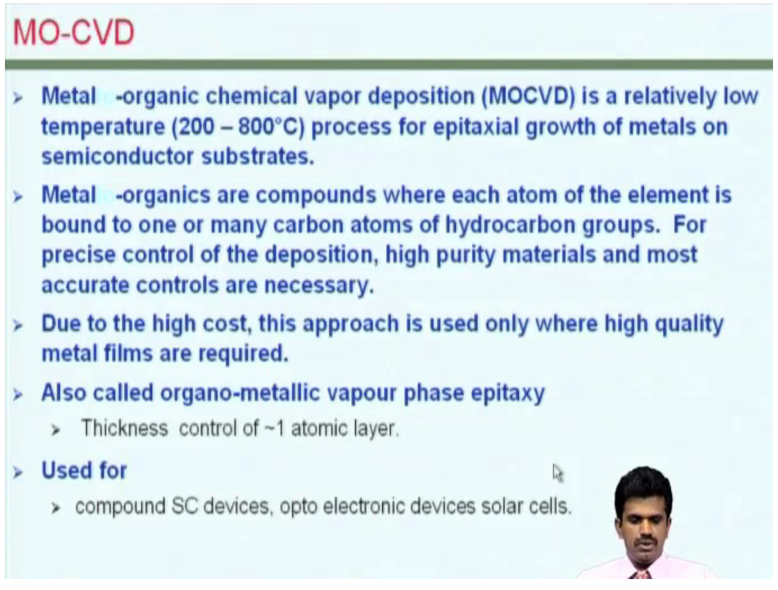

It is possible to deposit metallic films also by CVD techniques and typically these are called MOCVD Metal organic chemical vapor deposition schemes, so what we have is that precursor material is typically metal organic of the particular metal to be deposited, this results in extremely high quality films and you know but at very low rate of deposition. Hence it is used

for specialized component for example opto-electronic devices and you know for example gallium arsenide or gallium nitride based devices and things like that.

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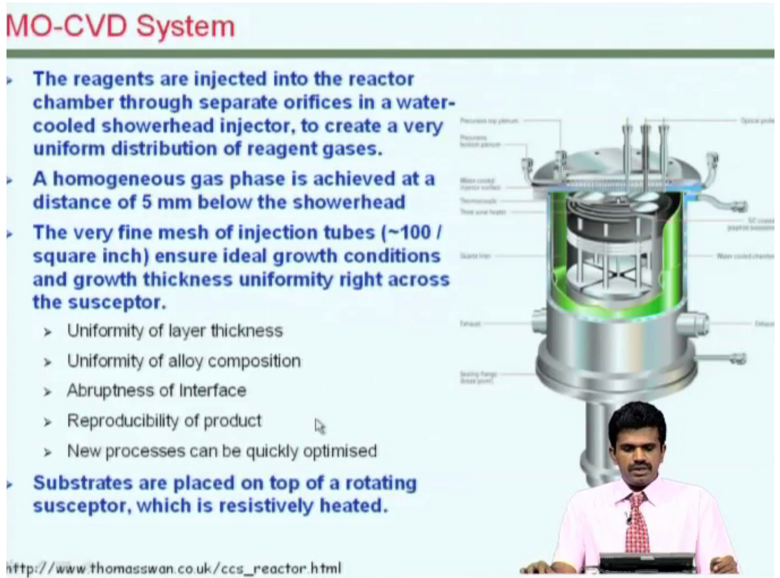

In a typical MO-CVD system variously reagents are injected into this chamber and just like in any other CVD scheme you know we make the chemical reaction to happen, and we also do some kind of rotations and things like that, so that you know a uniformity and good control of the film deposition can be obtained by this approach.

