Surface Engineering of Nanomaterials
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Lecture - 27
Sputtering Techniques

Hello, today we are going to start our new lecture on sputtering techniques. In our last lecture, lecture number 26, we have discussed about the different types of deposition techniques. So, in this particular lecture we are going to introduce the special technique which is called the Sputtering Techniques. So, before going to start that sputtering techniques first let us know that what is the sputtering what the method tells us actually.

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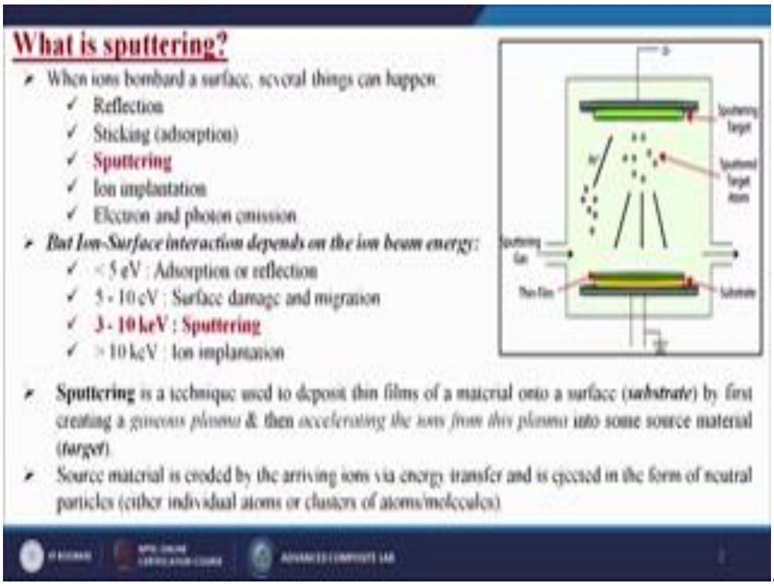

Sputtering is a one kind of methods in where the ions bombard on a surface, several things can happen, reflection, sticking or maybe the adsorptions, sputtering, ion implantation, electron and photon emissions. So, when all this is taking place onto the material surface, just in this particular topic, we are going to discuss only about the sputtering. So, from this particular figure we can understand that there is one vacuum chamber, then in that vacuum chamber we are injecting some kind of sputtering gas generally the argon gas we are going to use, in this particular case as a inert gas that argon actually, it is divided into ion, argon ion that ion is heating onto the sputtering target, then when it is bombarding onto the sputtering target, then it is that sputtering target is releasing certain kind of ions or maybe the atoms and which is directly coming onto the substrate and making a thin film on top of that.

So, before going to know about the sputtering techniques let us know that what type of energy is required for doing this sputtering, but ion source ion surface interaction depends on the ion beam energy. So, as I already discussed that we are generating certain kind of ion energy that energy is heating our sputtering target by which that sputter target atom is coming.

If the ion energy is less than 5 electron volt, it is known as the adsorptions or the reflection process if it is various from 5 to 10 electron volt then it will create the surface damage and migrations if it will lie in between the 3 to 10 kilo electron volt that process is known as the sputtering techniques and if it is more than 10 kilo electron volt, it is known as the ion implantations. So, here the main criteria is that energy that how much energy I am giving directly to the target or maybe the sputtering material so that it can release the atoms and it can deposited onto the substrate.

Sputtering that definitions is a technique used to deposits thin films of a material onto a subs surface, generally we are calling it as a substrate by first creating a gaseous plasma and then accelerating the ions from this plasma into some source materials is called the target. Source materials is eroded by the arriving ions by energy transfer and is ejected in the form of neutral particles either individual atoms or clusters of atoms and molecules. So, what I am already discussed that here we are making that argon ion then that argon ion is heating that sputtering target then this kind of neutral atoms, it is directly coming from this sputtering target and it is depositing onto the substrate like a thin film.

First we have to know that what are the fundamental things that are working behind the sputtering techniques.

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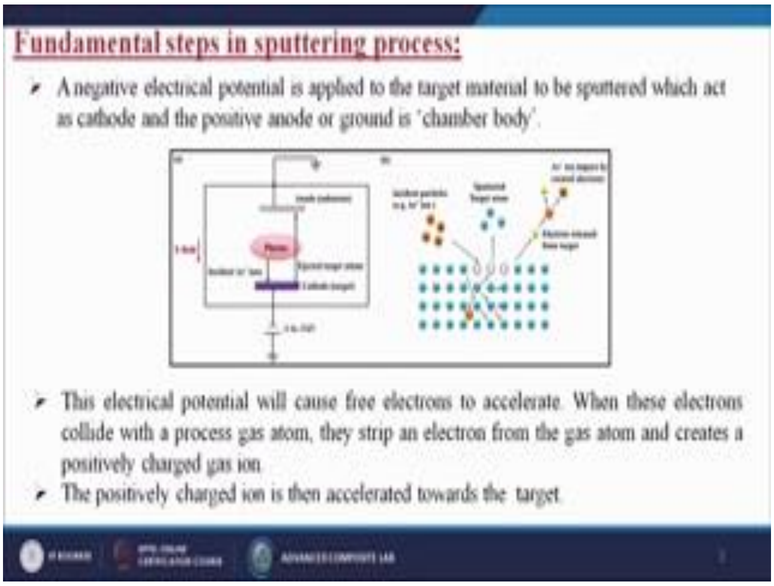

A negative electrical potential is applied to the target material to be sputtered which act as cathode and the positive anode or ground is the chamber body.

