Introductory Neuroscience and Neuro-Instrumentation
Indian Institute of Science, Bengaluru
Lecture No. 59
Physical Vapour Deposition: Sputtering

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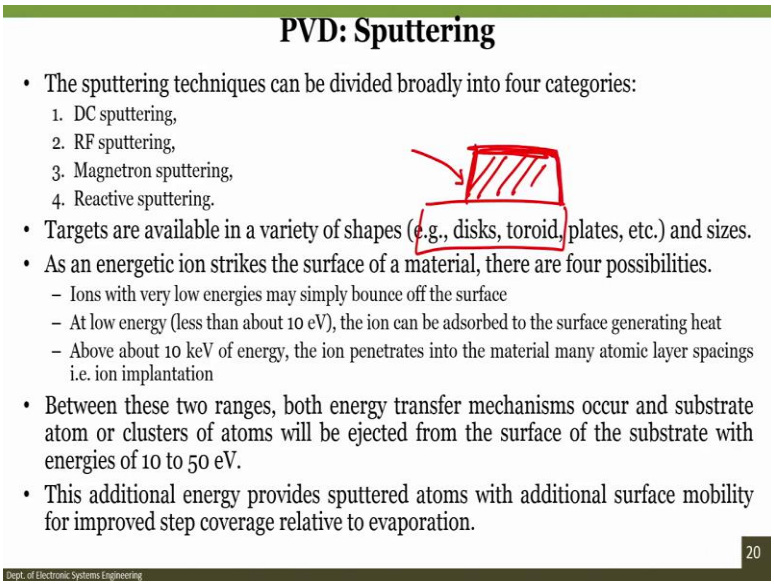

PVD: Sputtering

- The sputtering techniques can be divided broadly into four categories:
  1. DC sputtering,
  2. RF sputtering,
  3. Magnetron sputtering,
  4. Reactive sputtering.
- Targets are available in a variety of shapes (e.g., disks, toroid, plates, etc.) and sizes.
- As an energetic ion strikes the surface of a material, there are four possibilities.
  - Ions with very low energies may simply bounce off the surface
  - At low energy (less than about 10 eV), the ion can be adsorbed to the surface generating heat
  - Above about 10 keV of energy, the ion penetrates into the material many atomic layer spacings i.e. ion implantation
- Between these two ranges, both energy transfer mechanisms occur and substrate atom or clusters of atoms will be ejected from the surface of the substrate with energies of 10 to 50 eV.
- This additional energy provides sputtered atoms with additional surface mobility for improved step coverage relative to evaporation.

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So, as I told you see the slide, the sputtering techniques can be divided broadly into 4 categories, one is DC sputtering, second is RF sputtering, third one is Magnetron sputtering and forth is Reactive sputtering. Targets are available in a variety shapes, examples are disk, toroid, plates, etcetera and of course sizes is as energetic and strikes the surface of a material there are 4 possibilities, one is ions with very low energy may simply bounce on the surface, if not energy, will just bounce off.

At low energy, the ion can be absorbed on the surface generating heat. Above 10 kilo electron volt you will be able to see that the ion penetrates into the material many atomic layer spacing which is the ion implantation and between these two ranges both energy transfer mechanism occurs and substrate atom of clusters of atom will be ejected from the surface of the substrate with energy is about 10 to 15 electron volt is additionally energy provides sputter atoms with additional service mobility to improve the step coverage of the.

So step coverage is, let say, I have a material which is pattern like this, now this is some material and these are substrate when you generally go for thermal view operation, what will happen that this step there is this one will not be covered properly, but in case of sputtering, this step coverage that means this particular step will be covered properly. So, I want to deposit a film on this particular block, so in this sputtering case I will have some kind of proper step coverage mechanism, while in case of the thermal view operation it is the step coverage is poor, so that is advantage of sputtering that improve step coverage.

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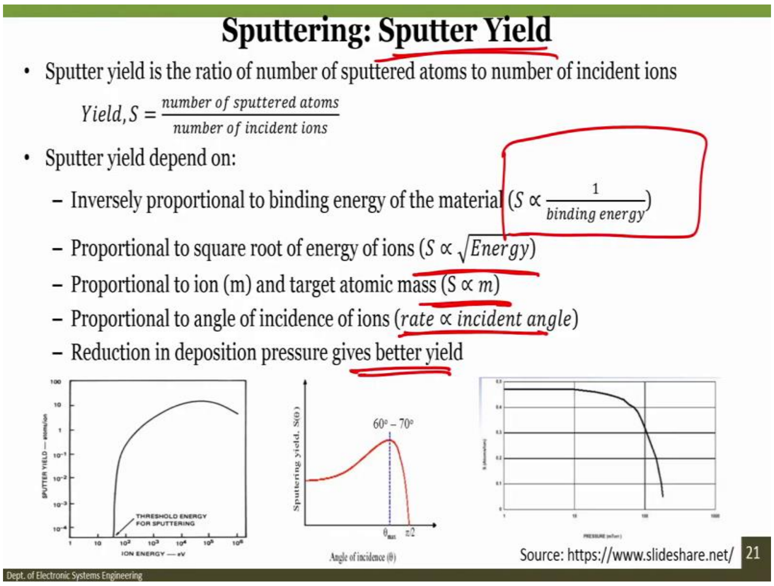

Sputtering: Sputter Yield

- Sputter yield is the ratio of number of sputtered atoms to number of incident ions

$$Yield, S = \frac{number\ of\ sputtered\ atoms}{number\ of\ incident\ ions}$$

- Sputter yield depend on:
  - Inversely proportional to binding energy of the material ($S \propto \frac{1}{binding\ energy}$)
  - Proportional to square root of energy of ions ($S \propto \sqrt{Energy}$)
  - Proportional to ion (m) and target atomic mass ($S \propto m$)
  - Proportional to angle of incidence of ions ($rate \propto incident\ angle$)
  - Reduction in deposition pressure gives better yield

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When you talk about the yield, yield will be number of sputter ions divided by the number of incident ions, that means that how many number of ions are incident onto the target and respectively how many numbers of sputter atoms are ejected. So, that means it is equal to 1 that means you have a better ratio, if is less than 1 also is better but it is also, the yield also inversely proportional to lot of to binding energy, it is proportional to square root of energy of ions and proportional to ion and target atomic mass and finally proportional to angle of incident and reduction deposition pressure gives a better yield.

