Technology of Surface Coating
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Module 1
Lecture No 13
Cathodic Arc Evaporation Depositions

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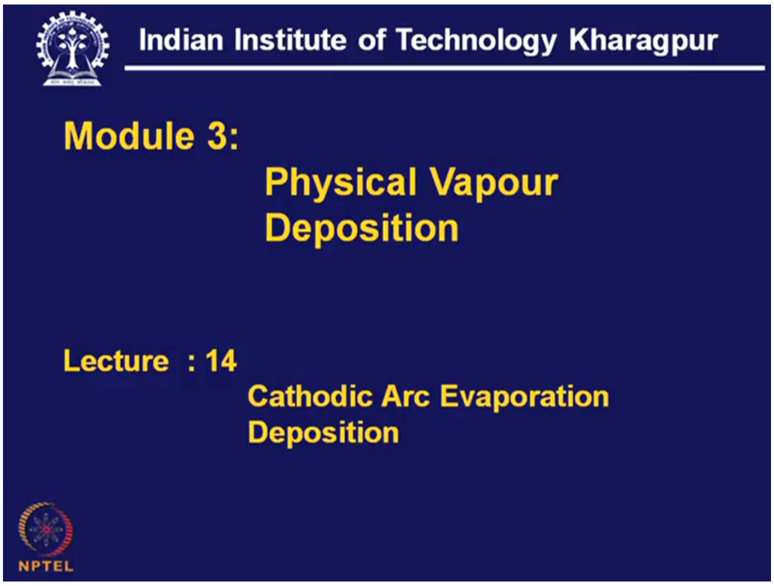

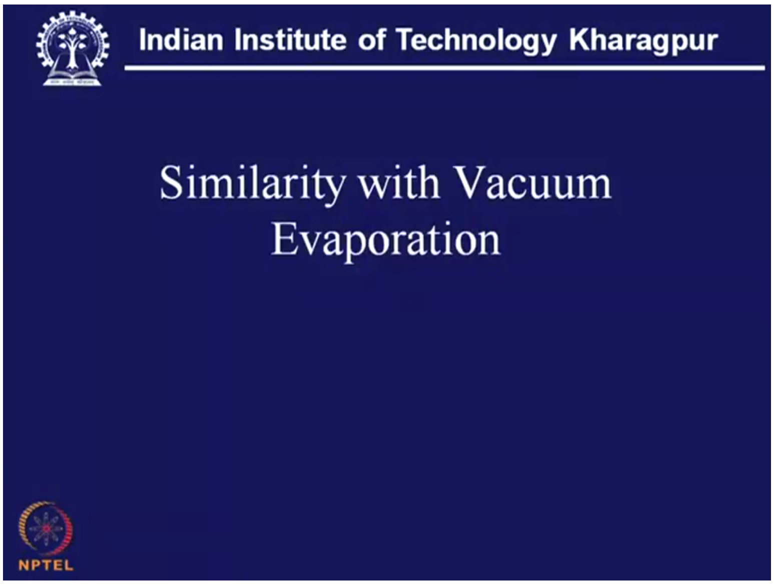

Cathodic Arc erosion deposition, Cathodic Arc evaporation deposition and this particular method has something in common with the vacuum arc evaporation that means this cathodic arc evaporation it has certain similarity in principle with vacuum evaporation.

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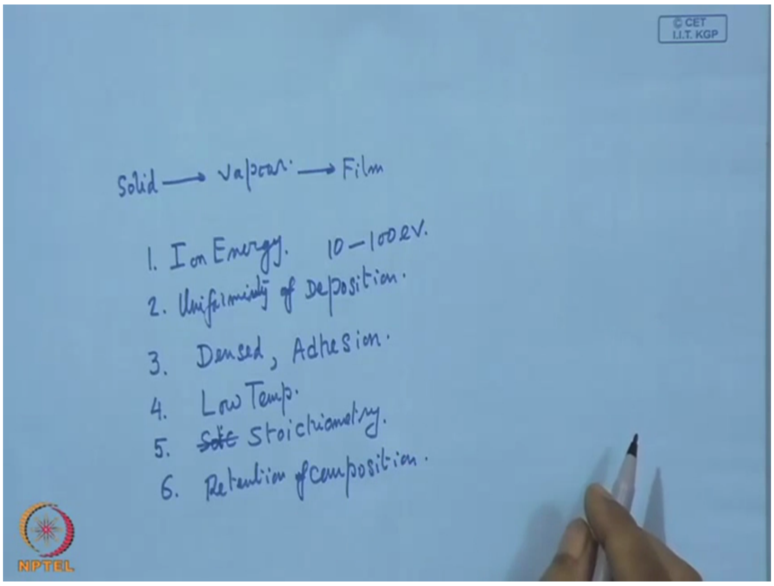

It is exactly that from a solid to vapour and this solid to vapour transformation and then followed by a film that is the route it is taking place and that is common for both. However for this arc evaporation there is one difference that in this case in this normal vacuum evaporation this metal flux that is mostly in atomic level, however in case of vacuum arc evaporation it is mostly aimed ionic state that means this metal which transformed into vapour and it is no more in the neutral state but that has gained an ionic state.

Now this arc evaporation it is actually an old principle which has been intelligently used for this particular purpose. Now this arc melting arc refinement of metal that has been that has been old technology which has been used since long. Similarly we do have other process like arc spray, arc deposition, arc welding, arc cutting like those but here this arc is used for deposition of the material by taking this material from a source which is solid and then transforming it into a vapour and which is mostly ionised.

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Now what other distinguished features of this arc evaporation, this cathodic arc evaporation number 1 what we can say that this energy density power energy, ion energy high ion energy that means the flux of ion which will finally arrive at the substrate surface that is having a high ion energy it can be in the order of even 10 to 100 electron volts, this is number 1. Number 2 what is also important in this case uniformity of deposition of this flux over relatively large substrate area this is very important and interesting. Considering the size of many engineering component and complexity of the geometry, so this is also one distinguished feature, so these are from the deposition point of view so this is number 2, so this is uniformity of deposition.

What is further what we can see that is the quality of the coating, now on the quality of the coating side we can have a highly dense coating, so it is a densed coating with high-density that means it hardness should be quite high plus extremely good adhesion that is also another point. Now whenever we talk about any coating whether it is a metal coating or a metal carbide nitrate coating those things are of immediate interest that it is actually densification of the coating which simply reflects its hardness and adhesion of the coating means how long or with what reliability it can work like a functional coating, so that means it is a very strong interface.

Now this is one then comes what is very important requirement of substrate temperature, now in many process what we have seen that these substrate temperature has to be elevated to a certain point to have proper interface formation through some diffusion of pseudo-diffusion some kind of comical reaction at the interface and at the same time modification of the structure or morphology of the coating, so without that temperature support it is almost impossible to get a good morphology which will simply assist in getting one of the best mechanical property. Say for example ordinarily we may end up with a porous columnar structure unless we heat the substrate to a certain level.

However in this case in this arc deposition this cathodic arc evaporation followed by deposition in this case what we find because of the high ion energy of this incoming flux, it is not only the adhesion is remarkably improved but also this coating can have a fine gran structure it is unlike thereof ordinary sputtering with conventional way of working porous columnar structure large column with gap in between but it can even lead to granular or (()) (7:28) structure in this cathodic arc evaporation, so this is one of the greatest advantage one can look in. Now so this is actually low temperature requirement.

So requirement of just low temperature may be 100 - 200 100 to 200 that may be the range and in this case it can be in there are many materials like some of those plastics we can be also well coated with good density and good adhesion and without having any damage to the basic substrate. 4^{th}, 5^{th} one what we can see that means it is also stoichiometric formulation of a compound over a wide range of deposition condition. Now this is something gives the flexibility in in operation of this process that means the process window is quite wide and one can deposit a stoichiometric compound even though little bit of those gas pressure very particularly the reactive gas pressure and the concentration of the cation that means this metal vapour so even then we can have a good stoichiometric formulation then comes also, so it is that stoichiometry.