In this particular figure, we can understand that here our anode is known as a substrate, we are having that cathode is target which is grounded and then we are making certain kind of electrical field inside by which we are creating that incident argon ions and which is heating the target substrate materials and then from there which is and heating the target materials and from there are it is creating certain kind of plasma and that plasma is directly heating onto the substrate itself.

In this particular case, we can see that we are having that incident argon particles directly, it is heating onto the sputtering materials then it is releasing the atoms that atoms directly, it is depositing onto the surface, but again that argon plus again it is adsorbing the electrons inside the chambers and then it is becoming that neutral. So, when it is releasing the energy, it is generating certain kind of plasma over there.

So that plasma is directly coming out for as exhaust the electrical potential will cause free electrons to accelerate when these electrons collide with a process gas atoms, they strip an electron from the gas atom and creates a positively charged gas ion, the positively charged ion is then accelerated towards the target. So, from this figure you can understand that here, this is generating the plasma gas over there or maybe the plasma ions over there.

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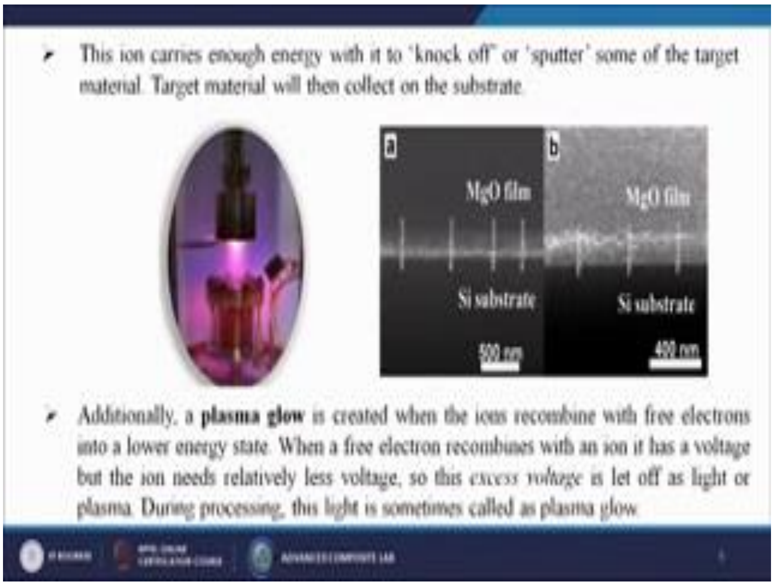

The ion carries enough energy with it to knock off or sputter some of the target material; the target material will then collect on the substrate itself. Additionally a plasma glow is created when the ions recombine with free electrons into the lower energy state. So, as I already have discussed that some argon plus ion which is directly heating those substrates let over the argon ion again, it is adsorbing those electrons and it is became the free electrons into the lower energy state when a free electron recombines with an ion, it has a voltage, but the ion needs relatively less voltage. So, this excess voltage is let off as light or plasma, this known as the plasma. During processing the light is sometimes called as a plasma glow.

The best examples for better understand of these sputtering process is like a pool game. So, you are having some balls and then hitting that balls so that it can hit the target materials and then from that target materials it directly go to the pocket where is nothing, but the substrate materials.

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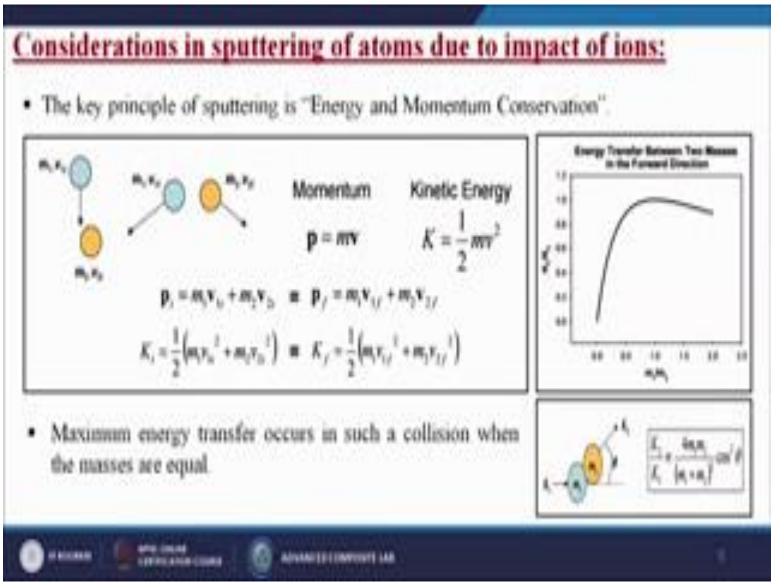

What are the considerations in sputtering atoms due to impact of ions, the key principle of sputtering are energy and momentum conversations.

Here you can see that we have given 2 balls into 2 different colors. So, one is in blue in color and one is in yellow in color, actually the 2 balls means 2 atoms, one atom is the argon plus atoms, another atoms is directly which is coming from the target material. So, these atoms are having certain mass. So, unless and until the mass of these 2 atoms will be equal, the sputtering will be possible. Maximum case, the maximum efficiency we can achieve when the more or less the mass of those atoms will be equal.

From this particular equation, some momentum energy is generating that is p equal to mv and some kinetic energy is generating is called K equal to half mv square. So, these should be the equal one; then maximum energy transfer occurs in such a collision when the masses are equal. So, from this particular case, you can understand that m 1 and m 2 is the ratio of 2 masses of the argon and the target material then when the masses are almost one; that means, masses are almost equal you can find that you are getting maximum energy in this particular zone so; that means, when the masses of the those gases or maybe the molecules will be the same will get the maximum efficiency of the sputtering techniques.