So, several parameters are responsible for improving your sputter yield, the first one like we discuss is that it is inversely proportional to this sputter yield which is given by S is inversely proportional to the binding energy. Second is it is proportional to the square root of the energy of ions, then it is directly proportional to the atomic mass, then this is directly proportional to the incident angle and finally if you reduce or decrease the deposition pressure, then your yield will be better.

These are some of the schematic correspondings to that and it is very easy to understand from the schematic itself that is angle of incident and sputtering yield how it is decided with ion energy in sputtering yield how it is decided and finally if you have pressure and versus sputtering yield as you can see as you decrease the pressure the deposition rate increases, in case of sputtering yield versus angle of incidence you can see that a 60-70 degree you have a better angle and that pi by 2 that decreases the sputtering yield decreases, at 60-70 you have a better sputtering yield. Finally, when we talk about ion energy, then you already know that it is square root of the sputtering square root of the energy.

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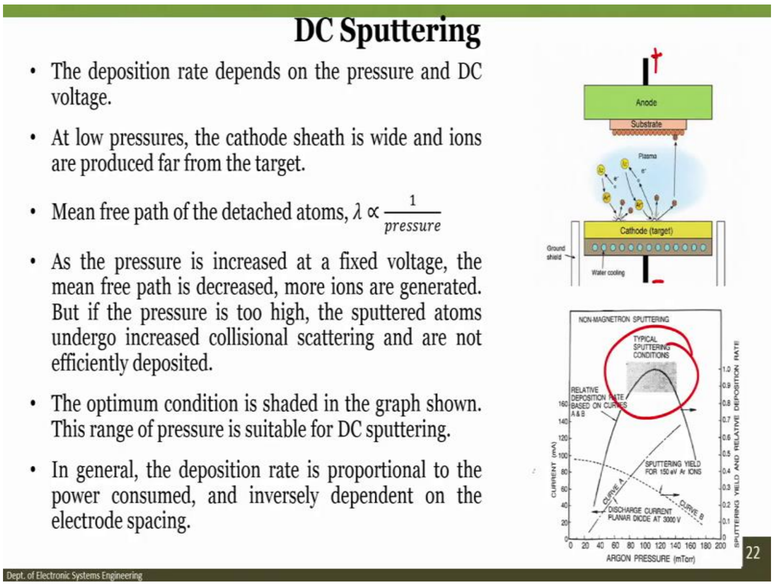

DC Sputtering

- The deposition rate depends on the pressure and DC voltage.
- At low pressures, the cathode sheath is wide and ions are produced far from the target.
- Mean free path of the detached atoms, $\lambda \propto \frac{1}{pressure}$
- As the pressure is increased at a fixed voltage, the mean free path is decreased, more ions are generated. But if the pressure is too high, the sputtered atoms undergo increased collisional scattering and are not efficiently deposited.
- The optimum condition is shaded in the graph shown. This range of pressure is suitable for DC sputtering.
- In general, the deposition rate is proportional to the power consumed, and inversely dependent on the electrode spacing.

So, let us quickly see 3 sputterings or 4 sputtering method, the first one is your DC sputtering. In DC sputtering you have an anode which is positive, you have a cathode which is negative and then there is a ground shield of course and water cooling because there will be generation of heat. And now either you put the target on the top or you can put target on the bottom, it does not matter, the target is generally at the cathode is negative and then substrate is positive the at low pressure the cathode shield is wide and ions are produced from the target, mean free path of the detached atom is inversely proportional to the pressure.

Mean free path is given by Lambda, as the pressure is increased at fixed voltage, the mean free path is decreased as you know because if the pressure is increased means vacuum is decreasing, if vacuum is decreasing that means from 10 raise to minus 5 it comes to 10 raise to minus 1, then the pressure is decreased, if the pressure is increased. If the pressure is increased, then and what happens is that mean free path would be poor and more ions are generated with the pressure is too high this sputter atoms undergo increase collagen scattering and are not efficiently deposited.

The optimum condition is shaded in the graph which is here this is optimal condition that is how much current should be applied versus how much argon pressure should be there, if we increase argon pressure and you keep it around 100 to 140, then you have a maximum sputtering parameter in this case of non magnetron sputtering, we are not talking about magnetron sputtering this is just DC sputtering can be DC magnetron sputtering also can be RS sputtering RF magnetron sputtering as well. So, in general deposition it is proportional to the power consumed and inversely dependent on the electrode spacing. So, that means that if I reduce spacing between this, deposition will be higher, if I increase it, deposition will be lower.

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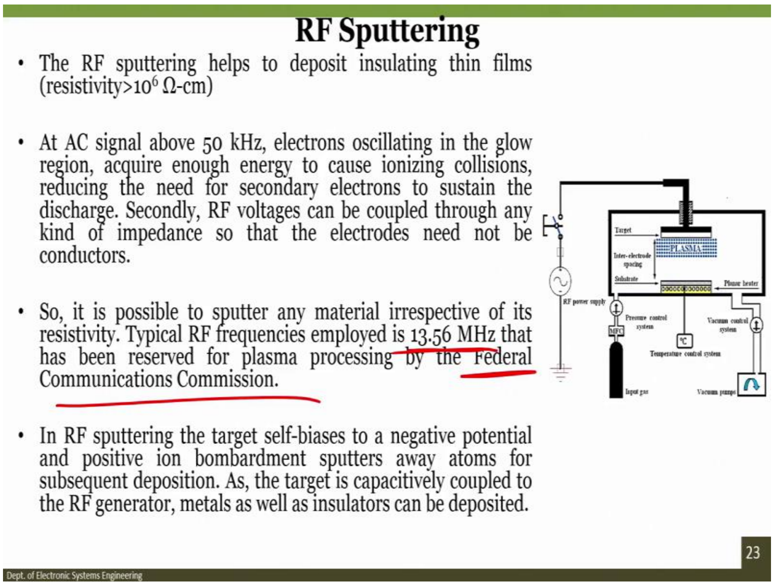

RF Sputtering

- The RF sputtering helps to deposit insulating thin films (resistivity>10^6 Ω-cm)
- At AC signal above 50 kHz, electrons oscillating in the glow region, acquire enough energy to cause ionizing collisions, reducing the need for secondary electrons to sustain the discharge. Secondly, RF voltages can be coupled through any kind of impedance so that the electrodes need not be conductors.
- So, it is possible to sputter any material irrespective of its resistivity. Typical RF frequencies employed is 13.56 MHz that has been reserved for plasma processing by the Federal Communications Commission.
- In RF sputtering the target self-biases to a negative potential and positive ion bombardment sputters away atoms for subsequent deposition. As, the target is capacitively coupled to the RF generator, metals as well as insulators can be deposited.