Stoichiometry of the compound that we can have, then come say if we are interested in alloy deposition. Now the formulation of the source material and formulation of the film in many cases it is our common experience that the composition of the original material and composition of the coating they are not same because of some difference in there are sputtering rate or any other deposition rate but in case of this cathodic arc evaporation depositions, this can hold this it can retain the composition of the target in the film, so it is also retention of composition.

So at least one can find out so many positive points in this particular process and that is why this process is has become so attractive not only for just a laboratory skill activity but this process has been skilled up to the commercial stage and many of the products particularly for those tools of mechanical manufacturing for those with different sizes, a large size, complex geometry and those materials where temperature requirement has to be within a limit, within a very low limit, in those cases this has become one of the greatest process of attraction and this has been day by day its use is increasing.

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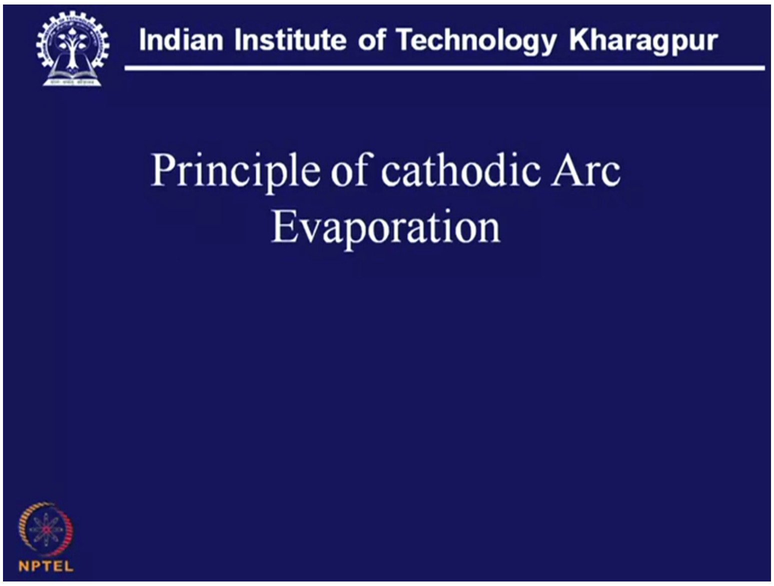

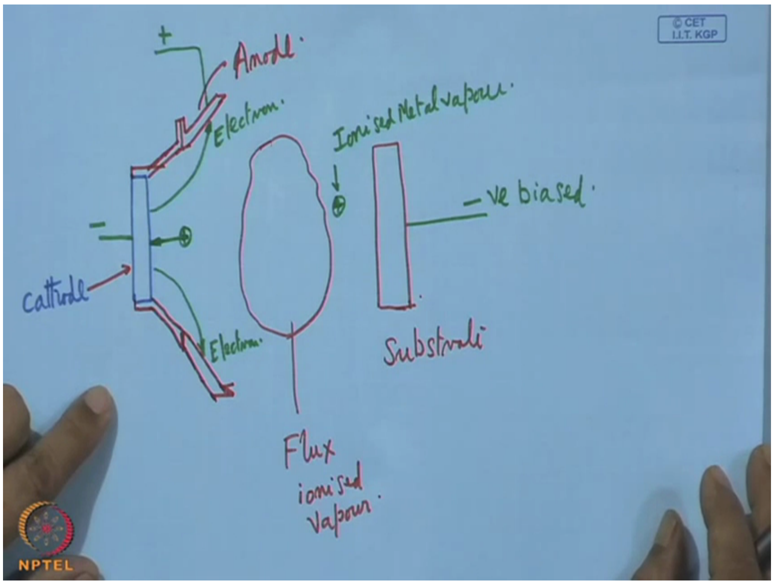

Now principle of cathodic evaporation, we can have a quick look to this process now here what we need to have we need to have one target, so this is actually a target which is the cathode, so this is actually the cathode material, cathode and then there should be one anode, so here we have one anode, so this one…Now what we have to do, we have 2 join this thing with this material, this is just a separator, so it goes like this. So similarly we have here one separator which comes like this, so this is actually the cathode this one and this is anode. Now what is going to happen, that here we have the substrate, so it is actually having a shape of a cone, now this is the substrate and here what we have this flux of ionised vapour.

So what is going to happen, so there will be so it will be negatively polarized and this will be positively polarized and cations with this flux it is going to hit the surface with the result of ejection of electron and this will electron will move in the surface, this is electron and as a result of this high velocity impingement because it is negatively polarized and as a result of this, this cations will strike the surface with the result of evaporation of the material and this material will be in this discharge that means 1st an arc is struck between this cathode and the anode and so we have a plasma environment and within this discharge area this cations that will be attracted towards the surface and then this neutral that will be ionised once it is within this and that will be pulled on this side, this is the metal, ionised metal vapour.

So this is actually ionised metal vapour and which will be attracted on this side, this will intercept this flux and at the same time in most of the cases this is also negatively biased, so it is striking the arc and then drawing this cations towards the surface, then ejection of the material by this evaporation and at the same time ejection of electron which are secondary electrons which will be attracted by the anode and during this period what is seen that it is not only that evaporating the material but at the same time it is also provided with high ion energy, so it is ionised metal vapour which is attracted on the surface. So the basic difference between this one and the conventional evaporation process it is that it is one arc discharge that produces the vapour in this case but in normal evaporation what we see it is directly heating the material, so that is the basic difference between normal vacuum evaporation and this arc evaporation.

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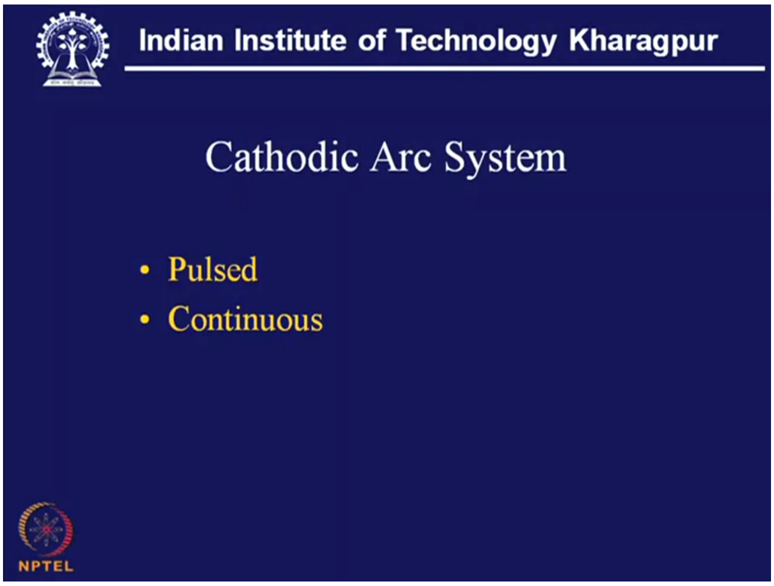

Now actually what can see, the system cathodic arc system we have 2 types, one is pulsed type another is continuous type. Now when it is a pulsed type, we have 2 options, option means in this case we have time interval for cooling of this cathode target but the throughput will be less however when it is continuous, in that case this throughput productive will be more but in this case there is a chance of non-uniformity of the deposition or non-uniformity of the erosion of the cathode surface and these are the 2 merits and demerits continuous arc's arc or pulsed's arc.