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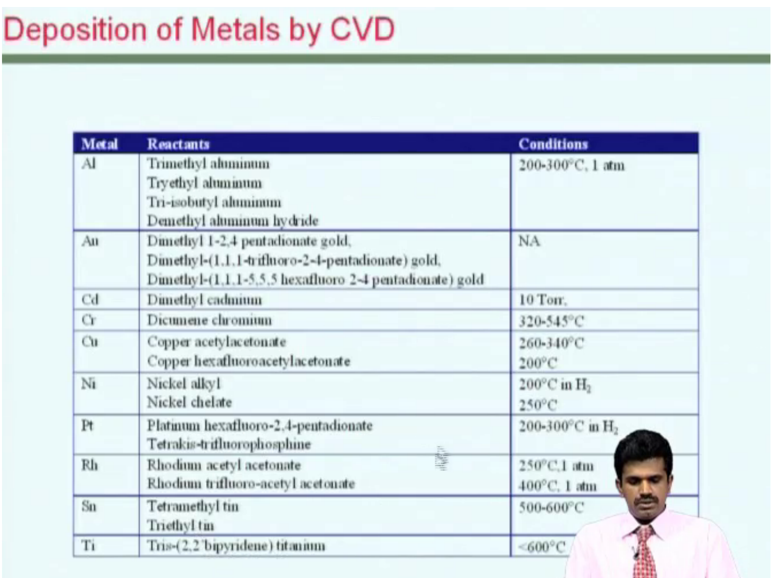

Metal	Reactants	Conditions
Al	Trimethyl aluminum Tryethyl aluminum Tri-isobutyl aluminum Demethyl aluminum hydride	200-300°C, 1 atm
Au	Dimethyl 1-2,4 pentadionate gold, Dimethyl-(1,1,1-trifluoro-2-4-pentadionate) gold, Dimethyl-(1,1,1-5,5,5 hexafluoro 2-4 pentadionate) gold	NA
Cd	Dimethyl cadmium	10 Torr,
Cr	Dicumene chromium	320-545°C
Cu	Copper acetylacetonate Copper hexafluoroacetylacetonate	260-340°C 200°C
Ni	Nickel alkyl Nickel chelate	200°C in H_2 250°C
Pt	Platinum hexafluoro-2,4-pentadionate Tetrakis-trifluorophosphine	200-300°C in H_2
Rh	Rhodium acetyl acetonate Rhodium trifluoro-acetyl acetonate	250°C,1 atm 400°C, 1 atm
Sn	Tetramethyl tin Triethyl tin	500-600°C
Ti	Tris-(2,2'bipyridene) titanium	<600°C

As you could see from the list here many metallic films can be formed based on their organic precursors that are used in this CVD systems.

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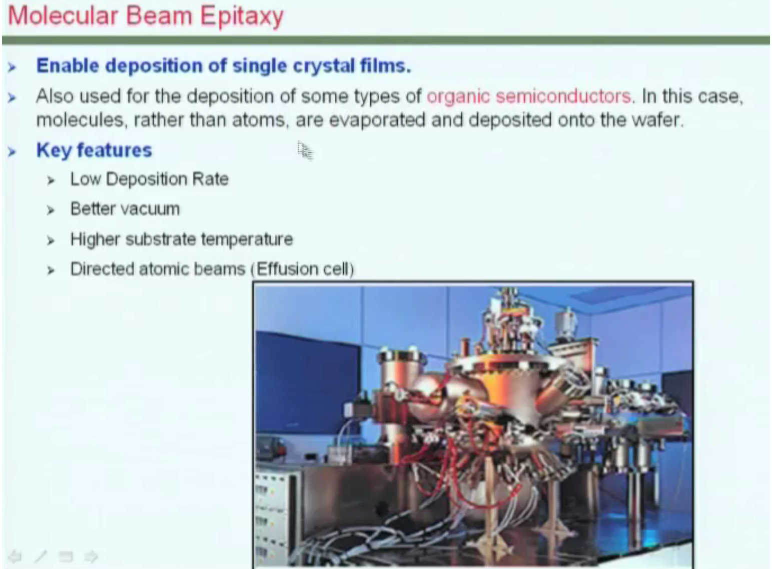

Then one more you know although not very much used in the context of microsystems per say, but even higher control of film characteristics can be obtained by an approach called Molecular beam epitaxy, where you know which is also a very low deposition scheme and as you could see from here a highly complex kind of a system used quite for this purpose as well.

