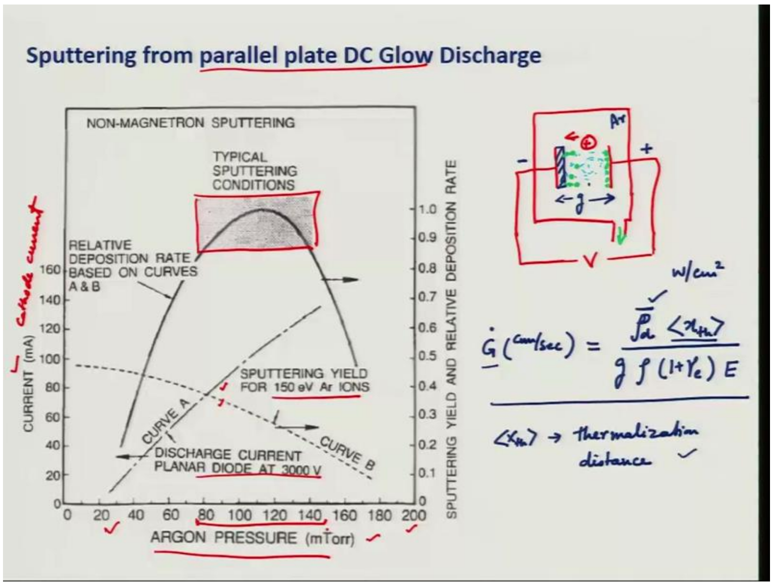
Fundamentals of materials processing-2

Prof. Shashank Shekhar and Prof. Anshu Gaur
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Module - 02
Lecture – 09
Sputtering continued

Welcome to lecture 9 of thin film deposition module, we are in this lecture, will continue our discussion of physical vapor deposition process called sputtering. Remember, in the previous lecture, lecture 8 we had discussed how these energetic ions which we have created as part of our plasma interact with surface of the cathode and this cathode is our target material which we want to deposit as a thin film on a substrate. So, let us look at what are the various parameters that governed the deposition rate or the deposition of thin film.

(Refer Slide Time: 01:07)



Before we start, let me give you a simplistic geometry of what we are doing a schematic. So, we have vacuum chamber in which we want to carry out the thin film deposition process by sputtering and sputtering we also have a cathode and an anode to create the plasma. So, these are cathode and anode and between which we apply a voltage v and cathode is also our target the material that we want to deposit on the substrate.

Substrate is either cap at the anode or at any other place in between inside the plasma. So, this is cathode this is anode and we will have plasma in between different regions of plasma cathode dark space cathode glow cathode dark space and negative glow. So, these are the essential parts of plasma which are considered if you have this distance very large then you can also have positive column now in this geometry the iron the positive ions are being escalated towards my target or cathode and resulting the sputtering process from the target and then this sputtered items which are coming out from the surface of the target will have some kinetic energy will travel some distance and then make a thin film layer at the substrate. So, this is the overall process of a sputtering.

Now, before we go here let me give you a very simplistic equation for growth rate or deposition rate in case of sputtering this can be described as if the deposition rate I say G dot in centimeter per second though the deposition rate should be very very slow of the order of nano meters per minute. So, of course, you can convert these units. So, this will depend on this is the power density of the plasma x th. This is will discuss this term divided by G, G is the gap between cathode and anode row which is the density of the material that you are depositing on your as thin film this is the density of thin film not the target. Target might have a different density than your thin film and how density wants to deposit the thin film will depend on various parameters deposition rate, substrate temperature and various other factors.

So, this is the density of the thin film 1 plus gamma e, gamma e is the again secondary electronic machine coefficient because we need secondary electrons to sustain the plasma because electrons in a d c plasma glow are always extended towards anode are being lost they are. So, we need to generate the secondary electrons to keep a continuous supply of electrons which will ionize the gas items and create gas ions and which will result in the sputtering process and e is the average energy of sputtering or sputtering ions.

This expression is not a, it is implied expression from various experiments, now we understand, this is the power density of plasma in watts per centimeter in square this x th is said term this is called thermalization distance. Now as we have said that once the sputtered items come out from the target, they have some energy typically between 2 to 10 electron volts, some kinetic energy and this kinetic energy is given to them by the energetic ions, now how far these items travel before they become thermalized?

A process of thermalization means that this access energy that these ions have these atoms has they will lose these in the process of collusions because as they start moving towards away from the target and towards the substrate they will collide with various ions or gas atoms. So, let us fix our gas also. So, let us, we have argon gas. So, they will interact with these and during this collusion process they will lose their energy once they lose their energy they are not travelling there towards anode.

