Lec 08 - Neural Implant Fabrication: Sputtering & CVD

Hi, ah welcome to this lecture. If you remember in the last lecture what we have seen? We have seen the E-beam evaporation and thermal evaporation which is part of the physical vapor deposition. Now, in this lecture what we will be looking at is the sputtering which is the next part of the physical vapor deposition. Now, ah if you recall ah the thermal evaporation ah had limitation that if the material that we need to evaporate has a higher melting point than the source holder right, the holder on which we we keep the material then we cannot use the material because ah the holder will start ah melting as well that is one. The second one is that ah the some of the material right ah and one of the common limitation that goes in PVD is the ah shadowing effect one and the ah how to how to cover the ah step right which is the step coverage. So, these are two issues generally ah that we face when we talk about the ah physical vapor deposition.

But then there was another system which we called E-beam electron beam deposition. In that the electron beam will heat the material on the crucible, crucible is again a source holder ah and the and the material loaded onto the crucible with will melt and will evaporate that was E-beam. Now, the third one that we will be talking today is called sputtering alright and the sputtering has advantage ah over E-beam or thermal ah such that the the it it can evaporate or it can deposit it is not an evaporation technique. So, let me just correct myself it is not an evaporation technique, but here we are using the ah mechanical way of depositing the material onto the substrate ok.

Ah The advantage of sputtering is almost every material that you want or any material that you want you can deposit ah onto the substrate almost ah because there are some exceptions that may not be we can we may not be able to ah deposit via the physical vapor deposition. Ah And and when we talk about sputtering there are four different types of sputtering one is DC sputtering direct direct current sputtering, second is RF sputtering radio frequency sputtering, third one is magnetron sputtering the effect of magnetron is to increase the rate of deposition ah and finally, we have reactive sputtering. So, let us see the slide and then we will go through that. So, as I told you the sputtering techniques can be divided broadly into four categories ah DC, RF, magnetron and reactive sputtering. The targets in this sputtering are of various type if you ah again recall in E-beam and thermal we were using beads ah or or wires right to as a as a as a source ah ah that we want to deposit.

In this case the target or the source would be disc ah toroid ah plates etc. and it comes with different shapes and sizes. As an energetic ion strikes surface of the material there are four possibilities. So, what happens is it is still ah we we we remember the chamber right. So, in the chamber you again create a vacuum it is a vacuum deposition and ah when the vacuum is there ah what happens that ah that that the that the energy that is provided to the target right ah will cause the ah atoms from the source or target to sputter and the sputtering atoms with with additional surface mobility will improve the step coverage and will also start depositing onto the ah substrate, but let us go one by one. So, what it says is as an energetic ion strikes the surface of a material ah the there are four possibilities.

First is ions with low energies may simply bounce off the surface. Second at low energy which is less than 10 electron volt the ion can be adsorbed to the surface generating heat. The next one is above 10 electron volt of energy the ion penetrates into material many atomic layer spacing that is ion implantation. We will we will talk about ah very quickly implantation ah techniques ah ah and and and how we can dope ah a silicon with n type or p type right. So, intrinsic silicon by doping can make we can make it extrinsic, but if you want to just create a ah ah sub a p n junction let us say right then how you can create this p n within a intrinsic silicon ah or even an extrinsic silicon we will we will see it is called a diffusion and ion implantation techniques.

However, what we have seen is that between these two ranges that is ah both energy transfer mechanism occurs and the substrate atoms or clusters of atoms will be ejected from the surface of the substrate ah with energies of 10 to 50 electron volt. So, if so the the idea is that you can keep the energy between 10 electron volt ah ah more than that and 10 kilo electron volt and somewhere ah this energy will help in creating or depositing the ah material. So, sputtering yield if you want to talk about sputtering yield sputter yield is the ratio of number of sputter atoms to the number of incident ions ok. So, so let again let me draw it. So, this is a chamber and this is the ah let us say substrate right and here we say that there is a disk correct.