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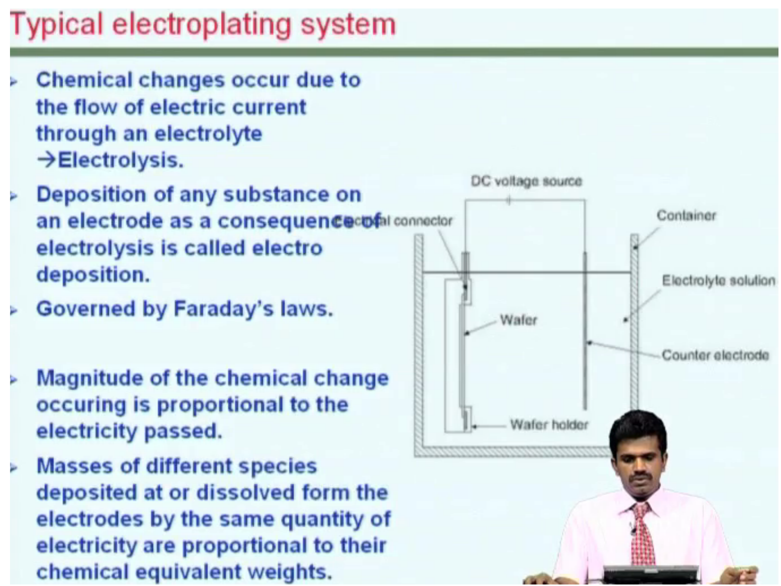

Changing gears one of the simplest approaches and probably the most widely known approaches is based on electroplating, sure you would have heard about this in various other context, what you would require is an electrolyte bar in which you apply a potential between the cathode and

anode and there is this deposition can be resulted in onto the wafer by process known as electrolysis.

It could be used again for a wide range of materials and this process is governed by Faraday's laws and which essentially it would convey that the magnitude of the chemical change is proportional to the current that is pass through this. And the masses of different species deposited you know is based on the electricity that is provided into this scheme.

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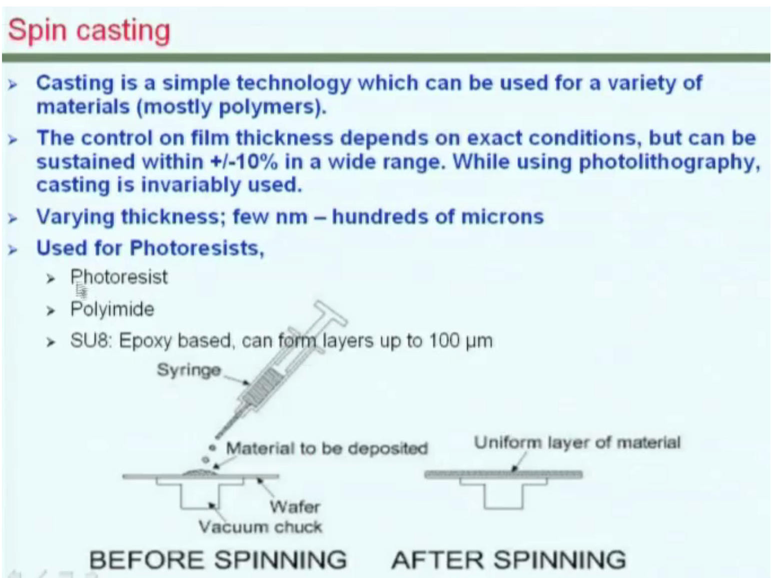

Another simple scheme is based on spin-casting or spin-coating, this is typically used for polymeric materials including photoresist, what we have here is wafer on a vacuum chuck which would be rotated and what we do is we pour a few drops of the materials to be deposited and then spin this at several thousand RPM under control after holding it with vacuum. So when you are spinning the droplets would be spread into a thin film based on the centrifugal force and the surface tension and the rate of RPM are control basically to obtain various thickness films.

And reasonably good uniformity of thickness can be obtained a quick rate by this approach, there could be minor variation in the thickness though. And typically used for polymeric materials such as photoresists, polyimide and even SU8 which is incidentally a very common material becoming a very common material in the for microsystems applications.

