Fundamentals of Materials Processing-2
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Module – 02
Thin Film Deposition
Lecture - 10
Sputtering continued

Hello and welcome to lecture 10 of Thin Film Deposition, we will continue our discussion on sputtering process in this lecture. In the last lecture, we had seen that how by using AC plasma we can use the sputtering process more effectively. In this we will build on that and will go towards more energy efficient and large area deposition, but before we do that let us discuss the targets.

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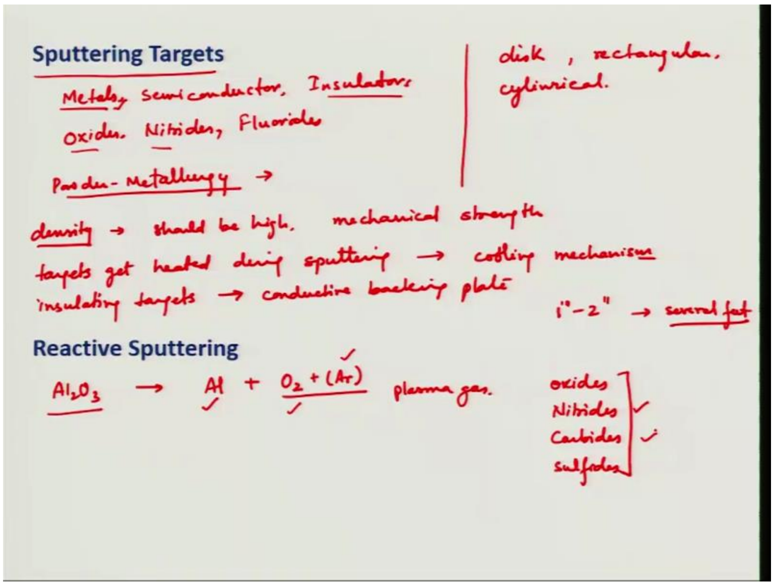

We had said that we can use various target as a cathode in our process so that the ions bombard on it, these targets can be made of metals, we can use metals, we can use semi conductors, we can use insulators, we can use various compounds like oxides, nitrides, fluorides, various compounds we can use and we can use also use oxides, nitrides of multi components because we had also seen that the how the stoichiometry is kept exactly as the composition of the target in the sputtering process.

These sputtering targets can be made if you are using a metal by forming. So, you start with the metal melt and you can solidify that metal in a required shape, for insulator, oxide, nitrides, you can use powder metallurgy root, to use the powder, to compress it and sinter it in a in the form of a target, these targets can be like disk, round, in rectangular, cylindrical and various other shapes. You can cast as disk or rectangles for metals or use powder metallurgy for insulators and oxides; oxides nitrides various other ceramic materials.

One issue that we should keep in mind the density should be high of these targets and to give them good mechanical strength because they are being bombarded by high energy ions. So, they should be keep their mechanical integrity, if they are not very dense they might just a fall apart during the process. Also during the process of sputtering when the high energy ions are bombarding on your target, this target gets heated.

Targets get heated during sputtering. So, there should be a cooling mechanism. So, usually this is a cooling mechanism at the back of this targets where by flow of water you can keep the you can keep extracting this heat so that this target do not get very hot and lose their mechanical strength in case of insulating targets, they should have conducting conductive backing plate where you apply the potential RF potential or RF signal. So, all these thing are taken into a into account when you are preparing your target and this targets can be as small as 1 inch to 2 inch targets in form of this rectangular to several meters or several feat. We will see that how this are used for large area deposition not only that you can also use reactive sputtering suppose for some reason you want deposit in oxide and getting the oxide target is not feasible of that material of that element you can start with metallic target, like for Al_2O_3, you can start with aluminum and have oxygen and may be plus organ has your plasma gas.

Now what would happen when you are depositing this film? You are sputtering aluminum in this plasma, but along with aluminum atoms, you also have oxygen ions. So, as your aluminum is getting deposited on the film on the substrate they will also react with oxygen ions to form al 2 o 3 on your substrate. So, this way you can use reactive sputtering for your thin film deposition of oxides, nitrides, carbides, sulfides, etcetera, also suppose you even if you start with target of aluminum oxides, there might be a change in stoichiometry when the thin film is being deposited. You can control stoichiometry or aluminum into oxygen ratio in the thin film by having some pressure of oxygen and you can adjust that.

