Lec 04 - Neural Implant Fabrication: PVD - I

Welcome to this particular lecture. If you remember in the last lecture what we discussed is how to make the neural probes, right. So, these are the devices, these are single shanks, these are multi shanks that are used to acquire the signal from the brain, that is why it is a neural probes, right, or neural devices or to apply electrical stimulation to certain regions in the brain, right. So, either it can acquire the signals from the brain or it can provide or stimulate a certain region in the brain, right? So, we saw a little bit about what those techniques are, let us understand a little bit in detail since we will have the lab class where we will show it to you how these systems or equipment or tools can be used, ok. So, if you remember we talked about physical vapor deposition, in physical vapor deposition there are 3 techniques, the first one is your thermal evaporation, the second one is electron beam evaporation and the third one is sputtering, isn't it? And for the chemical vapor deposition there are several techniques because it has CVD, within CVD which is chemical evaporation within that we have PCVD, LP CVD, AP CVD, we have ALD, we have MO CVD, right and so on and so forth.

Then once you deposit this material, right, whether it is metal, now in case of most of the devices that we will be learning as a part of this course, we will be depositing metal and insulator, ok, there is no semiconductor in between, that is why we will stick it to either depositing metal or coating or depositing insulator, that two things we need to remember. So, for depositing metal or insulator we can either use CVD or PVD, PVD is physical vapor deposition, CVD is chemical vapor deposition. Once you deposit the metal then you need to perform the lithography so that you can pattern the metal so as to form the electrodes along with the contact pads, isn't it? So, these electrodes are recording electrodes or stimulating electrodes. So, for example, if this is the area then either if I put an electrode it can record the signals because it is an ECOG signal, right, this is the area of the brain, okay, or it can stimulate certain region in the brain.

So, for that you need to have a metal, right. We will see electronics as a part of the TA class, right, how we design the electronics module to stimulate certain regions in the brain and we will also look into how to design this electronics whether it is 8-channel or 16-channel wired or wireless using an intern chip, ok. So, this is going to be very interesting because you will not only learn the way to design the device but also how to acquire the signal and how to stimulate, right? So, how to design the electronics for the same. Now, we we talked about photolithography because that is a photons are there are used to do the lithography, lithography as I yesterday or the last lecture, right, when I recorded have discussed that lithos and graphics which comes from the Greek word and there are certain steps in lithography which will be a separate class.

And finally, we either etch it which is anisotropic etching or or it is isotropic etching, we use wet etching or dry etching. In wet etching there are certain ways to etch certain metals. If you are etching the silicon as a substrate then we call it micro machining. So, we will understand all this stuff in the following classes. So, now let us see the slide if you remember we discussed this particular slide. Now, let us see the next slide.

So, we start with the physical vapor deposition and as it is written that PVD is a more versatile method than chemical vapor deposition. Why? Because it allows the deposit of almost all the materials used in fabrication, ok. When we say almost all the materials what does that mean? So, using PVD you can deposit metals, you can deposit semiconductors, you can deposit insulators. So, all three, all three categories of materials falling in that we can deposit using PVD. We can also do the co-deposition right multiple materials deposition.

So, in the case of PVD the surface reaction occurs very rapidly and so very little rearrangement of the atom occurs on the film surface. So, I will show it to you by drawing it in the next slide about what exactly this statement means, ok. But you need to understand that the reaction occurs very rapidly. So, it is a very rapid one and then very little time right for what? For rearrangement of atoms on the film substrate. Because of that or as a result thickness uniformity shadowing by surface topography and step coverage can be very important issues.

So, now let us understand in this module three things. One is your thermal evaporation, the second one is your e-beam evaporation and the third one is sputtering, ok. So, we will start with thermal evaporation. So, when we use these two statements right that a reaction occurs, surface area occurs rapidly and little time for rearrangement of atoms right this is true for all the three mod three systems or techniques evaporation or E-beam or sputtering, ok. So, here you can see there is a thermal evaporator, there is an E-beam evaporator and which one is thermal and which one is E-beam? This one here is a thermal evaporator, this one here is an E-beam evaporator, this one here is also an E-beam evaporator, ok.