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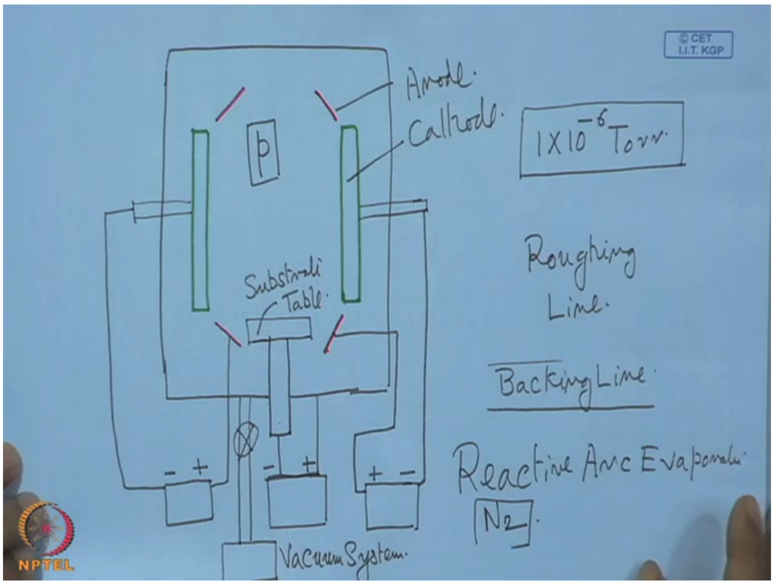

But cathodic arc system that means it is basically one if we can if we can see to cathode here facing each other and a anode is provided in this form and here what we have, we have one table for substrate support this is the table and the whole thing is put inside a vacuum chamber and here we have this terminals here too, so here we have 3 power supply, 3 power supply this is minus and plus, so what we have to have, it goes with this, so it is negatively biased, this one is positively biased, similarly we have another power supply here so this is just negatively biased and this one, this is positively biased and for the substrate holder, this is substrate table.

This is actually the cathode, anode we have that twin pair, we have dual cathode system facing each other and for this we have to have a negative polarization on this side and that can be also connected with the chamber or it can be also grounded, so in this case that will be floating but it can be also negatively polarized and it can be also, this part can be also grounded, so this is more or less a system and here we have to have one ignitor for ignition of this arc, so arc has to be struck between these 2, so this has to be there and apart from that we have one vacuum system that means this is actually the vacuum system and vacuum system means we have just like normal vacuum system and here at least a pressure of n to the power minus 6 torr that pre-vacuum is most desirable and for that we have.

We can have a system having both roughing line and a backing line that means on the backing line we have the diffusion pump and on the roughing line at the end we have it is backed by a roots pump followed by a vane pump, so these are the peripherals for evacuating the whole system, so that becomes a part of this one and apart from that we have this power supply and when we have to have say a reactive arc evaporation or deposition, in that case we must have admittance of a reactive gas say for example nitrogen and in this case it has to be a closed controlled entry admittance of this nitrogen definitely with the use of a mass flow controller, this is number 1 and number 2 is the process pressure inside.

So this process pressure inside what we like to have definitely that will be on the downstream side in this side here we are we must have a throttle valve and that should be properly throttled to give… Here we have a throttle valve and that should be properly throttled to give a process pressure of interest inside the chamber, so that with this flow of this reactive gas then with this arc voltage, arc current, substrate biased voltage, process pressure which are the basic parameter in the system we can have one of the effective coating on this substrate which will be placed on this substrate (())(23:59). So this is the basic system of this cathodic arc deposition.

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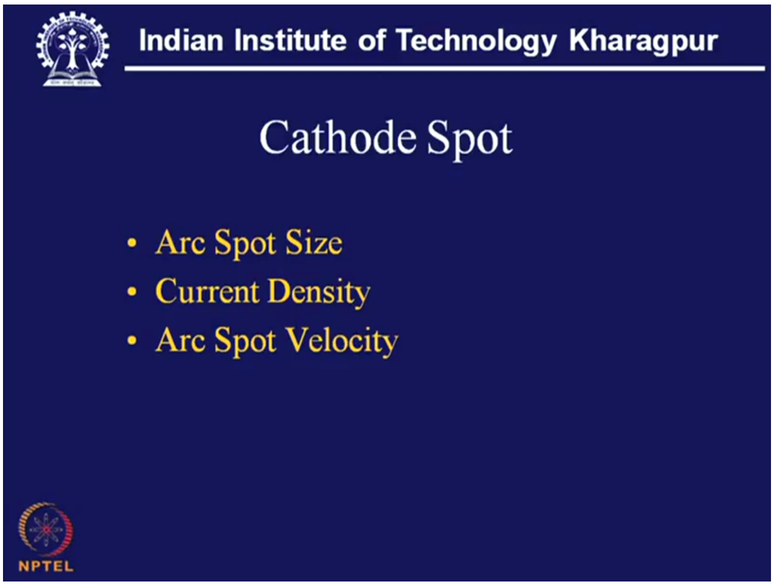

Now there is one term cathode spot now when this arc is struck, so there is a point where this arc is struck and that is the cathode spot and this arc spot size that is actually characterised it is very very small.

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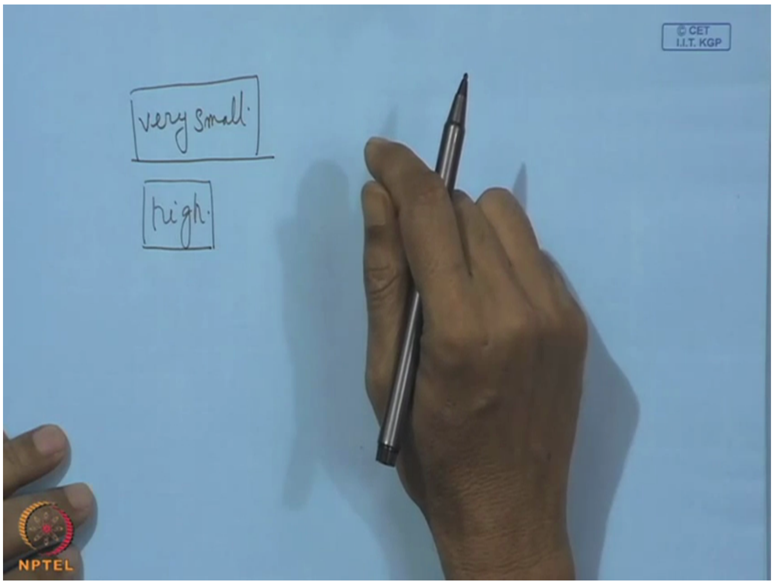

So spot size that is very small, so this is very small. Current density that is very high that is the characteristic feature of this cathode spot and also this arc spot that also moves it is not stationary and it also moves, it swings with a very high velocity, so the cathode spot that is actually characterised by a small size, its diameter then high, current density and also the high arc spot velocity, so these are the 3 characteristics of this cathode spot.

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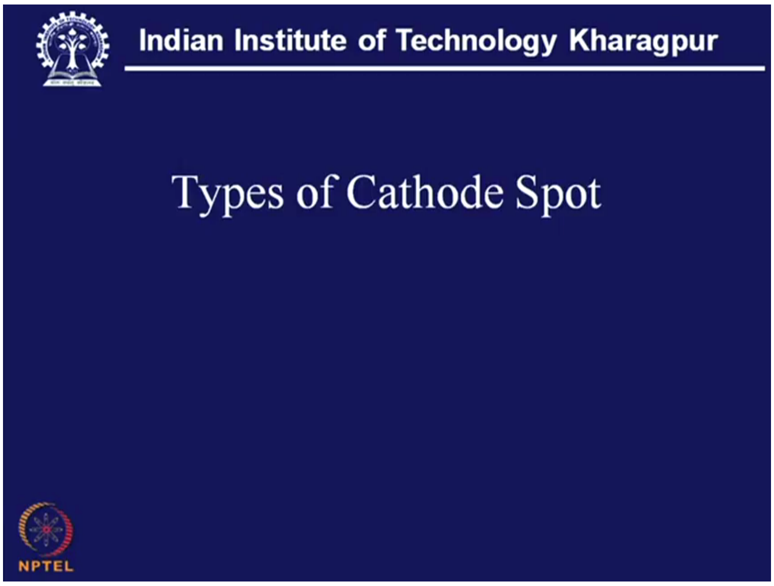

