Fundamentals of Materials Processing-2
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Module – 02
Thin Film Deposition
Lecture - 05
Thermal Evaporation continued

Hello and welcome to lecture 5 of Thin Film Deposition. In this lecture, we will continue our discussion on Thermal Vapor Deposition or Thermal Evaporation. So, in the last lecture, we had looked at the film thickness geometry and the non uniformity depending on the source size and dimensions. Before we move forward for large area deposition, let me introduce to you to another way of doing thermal evaporation in which we do not use heating. Sometimes it is very difficult to melt the material to vaporize it because it may be refractory metal with the melting point about 2000 degree C or 1500 degree C or it may have very low vapor pressure even after melting.

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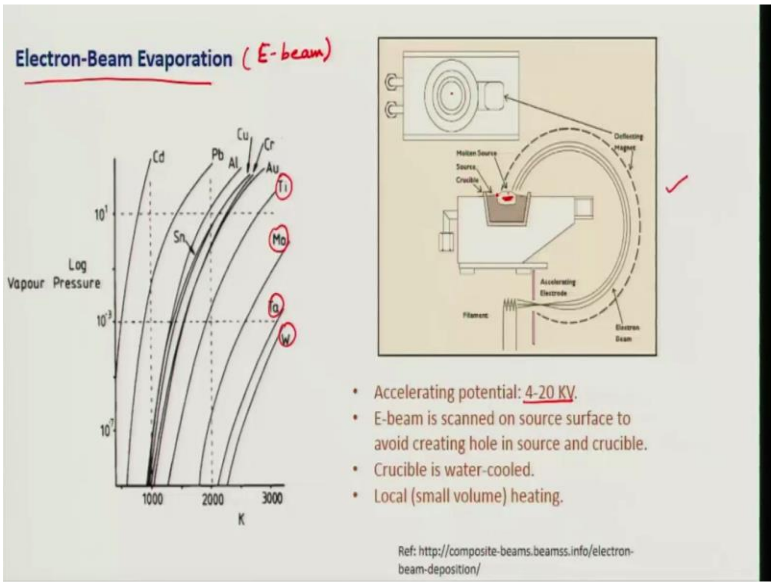

For such material what we can use is called electron beam evaporation or E beam deposition. Now as you can see that we need around 10 to the power minus 3 torr or 10 millitorr pressure for a material at that temperature to be able to do thermal deposition so that we have good enough flux for thermal deposition. But some of the material like titanium, molybdenum, tentillum, tungsten, we cannot get that pressure at say 2500

Kelvin which is very high, of course if we increase the temperature we can get high enough vapor pressure, but then it would be very energy consuming or non economical for production. What we can do is rather than melting the entire mass of the material, we can locally heat it and how do we do that? We use electron beam and electron beam we done direct on the top of our source material and electron beam carries large amount of energy and when this energy is absorbed by the material it melts locally and from there we can use it as for deposition.

This is a schematic diagram which shows how this E beam deposition works. So, here down had we have a filament which then heated gives thermionic emission and you get electrons which can be accelerated using and series of accelerating electrodes up to 4 to 20 kilo volts and then you have a magnet to deflect because electrons are charged particles when they are moving you can deflect their path by magnets. So, you can use deflecting magnet to guide them towards the top of your source.

This is your source part and this is your magnet part which guides the electron beam on top of your source and this is water cooled so that your crucible and the rest of the material remains cold. So, you are only heating where small area of the material then you can also raster your electron beam because electron beam is very sharp and point it. So, not to burn a whole, also the material at one point, it is usually rastered in a small area or scanned in a small area so that you heat a small area of the source material and from this your material is evaporated and gets deposited on your substrate which is kept at a slight distance from the source. This is way the electron beam evaporation works.

Now the source acts like a surface source in this case it is non directional, but it is only a small area surface. This shows you a typical design of multiple source E beam deposition. So, if you see that there are 4 pockets, 1, 2, 3 and 4 which can be rotated to bring into the deposition possible and you have electron beam is from this is rastered on this course. So, you can load in your deposition chamber up to 4 or may be sometime 6 source of different material suppose you want to deposit aluminum and then gold and may be a another layer of copper. So, you can put all these sources rotate to choose which you want to use the electron beam to heat that and then you get that materials gets deposited this is just an actual picture with pores for water cooling and electron beam is just comes on top. Everything else remains the same, it is just electron beam provides a way to locally heat the material.

Now there is another problem associated with these thermal deposition or thermal evaporation or electron beam deposition because these are all line of site process because once atom or molecule is ejected from the surface or go into vapor phase it travels in a linear direction in a straight direction it unless it collides with another atom or molecule. Now, since we are using this process in a vacuum chamber where the pressure is low that and if you remember we had said that mean free path we want to keep it large so that these atoms or molecules which are coming from our source are not colliding between themselves they are straight going towards substrate.