So these are all called physical deposition techniques. So, the methods or physical methods right produce the atoms that deposit on the substrate either by evaporation or by sputtering. Within evaporation you have thermal evaporation and you have electron beam evaporation, right. So, within evaporation there I have two and then there is a sputtering. So, this process of physical vapor deposition is sometimes also called vacuum deposition, why? Because the process is usually done in an evacuated chamber.

Now there is a reason for evacuating the chamber which we will discuss. However you can see here the systems carefully just see for a second and then we continue. Ok, so you have seen right now what you observed, what you observed? So one thing you may have observed in this system is see this is one kind of some system is attached here also and here also, right. Here you cannot see in this slide. What are these things right that I am putting an arrow here, this arrow or this one? These are your secondary pumps, ok.

These are your secondary pumps. So, the physical deposition techniques you have are primary pump and secondary pump. The primary pump is used to create a vacuum of 10 to the power minus 2 to 10 to the power minus 3 Torrs, ok. This is the vacuum that is created by the primary pump. Secondary pumps are different kinds of secondary pumps.

There is a getter ion pump, there is a turbo molecular pump, right and these secondary pumps are capable of getting us vacuum anywhere from 10 to the power minus 5 to 10 to the power minus 7 to 10 to the power minus 8 in certain cases Torr, ok. But without creating a base pressure of 10 to the power minus 2 to minus 3, we should not turn on the secondary pump. Very important statement without you having the base pressure of minus 2 or minus 3 in the in we should not start the secondary pump. Very important statement: you need to make sure that you follow this protocol, ok. Now having said that, let us understand a bit more.

Let me just erase this one. So, one thing that we have seen is a secondary pump. Both arrows show the arrows which are left here. This shows the secondary pump that is attached to the vacuum chamber, alright. Now we have this particular system, right.

So, let me just rub this one and get the pen back, ok. So, this system is kind of manually operated, ok. This one is automatic. This one is semi-automatic, ok. So, either it can be manual, it can be automatic or it can be semi-automatic.

This is manual, this is automatic, this is semi-automatic, ok. Thermal evaporation and EBM evaporation. Next what you see is windows. You see windows here 1, 2, 1, 2, 1, 2, correct. Every system has two windows, right?

What is the reason for having these windows? So, let us see what the reason is first, ok. So, the reason for having these windows is to observe the metal that is melted or the material that is melted and the material that gets deposited onto a substrate. Now where the substrate is kept? So, let me just give you some examples, show you something and then we can go back to the previous slide. So, there is a chamber, right that you have seen there is a chamber, correct and let us close the chamber. Now here in the top you have a substrate holder.

What is it called? Substrate holder. In the bottom you have a source holder, substrate holder and source holder. Source, so whatever material you want to deposit, right is a source. So, in this case this one that we have used is also called boat, BOAT boat. Instead of that you can also use a spiral kind of structure like this, right.

So, this is also used as a source holder. Now let us take a case of whether we have to deposit aluminum, right? So, these are aluminum chunks, but if I want to put a chunk in the source holder which is spiral in nature it is difficult. How will it hold? It cannot hold. So, this is your aluminum, right.

Aluminum beads or chunks whatever you want to say. So, in this case we will use wires, aluminum wires and you can load it like this. So, this one would be aluminum wires, easy, easy. Now substrate, what is substrate? Substrate is any material on which we are going to perform the experiments or we have performed the deposition and lithography whatever. So, base material is a substrate.

It can be silicon, it can be glass, it can be polymer, alright. It can be any other semiconductor other than silicon, ok. So, polymer you can say plastics, right. So, these are polymers. So, you can use several different materials as a base material that we call a substrate.

Now, these substrate holders can hold many silicon wafers. Let us say we have two silicon wafers with a clip attached. So, it will not fall and is a clip that is attached. So, the silicon wafer will not fall. Now you do not understand that this is exactly on the, so when there is a deposition, the deposition will be like this, correct.

Now when you want to deposit this material and it evaporates, right. So, first what do you need to do? This aluminum metal is in what? It is in solid structure, right. So, we need to first melt it and then it starts evaporating. So, when you melt it, right, how can you melt aluminum or any other metal or any other material, by heating.