RF sputtering, so in case of RF sputtering again you know that instead of DC you are applying a RF supply and there is a mass flow controller through which you can control the argon gas, the vacuum through which you can create the vacuum again you have your substrate and have your target and then there is a generation of plasma when you insert the argon gas.

See the principal remains same, only the way to the bombard the argon gas on to the target here it will be different because here we are using the RF sputtering method. The advantage of this sputtering method is it can be used very effectively for depositing insulating thin films or the films which are having greater than 10 raise to power 6 ohms centimetre resistivity, you understand the difference between resistance, resistivity, sheet resistance.

So, R rho and what is sheet resistance, how it is given, what is unit of it? Ohm centimetre, so this again very very very simple things but we do not take it further, we do not know the difference between resistance and resistivity, we even do not know how the resistance can be changed, for the unit of resistance? Of course we know it is ohms. How the, if I increase the length, what will happen to resistance? If I decrease the thickness, what will happen to the overall restivity of the material? Can resistivity of every metal would be different or it is same?

See of course it is different, but the point is very basic questions are generally asked in the interview process to understand how good your basics are, of course with the applications. So, have very strong basics, that is my point that you need to understand the difference between resistivity, resistance, piezoelectric effect, piezoresistive effect, Ohm’s law, Richardson law, thermoionic effect, how it is governed? So, this very very simple thing, cosine law.

So, a AC signal above 50 kilo hertz electron oscillating in the glow region acquire enough energy to cause ionizing collisions, reducing the need for secondary electrons and secondary RF voltage can be coupled through any kind of impedance so that electrodes need not be conductors, that means that we do not have to have electrodes that can be conductors because here we can, we are using the RF energy. Also it is possible to sputter any material irrespective of its resistivity, why? Because typically RF frequency employed about 13.56 megahertz that has been reserved for plasma processing by Federal Communications Commission which is FCC.

So, this is reserved, this is reserved for plasma processing which is your 13.5 megahertz generally you will find in RF sputtering system this is a frequency that people use. Now in RF sputtering the target self-biases to negative potential and positive ions bombards away atoms from the subsequent deposition as the target is capacitively coupled to the RF regenerator, metals, as well as insulators, can be deposited.

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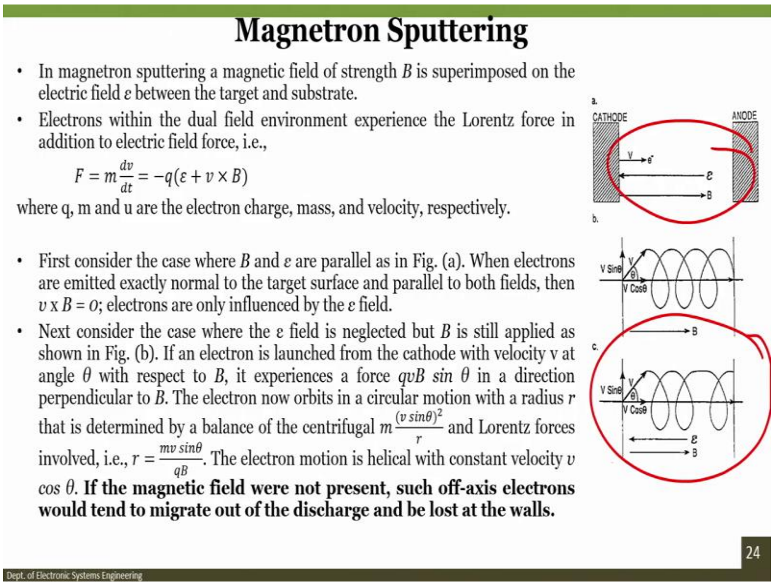

Magnetron Sputtering

- In magnetron sputtering a magnetic field of strength B is superimposed on the electric field ε between the target and substrate.
- Electrons within the dual field environment experience the Lorentz force in addition to electric field force, i.e.,

$$F = m\frac{dv}{dt} = -q(\varepsilon + v \times B)$$

where q, m and u are the electron charge, mass, and velocity, respectively.

- First consider the case where B and ε are parallel as in Fig. (a). When electrons are emitted exactly normal to the target surface and parallel to both fields, then $v \times B = 0$; electrons are only influenced by the ε field.
- Next consider the case where the ε field is neglected but B is still applied as shown in Fig. (b). If an electron is launched from the cathode with velocity v at angle θ with respect to B, it experiences a force $qvB \sin\theta$ in a direction perpendicular to B. The electron now orbits in a circular motion with a radius r that is determined by a balance of the centrifugal $m\frac{(v \sin\theta)^2}{r}$ and Lorentz forces involved, i.e., $r = \frac{mv \sin\theta}{qB}$. The electron motion is helical with constant velocity $v \cos\theta$. **If the magnetic field were not present, such off-axis electrons would tend to migrate out of the discharge and be lost at the walls.**

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So, the advantage of RF sputtering were the following. Now if you talk about magnet and magnetron sputtering what you see here is that in a magnetron sputtering a magnetic field of strength B is superimposed on the electric field between the target and the substrate. So, when you have your magnet, then then it will be superimposed onto this electric field as you can see the electrons with dual field environment which is a given by Lorentz force, Lorentz force you already know which is given by F = m dv/dt = - q (ε + v *B) where q, m and mu are the electron charge and mass and velocity respectively.

