Fundamentals of Materials Processing-2
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Module – 02
Thin Film Deposition
Lecture – 07
Plasma Physics continued

Hello and welcome to lecture 7 in this lecture we will continue our discussion on Plasma and Plasma physics. Remember in the previous lecture 6 we have discussed what are the different types of plasma, what is glow plasma and what are the different regions in glow plasma and how do we define plasma based on ionization factor. And we also discussed what happens when we merged one electrode in plasma. Now since we know that plasma consist of electrons ions and neutral species, we should also expect that these will respond to externally applied electric and magnetic fields. So, how does that happen? Let us look into that.

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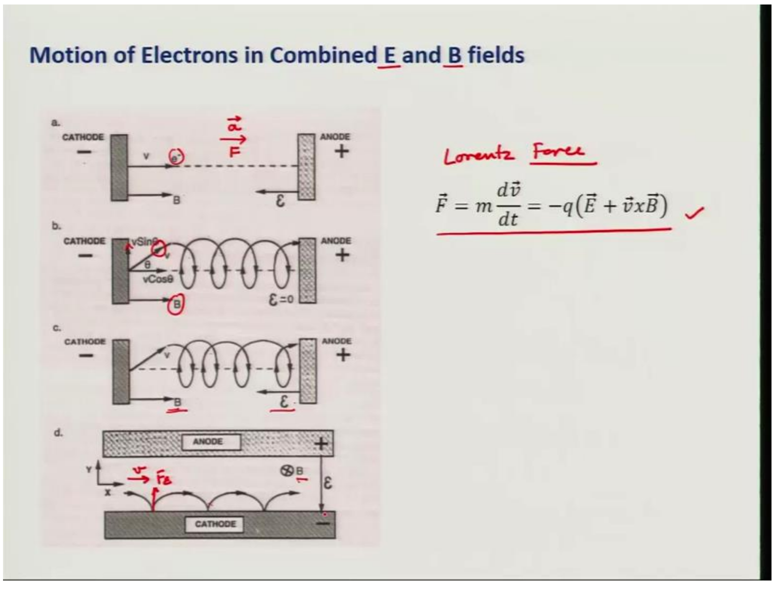

So, in this slide I am discussing motion of electrons in combined electric and magnetic field. So, in this figure as you see if a electron has velocity parallel to the direction of electric field, it will be a exhilarated in this direction towards anode, there will be exhilaration and force in the same direction on the electron.

Now, in this case both electric field and magnetic field are parallel. If the velocity of electron is parallel to magnetic field, then there is no effect of magnetic field on the electron. If there is a slide angle between magnetic field and the velocity, then the v cos theta component of the velocity will not have any effect of magnetic field; however, the vertical component which is v sign theta will see Lorentz force as per this expression acting on this electron and which will try to move it in a perpendicular direction and as a result of this v cross B will see a spiral movement of this electron towards anode if the electric field is not present. If both electric field and magnetic field are present then would this spiral motion along with this spiral motion electron will be also be exhilarated towards anode and this spiral distance will keep increasing and all this you can calculate using this expression of Lorentz force.

So, in the first 3 cases my electric field and magnetic field work parallel; what if I have perpendicular electric and magnetic fields. So, I have cathode and anode giving this electric field from positive to negative and I have a magnetic field which is into the plane of this paper, from top it is going into the plane of paper that is my magnetic field. So, any electron travelling in x direction with the velocity v will feel this electric field and also this magnetic field. So, it will be certain towards anode, but this magnetic field will try to bring it back to the cathode.

So, the electric force F e will be towards anode, but the magnetic force will be towards it depending on the velocity it will try to bring it back to the cathode and then will see a hoping motion of electron on the cathode. Now why is that important? It is important if you understand that we do not want to lose our electrons to anode, once electrons reach anode they are of no use towards; we want electrons to exhilarate ionised the gas and then probably come back to cathode and exhilarate again and ionised the gas, if that is happening then we do not have to provide any secondary electron from cathode, which requires additional voltage or additional energy. If we can utilize or general the same electrons again and again to ionize more and more gas atoms then we can have a self sustained plasma at much lower fields.

So, that is why perpendicular electric and magnetic fields are very important for to have plasmas at lower voltages and how this is utilized for our thin film deposition process will discuss when we discuss sputtering process.

