Fundamentals of Materials Processing-2
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Module – 02
Thin Film Deposition
Lecture - 06
Plasma Physics

Welcome to lecture 6 of Thin Film Deposition module of this course, we are discussing thin film deposition methods and in this we are discussing specifically first physical vapour deposition methods PVD methods and among PVD methods, we have discussed thermal evaporation and electron beam evaporation and next what we want to discuss is another physical vapour deposition method called sputtering. But before we go to sputtering, we will discuss plasma and plasma physics in next couple of lectures because plasma is very important for thin film deposition processes and many thin film deposition processes use plasma.

In the next 2 lectures we will first discuss plasma and it is physics and then we will go to sputtering to start with what is plasma.

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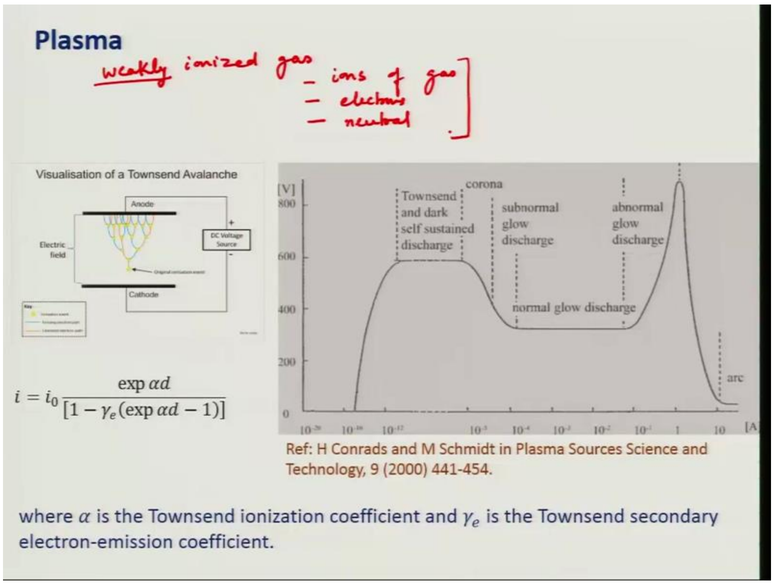

Plasma can be defined as weakly ionized gas. So, let me write it down here, it is a weakly ionized gas, we will discuss on this weakly ionized later, but it is ionized gas and which consists of ions of gas, it consists of electrons and it also consists of some neutral species. So, these are the 3 main consequence of plasma and in effect in plasma they are present in such a number that over all plasma is charge neutral.

Now, you would have seen plasma at many places and you would have seen a glow associated with the plasma, but not all plasma might have a glow. So, there are different types of plasma and they have different regimes in which they exist. So, those we will discuss here, but let me first discuss with the help of this schematic diagram, but how plasma is created. So, suppose you take 2 anodes or 2 electrodes, one is anode and one is cathode and you connect it with the voltage source and you increase the voltage. So, what would happen that there are some electrons always present in your natural environment.

First electron will start to accelerate towards anode as it is accelerating towards anode, it will impact or collide with gas molecule or atom and in the process it will ionize this gas molecule or atom and 1 electron from the gas or molecule will come out, and there would be a positively charge ion of gas and gas atom and also you will have one additional electron. Now these 2 electrons will be accelerated by this potential. Now these 2 electrons will further multiplied to give you 4 electrons and 16 and so on and so forth and then you will have a cascade of electrons and in the process, we are also creating these ions and this avalanche process in which electrons are multiplied, it is called Townsend avalanche, and it is also called Townsend avalanche break down in which this electron current increases very rapidly because you have so many electrons being produce due to the process of ionization then you do not have a control over the number of electrons and the current.

Let us switch over to this graph here which shows nation between voltage applied between the electrodes and the current. So, this is, on this y axis is voltage and on x axis we have current. Now if you see that initially there will be very small current or negligible current 10 to the power minus 16 or low below that, as you increase the voltage the current will also increase to some extent you need initial very high voltage to introduce some more current because they are very much less ionization.

But after certain point you will reach an extent of electrons then you do not need to increase voltage to increase current because these electrons will be self multiplying due to the process of ionization. So, if you see in this range the current increases at the same voltage you do not need to increase voltage to increase the current then there will be a phase where actually the voltage to sustain the same level of current decreases in and the current creeps increasing still. So, to control the current we need to decrease the voltage and these are the Townsend and dark self sustained discharge, corona discharge and then you have a region of normal sub normal to normal glow discharge.