The first, let us consider the case where (magnet) magnetic field and electric field are parallel as shown in figure a which is shown here, when electrons are emitted exactly normal to the target surface and parallel to both the fields, then what will happen? When you see the mu into into B will become equals to 0, all electrons around influenced by the electric field. See, when you have this equals to 0 that means what is the role only electrons are responsible for the field or influencing the field.

Now if we consider the case where electric field is neglected but only magnetic field is still applied as shown in figure b, which is here, what will happen? The electron is launched from cathode with velocity v at a angle theta with respect to be it experiences a force which is given by this equation in a direction perpendicular to the magnetic field. And what will happen if that is the case?

The electron now orbits in circular motion like this it keeps onorbiting a circular motion with radius r that is determined by centrifugal and Lorentz force is given by these equations and electrical electron motion is helical with constant velocity which is given by this equation if the magnetic field were not present such off axis electron would tend to migrate. Now here we are kind of of managing the electron to be within the certain region and that is why the deposition rate would increase.

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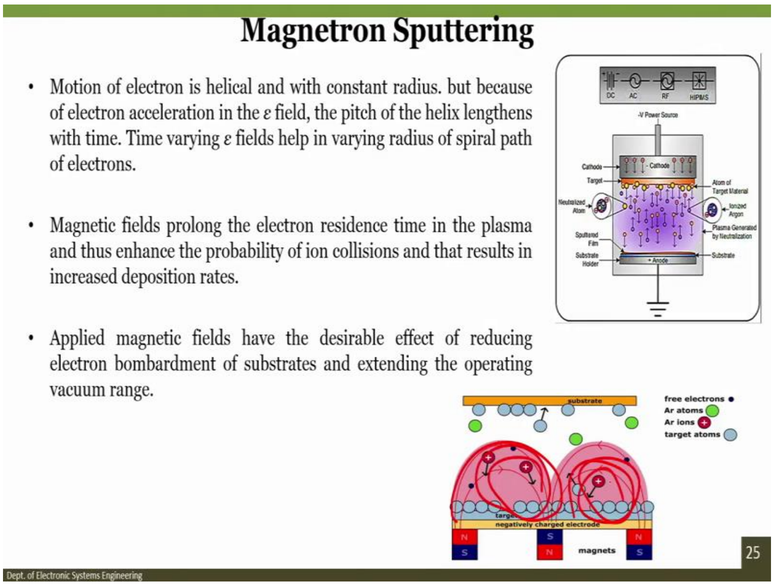

Magnetron Sputtering

- Motion of electron is helical and with constant radius. but because of electron acceleration in the ε field, the pitch of the helix lengthens with time. Time varying ε fields help in varying radius of spiral path of electrons.
- Magnetic fields prolong the electron residence time in the plasma and thus enhance the probability of ion collisions and that results in increased deposition rates.
- Applied magnetic fields have the desirable effect of reducing electron bombardment of substrates and extending the operating vacuum range.

Further, if you see the magnetron motion of electron is helical and with respect to radius but because of the acceleration of a magnet, a electric field the pitch of helix pendants with time and because the pitch will send them with time, what will happen? That will be more bombardment of the ions on to the target resulting in a disclosing of atoms faster. When you have higher dislodging of atoms, your deposition rate increases, the deposition rate improves.

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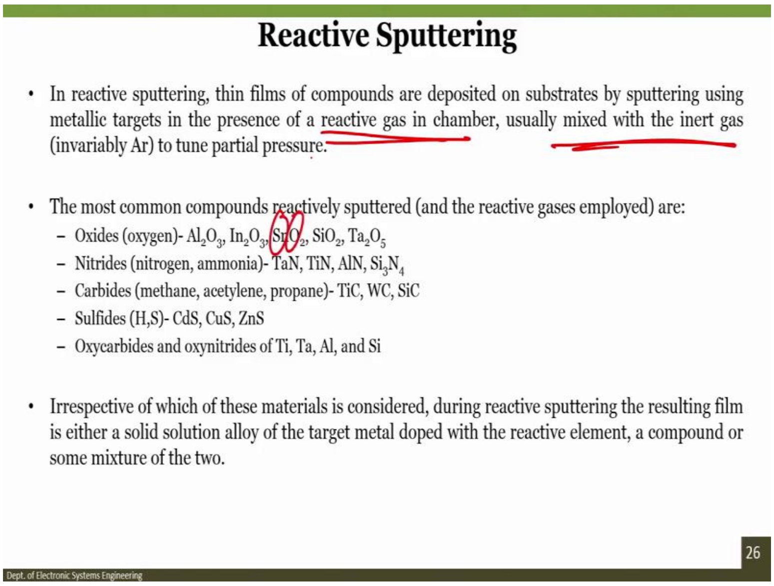

Reactive Sputtering

- In reactive sputtering, thin films of compounds are deposited on substrates by sputtering using metallic targets in the presence of a reactive gas in chamber, usually mixed with the inert gas (invariably Ar) to tune partial pressure.
- The most common compounds reactively sputtered (and the reactive gases employed) are:
  - Oxides (oxygen)- Al_2O_3, In_2O_3, SnO_2, SiO_2, Ta_2O_5
  - Nitrides (nitrogen, ammonia)- TaN, TiN, AlN, Si_3N_4
  - Carbides (methane, acetylene, propane)- TiC, WC, SiC
  - Sulfides (H,S)- CdS, CuS, ZnS
  - Oxycarbides and oxynitrides of Ti, Ta, Al, and Si
- Irrespective of which of these materials is considered, during reactive sputtering the resulting film is either a solid solution alloy of the target metal doped with the reactive element, a compound or some mixture of the two.

So, now let us go to last one which is a reactive sputtering. In reactive sputtering, thin films of compounds are deposited, so not only just one film but multiple films you can deposit compounds can be deposited, for example if you want to deposit aluminium oxide or you want to deposit indium oxide or tin oxide or indium tin oxide or silicon dioxide or tentanium nitrite, titanium nitride, aluminium nitride, silicon nitride or you want to deposit titanium carbide, you want to deposit copper sulphate, zinc sulphate you want to deposit oxycarbide like a titanium, tantalum aluminium and silicon all these things are possible if we go for reactive sputtering.