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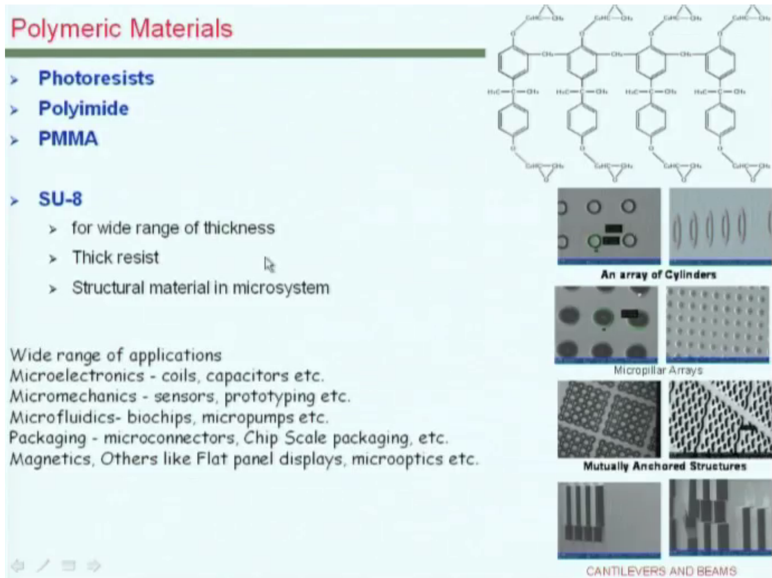

So let us look at some of the polymeric materials that are typically used. Photoresist is a resist material and as you will see soon in another lecture, this is required for the pattern transfer in most instances. Polyimide and PMMA polymethyl methacrylate are very common materials plastic materials, polymeric materials used in various microsystem applications. As I mentioned SU8 is fast becoming a another popular polymeric materials which can have a wide range of thickness.

So when you need a thick resist materials for some reason one can use SU8 and it can also be used as a structural material, it is a polymeric material and the bonding between these different polymeric chains are so strong and hence it has a wide range of applications in microelectronics, micromechanics, microfluidics and even to some extent you know some kind of packaging can be done using this method, in the facility that is here have done a wide range of structures for microsystems using SU8 materials and as you could see from the images here.

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Parameters in Film Quality

- Film composition
- Grain size
- Thickness
- Uniformity
- Step- coverage
- Adhesion
- Corrosion resistance

Let us look at you know how one can determine the quality of the film because it is essential in you know repeating reducing materials and devices and things like that. Composition of the film is obviously important because you know that determine all the other characteristics with. The grain size is also important because that as you seen in the case of polysilicon that decides the overall you know characteristics including the electrical characteristics of the film material.

Thickness can be controlled but yet you know the thickness that can be formed, as well as the uniformity of the thickness that can be you know of the film that can be realized obviously important in realizing the devices. In the context of deposition of films another important parameter is the step-coverage this happens when you are depositing a thin film onto a geometry that is already formed.

And see for example you have a wafer in which some kind of you know structure is formed which has step variation pre-existing, so in this case when we transport materials from a source on to this surface typically a line of site role is valid there, and hence the vertical edges of the structures may not get coated in most of the approaches.

So there are you know approaches such as rotating the wafer holder or you know only to use non-line of site approaches for depositing films when a continuous average over stepped geometries are required. Adhesion is obviously critical in retaining structures attached on to the

surface of the wafer. It is also important that you know the materials that we would chose are corrosion resistance, so that the performance retained over a period of time.