So, you can melt aluminum by heating. Since you are melting by heating, you are applying thermal energy, right. So, you are applying thermal and that is why it is called thermal evaporation. You are applying heat to melt the aluminum material and it gets melted and starts evaporating and depositing on the substrate. Substrates can be silicon, can be semiconductor, can be glass, can be polymer, any material, base material on which we have to deposit the metal or semiconductor or insulator, easily. Now you need to create a vacuum, right and you we also discuss about the windows, we also discuss about the windows.

So, we will come to that window point, ok. Since we are talking about this one, the first thing you need to understand is there is something called this, you can see these checks, right, this box. It is called QCM, QCM. QCM stands for quartz, quartz, right, quartz you know, quartz is what crystal, crystal, quartz crystal M for monitor. So, quartz crystal is used to monitor the rate of deposition of the metal onto the substrate which is loaded onto a substrate holder.

So, this quartz crystal monitor works on what kind of effect, principle? It works on piezoelectric. What is piezoelectric? When you apply a pressure change in the voltage, apply pressure change in voltage, piezoelectric. Now if there is a deposition of this metal onto the QCM, the QCM, from the QCM we can read what is a rate of deposition of aluminum, right, because it works on the piezoelectric effect and that rate of deposition of the metal or material can be converted into a in readable form onto a display and we will know what what is this what is the rate of deposition generally it is in angstrom per seconds, ok, is in angstrom per seconds. So, it is 10 angstrom or 50 angstrom or 100 angstrom depending on how fast you want to evaporate this material, all right. Now there is a shield,ok, it is a metal shield here and it is a metal.

So, this material cannot pass this metal sheet, you can say it is a shield, right, shield. So, this one is your shield, ok. Now if the shield is between the source holder and between the substrate holder, then the material that gets evaporated cannot reach the substrate, easily, because a metal sheet, right, cannot pass through metal. So, once you melt the aluminum, right, if you can you can observe, now to observe this melting of aluminum what you require? You require a window, isn't it? When you because once it is melted then you open the shield, so that the deposition starts, right. So, still melting you do not open the shield because ah it is not that complete melting we have to wait, so that the evaporation will start.

If when it starts melting it starts evaporating, but we do not want to do that. So, we want to melt all the aluminum pallets or chucks or beads, right, onto the loaded onto the boat, right, before we open this shield, so that the evaporation will start. Now how to observe this melting is by using the bottom window. You can see here in this case here, in this case here, easy, understood the role of window? The windows are to observe if the melting is done or not. Now that is ok, now we understand what is the role of the bottom window.

What is the role of the top window? What is the role of the top window? Now you can understand. This substrate holder ah you want to see that the wafers are properly loaded, they are not falling, the deposition is occurring, right. Then you can use and sometimes the substrate holders in all the new PVD rotates. What is the role of rotation? When you rotate the substrate holder and you deposit the material, the deposition is uniform, the deposition is uniform. So, to rotate the substrate holder, right, such that the uniform deposition occurs on the way onto the substrate.

So, if you want to observe what is going on to the substrate or what is happening to the substrate, you can use the second window which is on the top here, here, here, right. So, window

1 is for your source holder. So, window 2 is to look at the substrate loaded onto the substrate holder, easy right, easy, very good. So, QCM, we talked about the top deposition shield we have to. So, we have to rotate the shield, we have to rotate the shield.

It will come out from the path right between the source and the substrate. It will come out of the path which is between source and substrate. Now we say that all these PVDs are also called vacuum deposition, right, vacuum deposition. Why vacuum deposition? Why vacuum deposition? Why vacuum deposition? Because VACUUM ok, VACUUM vacuum deposition. Why vacuum deposition? Because we create a vacuum, but why create a vacuum right? Can we not deposit the material in the presence of air at atmospheric pressure? Why create a vacuum? That was the reason behind creating vacuum right.