Why? Because on reactive sputtering thin films of compounds are deposited by sputtering using metallic targets in presence of reactive gas in chamber usually mixed with the inert gas and irrespective of which of this material is considered using reactive sputtering the resulting film is either solid solution alloy of the metal doped with reactive element, a compound or a some mixture of two. So, either it can be just that this is a mixture or it is alloy or it is a compound.

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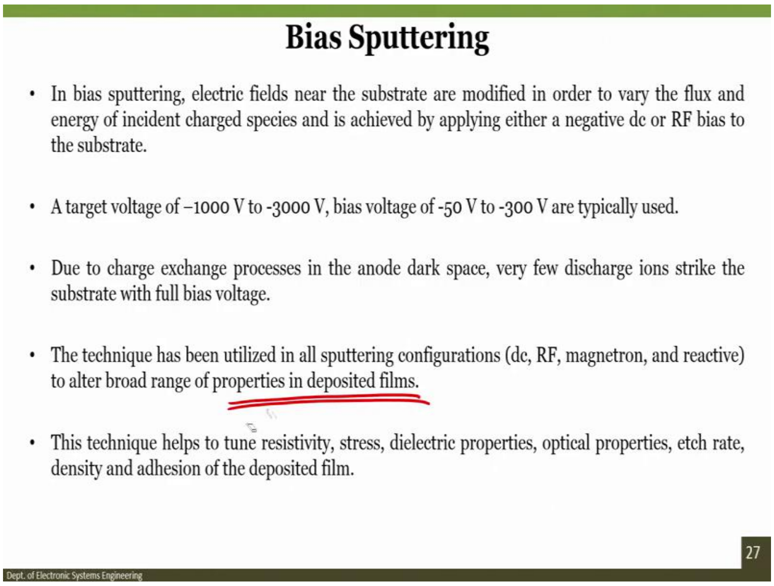

Bias Sputtering

- In bias sputtering, electric fields near the substrate are modified in order to vary the flux and energy of incident charged species and is achieved by applying either a negative dc or RF bias to the substrate.
- A target voltage of –1000 V to -3000 V, bias voltage of -50 V to -300 V are typically used.
- Due to charge exchange processes in the anode dark space, very few discharge ions strike the substrate with full bias voltage.
- The technique has been utilized in all sputtering configurations (dc, RF, magnetron, and reactive) to alter broad range of properties in deposited films.
- This technique helps to tune resistivity, stress, dielectric properties, optical properties, etch rate, density and adhesion of the deposited film.

So, in a bias sputtering electric fields near the substrate are modified in order to vary the flux, it is a game of improving the flux, modifying the flux, modifying the magnetic field, modifying the electric field and to improve the way you dislodge the atoms. So, a target voltage of about minus 1000 to minus 3000, while a bias voltage of minus 50 to minus 300 is applied. Due to charge exchange processes in anode dark space very few discharge ions strike the substrate.

The technique has been utilised in all sputtering configuration, that is bias sputtering is used whether you use DC, RF, magnetron, or reactive sputtering to alter broad range of properties of the deposited film. Depending on the field that you want to deposit the bias voltage and the target voltage are modified. This technique helps to tune resistivity, stress, dielectric properties, optical properties, so people who go and understand the thin-film physics and thin film electronics and thin film deposition techniques, they had to play with this particular parameter, how we can improve the stress of the film?

How can change the dielectric properties of the film? How we can improve the optical properties of the film? How you can tune the resistivity of the film? So, if you want to do that, then you have to change the parameter like bias voltage like your target voltage. So, this sputtering helps you to change those parameters and that is why it is good technique to improve the overall the quality of the film.

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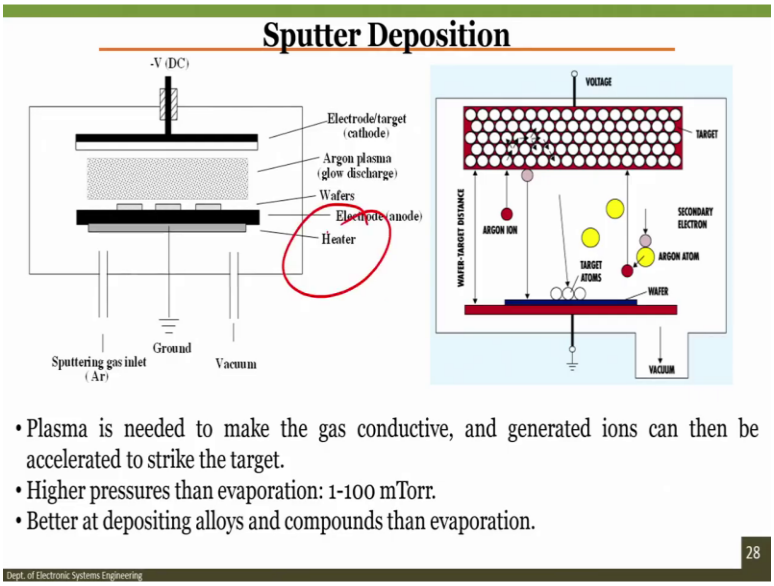

Sputter Deposition

- Plasma is needed to make the gas conductive, and generated ions can then be accelerated to strike the target.
- Higher pressures than evaporation: 1-100 mTorr.
- Better at depositing alloys and compounds than evaporation.

So, if you see the slide, it is same thing that we are discussing from previous slides, that sputter deposition, you either go for DC sputtering and here you can see there is a heater, the electrode wafers, now what is the role of this heater? You see, when you have a heater then the when you deposit the atoms onto these substrate, they can aligned it. So, instead of getting a amorphous film we can get a polycrystalline film, this advantage of heating the film during deposition are to is to improve the crystaline property of the film.

Now plasma is there to make the gas conductive and generate ions can be then accelerated to strike the target we know that, higher pressure, then evaporation about 1 to (1000) 100 milli torr better at depositing alloys and compounds than the thermal evaporation.