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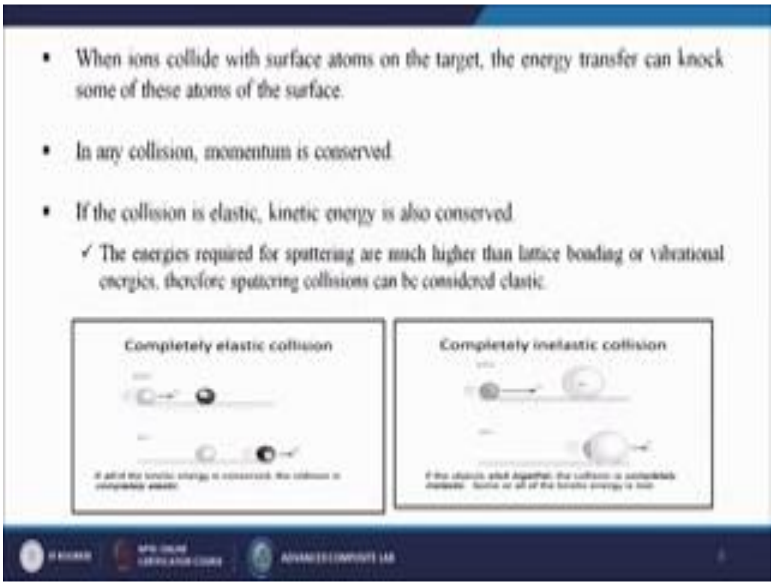

When ion collides with the surface atoms on the target, the energy transfer can knock some of these atoms of the surface. In any collisions momentum is observed, if the collision is elastic, kinetic energy is also conserved, the energies required for sputtering are much higher than the lattice bonding or vibrational energies therefore, sputtering collision can be considered elastic.

Elastic means it is a perfect example of the pool game whatever I have already given so; that means, we are having 2 balls, when the mass of this 2 balls are equal then they will generate the same momentum over there. So, one ball just heat will another ball so that whatever the kinetic energy, it will gain the same kinetic energy will be transferred into the same second ball and the second ball will achieve those kinetic energy and directly it will heat onto the material or maybe it will heat onto the substrate itself.

Here is the examples that where we are getting the complete elastic collisions where we are getting the completely in inelastic collisions. So, in the first cases, we can see the size of these 2 balls means molecules are almost same. So, when these balls are heating this ball, the second ball is getting the same kinetic energy and momentum and it is rushing towards the substrate itself. So, in all are the kinetic energy is conserved the collisions is completely elastic generally we prefer this one for our sputtering techniques.

But when we are talking about the inelastic collisions you can see from this particular figure that mass of these balls is half of the ball mass of the second one. So, here if it is m, it is 2m so your substrate, your target materials molecules atoms mass a twice then the mass of your argon atoms.

What will happen when it will heat? It is having some momentum, but that momentum it needs more, but it cannot generate that kind of momentum because momentum depends upon the m into v, but here the masses half of these. So, when it will heat this material, it will not move. So, in that particular case, what we have to do? We have to either take the same balls or these materials momentum should be higher which is not possible at all. So, in this particular case, what will happen? These targeted argon ions; it will simply stick onto the target materials. So, there will not be any sputtering or maybe the bombardment will be taking place.

If the objects stick together, the collisions is completely inelastic some or all the kinetic energy is lost because it will not transferred from one body to the another body what are the key factors for proper sputtering.

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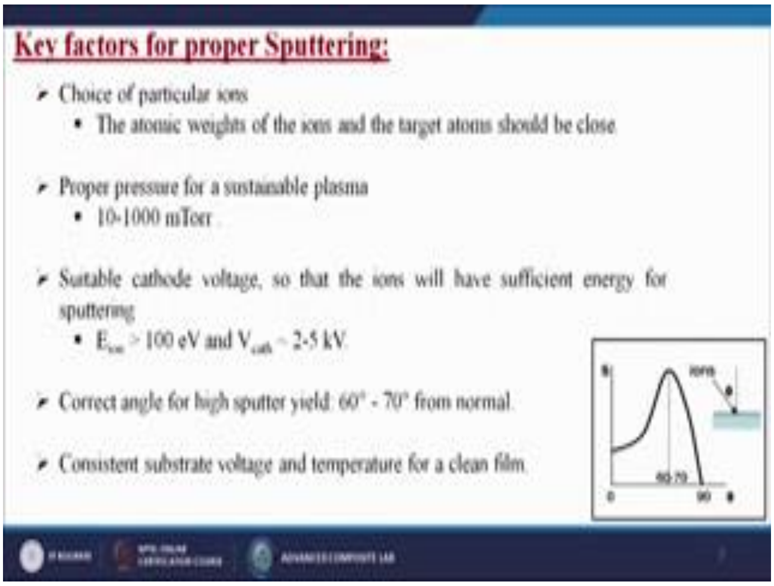

First is the choice of particular ions because we have to know that what ion will heat another molecule or maybe another material and what are the masses of those materials? If the masses of those materials will be equal then you will get the best sputtering materials also or maybe the best sputtering results.

The atomic weights of the ions and the target atoms should be closed proper pressure for a sustainable plasma 10 to 1000 millitorr, you have to maintain inside the chamber suitable cathode voltage so that the ions will have sufficient energy for sputtering e ion is more than 100 electron volt and voltage at the cathode should be various in between 2 to 5 kilovolt. Correct angle for higher sputter yield 60 degree to 70 degree from normal consistent substrate voltage and temperature for a clean film.