How much oxygen to keep because your main plasma gas will remain the organ which is neutral, but you can adjust oxygen plasma pressure to adjust the stoichiometry of your oxides, similarly from nitrides, you can use ammonia or nitrogen for carbides, you can use some carbon containing gases like methane. So, reactive sputtering can also be used to give a more versatile look to this sputtering process and it is very widely used large area deposition process in industry. Now we have seen that how having in AC plasma helps, but there is a better way of doing it, even improved version and this improved version is called magnetron sputtering.

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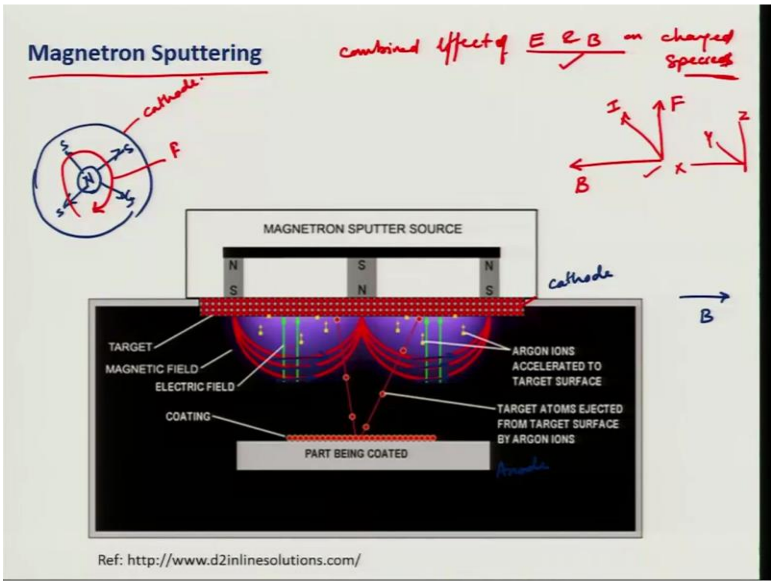

Let us discuss this now, magnetron sputtering if you recall, we had discussed the combined effect of electric and magnitude fields on charge species.

We had discussed this part when we are discussing plasma, now this exactly phenomena is utilized in more efficient sputtering targets, which are called magnetron, this figure shows you how a magnetron work, we all know that if I charged, species is moving in a magnetic field, there is a force on this and if my magnetic field is in this direction and current I is in this direction and force would be in this direction. So, we can; let us say that this is x y and z. So, this is right hand root, if my current is in this direction along the index finger and the magnetic fields is along the middle finger then the force would be upwards like in the direction of the thumb which is shown here.

Now let us come to this picture which describes magnetron, in this you see that we have target here which is represented by red dots and there is a magnate behind that design of the magnate is such that this magnetic lines are this parallel lines here. So, this is the magnetic field lines at this point. So, this is the magnetic field direction, in this picture electric field is in this direction. So, of electric field is in this direction which means the electron current is going in the other direction these green because this is cathode and anode this is anode so, my electric field in this direction.

When we have this perpendicular electric magnetic field, the force on the electron will be in the third direction; third perpendicular direction which is in the plane of this screen or the paper my force on the electron is in this direction now. So, it will force the electron to move in the direction of plane and then what we do is have this target and the magnetron in form of a circle. So, this is the side view and the top view of this would be like this. So, we have in the middle I have my north pole and my south poles are here now the electric field lines if you are looking from the top are perpendicular to the plane magnetic fields line are redial. So, these 2 we will affect the motion of electrons in a direction which is along this. So, this is the force on electrons, what would happen? These electrons will start circular motion at the surface of my magnetron and there will be confining to this region.

When there confine to this region, there are not being lost and same electrons when they are making many circular parts they are ionizing gas ions very close to the surface of your target they not ionizing gas ions far away they are very close to the surface and once they are very close to the surface then the ions which are being produced here due to ionization process they are not being lost anywhere because they quickly get accelerated towards cathode. So, this is my cathode target behind which I have put a circular magnetron.