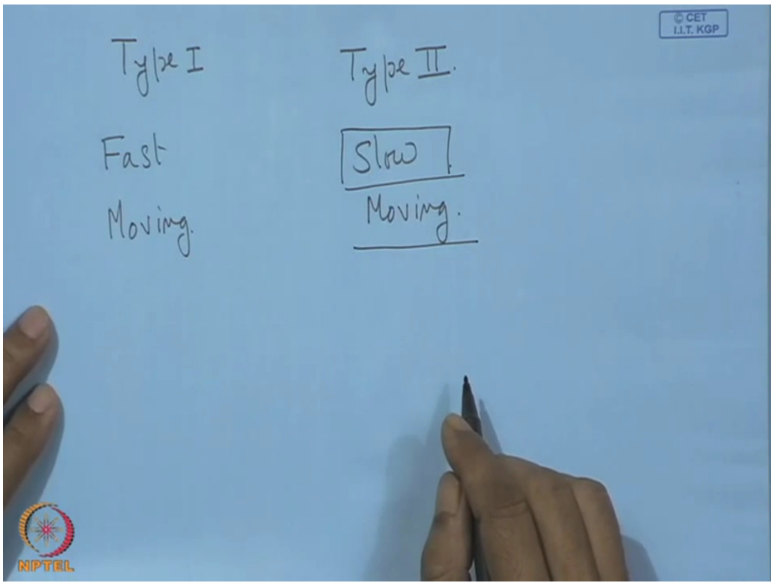

Now types of cathode spot, now types of cathode spot what we have? We have 2 types of cathode spot, one is called type 1 and type 2. Now type 1 that is fast moving and type 2 is slow-moving. Now this happens on a cathode surface that means it is actually that target surface. Now when the target surface is absolutely fresh and in that case there may be some contamination on the top surface in that case this cathode spot that can move with a very fast with a high velocity but when it is already an used cathode with a mark of all sort of erosion at means on the surface then it is slow-moving, then it is slow-moving then it becomes a slow-moving surface, so we have type 1 fast moving and type 2 as slow-moving cathode spot.

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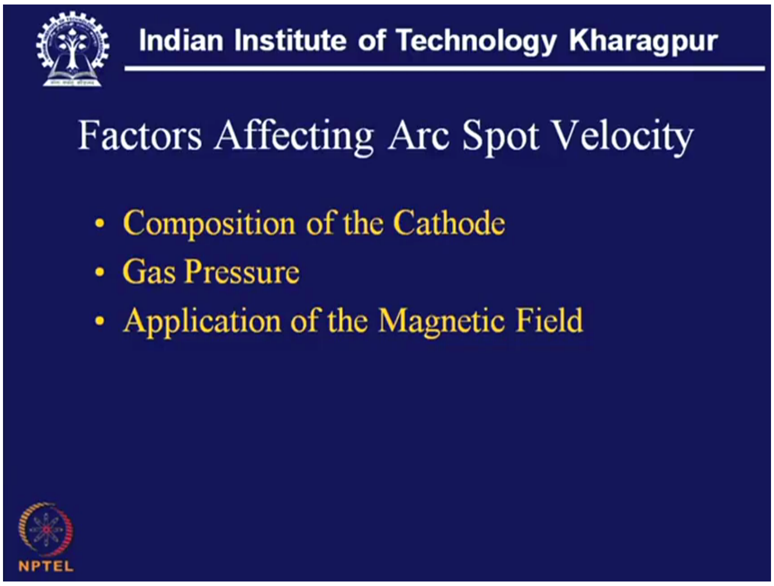

Now factors affecting arc spot velocity, now it is actually what we have seen composition of the cathode material that matters very much in this determining the arc spot velocity then comes the gas pressure inside the chamber and that is necessary to have this arc deposition process, conduction of this arc deposition process and the same time if we incorporate some of the magnetic field inside that is also going to influence this arc spot, so these are the 3 things which can affect this size of this arc spot.

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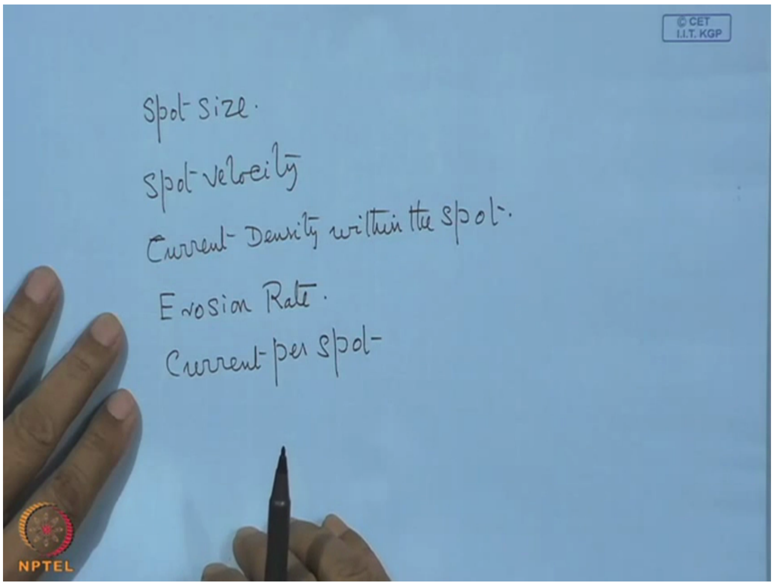

Now specification of the cathode spot, how we can characterise this arc spot, this cathode spot? Number 1 spot size then spot velocity, ion current density, current density within this spot then erosion rate and also the current average current for spot, so at least we have few of those parameters which starts with spot size, spot velocity, current density within the spot erosion rate of the spot and current per spot, so these are the few parameters which can characterise this cathode spot.

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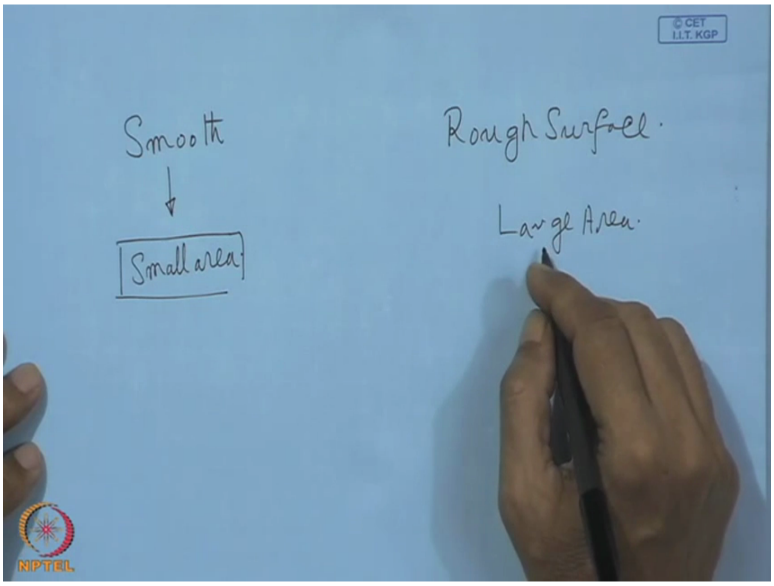

Now comes influence of target surface, now influence of target surface means where we have, we can have say smooth surface, polished surface, smooth and one rough. Now in smooth surface this arc moves over a small area, so here it is actually covering a small area whereas when it is a rough surface it covers a large area and in this case what happens? In fact large area rough surface when we have micro groups scratches what is our experience that in those are actually serves like the store of all foreign elements or contaminants and over that it can follow that scratch path because of this very presence of foreign particle or contaminants material and that is why it covers a large area in the surface is full of undulations waves, scratches and other (())(31:22).

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So this way we can also find out the influence of the target surface it is mostly the roughness or whether it is a polished surface.