Here I will in the next slide, I will discuss about what is the incidental angle, generally we have to follow because I am having this pointer in my hand. So, if simply I will drop this one, it will heat the material directly or may that it will be heat the floor directly. So, what will happen? What type of the molecules are there simply that molecules will go inside it or maybe it will be closely packed, but if I will through it like this way into some angles. So, what will happen? It will heat into some incidental angles so that some molecules from the target it will directly come and it will deposit onto the substrate itself.

In this particular case, you can see that when we are following that 90 degree means directly the incidental angle is perpendicular. So, you are getting totally 0 values, but if you are following the 60 to 70 degree then your efficiency is the higher means bombardment or maybe the releasing of that atoms from that target is higher. That is known as the sputter yield.

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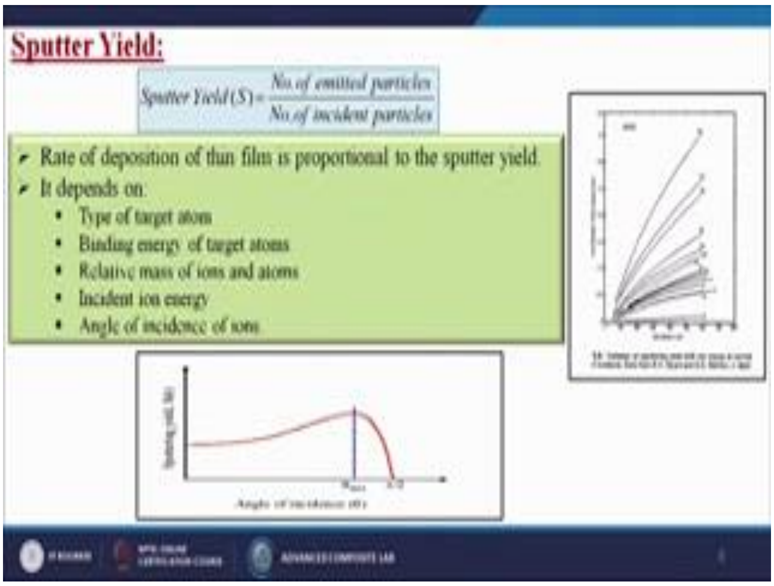

Sputter yield is nothing but the number of a emitted particles, number of the incident particles means how many argon atoms I am using to releasing the target atoms. If so, I will release only one argon atoms and it will release 10 argon atoms. So, the sputtering yield will be 10 so; that means, I am using less energy, but still I am getting the more results.

Rate of deposition of thin film is proportional to the sputter yield, it depends on type of target atoms, what type of atoms, whether it is closely packed or maybe the loosely packed and how much energy it needs to release from the target substrate surface. Binding energy of the target atoms relative mass of ions and atoms incident ion energy angle of incident of ions. So, these all are the key parameters for choosing the sputtering material.

Then from this particular graph, we can see that angle of incidents and the sputtering yield so whatever already I have explained that if it is totally 90 degree; that means, simply it will drop from the top and directly heat to the bottom at that particular case, the sputtering yield is almost 0, but when we are making it around 60 to 70 degree, we are achieving the maximum sputtering yields strength and the right hand side figure; it has been taken from some general paper, it has been made by R V Stuart and K V G K Wehnar. So, they have derived for different materials, how the sputtering yield is varying. So, we are having some kind of ion energy. So, at the 600 ion energy electron volt ion energy so, we are finding that at argon atmosphere the silver is giving the maximum sputtering yield then copper then palladium. So, like this way, it is going to the down.

We have till know discussed about that, what is the sputtering? How we are doing the sputtering? Now our main concern is that why we are going to use these sputtering techniques for preparing the thin film. So, in my last lecture and till know I have discussed about the different types of depositions techniques. So, now, I am going to discussing that what is sputtering, but before going to know we have to know that why we are doing this kind of sputtering techniques, what are the logic behind it, what we are getting from that.

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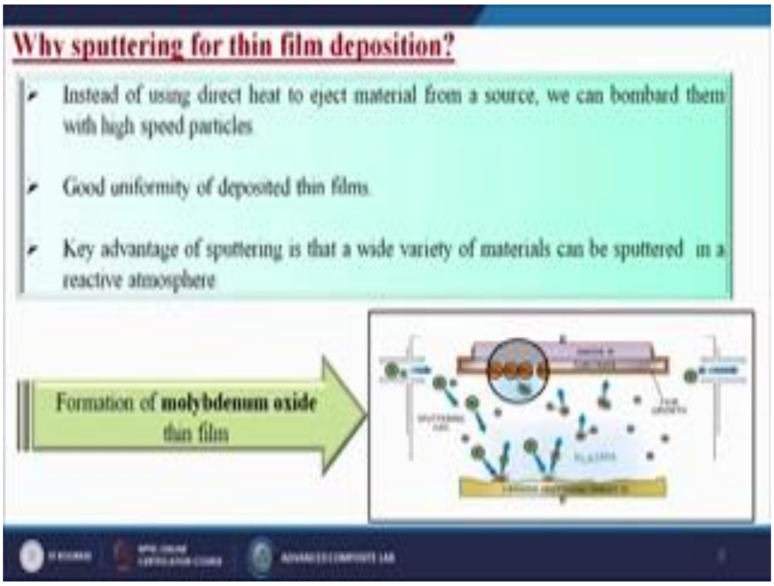

Instead of using direct heat to eject material from a source, we can bombard them with high speed particles, good uniformity of the deposited thin films and the thing is that here you are getting the purity of that particular coating because you are heating that material, it is releasing certain kind of ions so that ion is directly coming and it is depositing onto the thin films. So, here is a less chance of any kind of impurity over there and the whole thing is doing we are doing to the closed chamber.