Now if the argon is used as a ah gas then the number of ah ions incident onto the ah this target right at a high energy electron volts or a high energy and somewhere around 10 electron volts this is a bit less than that because we said in the range right. What will happen is that the atoms ah from this particular ah target will be dislodged will be dislodged and will start moving towards and it will start moving towards. So, let me just create the eraser. So, when when this happens the when this thing happens and when the ah ions are incident on to the source or target the atoms will be dislodged and will move towards the substrate and where is our substrate? Substrate is here right like any other PV detecting. So, when this happens the deposition will start occurring and you can see that what will happen that when you when you have ah when you the when the ions are incident on to the target ah how many ions are incident corresponds to how many atoms are sputtered right or dislodged from the material ah is called something as a yield.

So, sputtering yield can be defined as number of sputtered atoms right number of atoms coming out from the target dislodging from the target this is this is our source or target because we are targeting this material by incidenting the ions which ions are gone right then to create the sputtering that means, dislodging the atoms and depositing on to the substrate. What can be our substrate? Substrate can be silicon, can be glass right, can be any polymer anything on which we want to deposit our material. So, number of sputtered atoms divided by number of incident ions right how many atoms are sputtered corresponding how many ions are incident. So, sputtering yield depends on following things ok the first one is the binding energy. So, sputtering yield is inversely proportional to the binding energy ah it is proportional to the ah the the square root of energy and proportional to the ion and target atoms that is S is proportional to M finally, it is proportional to the angle of incident that is rate is proportional to the incident angle and reduction deposition pressure gives a better yield.

So, as as much as you can reduce the pressure the yield becomes better now this this ah graphs or plots shows the same thing. So, let us understand this plots. So, let me again use the eraser and erase the this particular drawing and then when we see the this plots what we see we see that this y-axis is sputtering yield x-axis is ion energy. So, as you increase the energy the sputtering yield starts increasing right a certain point it will start reducing the ah sputtering yield and finally, it starts somewhere around this point is very high energy is kind of dipping it down right. So, this shows that what kind of ah energy we can use which we called as a threshold energy ah after which the sputtering will start right.

So, this is here we have written or you can see threshold energy for sputtering. What is this graph shows? This graph shows that this sputtering yield is how it is corresponds to the angle of incident. So, in this graph you you can see that as the angle of incidence increases as sputtering also increases, but then suddenly around pi by 2 ah it it is it drops or in fact, it is what we called as a theta max right angle of incidence with the max angle at which ah this sputtering yield is maximum. So, you can see around between 62 and 70 degree the sputtering is yield is maximum. Finally, ah with pressure right ah how what happens? So, as you ah reduce the deposition pressure the the the yield is higher which you can very very well see from this particular plot ok got it.

So, why we are not going into the physics of this sputtering is because we want to use this system to deposit a material onto the substrate and and fabricate devices with our understanding about PVD or CVD. That is why I am not getting into details about what atoms, how it looks like, what is the rate right, but to understand that there is a physical reputability and then there are three techniques thermal E-beam sputtering and how it works right. So, that you and we we also have corresponding lab videos right you can where we have recorded how the E-beam operation works, what how chamber looks like, ah where is the QCM, Quartz crystal monitor, where is the substrate holder, how the source looks like, how you can close the chamber, how the vacuum is created, primary pump, secondary pump, ah how the pressure are measured right. There are two pressure gauges ah one is Pirani gauge for the ah pressure close to 10 to power minus 3 torr, then there is a panning gauge that goes to minus 4 and about let us say about minus 7 torr ah and then how the reposition occurs within the chamber. So, this for thermal we have recorded, for E-beam we have recorded, for sputtering we have recorded.

So, you can see those recorded videos from the experimental laboratories as a part of this course. The what happens within is what I am trying to cover right, but there are many more things ah which is related to physics that we are not going into depth for this particular course ok. So, what you need to understand is that ok there is thermal reposition, there is E-beam operation, there is sputtering. In sputtering ah the number of incident ions if I if I improve the if I if I increase the number of incident ions how many atoms are dislodged is called sputtering yield and what it depends on, it depends on the energy, it depends on the ah angle of incidence, it depends on the pressure right This is what I want you to remember ok. Now let us go to the next slide.