Because once they start from the cathode they have a preferential direction because of the change in momentum process, but once they undergo these collisions they become they lose their energy they start moving as any other gas item and they becomes thermalized. So, all these parameters so, it is obvious that if you have higher power density of plasma then you will have higher growth rate, it is very easily understood because if power density of plasma is higher more ions are present to bombard on the target resulting in more sputtering. If this distance thermalization distance is higher, then more of the atoms which are being sputtered will reach the substrate and result in thin film deposition rather being lost to the walls of the chamber or any other direction if this parameter is large then you will get more deposition rate.

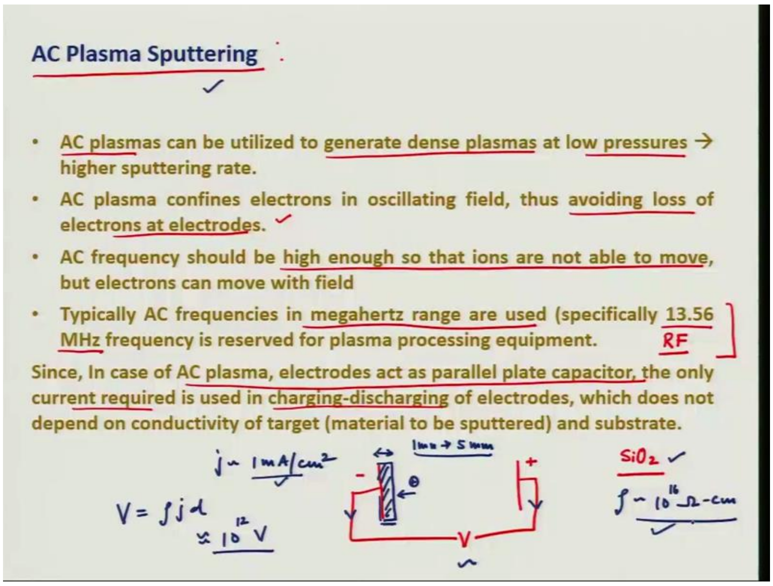
If with this distance between cathode or target and substrate is large then of course, your growth rate will go down because it will act against this thermalization distance if this secondary emission coefficient is very large then your growth rate will go down and also if this energy of the ions the sputtering energy is very large then also your deposition rate will go down.

Now let us shift focus to the graph on the left hand side this graph is on x axis, we have argon pressure for the same energy of the ions energy of the ions is kept same and pressure is varied and we can measure the current this is the cathode current this is cathode current due to ions and on the right hand side we we can record the sputtering yield and relative deposition rate.

We have 2 curves here, curve a and curve b, you can see that discharge current increases will increase in pressure you have higher pressure; that means, you are creating more and more argon ions which will so that more and more argons argon ions are reaching the cathode resulting in more current and it increases with argon pressure. However, the sputtering yield will starts to go down why is that because if ions this large number of ions the energy of the ions which are reaching the target will be less because of various interaction with the between the atoms and the ions and collision. So, the energy though these ions are reaching the target and the current is increasing their energy will be less. So, they will result in less sputtering if they result in less sputtering then will have less deposition. So, combination of these 2 curves is this curve right here which gives you a relative deposition rate and from this you can find out that this as sweet spot a sweet region where you have the highest deposition rate possibly and these are somewhere around 100 millitorr of the pressure. So, that is why you need to have 100 millitorr pressure, if you have too high then your deposition rate will go down if you have to too low pressure your deposition rate will go down.

This is the geometry for parallel plate DC glow, how can we improve on this because these rates are very slow and at this pressures we do not want to up at a this pressures because if you remember from the partial curve if the pressure and distance is pd product of p and d is very large then you need to have higher break down voltage we want to lower our operating voltages and one way to do that is to lower this pressure and, but if we lower pressure our deposition rates go down. So, how do we overcome this?

(Refer Slide Time: 12:20)



We can use AC plasma for sputtering process how does this help remember we had discussed the AC effects in the plasma and the plasma frequency and the oxidation of electrons. So, one of the benefits is that you can utilize AC plasma to generate dense plasma at low pressures and at low pressures because this less collusion between ions the sputtering rate would be higher because the ions reaching the target or cathode would have higher energy.

Also AC plasma confines electrons in oscillating filed. So, simultaneously both electrodes are acting as anode and cathode. So, electrons are oscillating between these 2 place. So, they are not being lost at any of the electrodes you can adjust the frequency such that they will not be able to reach any of the electrode and they just keep oscillating in between and in the process ionize more and more gas ions. So, ones you are not losing any electrons at the electrodes then you do not need to be depending on the secondary electron generation or secondary electron emission. So, that is helps in creating more and more ions at a lower voltage, but the AC frequency should be high enough so that the ions are not able to move, ions should always be moving towards target they should not be oscillating.