Another key advantage of sputtering is that wide variety of material can be sputtered in a reactive atmosphere; here this is a very good example of the molybdenum oxide thin films. So, in this particular case, we are introducing the argon gas inside the chamber, then we are having some cathode sputtering target. So, directly that argon atom is heating those one say then from here we are generating the molybdenum particles then that molybdenum particles is going and it is depositing onto the substrate, but here we are doing another more advanced techniques, what we are doing? We are giving a layer of oxide onto this substrate. So, it is releasing the oxygen and from the target, you are getting the molybdenum. So, what is happening? They molybdenum an oxen they are reacting together they are forming the molybdenum oxide and then that molybdenum oxide is depositing onto the target material. That is why it is called the some kind of reactive sputtering techniques. Then we have to know that what are the different types of sputtering based on power sources.

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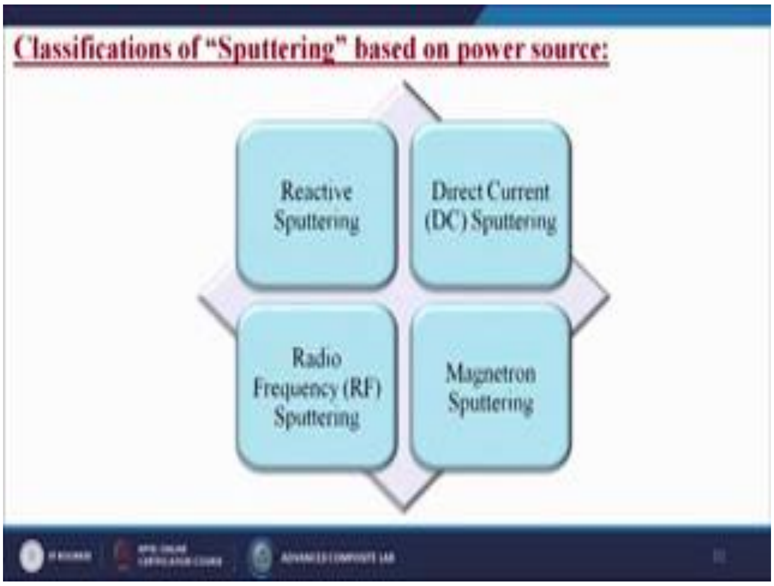

First one is called the reactive sputtering then direct current sputtering magnetron sputtering and radio frequency sputtering. So, as I already told any how we have to agitate the target material. So, in which way we are going to agitate the target material depending upon that we are doing this kind of classifications; simply we can use the heat energy so that the sputtering atoms can come either maybe we can use some certain kind of DC current or maybe some kind of magnetic force or maybe some kind of radio frequency so that, that atom can directly come from the sputtering target.

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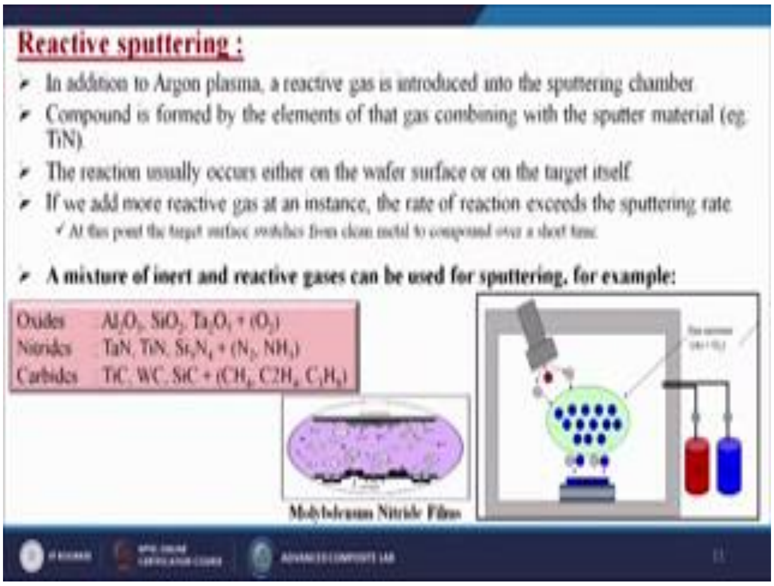

Reactive sputtering in addition to argon plasma, a reactive gas is introduced into the sputtering chamber compounds is formed by the elements of that gas combining with the sputter material that is titanium nitride. So, I will give you the example into the details, the reactions usually occurs either on the wafer surface or on the target itself, if we add more reactive gas at an instance, the rate of reaction is exceeds the sputtering rate at this point, the target surface switches from clean metal to compound over a short time. So, the reactive sputtering is nothing but we are introducing the argon gas into the chamber as well as we are using another gas inside the chamber. So, these sputtering and these argon gas and another reactive gas they will form a new ions that ions will heat your target materials then target materials will release some kind of ions that will mix with the reactive gases they form a new material and then that new material will be depositing onto the substrate.

In this particular gas, a mixture of inert and reactive gases can be used for sputtering. So, for example, here we are taking the argon gas along with the oxygen. So, both we are introducing into that chamber, then these oxygen argon and the oxygen they are creating into the some ions then that ions is heating onto your target materials then that oxygen and then that these target materials ions will form a new materials and that new materials will be deposited onto the substrate itself. So, here if you want to generate the oxides generally we are using the alumina oxide, silicon dioxide, tantalum oxide, plus oxygen, if we want to make the nitrides then tantalum nitride, titanium nitride then mixture of the nitrogen and ammonia gases, we can use for carbides we can use titanium carbide or maybe the tungsten carbide.