So, the reason behind creating a vacuum is to improve the mean free path. What is a " free path"? So, the mean free path is a time that the material that is that evaporates right. So, atoms collide with another atom or molecule right in the chamber right. So, how much path it has traveled right from source to the substrate. If this is x right, yeah has it travelled full x or x minus some path right or x minus 2 x whatever it is right or it cannot be 2 x you know that.

So, I am just saying for example 10 centimeters is there is it traveled 2 centimeters or 5 centimeters or 8 centimeters or it either is there is no molecule that will hit or atoms that are hitting the other atom right and it has a large mean free path. So, the mean free path is important because then the ah deflection would be less and then the deposition would be faster anyway. So, the reason for having vacuum is to improve the mean free path mean m e a n mean free f r e e free path p a t h path. So, please Google it.

So, you know better about the mean free path ok. Now if we see the slide what we see next one is that ah there is a meter here right and there is a variac what is that variac v a r i a c variac variac is variable a c. So, you can vary the voltage here in e beam operation right there is something else. So, first let us understand thermal evaporation ok. So, we concentrate on this particular ah figure or picture and here you have a current meter you see here is a current meter because when you apply a voltage and this is a boat right you apply a voltage across the boat right. So, you apply a voltage across the boat. This boat is nothing, but a metal which has some resistance right.

So, when I apply voltage and there is a resistor, what will generate the current will be there right current will generate and because of the flow of current and I squared R heating which is also called joules heating this resistor or the boat right will start heating up. So, when it starts heating up the material within it will start melting correctly. So, to apply this voltage we use this variable a c variac and you can observe the current in the current meter here. So, that is a reason for having this particular block. Here if you see it is a very faint image I am sorry about that, but there is a ah ah LED display ok.

In the new system there are LCD displays. You can see the LCD here right or even you can see it here right. So, in particular here this is the one. So, here you can see very clearly the rate of deposition ok and we can measure this rate in terms of angstrom per second angstrom per second. So, whether LEDs or LCDs it does not matter, this is just a kind of display, but my point is in the system this is the LED one while the other two are LCD one ok. So, this display is used for what I said that is used for measuring the rate of deposition of the material that we are depositing onto the substrate.

Another thing that you need to understand is that generally PVD is used for depositing metal, but it can be very well used for dielectrics as well and generally is for the metal deposition, but it can very well be used for dielectrics ok. So, we talked about vacuum, we talked about the primary pump, secondary pump, we talked about QCM, we talked about substrate, source, the power that is given to the source it melts it deposits as simple as that right. Now, what are the gauges to measure this pressure because we said 10 to the power minus 3, 10 to the power minus 6. So, where are these gauges right? So, there are two gauges one is called Pirani gauge and second is called Penning gauge you see here this is a gauge ok, this is a gauge. One is Pirani gauge for primary or for the vacuum which is in 10 to the power minus 2 minus 3 range where while the Penning gauge is used for vacuum more than 10 to the power minus 3 like 10 to the power minus 4 and so on ok, not really more by in terms of range 10 to the power minus 4 onwards right.

So, Pirani is 10 to the power minus 2 minus 3, Penning is 10 to the power minus 4 onwards or minus 3 onwards in a way. So, the other thing here that I wanted to show you would be whether the substrate can be rotated or not. So, see this is the rotation, this is the rotation means of course, there is a motor that will rotate and so, the substrate holder will rotate right. So, this is the system that is on the top of the chamber which is connected to the substrate holder which is inside the chamber and will rotate the substrate. The reason for rotation is to have a uniform deposition of the material onto the substrate. So, more or less I think I have discussed about the chamber, it is vacuum pump, the gauges, the windows, LCD or LED displays, the variac right heating and other things.

So, as you can now it just tells me one thing here: suppose I have aluminum right which is ok I have a boat and I load the beads and I give a voltage and there is a current flowing right because this is a resistor. So, now, what will happen is that this boat will heat up and the material starts evaporating this much we have understood. If it is not aluminum, that means, at the melting point, the melting point of source in this case it is aluminum right should be way less than the melting point of source holder material. So, this boat is our source holder isn't it boat is our source holder the melting point of the source. So, in this case it is aluminum, but if I do not want to use aluminum anyway I want to use some other material.