If the frequency is higher, then these ions will not filed of act of that frequency because ions are heavier, they take some time of inertia and other things to realize that there is a change in priority and by the time they realize the quality is changed again. So, they can keep moving in 1 direction, in which direction we will discuss this because in AC plasma there is no fixed anode or cathode, but the AC frequency is should be high enough so that ions are not able to move, typically AC frequencies are in megahertz range for this effect and specifically this 13.56 megahertz radio frequency, these are called radio frequency or RF and we have to this we called it RF plasma this result of plasma processing equipment many process material processing depends on this RF plasma, be it sputtering process, reactive ion etching or PCVD which we will discuss later. So, all these are based on 13.56 megahertz.

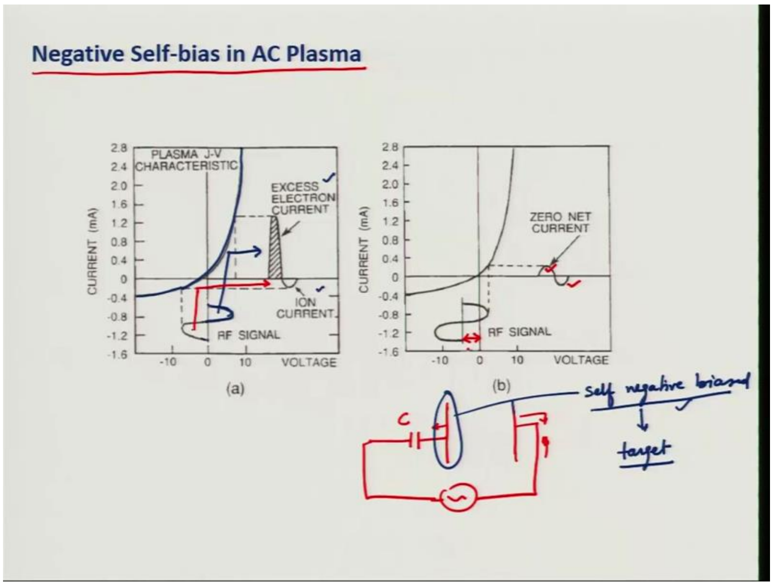
Now in case of AC plasma electrodes acts as plate parallel plate capacitor the only current required is to use in charging and discharging of electrodes. Now see this effect suppose you have these electrodes and with the dc voltage and fixed cathodes then what would happen that suppose you want to deposit an insulating material like SiO2, it is not conducting. So, you would have a target which is of silicon oxide.

Now, suppose this target thickness is of the order of 1 millimeter or 1 to 5 millimeter, typical thickness because you are to deposit this material on to the substrate not more than few microns, few 100 nano meters at a time. So, typical target thickness is our 1 to 1 mm. So, this is the thickness, now if this is SiO2 fix as resistivity of the order of 10 to power 16 centimeter and the voltage drafted here within the target would be very large and suppose we need around 1 milli ampere current right, ions positive ions which are moving here should result in some current and of the current density of the order of 1 milli meter per centimeter square. So, this is for an insulating target where the density is very high. So, if you calculate that the potential drop across this voltage to sustain this current density with this resistivity can be given at this resistivity j into this thickness and this comes out to be order of 10 to power twelve volts or so, for this insulating sub strain target.

Now, sustaining these kinds of voltages are very difficult you cannot practically use this. So, for insulating targets or the other things the similar things happens at the anode when this film is being deposited of SiO2, this becomes insulating. So, there is no way to flow the current between these 2 plates. So, how do we overcome this problem using AC plasma? It is because AC plasma the plasma everything here behaves as dielectric there is no current flow between electrodes the only current that flows is because of charging of this plates in the external circuits because ones this plate becomes from negative to positive the current flows if we have an AC plasma in both directions to reverse the polarity that is the only current that is flowing there is no current flowing between the electrodes. So, there is no need for this high current so and in this case we can we just want this ions to be accelerated. So, in this case, we can use insulating targets or substrates. So, that is one additional benefit of using AC plasma that we can use insulating targets to deposit insulating films.

Now remember again in AC plasma there is a fixed anode or cathode right because they keep changing with high frequency. Where do put our target? Remember we had said when we were discussing dc plasma that our cathode is where we put our target right we put our target at the cathode and the positively charged ions are accelerated towards cathode they bombard on our target and then result in sputtering atoms bus, but in the absence of an absence of defined cathode or anode where do we keep our target as it happens as it happens that when we put any electrode in an AC plasma.