These all are the various applications. So, what type of materials we are going to deposit onto the substrate? You have to know that materials, you have to take the ions of that particular material so that it will heat onto the target materials and then both will react each other and then they will form that material which we want and that will deposit onto our substrate itself.

Next one is called the Direct current sputtering, it is the simplest and most frequently used with electrically conductive target materials like metals.

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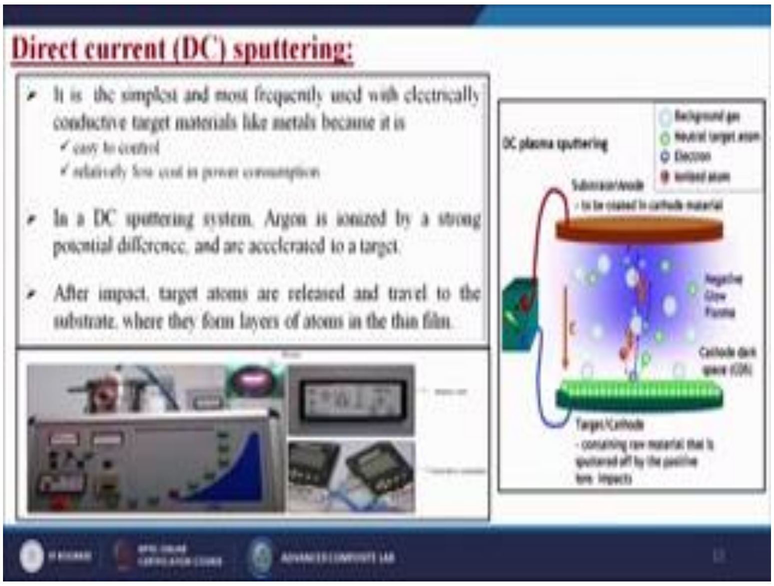

Because it is easy to control, relatively low cost in power consumptions only difference is that here we are using the DC current in between the cathode and anode and we are generating a high potential difference in between the cathode and anode by which your target materials is releasing certain kind of molecules and that is depositing onto your substrate materials. So, in a DC sputtering systems are argon is ionized by a strong potential difference and are accelerated to a target.

In this particular case, we are applying the DC current so that the argon is becoming the argon plus ions then that is heating the target material after impact, the target atoms are released and travel to the substrate where they form layers of atoms in the thin film. So, these all are the machines of what we are using for direct current sputtering. So, in the right hand side figure, it is giving you a schematic view of the direct current sputtering process.

What are the advantages? It can be relatively inexpensive cost effective collision for coating a wide range of decorative metal coatings, it is easy to adjust film thickness because current is direct proportion to the film thickness. So, if we need the more thickness then we have to keep this experiment for the longer time so that the potential difference will be the more and the thickness will be increased and adhesion strength is very very high in this particular case.

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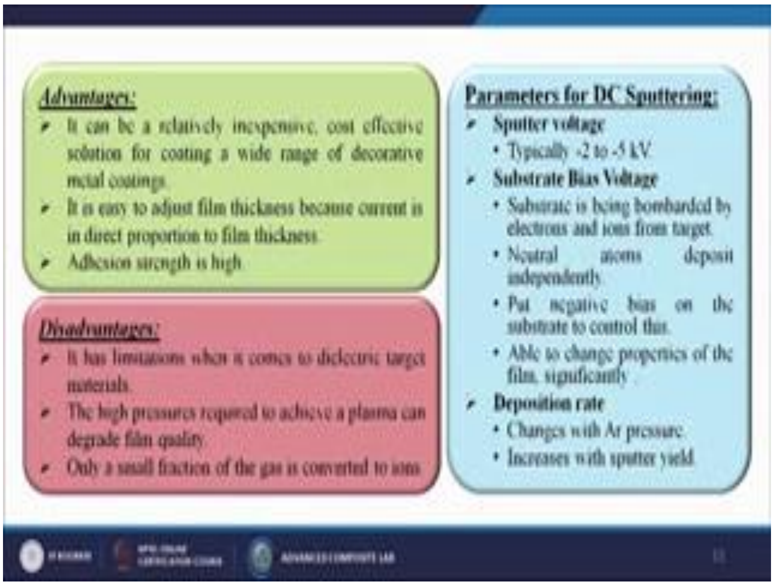

Then what are the disadvantages? It has limitations when it comes to dielectric materials, the high pressures required to achieve a plasma can degrade film quality because our source target materials and substrate material should have high temperature resistant because the plasma will be generated inside the chamber. So, it should not be decomposed with the plasma temperature or maybe the because of the plasma temperature.

Only a small fraction of the gas is converted to ions that all are the disadvantage for this particular process. Then parameters for the DC sputtering, sputter voltage generally depends from minus 2 to minus 5 kilovolt; substrate, bias voltage substrate is being bombarded by electrons and ions from target; neutral atoms deposit independently; put negative bias on the substrate to control this; able to change properties of the film significantly.

What are the deposition rate changes with argon pressure increase with sputter yield; that means, whatever the potential difference will generate if we increase the potential difference? So, automatically the amount of the sputtering will be more, not only that the molecular size of that argon gas and the target gas will be the same so that the sputtering yield will be increased so that we the sputtering time will be less.

Next one is called the RF sputtering, the radio frequency sputtering.