In this unit very less voltage to sustain large amount of currents, beyond this if you want to increase the current then you have to increase voltage again and then after the threshold you will start to see arching. So, this is the whole process under which different types of plasmas exist. In this course we use normally your discharge.

Our main attention will be focussed in this region somewhere here where we have glow discharge and that we see as a glow in the plasma. Now let us come to this expression here which explains the electron current as a in the plasma. So, alpha is the Townsend ionization coefficient because as more and more gas atoms are being ionized more electrons are being produced which will carry the current.

The current increases, there is another factor gamma e which is Townsend secondary electron emission because once electrons reach the anode they are lost, they will be part of the external circuit then you need to have a supply of secondary electrons which is given by gamma e. So, and the current expression the electron current in Townsend discharge is given by this expression.

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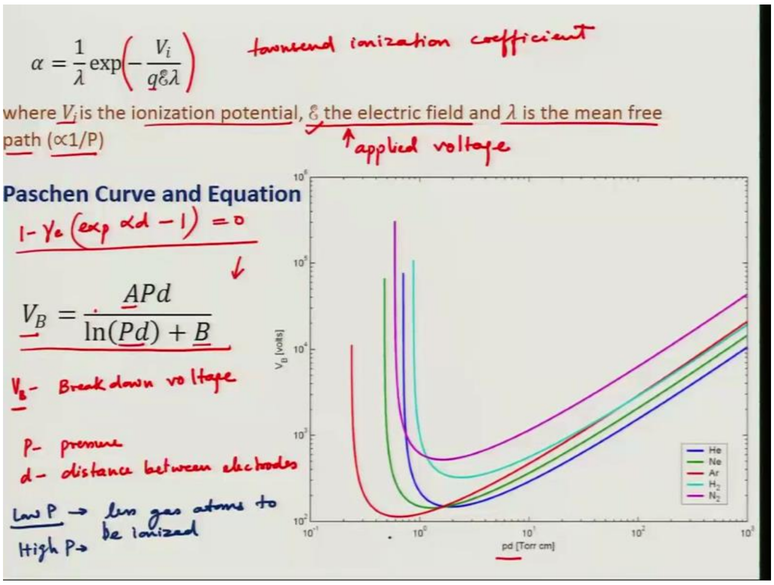

Now, this alpha which is Townsend ionization coefficient is given by this expression, let me give you the brackets here and this is the Townsend ionization coefficient and V i is the ionization potential of the gas atom or molecule, it defines that how much energy you require to take out one electron from the gas atom, e is the electric field and lambda is the mean free part of the gas, which is as you remember might remember from the previous lectures depends inversely on the pressure and q is the charge. We have this expression for alpha.

Now to have self sustained plasma, this current should be very large in this region. So, you do not have to tried any additional voltage for plasma 2 you keep it keep itself allies. So, in that case this I will tend to infinity very large and which means that this factor which is in the denominator must go to 0. 1 minus gamma e, we go back to copy it exponential of alpha d minus 1, this expression should be equal to 0. At a voltage when this expression because alpha as this electric field which depends on the applied voltage this is the applied voltage. So, this expression depends on the on the applied voltage.

So, once this expression becomes 0 the current will try to go to infinity and from this we can calculate quantity called break down voltage. So, v b here is the break down voltage for that gas. So, break down voltage means that after this voltage the plasma will be self sustained. So, you need to applied this voltage to have plasma self sustained plasma. Now a and b are coefficients in this and this v b depends on product of P and d - P is the pressure and d is the distance between electrodes. V B by d will be might break down field.

Now these this equation is known as Paschen equation and the curve which are shown in this graph are called Paschen curves and these are shown for different gasses how the break down voltage changes with the product of P and d pressure and the distance. So, if you see that these curves for a fixed separation between anode and cathode at low pressures you need very high voltage and also at very high pressures you need very high voltage now we can explain this phenomena like this in the low pressure regime when the pressure is low they are less gas atoms to be ionized. Now 1 electron is travelling from cathode to anode and if the gas pressure is low it is going to encounter very less number of gas atoms and ionize less number of atoms there by giving rise through less number of electrons. To increase the current you need to increase the voltage that is in the low pressure.