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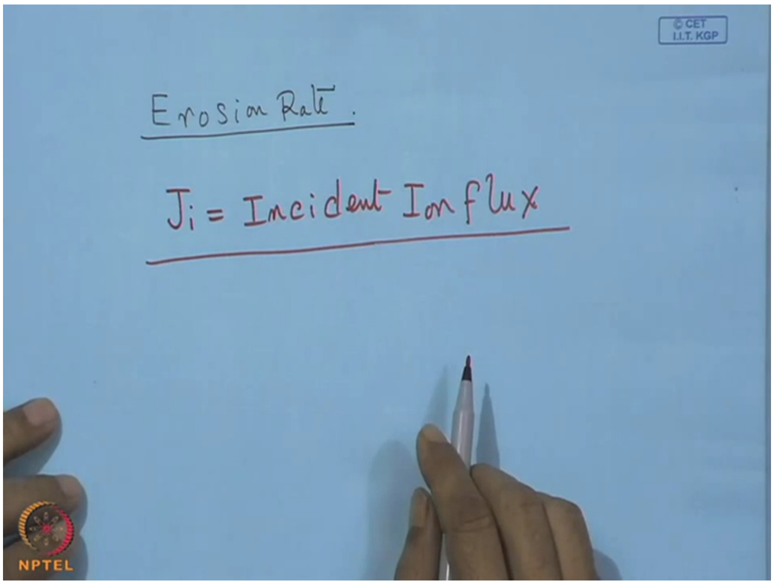

Now it comes the influence of pressure, the influence of pressure means here what we find? That this deposition rate or erosion rate, so influence of pressure what we find that erosion rate that is one of the parameter, erosion rate of the target that is one thing what we like to have but at the same time what we also like to see at this Ji that means this is incident ion flux, incident ion flux that is arriving on this substrate surface. Now with increase of pressure what happens?

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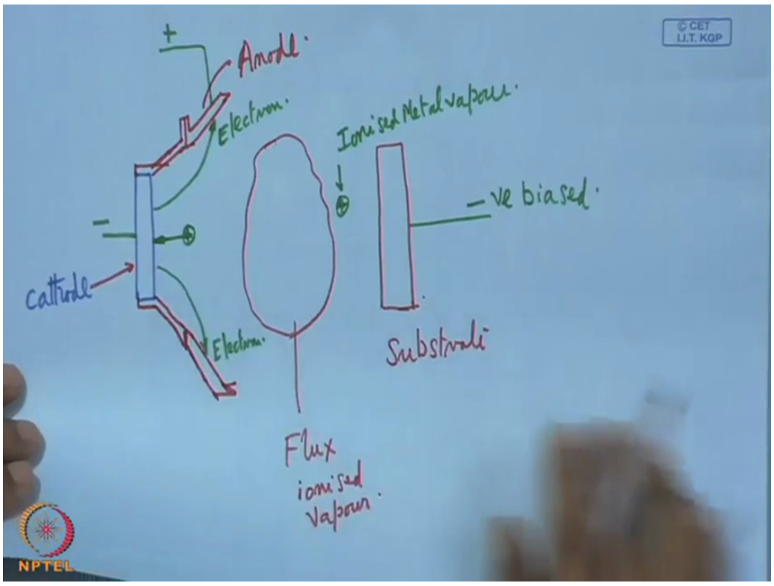

In many of the cases what we can see, we can refer to one of the figures in this case this figure that here this to leave the surface causing some erosion that means material is gradually leaving the surface and that means there is loss of material on that side, so material is leaving and being deposited on the substrate, however with increase of pressure there will be this gas scattering that will lead to increase of gas scattering because of this SOD substrate target distance that is more than that of the main free path and in that case higher pressure will promote collision and scattering of this particle and they cannot move in this direction but the most likely they will be re-deposited on this side, so incoming flux will be less with increase of pressure.

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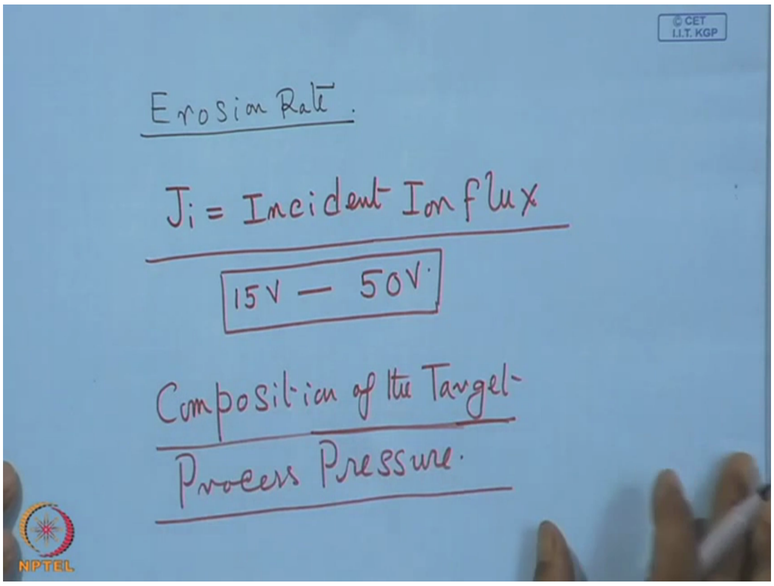

Now factors which can affect this arc voltage, now arc voltage is also one of the parameters, now this arc voltage can be say may be it is actually arc process, it is a low voltage high current, so arc voltage will be say for example 15 volt this is just for illustration giving one example that could be one range of arc voltage. Now factors affecting arc voltage number 1 is the composition of the target and number 2 that is the process pressure, these are the 2 important parameters which effects this arc voltage.

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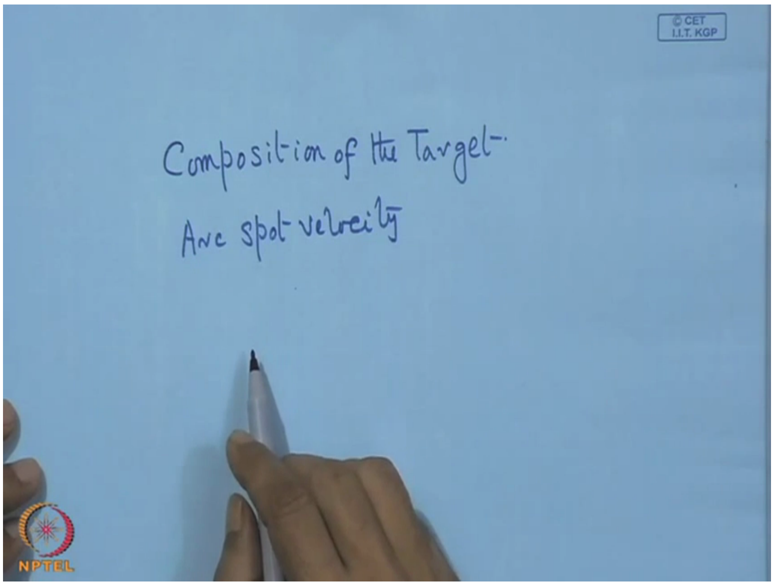

Now here along with arc voltage another thing is also important that arc current density, so factors which may affect arc current density, those are also number 1 what we can write here composition of the target and also this arc spot velocity, so these are the 2 which will affect immediately this arc current density which is one important parameter, so far as erosion rate or yield of this arc deposition is concerned, so we have seen that what are those factors which can affect arc current density and arc voltage.

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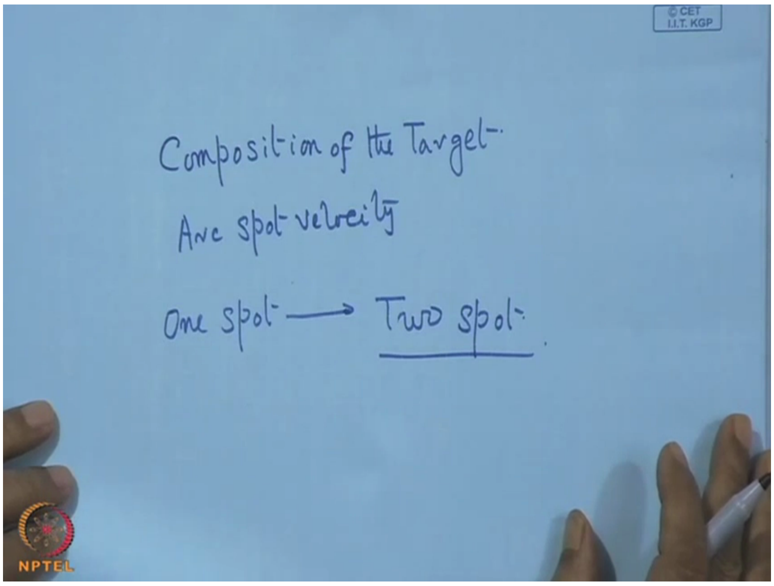

Now splitting of cathode spot, we have mentioned the cathode spot where this arc is concentrated, it is struck. Now this cathode spot need not to be just one. It starts with one spot but that can be split into 2 and that happens when the arc current increases and because of this instead of one spot we may have 2 spots, so that is called splitting of cathode spot. Now here the number of cathode spots versus arc current, this is one interesting observation.