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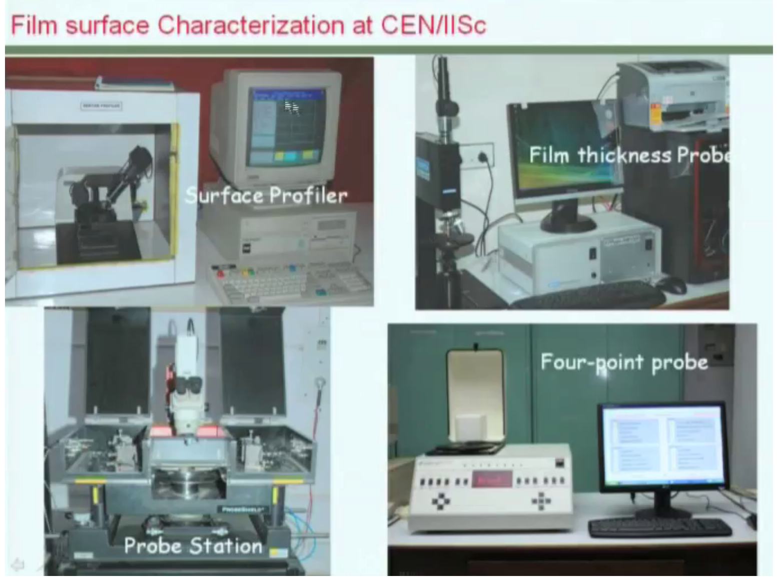

The film characteristic that I have mentioned are evaluated using various instruments that are shown here. The thickness as well as the uniformity of the thickness can be evaluated using a surface profiler, what you see here is a contact type surface profiler, where there is a scribe which would actually move and its position is recorded, and based on deposition of this tip of the scribe one can determine the height of the surface of the film.

There are several optical methods in which a film thickness can be measured, there are electrical techniques in which the film conductivity and other characteristics can be evaluated, there are methods based on probe stations for measuring various other electrical characteristics for example junction FET, the capacitance and things or quantities like that could be measured by using accurately position probes on to the devices that are formed on the wafers.

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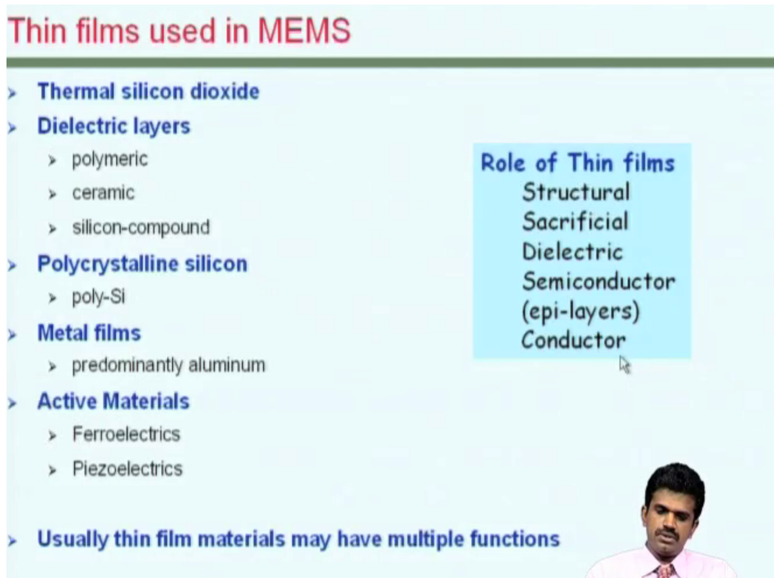

Let us also look at you know the typical thin films that are used in the context of microsystems, as we have seen in the beginning thermal oxides of silicon is a important component in this context. There are various dielectric materials other than silicon compounds that could be used in microsystems and this includes polymeric materials some of those I have already discussed.

For also several ceramic materials and as you have seen this could be deposited using techniques such as the RF sputtering, because these are typically non-conducting materials and also the PLD kind of techniques. And we have seen various chemical deposition schemes for the deposition of silicon compounds. And as I mentioned polycrystalline silicon is another important material in the context of microsystems.

We also would require metallic films all the polysilicon is conducting in many cases that is the conductivity is probably not sufficient, and we would need to look at metallic films and you know various materials including aluminium are used in this context. In the context of smart microsystems we also come across various smart materials typically and they are also called active materials this includes ferroelectrics and piezoelectrics.

These have very interesting characteristics and could be used in several sensors and actuators, once again these are essentially ceramic materials and the same methods that we discussed here which are sputtering or laser based techniques could be used for their deposition as well. And as

you have seen previously these thin films can have multiple functions. You know for example the very common example is the case of polysilicon which could be used as a structural material and also used as a contact material.