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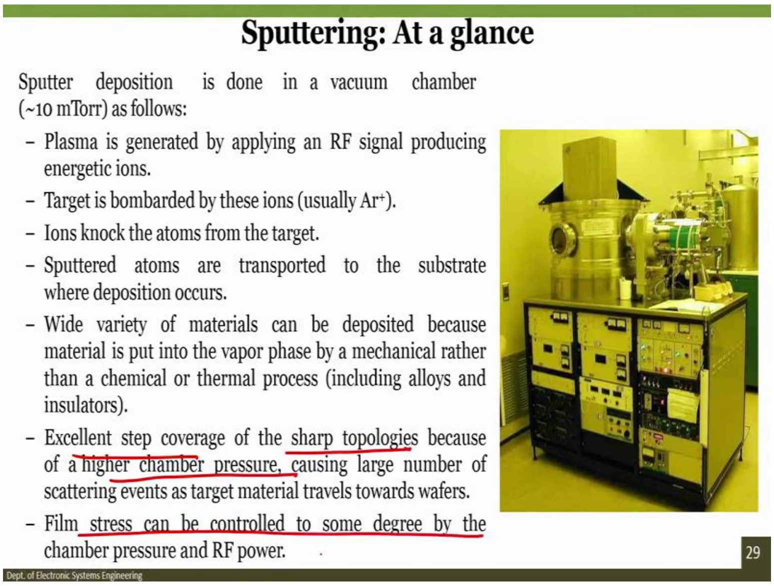

Sputtering: At a glance

Sputter deposition is done in a vacuum chamber (~10 mTorr) as follows:

- Plasma is generated by applying an RF signal producing energetic ions.
- Target is bombarded by these ions (usually Ar^+).
- Ions knock the atoms from the target.
- Sputtered atoms are transported to the substrate where deposition occurs.
- Wide variety of materials can be deposited because material is put into the vapor phase by a mechanical rather than a chemical or thermal process (including alloys and insulators).
- Excellent step coverage of the sharp topologies because of a higher chamber pressure, causing large number of scattering events as target material travels towards wafers.
- Film stress can be controlled to some degree by the chamber pressure and RF power.

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And if you see this is, this is the system, it looks like the which is the RF sputtering system and do not worry about the complexity of system how it looks, when you operate it, it is not that difficult. Of course, you want to design one you need to take care of lot of other parameters but fortunately you will just operate the system you are not in the designing of this particular system but you should know each and every part of this system.

So, for example like I said QCM, how we know the pressure? So, for the pressure which is less than 10 to the power minus 3 torr, we can use pirani gauge for pressure which are about 10^{-3} torr which is minus 4, minus 5, minus 6, minus 7 you have to go for penning gauge, so what are those gauges? What are the principle of using those gauges? On which principle does gauges are operated these all things we have to understand but anyway there is a totally different topic do not worry about it, you understand the sputtering is a way to deposit a film.

And inspite, the deposition is done vacuum chamber you already know that, rest of the points we all had already discuss, so I do not want to re-discuss these thing except that you can see that there is an excellent step coverage, sharp topologies because of a higher chamber pressure and film stress can be controlled to some degrees by chamber pressure and the RF power, so that is very important parameters.

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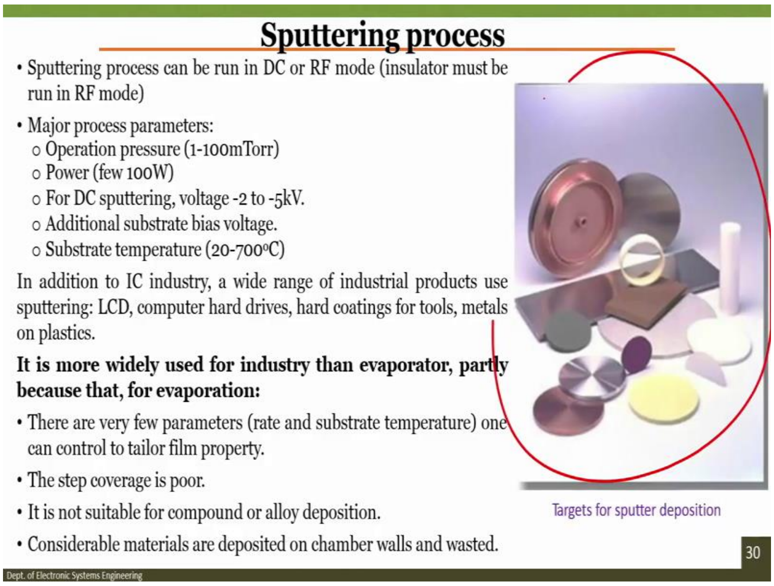

Sputtering process

- Sputtering process can be run in DC or RF mode (insulator must be run in RF mode)
- Major process parameters:
  - Operation pressure (1-100mTorr)
  - Power (few 100W)
  - For DC sputtering, voltage -2 to -5kV.
  - Additional substrate bias voltage.
  - Substrate temperature (20-700°C)

In addition to IC industry, a wide range of industrial products use sputtering: LCD, computer hard drives, hard coatings for tools, metals on plastics.

It is more widely used for industry than evaporator, partly because that, for evaporation:

- There are very few parameters (rate and substrate temperature) one can control to tailor film property.
- The step coverage is poor.
- It is not suitable for compound or alloy deposition.
- Considerable materials are deposited on chamber walls and wasted.

Targets for sputter deposition

Now if I want to further understand, then you can see that these are the some of the targets that are used for sputter deposition and the major operating parameters as now you already know would be your operating pressure or it can be power this is sputtering voltage, substrate bias, susbtrate temperature and in addition twice in the industry of wide range of industrial products are using sputtering, for example LCD liquid crystal display, your computer hard drives, if you see the CD you will see the coating and their coating is using this sputtering you will see that hard coding for tools, metals on plastics and many and many more.

Of course, it is more widely used for industry than evaporator, in industry sputtering is preferred over evaporator partly because for the evaporation there are very few parameters that one can control, second their step coverage is poor, third, it is not suitable for compound or alloy and finally consider materials are deposited on the walls and wasted in case of sputtering that is not the case.