So, as we have ah as we know ah that thin film reposition can be spin coating, spin coating we will we will talk as a part of the ah ah photolithography section ah and then in PVD what we have seen physical transport material from source to substrate because either by E-beam or by sputtering or by thermal. So, either by evaporation or by sputtering we are we are depositing a material from the source to the substrate. Example is ah evaporation and sputtering ah no chemical reaction is involved except reactive ions, reactive sputtering no byproducts ah are are generally generate are there ah generally possessed after creating a very high vacuum and the difficulty or limitation is the poor step coverage. Now let us talk about chemical deposition. CVD is a chemical process used to produce high purity, high performance solid materials ok.

The advantage of ah CVD which is chemical deposition is the step coverage becomes excellent because the the reaction occurs across the substrate. So, what does it mean? Let us say you have a substrate like this ok substrate and then you have deposit a material and then you have patterned it. So, it looks like this ok this is your material which is patterned. Now I want to ah deposit another material on to this this pattern all right such that it should also get deposited in this area as well all right. So, if I use chemical reposition then the reaction occurs across this particular step right everywhere because the gas is everywhere.

So, what happens during this one the this step here this angle here this step right is uniformly deposited. So, the the coverage is getting better in terms of chemical and ah you can see in terms of the ah thermal oxidation or EB mu operation the thermal reposition or EB mu operation or even sputtering the step coverage is poor from this figure you can see see it is not really covering the oxide ah properly, but if you go for CVD this will not be there. So, good step coverage, good film quality ah is used to deposit silicon and die dielectrics the only limitation you can say or or you need to be careful is that there are byproducts ok because when there is chemical reaction the byproducts are there. So, this is the ah difference. Now let us understand spin coating ok.

So, spin coating is a procedure to deposit a thin film uniformly on a flat surface ok. So, you have this ah substrate let us say and if I let us say you want to hm spin coat of photoresist photoresist photoresist. If I want to spin-coat the photoresist onto this particular substrate what is the procedure? The procedure is that I will first ah drop this one ah photoresist on to the substrate like something like this right and then I will spin it whole whole thing ok whole substrate I will spin it at a high rpm what is rpm rotations per minute. So, as as soon as I start spinning this substrate what will happen? The photoresist on the substrate will also gets starts spinning and you can see from this ah this image right and spin in one of the directions either clockwise or anticlockwise and finally, when you do that the uniformity becomes better ok. So, these are the spin coating was when you spin the substrate now if you spin the substrate the question is why it will not fly right because the substrate is kept on a chuck and the chuck is ah with a vacuum.

So, the substrate is holded by a vacuum and then it is rotated. So, in a very simple terms ah this is kept on a chuck like this and then there is a vacuum ok. So, this vacuum is created with the help of a ah pump ok. Now if you rotate this this whole is a rotating chuck all right and the including this spindle the spindle. So, it rotates there is a vacuum that is created and the ah the resist will get deposited.

Now we are talking about a resist, but you can talk about any other material which is in the ah which you want to deposit using this spin coating ah particularly I will show you the example of spin coating when we talk about the photolithography ok, but spin coating via spin coating we can we can ah coat ah some of the materials ah. For example, you want to ah deposit a PCT via sol jet technique right PCT is a piezoelectric material ah and sol gel technique ah we create this material then then we spin coat it on a on a on a substrate. So, the easiest method to deposit a film because you have to just put a drop ah or or few ml of that material and then spin coat it right. We do not require vacuum we do not require very high vacuum like 10 to power minus 6 minus 7 ah and then ah we do not have to worry about ah complex mechanism of heating the ah source or using electron beam or or incidenting the ions right ah. So, this is very easy way of depositing the ah material on a flat surface.

Flat surface because we are talking about silicon or we talk about the ah glass ah what happens if there is not flat surface it will not get deposited uniformly. So, now if you ah understand this this much what can can be ah what what are the parameters on which this deposition ah relies on right. The first one is the angular speed. So, if you increase the rotation the thickness would decrease if you decrease the rotation thickness would increase then the viscosity of the liquid the liquid is extremely viscous very difficult to deposit. Then it depends on the concentration of the solution then common spin coating defects if what are these possible spin coating defects you can see ah bubbles or pin holes you can see here.