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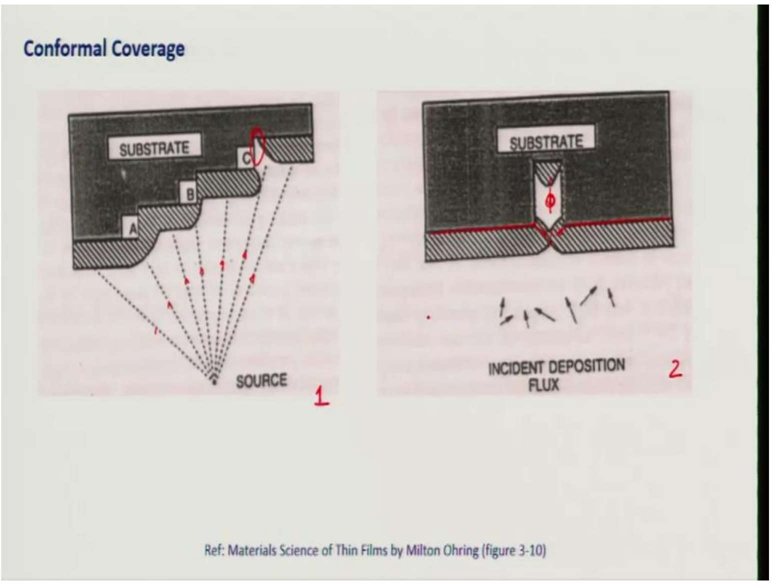

Now, since it is a line of sight process, if you see in this figure 1, here we have substrates which have some steps A B and C and D. So, we have these steps, now my source is line of sight process. So, it is going in all directions. So, if you see that this corner is expose to the line of travel of these atoms and molecules. So, this corner gets filled or there is a material deposit in this corner as the film gets deposited on this ledge A B and C. Now this corner which is here, it is not exposed to the line of sight or from the source. So, there is no material deposition here and this is called non conformal coverage because it is not conforming to my substrate size and surface features many times we have these surface features and of high aspect ratio. So, these kinds of things become a problem.

Another problem is as you can see in the figure number 2 is that if you have a high aspect ratio, we have of whole in a substrate which you want to fill with metal which very often is required in semiconductor industry when you make contacts. Now as you see if your flux is coming uniformly then it gets deposited on this surface here and here as well as it goes inside, but since material is also depositing here before there is a chance to for this area to get filled up this mouth of this gets closed, during this whole unfilled region inside which may create problem in functioning of the device or in the life time of the device.

This is another problem with the processes which required line of sight then thermal evaporation and E beam deposition these both are line of sight process because these are done at lower pressures and once and all the flux moves in the linear direction. So, this is another challenge how to have a uniform deposition when you have some features on your substrate. One way to do this would be that you rotate your substrate, if you rotate your substrate this edge or this corner of the substrate will move in sometime and will be will come on this side where it will get exposed to the flux that is one way or you can have a directional source, so that all the flux goes in from this side and gets filled and then use another directional source to fill from the other side.

So, these are some practical solutions to overcome this.

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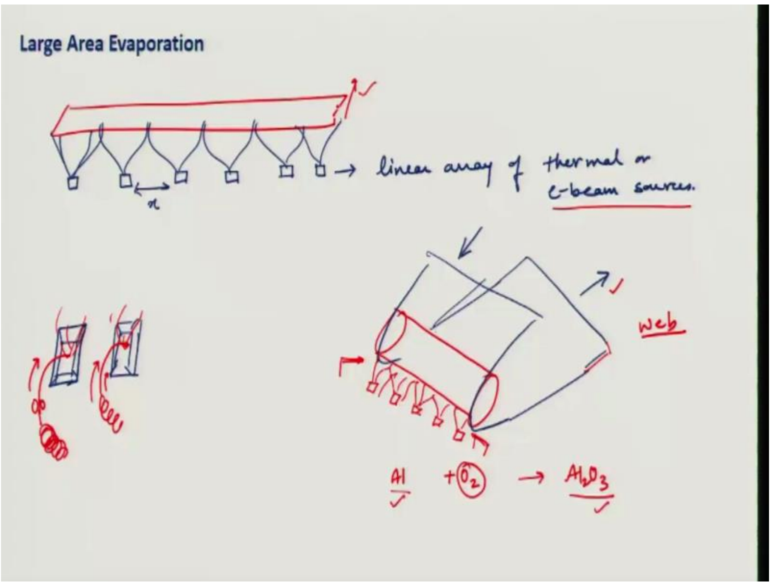