Since the electrons are very close to cathode surface most of the ionization happening close to surface of the cathode and remember that most of the potential is at cathode dark space which is very close to cathode. So, all the potential is just there. So, ions are accelerated in that potential without being lost to anywhere else, this is the very high highly efficient process of using sputtering and you can use utilized this effect even further which we will see in the next slides. So, this is called a magnetron sputtering because you are using magnetic field also to confine electrons.

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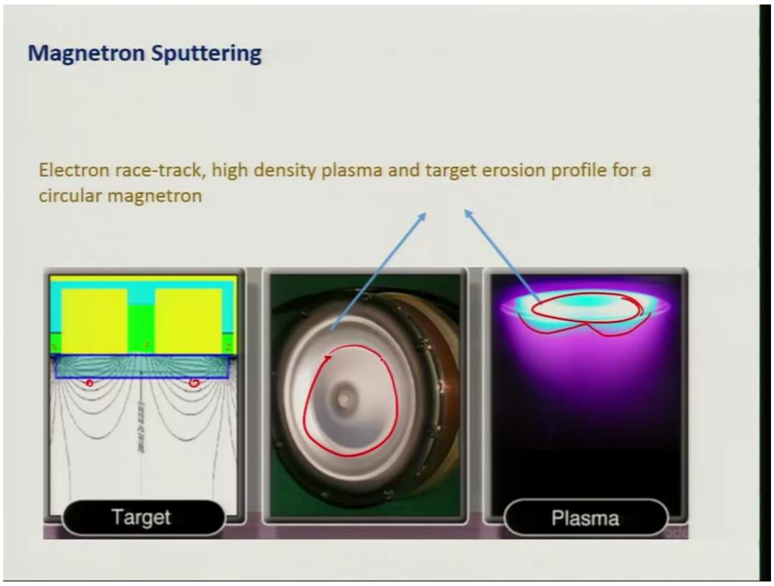

This is again the representation of the same graph, now since the electrons are moving in a race track, the target erosion, this is my cathode target you see that, it is eroded along this race track because the electrons are confined along this race track. So, they are moving in an odd of plane along these parts at the certain radios. So, electrons are confined here. So, the ions are being produced mostly in this region and as soon as they are produced, their accelerated towards target. So, most of the erosion happens in this race track and since this happens for this kind of gun you cannot utilized the material completely because it is eroded here and not completely not uniformly and you can also see the lops in the plasma in this circular plasma region at because it is they are most of the action is happening along this race track.

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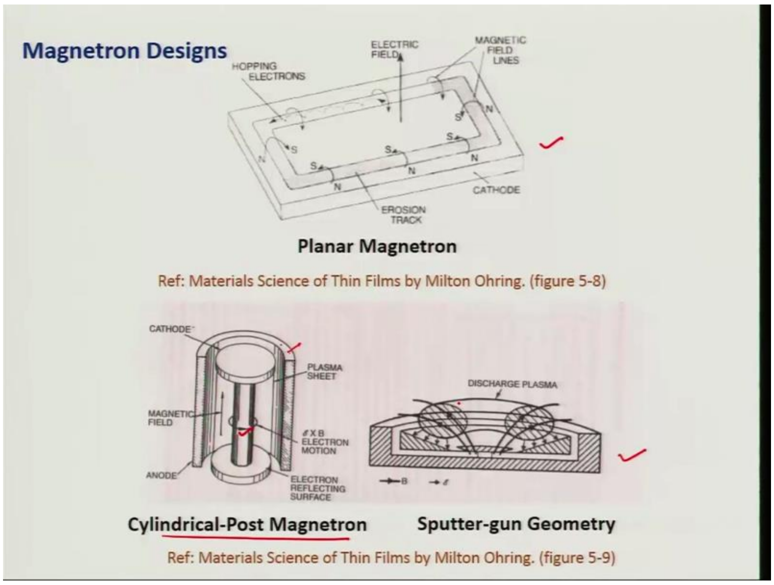

Now, there are different designs of magnetrons, this is a planar magnetron in which when you have this north and south pole like this and electric field is perpendicular, the electrons perform this hopping motion along the race track, but they are confine very close to cathode.

This is one diagram, you can also have cylindrical post magnetron in which where cathode is something like this and you have magnetic field. So, this is your cathode and you have motion of electron and along this race track as shown by this, this is the motion of electron, this is a sputter gun geometry slightly better optimize compared to this and you can see that at any given point the design is such that magnetic fields and eclectic fields are at right angles and to force electrons in a circular part where they create the plasma.