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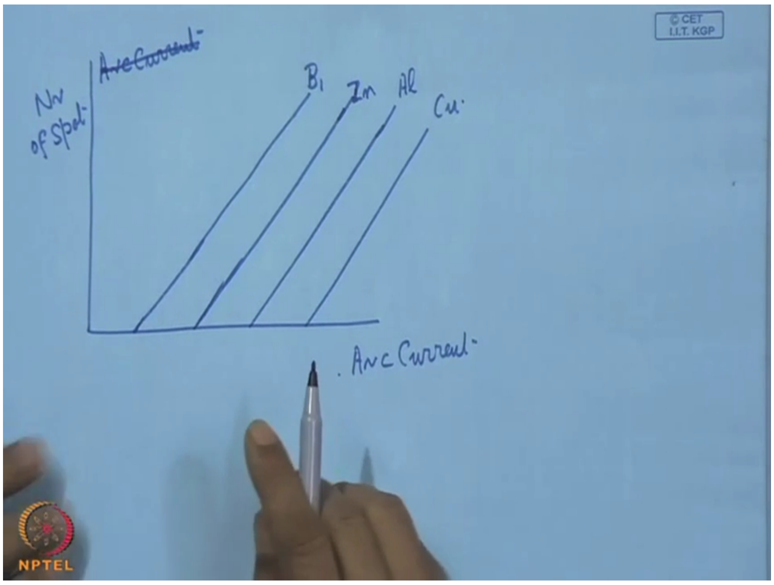

In that what we can see here that arc current and it is also the number of spots, so what we can see here that for this we have this graph and here what we can see that this is for different material and with this different material what we can find? That this arc current and number of spots that means with increase of arc current and this is particularly for one material then it can be zinc, it can be aluminium and it can be copper and with this we can find out this number of spots versus arc current, so this is actually arc current and this is number of spots. So there is a particular current below which they will not be any generation of spot and with increase of this arc current, we can have this number of spots which will increase with this increased of arc current.

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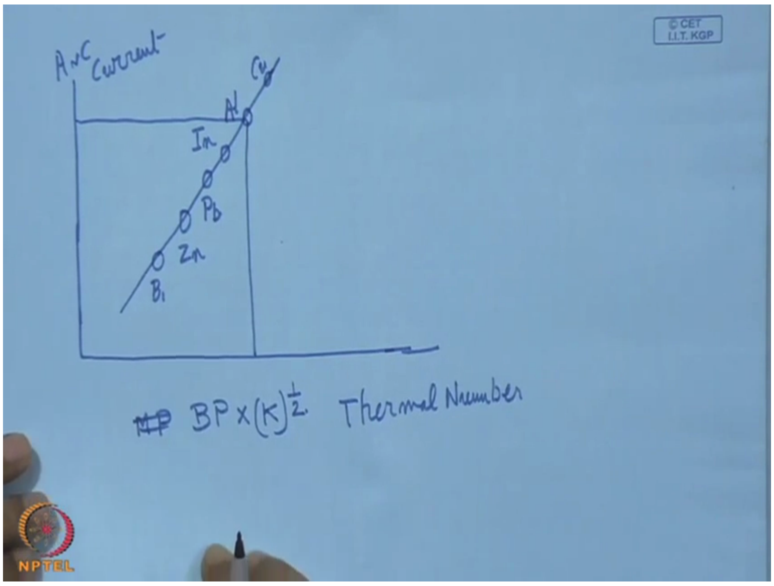

Now here what can show also that this is also arc current or spot splitting versus it is thermal property, so this is actually the arc current with against this thermal property and here we have…and thermal property means here it is actually melting point it is actually boiling point, boiling point into root over of thermal conductivity, so this is actually thermal number, so this is actually a thermal number, so from this thermal number what we can get? That means we get from this thermal number a position, a graph and from this graft, what we can find out?

That means on this line will be located various materials say we start with bismuth then zinc then lead we can also have indium then aluminium and copper.

So they are more or less lying on this, so this gives a relationship that means it depends upon the thermal number typical of one element which we can get by this boiling point into root over of its thermal conductivity and against that we can find out one arc current which can give give into this splitting of the spot that means one single spot will be split into 2 and that is related by this arc current which is required. So for aluminium this is actually the thermal number and from that we can get this arc current, so this is typical of aluminium, so for each element we can have such a plot.

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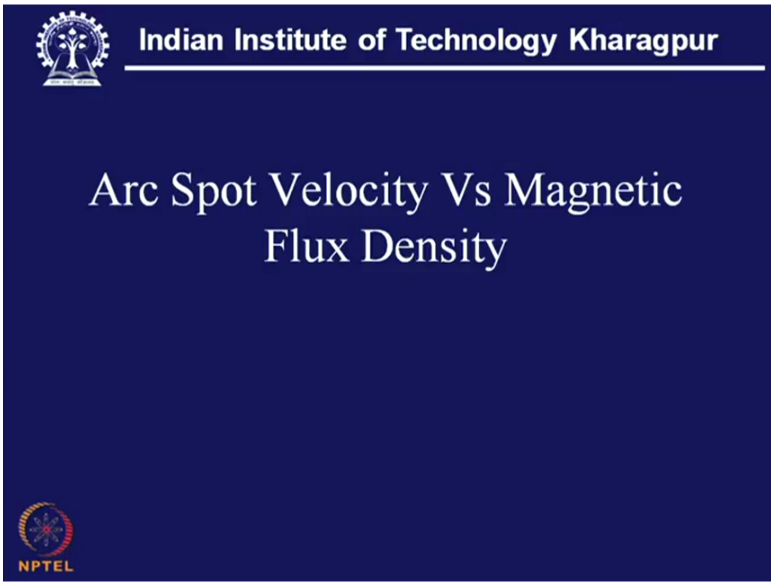

So this is actually arc spot velocity versus magnetic field acts density. Now incorporating one magnetic flux we can also increase the arc spot velocity.

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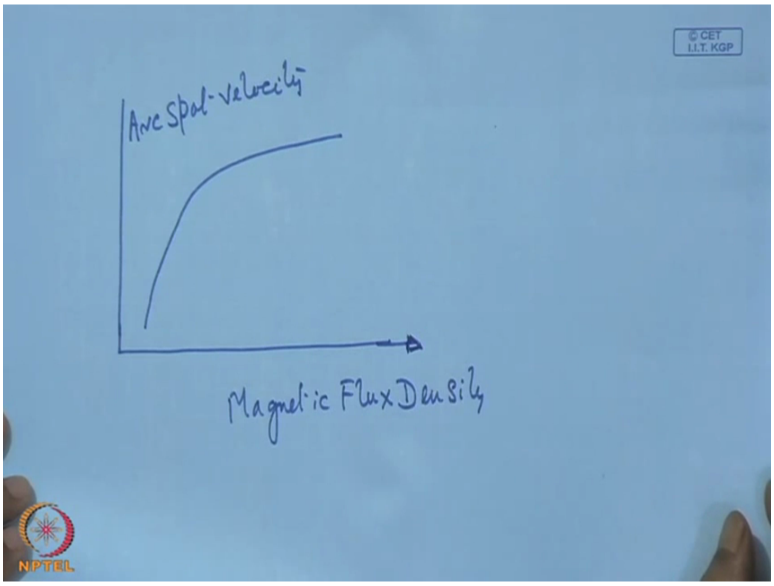

So this way it can be illustrated that means this is arc spot velocity and on this x axis it is magnetic flux density and we can have a curve like this, so this shows at least in this zone the arc velocity is very much influenced by this magnetic flux density and if you like to increase the spot the velocity for to facilitate some of the various aspect of this process say some parametric control or the property control in that case this magnetic flux density definitely is going to affect this arc spot velocity and that can be used to our advantage. Now arc velocity versus cathode current, so this is also another relationship, this arc velocity with which it is swinging or it is moving from one spot to the other and for that there is another co-relation and this co-relation we can also find here.