So the roles of these thin films multifaceted and you know for various purposes these materials are used in the context of MEMS and microsystems.

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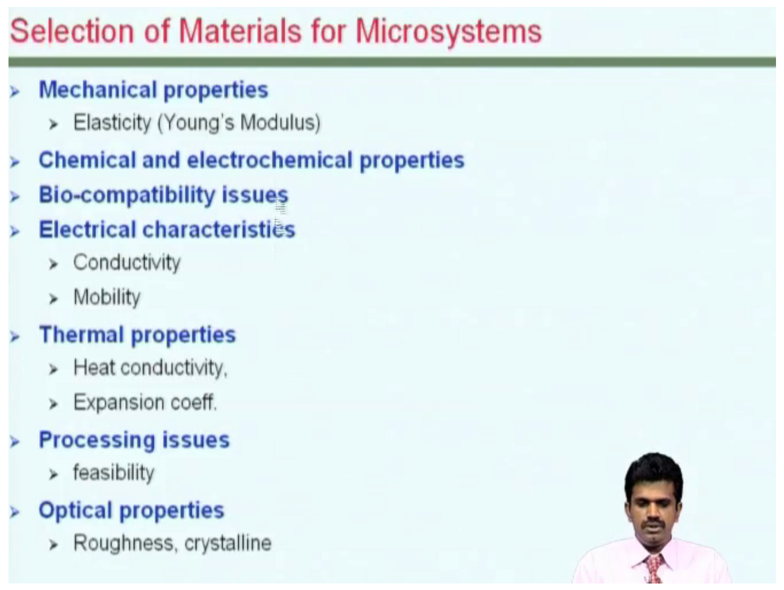

Now we can also look at how these materials are chosen for various applications in microsystems especially in the context of microstructures one would want to primarily look at the mechanical properties, the elasticity, the Young's modulus of the material, and as I mentioned that depends on the material per say as well as how it is deposited. The chemical and electrochemical properties of various materials are relevant.

Bio-compatibility issues have to be looked at you know whether these if you are building let us say system on chip or bio-reactors you know this becomes very critical. Electrical characteristics especially for semiconducting materials one need to look at the mobility and the doping level which would essentially result in the conductivity. Then thermal properties such as the heat conductivity, the expansion coefficient are very critical.

Especially when we have multiple layers of thin films having different materials their expansion coefficient have to be looked at very carefully, so that you know there is no thermal stress between the various layers of films that are formed on the surface. Another critical issue when we are selecting materials is the feasibility of various processing capabilities that are available you know and how we can deposit and pattern these materials and whether the requiring microstructures are available using it.

In optical properties are also important because that plays a major role in determining in many of the other characteristics of the film.

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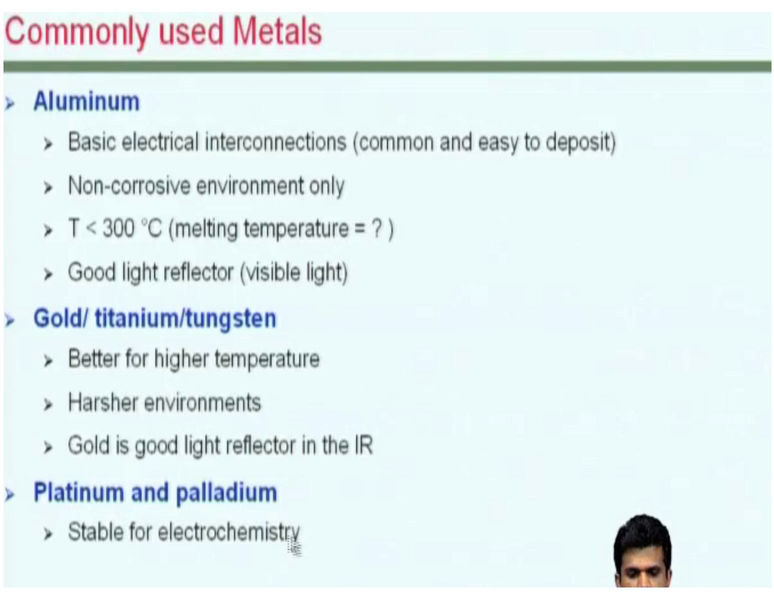

Commonly used metals include Aluminium, Gold along with some other layer below that, there also Platinum and Palladium which are used in several contexts.