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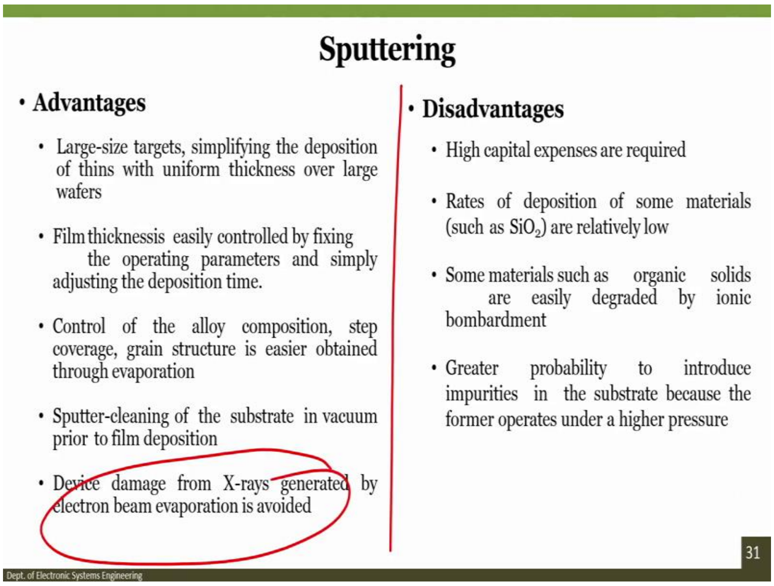

Sputtering

- Advantages
  - Large-size targets, simplifying the deposition of thins with uniform thickness over large wafers
  - Film thicknessis easily controlled by fixing the operating parameters and simply adjusting the deposition time.
  - Control of the alloy composition, step coverage, grain structure is easier obtained through evaporation
  - Sputter-cleaning of the substrate in vacuum prior to film deposition
  - Device damage from X-rays generated by electron beam evaporation is avoided
- Disadvantages
  - High capital expenses are required
  - Rates of deposition of some materials (such as SiO_2) are relatively low
  - Some materials such as organic solids are easily degraded by ionic bombardment
  - Greater probability to introduce impurities in the substrate because the former operates under a higher pressure

So, if I want to consider advantages and disadvantages of sputtering system I can consider this advantages, first is that in sputtering a large size target can be spotted with a uniform thickness over large wafers, film thickness can be controlled control of alloy composition, step coverage, grain structure can be done. Sputter cleaning of the substrate in vacuum prior to film deposition is possible, device damage from x-ray generated by electron beam is evaporated, is avoided because in case of electron beam if I incident an electron beam there is a generation of X rays, we know it, right? In physics.

So, if I want to avoid those X-rays then I would go for sputtering, however like every system sputrtering also has some limitations, the first limitations is expensive, the second limitation is that the deposition rate for some material like silicon dioxide it is extremely low, third limitation is material such as organic solids are easily degraded while during the early bombardment and finally , the greater probability to introduce impurities in substrate because of because it operates under a high pressure.

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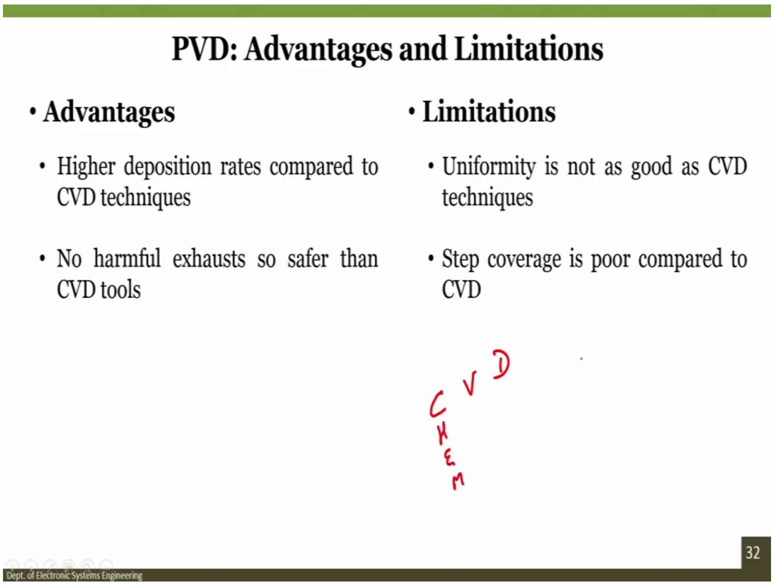

PVD: Advantages and Limitations

- **Advantages**
  - Higher deposition rates compared to CVD techniques
  - No harmful exhausts so safer than CVD tools
- **Limitations**
  - Uniformity is not as good as CVD techniques
  - Step coverage is poor compared to CVD

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So, let us say advantages and disadvantages of PVD. Now, until you know CVD it is very difficult for you to understand how what are the advantages of PVD over CVD, however since we do not required to go in detail about CVD in this course, I will just tell you CVD stands for Chemical Vapour Deposition, chemical vapour deposition. So, there are certain advantages of chemical vapour composition and several disadvantages, the PVD has advantage like high deposition rates compared to CVD and one biggest advantage is there that there are no harmful exhaust.

In chemical vapour deposition, the byproducts are generally exhaust and which are harmful in nature while, the limitation of the PVD compared to CVD is that uniformity in CVD is better in PVD it is not as great as CVD, of course sputtering is better than thermal and e-beam but it is not as good as the chemical vapour deposition and finally, the step coverage of the CVD is better and in the PVD step coverage is poor compared to CVD. Again, if we just compare PVD sputtering is better for the step coverage but if you compare PVD versus CVD, CVD is better for the step coverage.