In the high pressure region what happens is that you have too many gas atoms in the path of electron. So, when the electron is accelerating, it will ionize the first gas atom that it collides with, but between this and the second collegian, the electron does not accelerate enough or does not gain enough energy to ionize the next gas atom because there are too many collisions between gas atoms and electrons. So, electrons do not get sufficient time to gain energy in the potential field. So, in this case also you need to increase the voltage to have the self sustained plasma or have a break down voltage.

Looking at this you can see that there is a sweet region of P and d with there you need very less voltage to have self sustained plasma and it is this region we should be working in, so that we do not have to apply very large amount of voltages.

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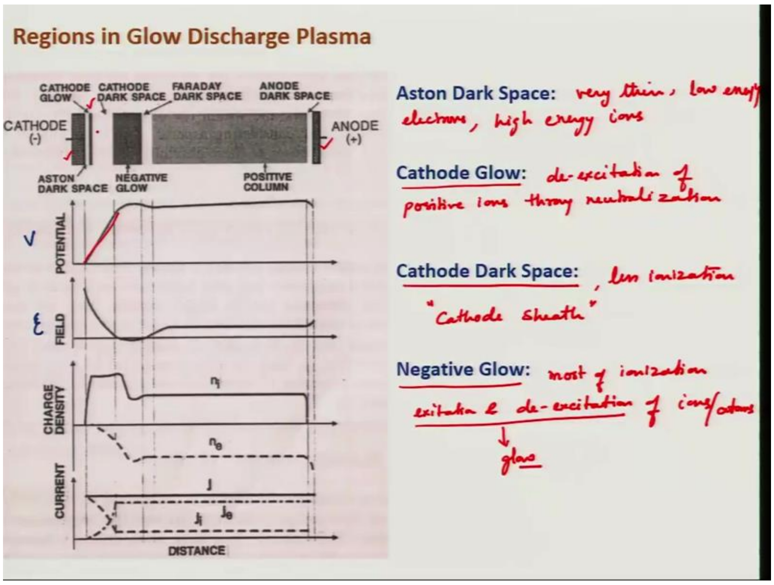

Now, if you have a plasma between 2 electrodes, they are different regions of the plasma, it is not uniformly distributed, what are these different regions are shown in this curve; in this diagram on the top and how the potential field v, electric field, charge density, number of ions and electrons and the current there is in these different regions, it is shown below this diagram, we will discuss few of these regions which are of most important to us.

Now if we start from cathode which is our negative electrode the first region we have is called Aston dark space. Now this Aston dark space is very thin and it contains very low energy electrons remember electrons are being generated at the cathode, cathode is negatively charged. So, it will repel the electrons, but since electron did not gain enough energy by acceleration only the low energy electrons are aligning in this region and also this as high energy it should be energy naught e high energy ions.

Now, contrite to electrons, ions are coming from anode or they are present here, they are accelerating towards cathode, they are accelerating towards cathode. So, just before they impact the cathode their energy is highest. So, high energy electrons are found in this region. Then we see a very thin region of glow which is called cathode glow. In this what happened is de-excitations of positive ions through neutralization, we will discuss this. Now what is happening in this region which is cathode glow is that you have positive ions which are accelerating towards cathode and in the process when they interact with electrons somewhere in the negative glow region they get excited which means some of their electrons of these ions go to excited to higher energy state. So, which is in excited ion then this excited ion comes to this it interacts with the low energy electron and gets de excited.

That means, electron from higher energy state in the ion false back to its original low energy state and then that happened it emits a photon which is the glow and that we see as cathode glow and after that exist the cathode dark space which is the most important region of a plasma because the entire voltage that we apply across these plates exist between in this cathode dark space. So, in this region electrons are starting to gain energy by acceleration and also they are less ions here because as they are coming close to cathode they are going to impact in the cathode. So, ions do not hang around in this region.

In this region less ionization because electrons do not yet have very high energy and almost all the potential difference which exist between cathode and anode between these 2 electrodes is between is exists in the cathode dark space and this is dark because they are no excitation or de-excitation in this region. This region is also known as cathode sheath.

The next region is negative glow, in this negative glow now most of the ionization process happens, most of ionization of the gas atoms in this region and we have both electrons ions and excitation and de-excitation of ions slash atoms. So, this is the most active region of what is happening in the plasma electrons have gain sufficient energy to ionize gas atoms and now some of these gas ions are either excited or de-excited and in the process they give a glow.