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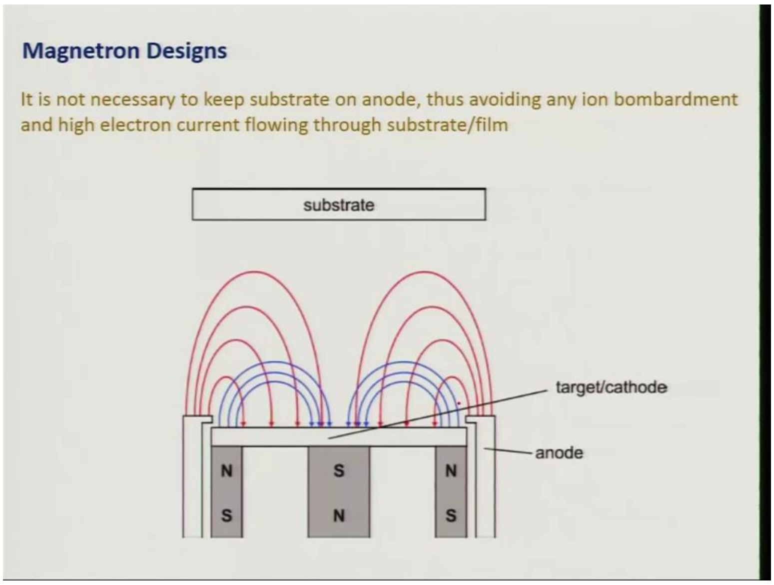

Now it is not necessary to keep your substrate on the anode because anode is another electrode. So, what you can do is to separate out the substrate form plasma, we do not want any effect of plasma on my thin film, we do not want any of the energetic ions of plasma or electrons of plasma to interfere with my thin film for various reasons. So, you can also have anode very close to your cathode or target, in this geometry such that that at any place the electric field and magnetic fields are at right angle and which will force electrons have to move in out of plane in this geometry and in a race track.

You can avoid keeping substrate anode or having any effect of plasma on your thin film by keeping the plasma separate from your substrate, this is also used because to avoid any ion bombardment and high electron current flowing through substrate or your film for various reasons, if you want to avoid that you can use this geometry now come to large area deposition.

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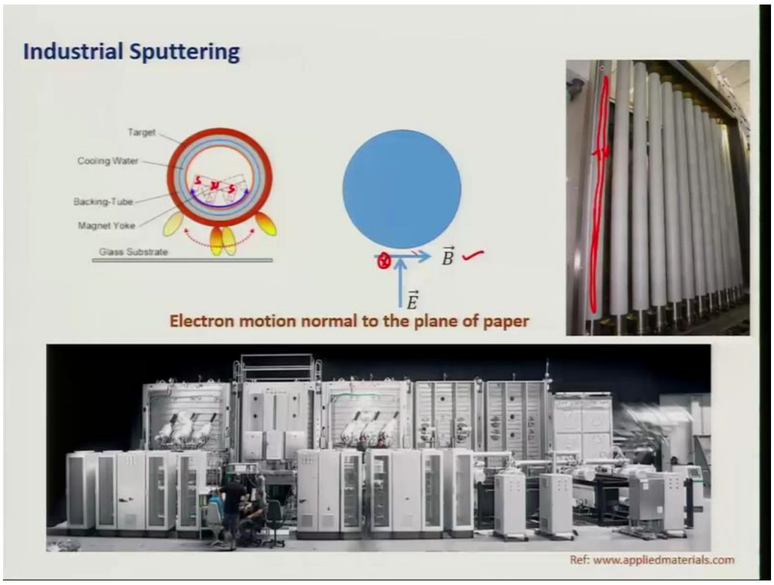

This is what is an industrial scale physical vapor deposition tool of applied materials and this is mainly for a sputtering. So, this is one sputtering chamber where you have an array of cathodes in form of cylinders long cylinders what is inside this cylinders is this magnate, in this magnate there is a north pole and south pole. So, the magnetic field on the surface of this cylinder is in this direction. Right next to it to each of this a cylinders is an another electrode which is gives the perpendicular electric field, in this geometry the motion of electron will be in an outer of plane of this paper or if I show it on this the electrons will be moving in this direction. So, the race track will be in this direction.