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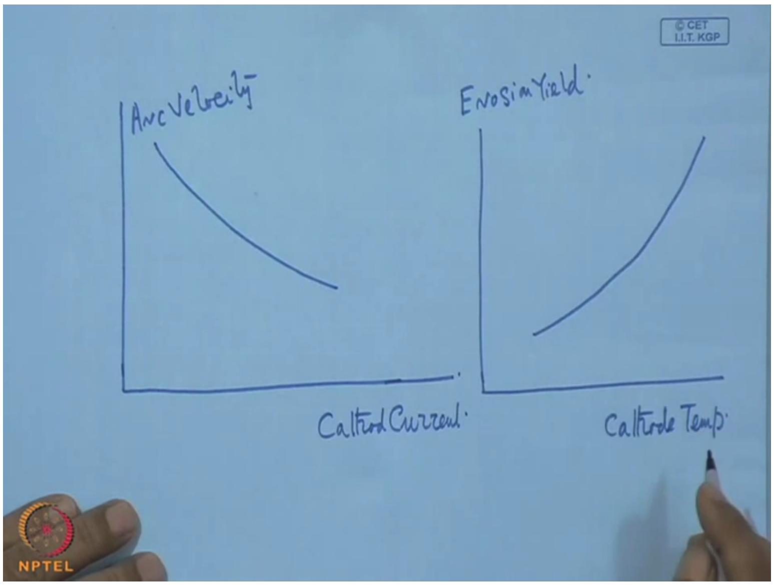

And cathode current and this we can see that it is like a falling curve that means if we increase the cathode current then this arc velocity is going to fall, so it is something like falling however if we see another one erosion yield, in fact if we see the erosion yield, in that case what we see that this erosion yield is actually…it will increase, erosion yield will increase with this cathode temperature, so actually this is cathode temperature, so here this erosion yield is going to grow with this cathode temperature.

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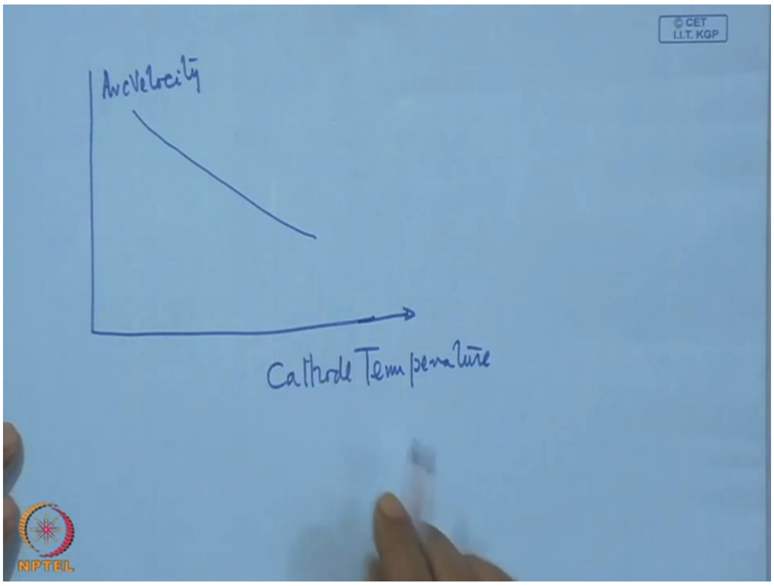

Another thing also we have to look that this arc velocity and cathode temperature that is also a falling curve that means with increased of cathode temperature arc velocity is falling.

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Now this is actually confinement of the arc spot, now arc spot can move in a random manner over this arc surface or any surface which is at the cathode potential and if we just allow this thing in that case what may happen? Once if it leaves that spot then it can be extinguished or there will be non-uniformly erosion of the cathode material. Now to have more uniformity in the erosion of the cathode and more uniformity in the deposition there has been some attempt confined the arc spot within some within the cathode area and one of that is called with one passive confinement.

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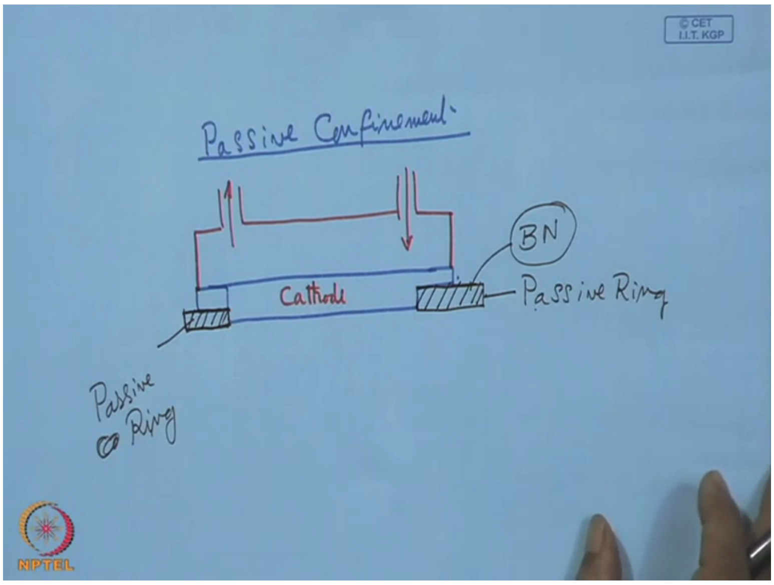

We have magnetically guided arc but before that we can also look passive confinement of arc, passive confinement. So in passive confinement what we see? That means this is actually a cathode, this is the cathode which is of course water cooled, this is the cathode and just beneath it we have the water jacket, so this is the water cooled and this is the cathode or the target, so this is the cathode and on the 2 edges what we have? Here in this border here what we have 2 rings, passive ring.

So it comes like a ring surrounding this cathode and when it is a passive ring in most likeness it is actually a ring made of boron nitride, so this boron nitride is used for restricting the movement of the arc and it is confined within this top surface of the cathode and it cannot just leave this place and it is well within this cathode surface that means this is this ensures uniform erosion of the cathode and uniform deposition of the organized flux over the substrate, so this is actually passive ring.

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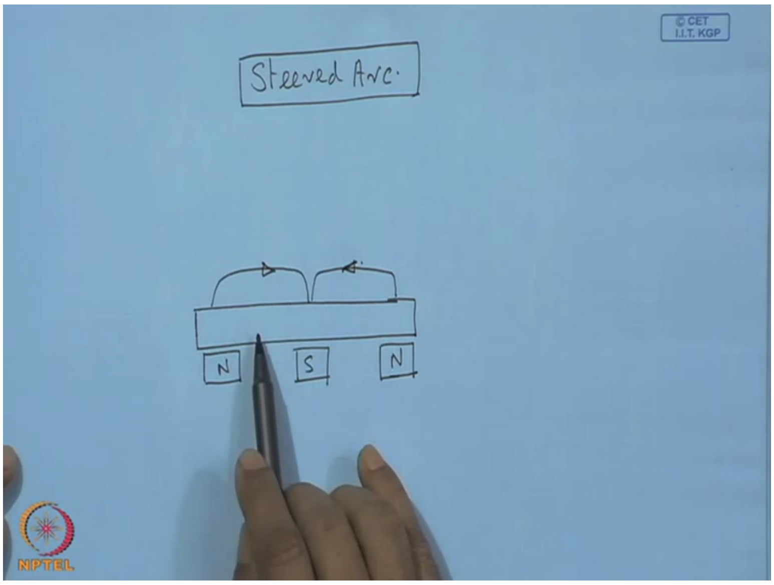

Now we can look into magnetically guided arc, so this is also sometimes we can call it a steered arc that means by this magnetic flux this part of this arc that is also confined and with this what we get, we get also a particular trajectory on the moment of the arc and thereby it is also possible to have uniform erosion, uniform removal of the material from the arc surface which may lead to uniform deposition of the material on this substrate surface.