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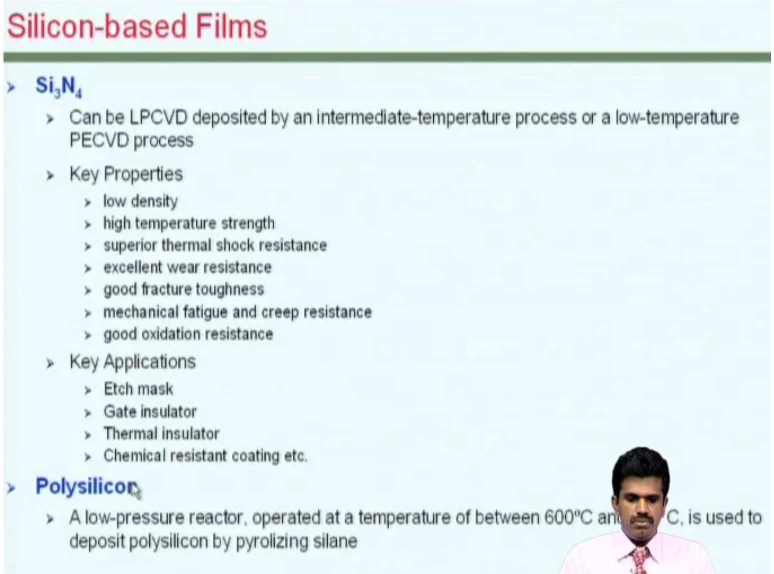

There are several silicon based materials that I have talked to you about for various applications including you know the insulator and as a coating, but more importantly in many cases as an etch mask I will come back and discuss about the use of silicon nitride as an etch mask, when you talk about etching of a silicon wafers. Polysilicon as I mentioned is another important silicon based methods.

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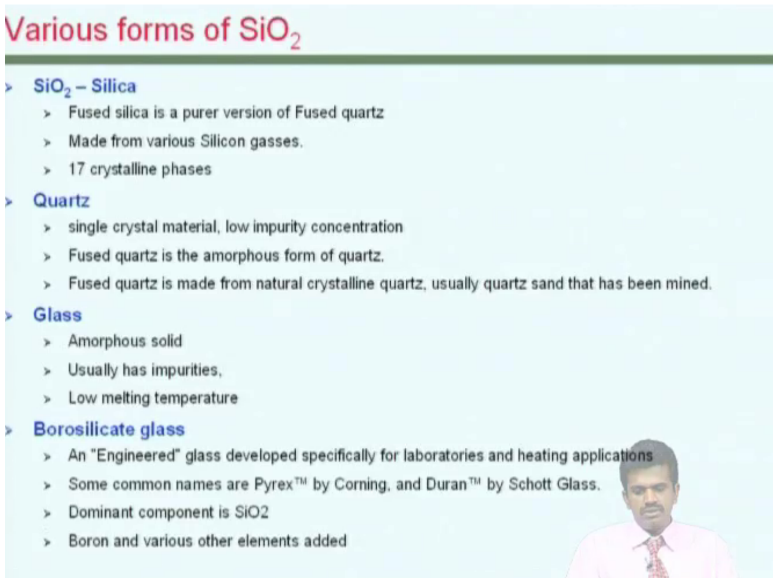

There also several forms of silicon dioxide which are used in microsystems, silicon dioxide can be used as you know as a thin film, it is also used as a substrate material in various context for microsystems. And various silicon dioxide is also the constituent of glass and various forms of glass are also used in microsystems. So what we have seen in this lecture today is a several set of

schemes with which thin films could be deposited and you know a list of thin film materials that could be used in microsystems.

So I hope this could be useful and I would like to stop here and we will discuss about various patterning techniques in subsequent lectures. Thank you.