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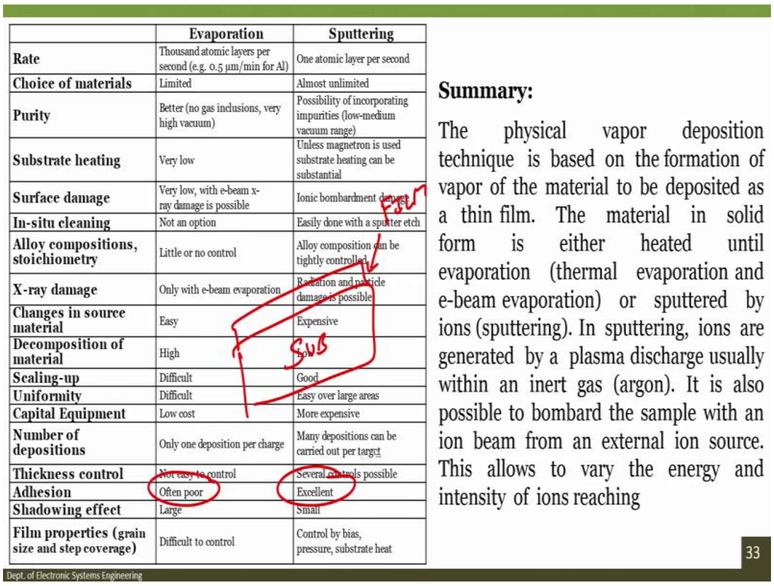

	Evaporation	Sputtering
Rate	Thousand atomic layers per second (e.g. 0.5 µm/min for Al)	One atomic layer per second
Choice of materials	Limited	Almost unlimited
Purity	Better (no gas inclusions, very high vacuum)	Possibility of incorporating impurities (low-medium vacuum range)
Substrate heating	Very low	Unless magnetron is used substrate heating can be substantial
Surface damage	Very low, with e-beam x-ray damage is possible	Ionic bombardment damage
In-situ cleaning	Not an option	Easily done with a sputter etch
Alloy compositions, stoichiometry	Little or no control	Alloy composition can be tightly controlled
X-ray damage	Only with e-beam evaporation	Radiation and particle damage is possible
Changes in source material	Easy	Expensive
Decomposition of material	High	Low
Scaling-up	Difficult	Good
Uniformity	Difficult	Easy over large areas
Capital Equipment	Low cost	More expensive
Number of depositions	Only one deposition per charge	Many depositions can be carried out per target
Thickness control	Not easy to control	Several controls possible
Adhesion	Often poor	Excellent
Shadowing effect	Large	Small
Film properties (grain size and step coverage)	Difficult to control	Control by bias, pressure, substrate heat

Summary:

The physical vapor deposition technique is based on the formation of vapor of the material to be deposited as a thin film. The material in solid form is either heated until evaporation (thermal evaporation and e-beam evaporation) or sputtered by ions (sputtering). In sputtering, ions are generated by a plasma discharge usually within an inert gas (argon). It is also possible to bombard the sample with an ion beam from an external ion source. This allows to vary the energy and intensity of ions reaching

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Finally, can see here if I want to compare the evaporation and sputtering with different parameters, then I can say that even you take about rate, the evaporation is faster when sputtering, the evaporation is slow, choice of materials in evaporation is limited; in case of sputtering you can almost sputter everything, purity is better here in sputtering it is of low or medium because low or medium vacuum range there is a possibility of incorporating impurities, the substrate heating is very low in this case unless you reuse magnetron if the substrate can be substantial.

Surface damage very low but electron beam damage is possible, in this case the possibility of surface damage is because of the ion bombardment, while in In-situ cleaning when thermal view operation is not possible but it can be easily done by sputtering you can clean the chamber by using sputtering itself. Alloy composition little or no control you can in sputtering you can deposit alloys.

Finally, there is X-ray damage is there e-beam in radiation and particle damage is possible but not because the X-ray. Challenge in source material is easy this is expensive as we already have discuss, decomposition of material is low in case of sputtering, scaling up is very good it is difficult in case of the evaporation, uniformity also is difficult in evaporation compare to sputtering because sputter can be used to cover large substrate areas. Number of the position only one portion per charge when in the case of sputtering there can we many depositions.

Of course when the capital equipment, one time instalment cost is more expensive for sputtering over thermally view operation, thickness control not so easy in this case several controls are possible. The adhesion to the, adhesion means what? How good your film is a struct onto the substrate. So, how good your film is adhesive to the substrate, in this case, in the case of sputtering, the adhesion is excellent; while in case of thermal view operation it is poor.

Shadowing effect is large in the case of sputtering, shadowing effect is small and finally you can change the film properties very easily because we have control, it can be controlled by bias, we have a pressure to change weather it is a substrate to heat, there is a bias voltage and target bias also is different. So, we can change multiple properties of the film while using sputtering while in case evaporation it is difficult to control.

So, if you want to summarise the the PVD techniques then how you can summarise that you can say that PVD is a technique which is based on the formation of vapour of the material to be deposited as a thin-film. Finally, the material can be in solid form which is generally heated until it evaporates, either you use thermal evoporation or you use e-beam evaporation or you can sputter it using the ions in this case we generally use argon gas to bombard the target and the sputtering ions are generated by plasma discharge usually within an inert gas like I said which is argan.

It is also possible to bombard the sample with a ion beam from an external ion source. So, finally this will allow to vary the energy and also ions reaching this target or the substrate. When ions reaches the target, the atoms dislodges and falls on the substrate and so how we can change the thickness of the film. So, the idea here is that, how you can deposit film onto a substrate using physical vapour deposition techniques, this is what we have covered in last 2 modules including this one.

So, let us see now as an example in the next module how to take a substrate, grow oxide, deposit of film using one of these techniques, pattern it to form a patch that can be used for several applications. We will take this in the next module, till then you look at this module once again, understand the concept, if you do not understand anything, please ask us through the NPTEL forum, we will, I will also have one more video where we will show it you how to operate a electron beam and a thermal evaporation system that we have in our clean room which is class 1000 cleanroom in the department.

And that will little bit help you to understand further of how a film is deposited onto a substrate. We will show you that as an experimental laboratory module and you will be able to understand it further in a better way, till then you take care, do let us know if you have any trouble through the forum and I will see you in next module which will be the last module on the instrumentation side covering the photolithography but using the PVD techniques. Till then you take care, I will see you in next class, bye.