So, this is about motion of electrons and we are mainly right now interested in motion of electrons because we want these electrons to generate more gas ions. When we come to sputtering there we will be using ions for sputtering process then we will worry about how these ions are moving. Now since we know that plasma is basically a collection of charges, negatively charge electrons, positively charge ions and neutral species. So, what would happen, how do we describe this plasma locally?

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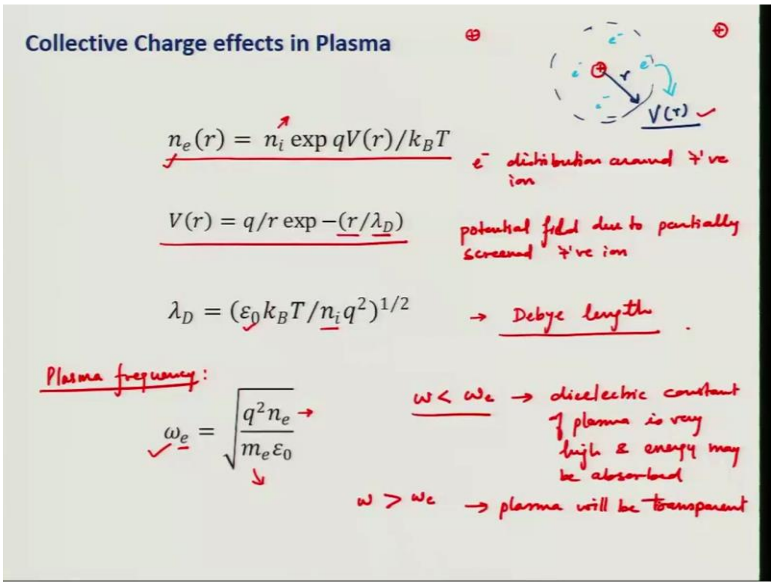

Suppose if I have a positively charged ion right at some place, we know that it will have a potential field around it. We call this potential V r because this will be a function of the distance from the ion.

So, there will be a potential distribution because of these ions, we are talking about just one ion, but we have so many ions and so many electrons. If there is a positive ion then we expect that there will be electron cloud around it because the electrons will be attracted towards positively charge ion. So, if we take another colour. So, we say that we have some electrons in this (Refer Time: 07:40) which are attracted towards this positively charged ion.

Now this will effect this potential field of ion because now my positively charged ion is partially screened by a cloud of electrons and this cloud of electron will also have a radial distribution which is given by this expression, where n is the number density of ions and this will be the total number density ions. So, if I have some positive ions here,

here. So, collectively what is the ion density, which also defines electron density in total, but how now these electrons are distributed around these ions in some radial manner and how they are distributed will depend on this potential field.

Now, this potential field itself will be given by this expression because now this is the positive ion is partially screen by electrons. So, it is not only the positive ion which is giving rise to the potential field, but it is the screening effect of the electrons around it also will guide how the potential field looks like and this will be an exponentially detained potential with a radial distance from the ion and this lambda d is an important parameter for plasma is called Debye length. Physically what Debye length means, it is a distance after which in plasma you do not feel the effect of this positively charged ion. So, if I have a positively charged ion here which is partially screened by electrons, at a certain distance if I put another charge because the combined effect of this ion and electron cloud around it this charge will not feel the effect of this ion.

So what is this distance? It is a distance called Debye length and this epsilon 0 is the permittivity of free space, and i is the density of ions. So, if you have large number of these ions then this Debye length will be very small. We can also define another quantity, let me label these first. So, this is electron distribution around positive ion and this is potential field due to partially is screened positive ion, this is Debye length and this quantity is known as plasma frequency. This plasma frequency is a frequency or is a time constant at which the plasma responds to any external fluctuation or any change in equilibrium. So, suppose you have a plasma with certain number of electrons and ions and certain distribution of all electrons around ions and if you for a brief time emerge the charge in that plasma, how quickly it will respond to it and come to a new equilibrium is given by this plasma frequency, it is a measure of this plasma frequency where n e is the number density of electrons, and m e is the mass of electron, q is the charge and epsilon 0 is the permittivity.

So, since electrons can respond very fast to any perturbation to this plasma. So, it only depends on how fast electron can respond to any changes we also have ions, but ions respond very slowly because of they are heavier mass. So, it is the electrons and hence this substitute of e that how fast the electrons respond. So, what are the uses of plasma frequency? Suppose there is a radiation, radiation with sudden frequency or if we change the potential at certain frequency. So, if this frequency is less than plasma frequency, in this case this dielectric constant of plasma is very high and this energy may be absorbed. So, suppose I have created plasma, the DC voltage and on top of this DC voltage I apply as small AC signal.