This is my electron race track on the surface of your cathode and that is where they will create plasma and they will generate sputtered atoms from the cathode or the target and the substrate is kept in front of it where they get deposited. In this geometry because there are some gaps so that to have a more uniform deposition, you can change the direction of the magnate, so you can have the magnate the pointing straight slightly to the left or to the right so that you can cover the entire area and deposit the entire area uniformly in front of that that particular cathode.

Now to avoid this race track situation that we had seen here which is not very very comfortable with industry because you do not want to open your chamber, take out this target reprocess it to reclaim the material you want to utilize once you have made the target as much as possible. So, for that you can have a rotation of the target. So, your target the cathode on top of this will keep rotating. So, at any given point, a new surface of the target comes behind the race track. So, race track is fixed which is managed by this magnate inside, but their target surface is rotating. So, you get a uniform erosion from all across the cylindrical surface which result in much more efficiency because you can almost utilized entire surface of this target deposition process and these kind of systems can be used to have a uniform deposition on over large area as large as 10 feet by 10 feet of class and these are mainly used in display industry for large area displays TVS and computer monitors.

Just let me describe this, this big station here there is a glass loading unloading region here and then is the vacuum load lock. So, first the glass moves in this and then you have various process chambers. So, one process after another can be carried out and this glass keeps moving from one chamber to another chamber in vertical position and while the thin films are being deposited layer by layer.

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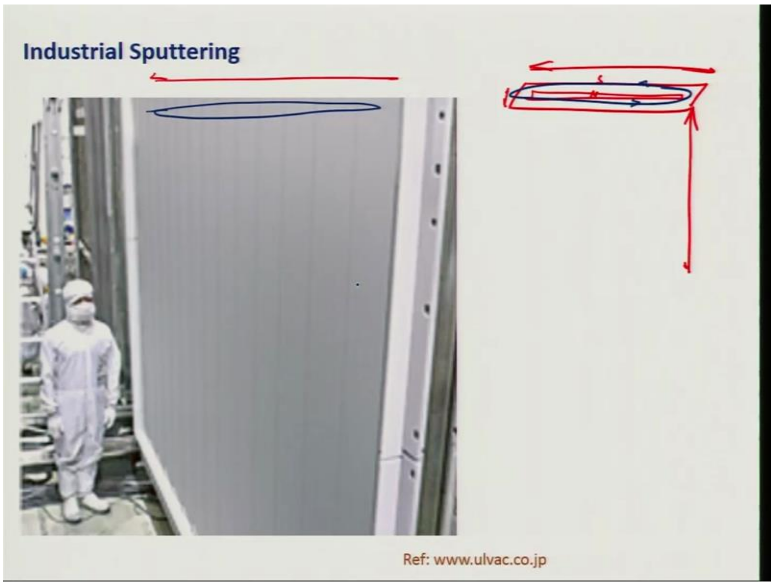

Now, this was; this rotary cylinder targets, you can also use geometry of the target where you have various spices of this, this target made separately and joint together to have a uniform target. So, this is uniform target it can be a again 8 feet by 8 feet to 10 feet by to 10 feet. Now, how do we use this for uniform sputtering? Again if we have a one magnate behind there will be a fix race track and fix race track means there will be a fixed erosion profile we will not be able to use this target efficiently and nor we will get very uniform deposition. So, what is done that you have this target and behind this you have a rectangular magnetron with north and south poles which is scanned. So, this is scanned behind this large target. So, this width of this would be exactly like this, but this length can be much smaller and the race track on top of this in the front of cathode will be like this. So, this will be the race track for electron motion and also the sputtering pattern.

Now you when you are scanning, you will have a sputtering from this region and you are scanning this across this entire length back and forth and then you will have a uniform sputtering from the entire target and the uniform deposition on your substrate which is kept in front of it, a large sheet of glass. So, this is another way of using large area as sputtering chambers and these can be very uniform less than 5 percent thickness variation across 8 feet by 8 or 10 feet 10 feet which is the industry norm for display industry. Now not only rigid substrate, you can also use flexible substrate like web coating, we had discussed for thermal evaporation or (Refer Time: 23:38) evaporation.