This process also gives a glow again after this there is a small dark space and then we have a positive column we have low energy ions usually are present as ions move towards cathode they gain more energy and towards anode there is also an small space called anode dark space. So, these are the regions of plasma given sufficient suppression between the 2 electrodes if you narrow down the suppression between these 2 electrodes all these regions will still exist the positive column will be reduced or sometimes it may in completely eliminated all these regions will still exist. So, positive column is somewhere away from the plasma it. It is no glow region this is not much happening there it is just many low energy positive ions are just present there.

These are the different regions of glow discharge plasma which is usually used in thin film deposition and for the sputtering process we will see that most of the time we only talk about the region up to negative glow from cathode to negative glow region.

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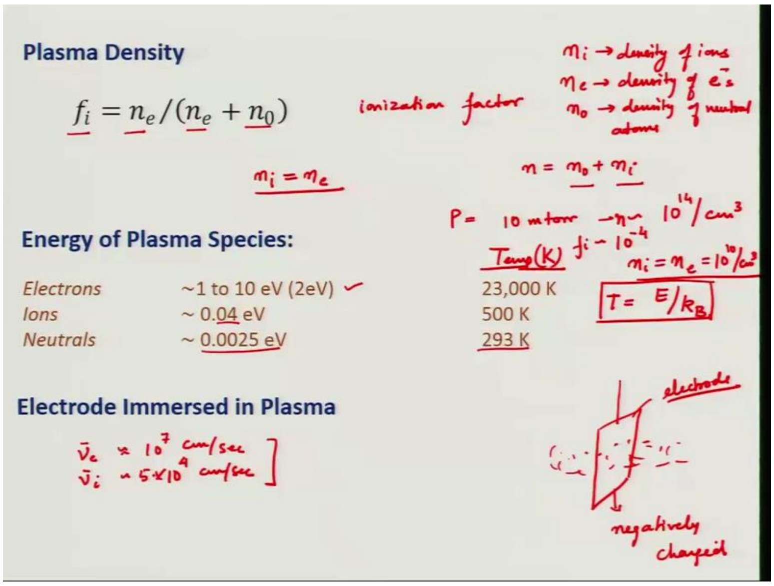

Now, how do we define plasma, like the how much plasma we have? Gas we can defined by pressure and volume, but to define plasma we take help of a quantity called ionization factor – fi, which is number of electrons divided by number of electrons plus number of neutrals. So, ni is number of ions or number density this is density per unit volume density of ions, ne is density of electrons, and no or n0 is density of neutral atoms.

Total gas density n will be equal to n0 plus ni, ionize; ions and neutral gas atoms and since the plasma has to remain charge neutral we should also note that ni it should be equal to ne and that is why we have used this expression ne rather than ni over ni plus no. Now to quantify it say for at a pressure of around 10 millitorr, the gas density is approximately 10 to the power 14 per centimetre cube, this is n total n and if for a plasma given plasma fi is order of 10 to the power minus 4 then we know that ni is equal to ne should be equal to 10 to the power 10 per centimetre cube and we know this is the region where we operate most often for sputtering process and these are called weakly ionized plasma because only 10 to the power minus 4 fraction of the gas atoms are ionized.

For heavily ionized plasma, you will have this factor 10 to the power minus 2 or larger than that. Not all the species in the plasma have same energy electrons have most of the energy to the order of 1 to 10 electron volts and if you measure their temperature by an expression that energy divided by Boltzmann constant then you will get these temperatures in Kelvin for different species. So, electrons have most of the energies neutrals are at room temperature and less energy and ions as slightly higher energy, so we have this plasma in which we have electrons ions and neutrals.

What happens if we take an electrode conducting electrode and put this in between plasma immerse it in plasma. So, I have this electrode, around it we have plasma what would happen to this electrode. Now we know that flux of electrons and ions will be impinging on it and since we know that electrons have higher energy and they have smaller mass. So, their velocities are much higher, velocity of electrons in plasma are order of 10 to the power 7 centimetre per second compare to ions which is around 5 into 10 to the power 4 centimetre per second. So, you can say that on average more electrons are impinging on this my electrode; if more electrons are impinging on it then positive ions then this will get negatively charged.

My electrode will become negatively charged and then this electrode becomes negatively charged, it means start to repel electrons and attract ions such that there will be a balance between the 2 and my electrode will remain negatively charged. So, if you immerse an electrode in plasma, it will self charged self to a slightly negative potential. With this we will stop here, in the next lecture we will discuss about how these charged species move in electric and magnetic field and how we use these for our benefit.

Thank you very much.