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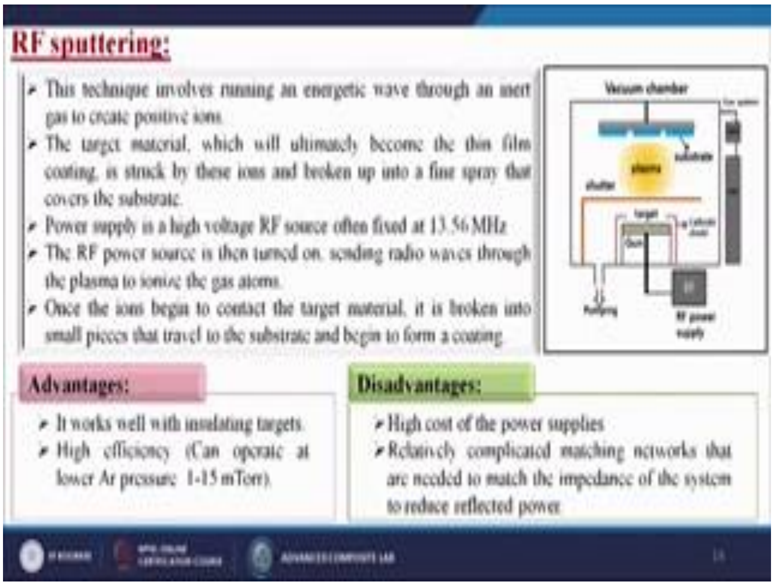

In these particular techniques, involves running an energetic wavelength, an inert gas to create the positive ions, the target material which will ultimately become the thin film, coating is stuck by these ions and broken up into a fine spray that covers the substrate. Power supply is a high voltage radio frequency source often fixed at 13.56 mega hertz. This is the standard value, but it depends or maybe varies from material to material, varies from target to target, varies from source to source, varies from substrate to substrate.

The RF power source is then turned on sending radio waves through the plasma to ionize the gas atoms, once the ions begin to contact the target material, it is broken into small pieces that travel to the substrate and begin to form a coating. So, these things we can easily get from this particular figure. So, here I am having the target. So, here we are generating certain kind of radio frequency over there then that target we are having we are doing the pumping over there so that it will became into the vacuums then we are injecting the gas over there then that gas is divided into argon plus ions then these ions and broken up into a fine spray that covers the substrate itself then it is heating the target material that argon ion then we are having one shutter means like a shield over there. So, that ion is heating through this shutter so that it is divided again to the small small particles then that small particles is directly coming on to the substrate and it is giving a fine uniform coating.

It works well with insulating parts high efficiency can operate at lower argon pressure, generally 1 to 15 millitorr, what are the disadvantage is high cost of the power supplies relatively complicated matching networks that are needed to match the impedance of the system to reduce the reflected power.

Next is called the magnetron sputtering. So, these one is also a one kind of sputtering process. So, till now we are discussing that simple, the argon ion is coming, it is heating your target materials then it is generating certain kind of ions and molecules that ion and molecules is directly going onto the substrate and it is depositing onto that particular material and doing the coating, but there is certain problems, the problem is that when we are generating that ions and molecules some ion and molecules is going onto the substrate some ions and molecules can heat your target materials can heat the wall of your experiment chamber.

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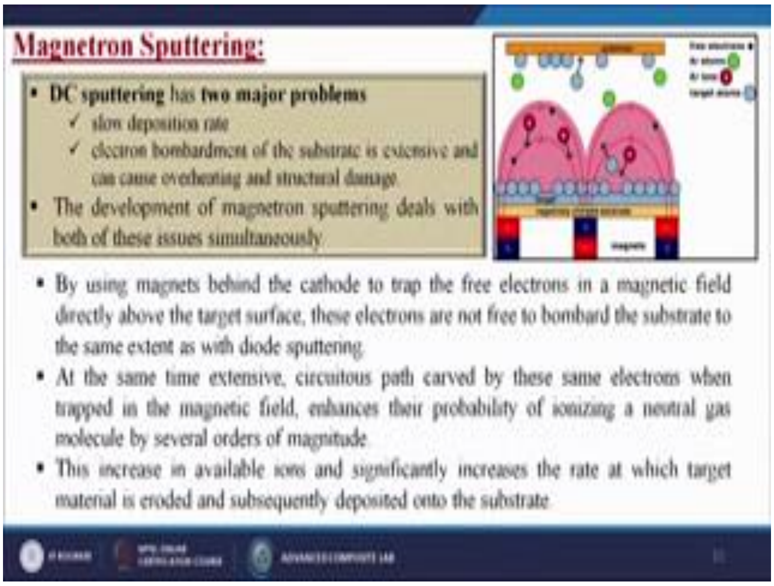

What we are doing over here? Here we are generating certain kind of magnetic field with some kind of electron filed so that that ion cannot go to the anywhere directly it can go onto the substrate itself.

Here DC sputtering has 2 major problems; slow deposition rate electron bombardment of the substrate is extensive and can cause overheating and structural damage the development of magnetron sputtering deals with both of these issues simultaneously. So by using magnets behind the cathodes so, these all are the magnets generally we are using behind the cathodes to trap the free electrons in a magnetic field directly above the target source, these electrons are not free to bombard the substrate to the same extent as with diode sputtering because there is certain kind of low weak argon ion atoms also. So, there that is that cannot do any kind of effect onto that sputtering technique.

We can capture those free electrons easily, at the same time extensive circuit circuitous path carved by these same electrons when trapped in the magnetic field enhance their probability of ionizing a neutral gas molecule by several orders of magnitude this increase in available ions and significantly increase the rate at which target material is eroded and subsequently deposited onto the substrate itself.

Simply we are generating certain kind of magnetic field through that these targeting atoms is rotating onto that and several times, it is heating this target materials so that it can generate more molecules, more atoms and then directly it can go on to the substrate itself. So, it is a one kind of recycling process generally we are adopting in this particular case.