So, AC signal is fluctuation in voltage. So, how fast my plasma will respond to that change in voltage will depend on the frequency of that AC signal and if AC signal is less than this plasma frequency, it is means slow moving, slow fluctuating signal then this plasma will respond to it, it will try to accommodate for the positive cycle on negative cycle of that voltage and that energy it will absorbed.

On the other hand if omega the radiation is greater than plasma frequency, then this plasma will be transparent, other plasma will be transparent to that radiation or it will not see the effect of that fluctuation. See this way it takes if you change something it take some time to electron to respond to it and if you change it again before electron realizes they has there is some change then it will in effect will not see that change, if you change the voltage very frequently very fast then electron will not have time to respond to it and in effect is plasma will be transparent or it will not see that field or that signal or that radiation of a frequency higher than plasma frequency. So, this is also in important part and it we will discuss this in detail later.

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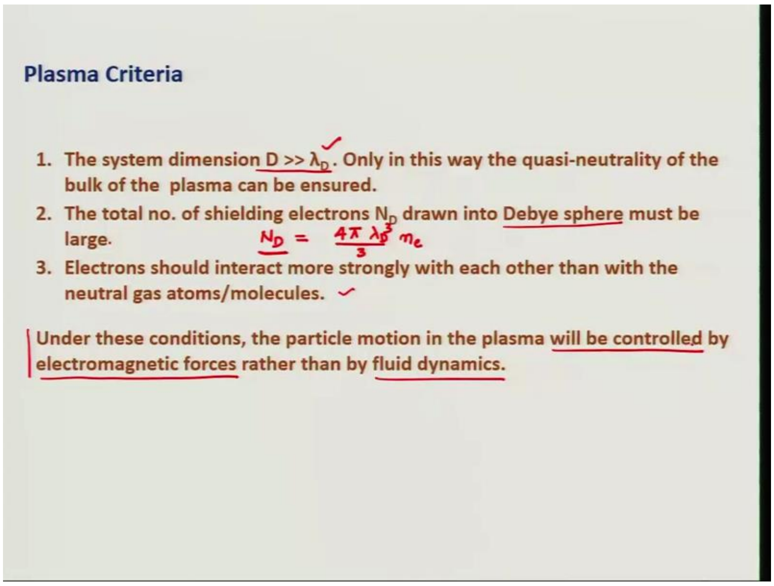

Now, based on these considerations they are certain plasma criteria which plasma should full fill; first of all if you if I am creating a plasma in a system between 2 electrodes, so the gas is going to fill the entire volume, it will not be on only between the 2electrodes. So, for the plasma the system dimensions should be much larger than the Debye length. So, you cannot create plasma if your system is smaller than the Debye length because you need to have Debye length at any electrode; only in this way quasi utility of the bulk of the plasma can be ensured this is one condition. The total number of shielding electrons drawn into Debye sphere must be large, which means that around a positively charge ion you have a Debye sphere in this some electrons are shielding it and that Debye's sphere is a sphere of Debye length.

So, N D which can be given as 4 pie lambda D q over three; this is the volume of the Debye's sphere into n e density of electrons. So, this number should be very large and also electron should interact more strongly with each other than with the neutral gas atoms are molecules. So, this is also an important criteria and these are important because only under these conditions the particle motion in the plasma of electrons and ions will be controlled by electromagnetic forces, rather than by fluid dynamics.

So, gas is the fluid and the motion of a gas can be also be described by fluid dynamics, but since we want to control the motion of these charge particles and utilize their motion for our benefit, we need to have these we have to make sure that these plasma criterion is satisfied. So, that we can control the motion of these charge species by electromagnetic forces since we are talking about electromagnetic forces we had already seen the effect of electric field and magnetic field let us go to the effects of alternating field.