So magnetically, so magnetically guided arc means here what we have? We have this cathode surface and here we have this magnetic pole and this is the lines of force, so arc will be guided by this lines of force and by changing the position of this pole and by widening the change in the field pattern, the moment of this arc that can be also regulated by simply changing this lines of force or the area of this field, configuration of the field. So that way also it is possible to have the motion of the arc according to a particular pattern and according to a particular requirement.

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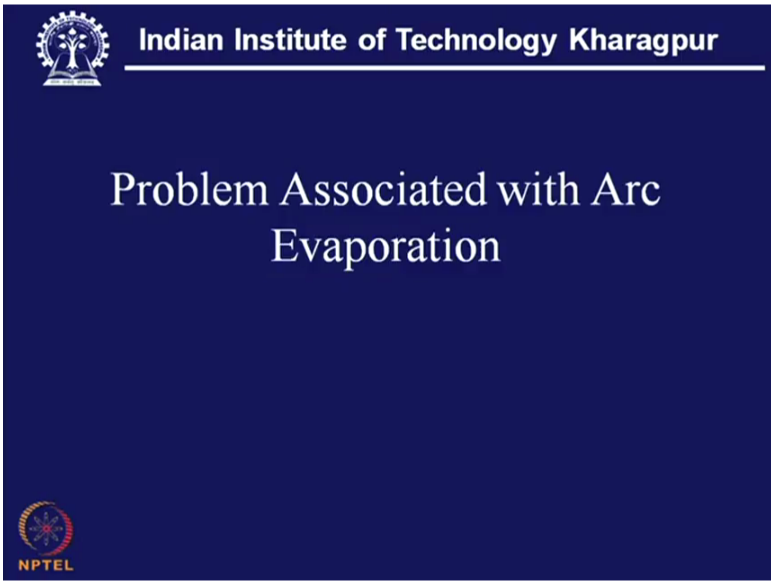

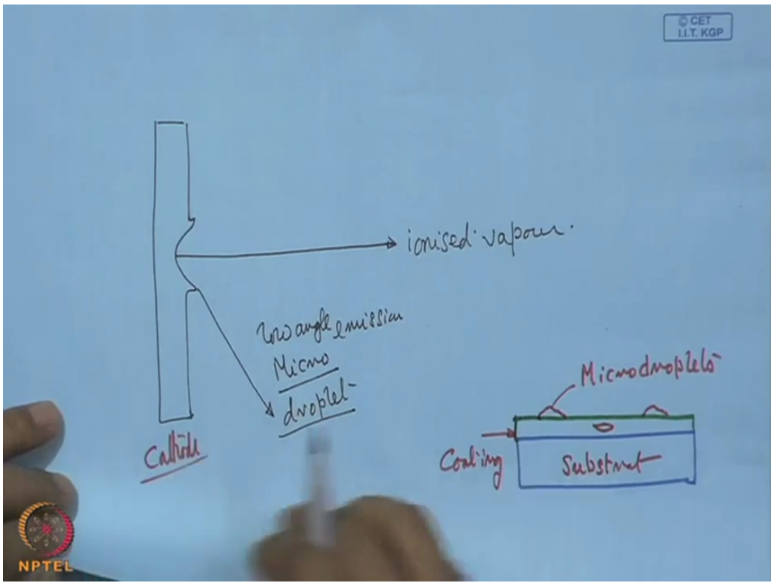

Now problem associated with arc evaporation is mostly one of the main issue here comes that is the form formation of the droplets, so what we can see here, so this is one arc and that comes like this, so this is crater formation and what happens on the side we have ionised vapour but in the low angle what we have it is actually the droplets, micro droplets and this micro droplets will may fall on the substrate surface if it is not properly oriented and in that case it is a low angle, low angle emission and it may fall on this cathode surface on the substrate surface which is having a uniformly deposited coating but unfortunately over the surface we can have such kind of deposition of the droplets like this.

It can be something well within and then this structure will totally lose its characteristics and these may be the spot or the zone of weakness because of the non-homogeneity of the coating, so one way of handling the problem is to have to have deflected in this droplet, so that they should not…this is substrate, this is coating and these are micro droplets which condense. So one thing is to, to have proper deflection of this thing so that it cannot just fall on the surface or arrive on the substrate surface or it can be also filtered, so there are some upcoming technologies by which these are in the very primitive stage at their infancy but those things are upcoming technology which can be used for filtering those globals which comes in the form of liquid that means instead of vapour what we get? We get mostly a droplet in this form and this is actually because of the low velocity of the arc and because of this non-uniformity, we can expect this droplet to form in this area of this cathode surface.

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Now application of cathodic arc evaporation, now from application of point of view application is almost unlimited in that. This can be used for deposition of refractory materials or their compound.

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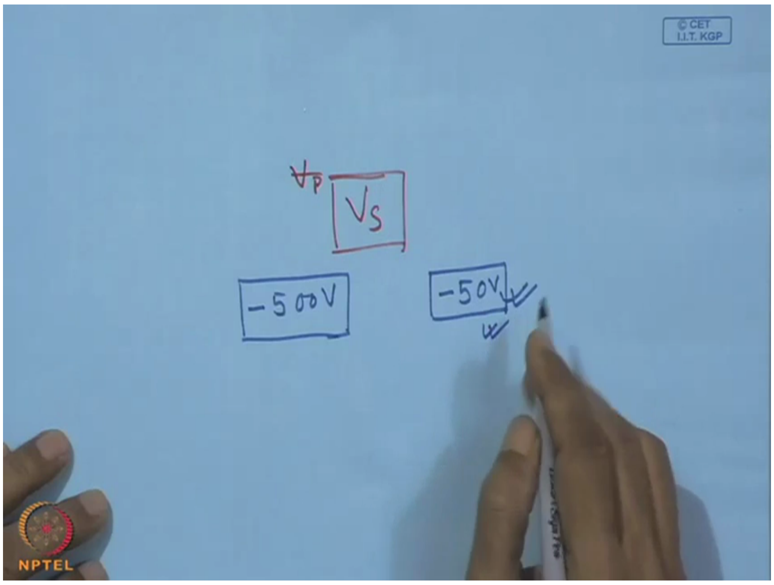

One illustration will be very meaningful here say biased voltage that is one of the important parameters and all this deposition process. Now when it is iron plating what we have, we have a biased voltage of minus 50, however when it is this arc evaporation there we can have just minus 50 volt, so with that what we have the deposition rate is it not going to be affected. However this is possible because of the high ion energy of this incoming flux that makes things that makes the things possible and the whole problem can be handled with just this low value that means minus 50 volt instead of this 500 volt and at the same time it is also the low temperature.

So it is refractory materials and compounds of all those transitional elements that is singly as a single element or as a co-deposited composite for in composite formation their compound can be also well used by this reactive sputtering and in this case what is very important to have that is the process pressure and this flow rate of this reactive gas and also this biased voltage which is useful in getting this particular morphology which is of use much use to get the desired mechanical property.

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So with this we can summarise that arc evaporation has some similarity in principle with that of conventional evaporation that means it is solid to vapour, vapour to solid in the form of film but in case of arc evaporation it is the ionised vapour flux which gets deposited over the surface. In this case it is low voltage high current process, this process has a flexibility of getting good stoichiometric of a compound, this process allows to deposit the material at a very low temperature and also the process is flexible in that it is deposition rate is extremely high. So we can have dense coating with a very good adhesion and with a high deposition rate in…unlike that of any sputtering process.

So that way this process is extremely useful and attractive when it comes to deposition of a thick layer covering a large area particularly for all mechanical wear parts and tools of production but only one limitation is formation of this micro liquid drops and this is because of the cathodic spot which is causing this problem and this can be handled just by diverging, deflecting this hard this liquid global or it can be properly steered that means the residence time should not be very high at a particular position and it can also be filtered, so with this filtered cathodic arc or by suitable deflecting mechanism it is possible to eliminate remarkably this particular type of globals and we can also have some spotless coated material, coated film by this cathodic arc evaporation deposition process.