How we are generating, what are the physics behind it? We can discuss or maybe we can give some light based on the Lorenz forces acting on electron during the magnetron sputtering what the forces what maybe the words this Lorenz is telling.

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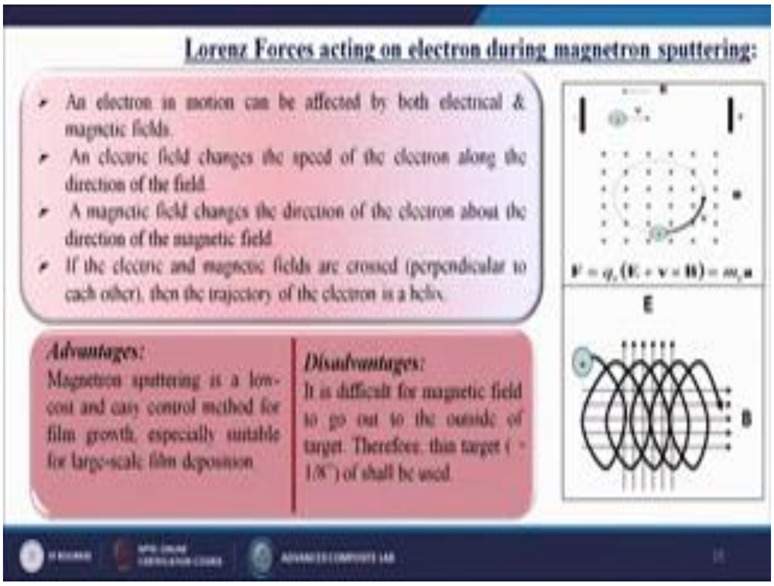

An electron in motion can be affected by both electrical and magnetic fields. An electric field a changes the speed of the electron along with the direction of the field. A magnetic field changes the direction of the electron about the direction of the magnetic field. If the electric and magnetic fields are crossed perpendicular to each other then the trajectory of the electron is a helix one. So that is why we are getting this kind of picture in our previous slide so simply it is rotating into this particular path.

What are the advantages? Magnetron sputtering is a low cost and easy control method for film growth especially suitable for large scale film depositions. What are the disadvantages? It is difficult for magnetic field to go out or to the outside of target therefore, thin target can be used; that means, whatever the argon ions, it is coming all the argon ions is not heating your target material to whole this all argon atoms. So, we are generating a magnetic field near the target materials so that all the atoms can be captured then it can rotate and it cannot go beyond that field and it can heat the target so that the efficiency will be more for this particular sputtering technique.

In our next slide just we are doing the comparison in between the different sputtering techniques which I have already discussed.

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First one is called the DC sputtering. So, where we are generally applying the DC voltage and the target must be conductive in that radio frequency sputtering applies an AC voltage to the target at frequency is more than 50 hertz target need not to be the conductive, this is the added advantage for the particular sputtering techniques where we can use the insulated materials semi conductive materials or maybe any kind of materials.

Then we have already discussed about the reactive sputtering where generally using some kind of reactive gases such as oxygen added to the chamber, reacts with target products forming the deposited materials. So, here we can introduce the nitrogen gas for making the nitrides, we can introduce the oxygen gas for making the oxides. So, any kind of compound materials, we can generate onto this particular sputtering techniques. And last one is the magnetron sputtering addition of magnets behind the target controls the movement of the electrons, increased ionization at cathode leads to higher yields because there is some weaker argon atom or maybe some argon atom is directly not heating to the target materials, it is escaping from that, we can capture all those electrons and so that it can heat the target materials and then target materials can release the molecules or maybe the ions. So, the efficiency will be much better than the 3 sputtering techniques.

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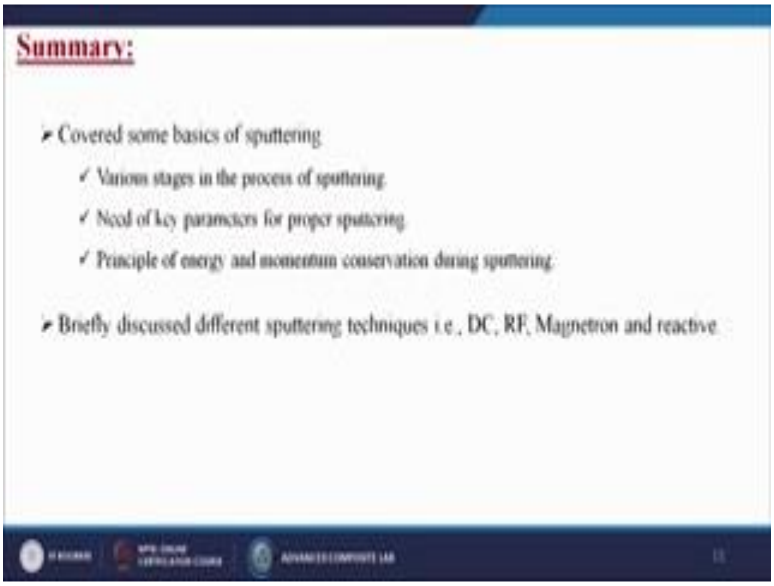

Now we have come to the last slide of this particular lecture and in summarize, we can say that covered some basics of sputtering techniques - various stages in the process of sputtering already we have discussed; need of key parameters for proper sputtering; principle of energy and momentum conservation during sputtering techniques. Briefly we have discussed about different sputtering techniques like DC, RF, magnetron and the reactive. So, this is the whole summary of the sputtering techniques which we are using for making the thin film.

Thank you.