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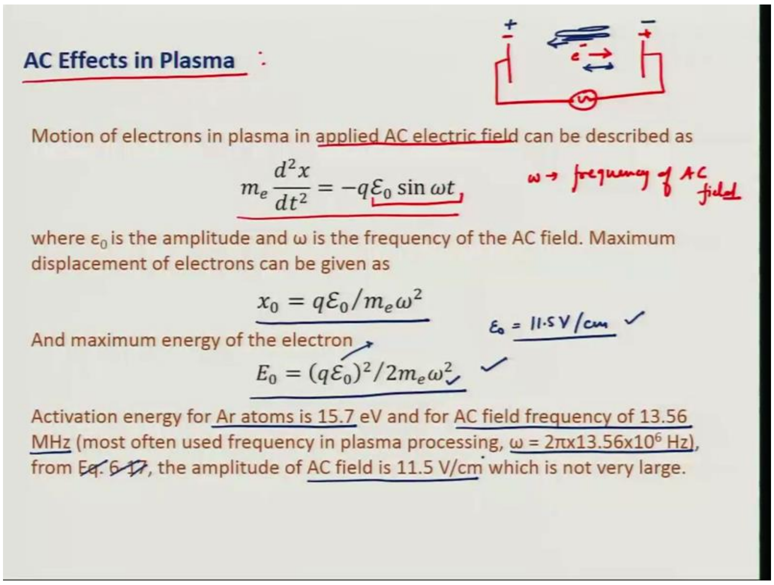

AC effects in the plasma what if we apply a alternating field. So, the motion of electrons again we are still discussing motion of electrons and plasma. So, motion of electrons in plasma in an applied alternating field can be described by this expression.

Where this is mass into exhilaration is, this is the force, where my force is electric field multiplied by charge and electric field is wearing sinusoidity with the frequency omega; omega is the frequency of AC field. So, suppose I have an AC field between two electrodes, let me make asthmatics here. So, and these are 2 electrodes and between which I have applied in AC field. So, I cannot define any of these electrodes as anode or cathode because half cycle one electrode will be anode, in the other half other electrode would be anode. So, and I have one electron right here. So, when the polity of electric field is such that this the electrode on the right hand side is positively charged electron will exhilarate towards this now in the other half cycle when this the there is a change in priority, then this electron will exhilarate towards the other electrode and it will not be able to reach either electrode because I have certain frequency and I am changing the frequency very fast.

So, what will this electron do? It will start to oscillate between the two electrodes. Now what is the maximum distance it can travel from its starting position? It will start to exhilarate in one direction and as soon as the field is switch switched or direction is split it will start to exhilarate in the other direction right. So, there is a maximum distance it can travel which is given by this expression over here at higher frequency it will this x 0 would be very small, it will lower frequency this would be large. As it is moving going to this x o distance it will gain energy because it is exhilarating till that distance and it will reach a maximum energy before it will start to decelerate and changes direction and then again exhilarate in the other direction. So, the maximum energy it will achieve is given by this expression here. So, this is the maximum energy of the electron in an AC field, where the field frequency is omega. Now why is this important? Because we want to use this oscillation in the maximum energy of the electron to ionize gas items to create plasma.

Now, activation energy of argon atoms is around 15.7 electron volt activation or ionization energy. Suppose my omega AC field frequency is 13.56 megahertz, which is most often used in thin film deposition or plasma processing. So, my omega would be two pi to 13.56 into 10 to the powers 6 hertz and sorry this expression is not here from this expression over here we can calculate the amplitude of AC field which is around 11 point volt per centimetre. So, if this electric field is 0, is around 11.5 volts per centimetre at this frequency then we can my electron will have enough energy to ionised argon atoms. Now once it ionise argon atoms it will lose it is energy, but there is the science are changed, the electric field is flipped, so it will start to assert in the other direction and gain energy again and then again ionised organ item and then again lose it is energy and start to assert in the other direction. So, you using small electric field we can ionised more argon atoms their by reducing our requirement of break down field.

So, this is one important effect of AC plasma because we can keep electrons away from the 2 electrodes. So, we do not have the loss of electrodes and also use this small electric field to ionised gas atoms. So, that is the effect of AC.

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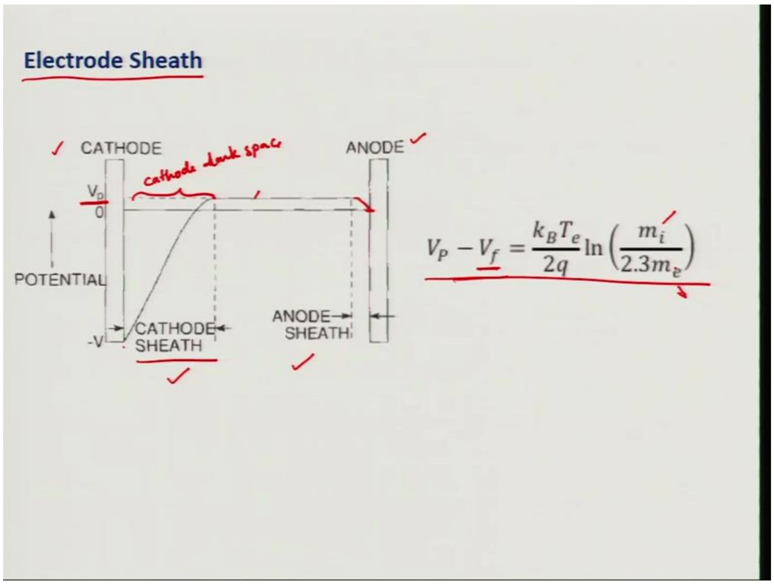