So, which has a very high melting point, suppose the melting point of the source the the statement here is that if we want to use thermal evaporation then the condition is that the melting point of the source should be way less than the melting point of the source holder material right. So, that this material which is the boat will not melt right while the source is melting, in this case the source is aluminum. But what if the melting point of the source is greater than the melting point of the source holder? In this case what will happen? In this case we cannot use the thermal evaporation system when the melting point of the source is greater than the melting point of source holder we cannot use thermal evaporation system. Everybody understood this much? Easy to understand right. So, this is a limitation. Then if I cannot use thermal evaporation what should I do right ,what should I do? So, that question remains: how can we overcome this limitation? So, if the here there are 4 statements the first one is that in evaporation techniques of physical vapor deposition a vacuum chamber is pumped down to less than 10 power minus 5 we have seen that evaporation atoms from the source condense on the surface of the wafer we have seen that as well ah and then the heater can be of resistive type then a junction filament and it heats up as current flows through it we also have discussed this thing.

The next one is but the most popular is the E-beam evaporation system in which a high energy electron beam is focused onto a source in the crucible using a magnetic field. Now the question is then why we have studied the thermal evaporation system? See there are 3 systems right: thermal evaporation, E-beam evaporation and sputtering. But the most popular in comparison of thermal or E-beam evaporation is that the evaporation techniques E-beam is better and how E-beam works we will discuss in the next class. But the point is, depending on the method of evaporation hardware evaporation techniques can be categorized as thermal evaporation and E-beam evaporation. So, like I said either you heat it which thermally heats the material and melt it and deposit it or you use an electron beam and the electron beam will fall and it will heat the material and material deposits.

Now, we will see the advantages of E-beam evaporation in the next class and understand a little bit about thermal evaporation. Let us see the thermal evaporation first and then we will end this class. So, that next class we focus on the E-beam evaporation ok. So, if you see the slide only one slide for you. You can see here that there is a vacuum correct in this figure then there is a source material, there is a heater right here there is a heater or resistance and there is a wafer holder at the top right there are wafers attached to it wafers is nothing, but your substrates right.

And when you create when you apply a voltage right this to the source material or source holder the material within the source holder will melt and will evaporate. This is the shield that I was talking about right in the previous things and this one is one of the source holders. It can have four sources for source 1, source 2, source 3 and source 4, four sources are there ok. So, this is within the chamber where we have taken the photos. There are four sources. So, you can have four different depositions. Whichever source you heat up right the source holder you heat up the source within that source holder would start evaporating. So, thermal evaporation relies on thermal energy supplied to the crucible or to board to evaporate atoms evaporate atoms travel through the evacuated space between source and the sample and stick to the sample surface reaction usually occurs very rapidly and there is little type of rearrangement of surface atoms after sticking now you can understand right.

So, once you melt the material it will immediately start depositing. So, it is so fast that the atoms cannot rearrange itself right, that is a statement that we have seen in previous slides. And second is thickness uniformity and shadowing by surface topography and step coverage are issues. So, because to improve the thickness or uniformity of the reposition we rotate the substrate holder ah still there is a shadowing effect which is not possible to overcome and there is some kind of step coverage issue. So, step coverages suppose this is a substrate ah holder this is a substrate holder and you have a substrate loaded onto it and on substrate you have some material like this ok. So, this is your material, this is your silicon and this is your substrate holder right.

Now let us say this is your silicon dioxide for example. Now you have to deposit metal everywhere. So, you have a boat and then you have some material and you evaporate it. So, it starts evaporating like this correctly everywhere. What happens is if I zoom in this area only this area. So, it is like a step now this like step the, this region which one, the material will not get deposited properly on the step area all right and that is why the step coverage in the thermal reposition or E-Beam operation is an issue which is not that much when we talk about sputtering and even better than sputtering for the step coverage will be your chemical vapor deposition.

So, with that let us not ah you know stretch it further and we will stop it here and let us focus on the next topic which is your E-Beam operation ah as a part of next class. So, till then you take care, see and understand and ask right. You are free to ask us questions on the forum and as I promised we will answer your questions as early as we can till then you take care bye.