(Refer Slide Time: 20:00)



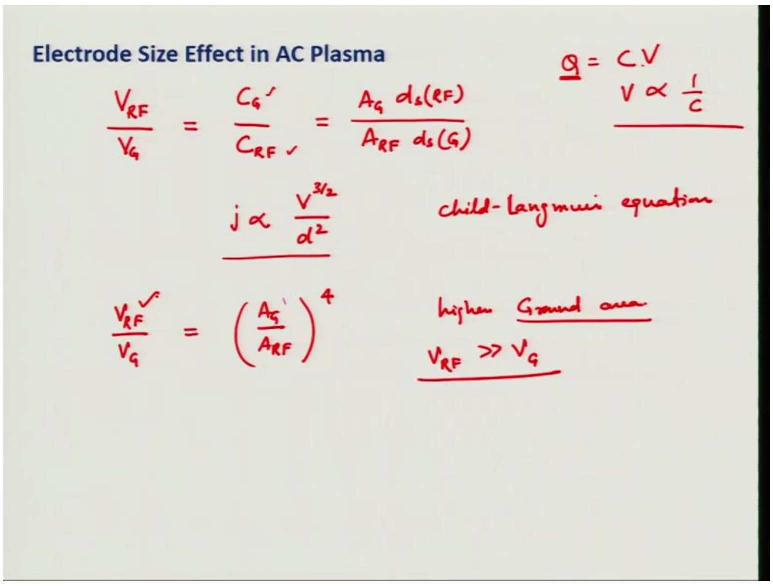
This is a negative self bias, we have discussed this also at any plasma any electrode if we in certain plasma it becomes negatively charged the similar effect is utilized here who have a self bias on one electrode which is slightly negative now let us see this in a configuration. So, we have we use a capacitor at one electrode. So, we have, we are using capacitor at one electrode. So, using this capacitor of some value we can define at there is no current flow from this electrode because of this capacitor is an insulating it only allows the charge no current flow from this; however, the current flow can happen to this plate.

Now, once we do that this electrode let me take another color is self negative biased and this becomes he target because it is self bias negatively because of the fact we will discuss here and so in an AC plasma, this target becomes negatively biased and we can use the ions which are moving towards this target and resulting is sputtering also recall here we have discussed that AC frequency should be high enough so that ions are not able to move or able to oscillate. So, they are not oscillating with the field, they are moving with this in one direction with the self negative biased towards target resulting is sputtering. So, our sputtering process is still going on, now let us discuss this effect in these 2 graphs.

Since we have put a capacitor on one electrode this the current flow in outside circuit will look like a diode because the current will flow when this while this electrode is being charged there is no current flow from this electrode so and diode characteristics is like this which is shown this is the iv characteristics of diode like the PN junction diode this is forward bias this is the reverse bias now on this electrode if you see that during the positive cycle on this electrode there will be large number of electrons which will be bombarding on it and in the negative cycle there will be less number of ions because ion cannot move that fast electrons can move very fast because of their lighter mass ions are heavier they will not be able to move that first. So, we have large electron current on this electrode an less ion current which is positive current less and this is my hardest signal which is applied this is the positive cycle which results in this electron current this is the negative cycle which result in ion current.

Now, if you see that no electrons are bombarding on that electrode our certain time it will developed negative bias such that when it becomes straightly negative bias if you see and on top of which I am applying my RF, RF signal then both currents become equal net current become 0. So, no more change in the potential of this electrode then this becomes slightly negative and this negative potential of the target is sufficient for to accelerate ions to words it to result in this sputter. So, this is how AC plasma works for thin film deposition.

(Refer Slide Time: 24:58)



There is also an effect of electrode size effect, now if we recall we have voltage which is RF voltage and there is voltage which is ground voltage. So, the ratio between these 2 voltages so this is the self bias voltage and this is the RF potential, RF signal, this is the AC potential, the ratio between them will depend on their capacitors, inverse of capacitors because we know that Q is equal to C into V charge being equal because charge has to be neutralized positive charge or manipulate should be equal to negative charge on the other plate.

In an ideal the electrode so my V becomes 1 over C so the voltage is distribution would be in accordance to their capacitors and this capacitance ratio we can define as a G into this is AG by D. So, this is for RF sheet thickness divided by this is the RF electrode and this is the ground electrode RF into DS and this is the ground.

We have small sheet distances at both ends at RF electrode and ground electrode. So, this is my RF electrode and this is my ground electrode. So, with respective this ground I am applying positive or negative potential to this RF electrode. So, if this is the ratio then an also we know that current according to child Langmuir equation depends on this equation, this is according child Langmuir equation and this is the space charge limited current, we had discussed this part when we were discussing plasma. So, we combining these expressions, we can say that V RF over VG will depend on AG over A RF taking these 2 distances almost equal to the power 4. So, if we have higher ground area then we will have V RF much higher than VG. So, all the potential drop would be at the RF.

This way we can make sure that not only the electrode, but the entire chamber is grounded with respect to the RF electrode. So, we can make the entire chamber as the ground electrode and have just one electrode on which we have we are applying our RF potential this way because this a G is very high over v RF would be much higher.

So, with this will stop at this part and in the next lecture will continue our discussion on the sputtering deposition and we will discuss various large area deposition techniques also in this sputtering.

Thank you.