Now, we are again coming back to DC field and we will discuss what is called an electrode sheet and in this we are mainly interested in cathode sheet. What happens that the remember that we had said that more than the time you can avoid everything else, but the most important part of a plasma for cathode dark space and negative blow, these are the important parts. So, you can bring the anode as close as the negative blow. So, this is my anode and cathode; since we had also discussed that any electrode placed in plasma will have slightly negative potential because of negative charge. So, anode will also have slightly negative potential compare to plasma potential, this is V p, this is the plasma potential combined plasma potential these electrons and ions and we had also discussed at most of the electric field or the potential is dropped in the cathode dark space this is also cathode dark space, this region and we see this potential drop here.

Now, this is the floating potential of the any electrode and this is the mass of ion and mass of electron, so if you emerged any floating potential or any electrode, how much lower it will be will depend on the relative mass is of electrons and ions. So, we can calculate this property if you know the mass of electrons and mass of ions. Now, based on this we can also quantify another property which is called cathode current; now we are moving our discussion from electrons to ions.

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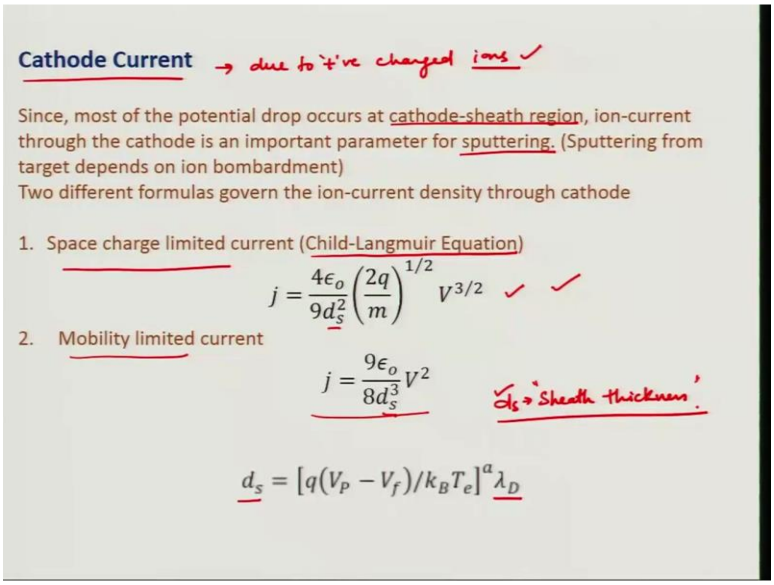

So, we are discussing cathode current and this is due to positively charged ions, remember that ions are positively charged they are moving towards negatively charged cathode and since most of the potential drop is in the cathode sheet region or cathode dark space the ion current through the cathode is in important parameter and it is specially for sputtering, because you have going to use this these ions for sputtering process electrons use is to generate ions and it is these ions which are generating plasma that we are going to use for sputtering process and the current how many ions are impacting or reaching the cathode will give to a ion current or cathode current.

These current can be described by these two equations, depending on two different conditions. In the first case it is called space charge limited to current and this expression is called Child-Langmuir equation. This space charged limited current exist when the motion of ions is defined by the electric field or the space charge in the cathode sheet region and mobility limited current is because of mobility and this exist when in the cathode sheet region there is collusion between ions. So, if the gas density is low, so that they are no ion ion collusions then we can use space charge into current. But if there is ion ion collusion then we should use mobility limited current expression and d s is an distance which is several multiples of lambda d this distance d s, this is called the sheet thickness sheath thickness or cathode sheath thickness - this is d s; this is a thickness of cathode sheet.

With this will stop our discussion on plasma; in the next lecture we will discuss how this plasma or the charged ions or positive ions in this plasma are used for sputtering process.

Thank you very much.