Now, let us talk about large area deposition and in this case, we will discuss both a thermal evaporation and electron beam evaporation. For large area deposition what we can use we can use multiple sources. So, if my substrate area is something like this, I am just drawing my substrate is very large I can use multiple number of a small sources in a linear array and such that the flux from all these overlaps and this overlap and this distance between the 2 sources can be adjusted such that this overlap and this area when being calculated arrayed up give you a uniform deposition. So, that is one way of doing large area deposition using thermal evaporation or you can also use similarly multiple or linear array of electron beam sources this is your linear array of thermal or E beam sources.

Now, one of these crucibles are small in size because you do not want to heat too much material because your evaporation is only happening from the surfaces so you would want to keep them amount of material very small, but if you keep that then after certain time of deposition you have to refill this crucible, then you have to shut down your process open the vacuum chamber take out these crucible we fill the material which will cause you delays in production. So, it is not very practical. So, for thermal evaporation what you can do is rather than having a crucible with fixed amount of material you can have a something what is called wire fed boats.

Instead of these crucibles, you have boats at all these points and a wire of the material that you want to deposit is continuously fed into this and there is a somewhere a big spool of wire and using some pole mechanism, you can feed this wire continuously into this boat and this boat is kept heated at a certain temperature so that as soon as this wire touches the boat it evaporates, it melts and it creates a small spool of molten material and from where it goes to vapor phase.

Now, you are not and you can have very small size of these boats, now you do not need to melt this entire spool of the material you are only melting very small amount and you are feeding this as per your deposition. So, this kind of wire fed boat systems are normally used for very large area deposition in thermal evaporation.

Electron beam do not have this problem because you are any way locally heating the source. So, you can start with large amount of source and you can locally heat and you can shift the position of electron beam to choose the different area as your source gets depleted. Now one more point here you can use the same method to deposit on flexible substrate also, you are no longer bound to rigid substrates or glass. So, for such cases what you have is you have a drum which is usually water cooled on top of which you have yours plastic substrate which is moving like this. So, it is being fed from here pulled from here. So, it is moving like this and you can place your sources as before in a linear array at one point such that when you evaporate it forms a uniform coating right and you can adjust the thickness of the film by adjusting at the rate of pull of this flexible substrate which is usually called the web. So, pull out of the web and also the feed rate of the wire into this boats which are catalytic constant temperature.

And you can also monitor do inline monitoring and you can adjust the temperature of these crucible to have a more uniform deposition across the width of the web not only that you can also suppose you want to deposit aluminum oxide, we know that aluminum can be melted at a lower temperature, aluminum oxide is a ceramic, you cannot melt it at below 2700 degree C. So, what do you do? You use aluminum source to evaporate aluminum or wire fed aluminum source and you have some oxygen gas environment you can put some oxygen nozzles right at these points. So, that when aluminum is being evaporated and it is moving from source to substrate it comes in contacts with oxygen and as we know that aluminum readily forms aluminum oxide and form Al2O3. So, by the time it reaches there, it forms Al2O3.

You can adjust and you can play with all this and to deposit not only aluminum, but aluminum oxide as well. These kinds of systems are normally used in food packaging industry. So, if you have a see your bag of chips inside of it, you see a shiny surface which is usually a aluminum and aluminum oxide, it forms a very nice moisture barrier and these are made by this process you can also used a electron beam evaporation if the vapor pressure of the material being evaporated is not very high. So, we have solved our problem of large area deposition and these our systems are available in a web width of say 1.5 to 2 meters which is something like this where width you can and you can have roll to roll deposition on the plastic sheets or if you have a rigid substrate like glass then you can have these about 10 feet by 10 feet class substrate which are moving in one direction and where these are being deposited. So, all these are these systems are available in market for deposition.

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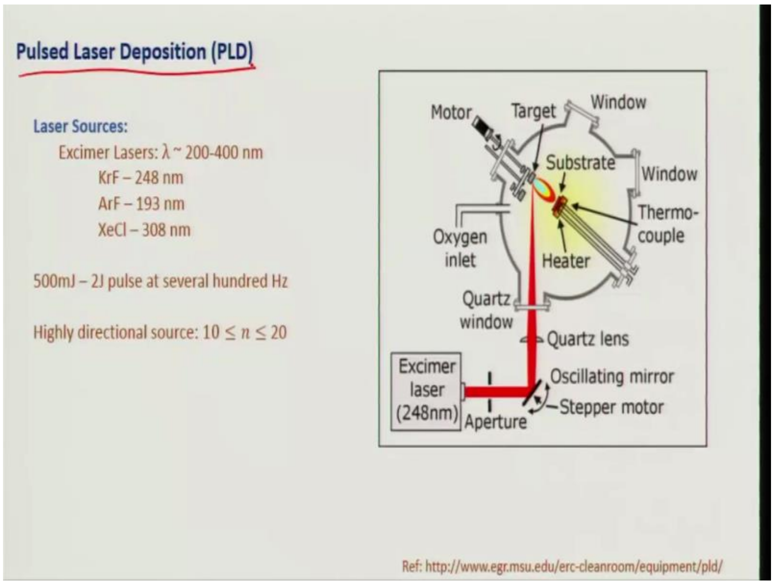