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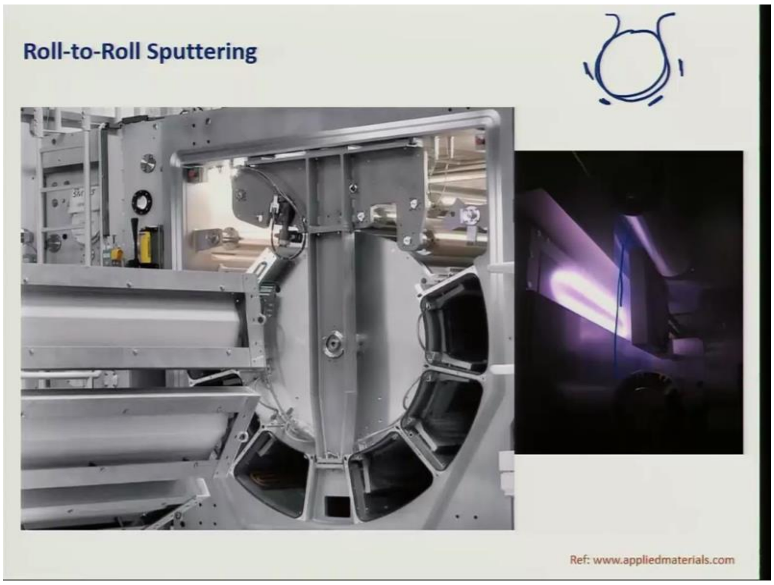

You can have a roll of web or flexible substrate which is moving in front of us sputtering target which is here.

As you move your web in front of this target which is being where the sputtering process is happening and you can control, the speed of this web to have uniform thickness deposition uniform thickness deposition at this moves across this sputter target and these can be very huge systems if you see this picture here from again from plaid material you see it has many chambers and there is a drum over which your web moves. So, there is a drum over which your web or the substrate moves like this and you have various sputtering units at for various thin films you can utilize all this for roll to roll sputtering at large widths and for very large area.

We had discussed that we can use AC plasma we can use magnetron where we have magnetic field now we can also couple these 2, how you do that?

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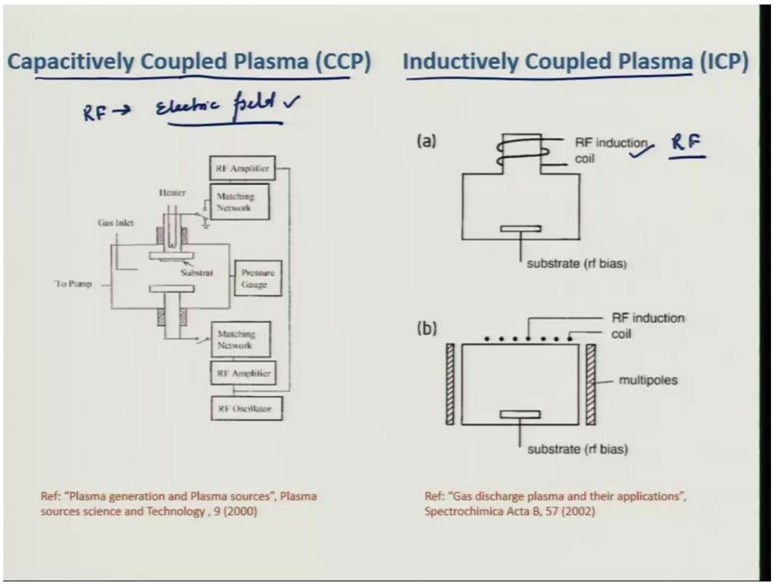

That we can have a capacitively coupled plasma or inductively coupled plasma - capacitively coupled plasma means my RF signal is applied to the electrodes to the middle electrodes where we I am applying my electric field. So, my RF is applied to electric field and this helps in because of its ac effect even improves the efficiency of magnetron. So, we have a magnate there, but we are changing the direction. So, electrons rotate back and forth or we can also use and inductively couple plasma where we are not changing the eclectic field, but we are changing magnetic field by RF plasma this way by changing magnetic field we can oscillate the electrons in the plasma for more, more higher efficiency.

These are more complex systems and they are very often used in various processes. So, with this, I will end my discussion on sputtering and this is also the end of week 6 for this course. In the next week we will start to discuss chemical evaporate deposition techniques.

Thank you.