In the end of this thermal deposition, I would like to discuss another thermal deposition method which is called pulsed laser deposition. As the name itself suggest that we are going to use pulsed laser to deposit our material and since we use lasers mainly with wavelength of 200 to 400 nanometers because these are called excimer lasers and these wavelengths are easily absorbed by most of the materials that we want to deposit. Some of the examples are either krypton fluoride, argon fluoride, xenon chloride or a mixture of these and these are their wavelengths.

Now, the schematic shows how this pulsed laser deposition system works. So, if we have excimer laser which is passed through an aperture through a stepper motor which, can be used to shift the position of this laser beam on to a target. Now target is a material which you want to deposit on the substrate, this is the target for this laser to hit from some quartz window and lenses, we can focus this laser on to the target. Now this laser is pulsed, it is not always on. So, it is pulsed at sometimes several 100 hertz. So, 100 hertz means 100 pulses per second and the energy of the laser is between 500 milli Joules to 2 joules.

Once this laser hits the target, it instantaneously melts the material and evaporates it instantaneous evaporation and it then it cools down very quickly. So, within these pulses metal is melting only at the surface and cooling down. Now it creates a kind of plume, so this if you see this part it is a plume and it as plasma inside. So, this plasma plume is create created by this pulsing laser and as you see this is a very highly directional source so you have to use a you can only deposit on a small substrate. What is nice about this is this is very good technique for laboratories because you can make target of any material and if you are not sure that if this material is good or not for your purpose that you want to deposit you can keep changing the target, you can play with their composition, you can use different targets, you can make it by a normal powder metallurgy route by compacting syncline and you can make different targets different composition and you can deposit and you test this is not widely applicable in industry.

So, this is mainly for lab to develop the material first, once the material is developed we can utilize other techniques to deposit that material on large area. But since we are not sure what material to use we can test by making small targets which is in our hand we can use powder metallurgy route to make these targets of different compounds.

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TABLE 13.5 Comparison of the Most Common Types of Materials Deposited by Various Vacuum Deposition Techniques

Method	Liquid Metals	Low Vapor Pressure Metals	Semi-conductor	Borides	Carbides	Nitrides	Oxides 1 and 2 Element	Oxides 3 and 4 Element	Flourides	Silicides	Sulfides
AMBE	X		X						X		
ALE	X		X								
CVD	X	X		X	X	X	X			X	X
IBAD		X		X		X	X		X		
IBD	X	X	X								
ICBD	X										
IVD		X					X		X		
LACVD	X	X	X							X	
MOCVD	X	X	X							X	
MBE	X		X		X				X		
PECVD	X	X	X							X	
PLD		X	X	X	X	X	X	X	X	X	X
S		X		X	X	X	X	X	X	X	X
TE		X					X		X		

Now, in the last slide, I will show you the fatality of this PLD method. So, in this chart various thin film deposition methods are being compared and x means that we can use this metal for these kinds of materials. So, if you see here, this is the region of the large interest that you can use oxides of 3 and 4 elements, oxides of 1 or 2 elements you can use in only by 1 or 2 methods, but you can use PLD for 25 oxides or 3 or 4 constituents which is very good and almost all kind of materials - low vapor pressure, metals check, semiconductors check, fluorides, silicides, sulfiders check and you can also adjust the sociometry of oxides, if you want to by having some oxygen or some usually this is done in an inert atmosphere in presence of organ, but you can have oxygen or some kind of nitrogen if you want to deposit nitride. So, you can adjust the sociometry on the fly when you are depositing. This is the very versatile method for lab to develop the material before you go for large area deposition at industrial level.

So, with this I will stop with thermal deposition or thermal evaporation techniques. In the next lectures we will discuss other methods of physical vapor deposition. Thank you.

Remember there would be an assignment after this week which will cover the topics covered in the first 5 lectures and it will be both the objective type questions and some numericals which answer you can always as MCQs will be given.

Thank you again.