Swirling and strict pattern you can see here. Non uniform coating you can see this one right. So, if I give like 1 2 3 and 4 then this one is 1 this is 2 this one is 3 and finally, this figure shows the fourth one hm. So, chuck mark you can see the chuck marks are there hm chuck is ah so, chuck is used to hold the wafer or a substrate. So, these are some of the spin coating defects.

Now, let us understand what are the limitations on spin coating. See defects are different than the limitations ok. The limitations are low throughput because one substrate you can load at one time and second one is control over the repulsion process and layer thickness is very poor because ah just by spin coating we need to make sure that the thickness comes uniformly from substrate to substrate over large quantity which is very difficult to really control. Ah What I mean by is that if you coat the same material at same rpm for ah on different or 100 substrates what is the ah accuracy of the deposition ah that you find it out. So, in this case it will be extremely poor.

Uniformity of the deposition film is very poor compared to other techniques. Compared to now when I say poor is not like really really bad, but when you compare to CVD or or PVD it is poor. Now, let us go to four basic types of chemical reparation. Now, from physical deposition we go to chemical deposition and just again understand ah from periphery ah what exactly ah are different kind of CVDs. So, when you look from that ah angle right or from the top we can see that ok there are four ah which one atomic pressure CVD, low pressure CVD, metal-organic CVD, plasma enhanced CVD right.

So, ah the advantages are high repulsion rate, simple high throughput which one we are talking about AP CVD. Then the disadvantages are poor uniformity, purity is less than LP CVD ok. So, if you want to quickly deposit you can you go for AP CVD. It is very simple and it is at a high throughput. Ah This is generally used for thick oxide deposition, but ah when you want to deposit a polysilicon or dielectric layer or and dope dielectric deposition then you go for LP CVD.

LP CVD has excellent uniformity ah and lower, but reasonable deposition rate than AP CVD. Then if you want to go for metal-organic CVD, the advantage of MO CVD is that ah it can deposit semiconductors, metals, dielectric and is extremely flexible, but the disadvantage is extremely toxic very toxic very expensive source material environment deposition cost are extremely high. It is used for low-cost optical ah 3, 4 technologies ah some of the metalization process tungsten and copper ah, but there is one more CVD which we will talk about when we are going to ah fabricate or I am going to show you an example of a fabrication is the PE CVD. Plasmin and CVD is used to force reaction that would not possible at low temperature. That means that ah this all the above CVD AP CVD, LP CVD, MO CVD they they suffer from one or second limitation particularly the temperature requires requirement is extremely high during the when the reaction occurs, but in plasmin and CVD the temperature can be as low as 100 degree centigrade and there is there are lot of advantages of low temperature chemical deposition and we will take an example and I will show it to you why PE CVD ah is preferred for certain fabrication techniques than other CVDs.

The disadvantage plasma damage is typical results typically ah that kind of results are obtained because of the damage from plasma and used for dielectric coatings like silicon dioxide and silicon nitride. So, at a glance if you want to see right ah let us take this particular schematic and what you see is there is a quartz tube and the quartz tube this orange color lines that you see are nothing, but a silicon wafers ok silicon wafers. So, so generally silicon wafers how you see is like this right, but when I when I stack it ah then it looks like this is not it if you stack it in this fashion it looks like this. So, these are silicon wafers and in the quartz tube when you load the silicon wafers and then you have heating coils and when you when you heat this particular quartz tube the initially you have to place the nitrogen. So, anything within the ah there any oxygen present within the quartz tube will be flushed out ok.

So, initially in presence of nitrogen you heat this particular quartz tube at a higher temperature generally we heat from 900 degree centigrade anywhere between 900 degree centigrade and 1200 degree centigrade to and and and most of the time ah we use this thing for silicon dioxide growth ok this is thermal oxidation silicon dioxide growth. Now once you ah reach this temperature of your choice then you can stop nitrogen and let the oxygen pass through the quartz tube what happens is when silicon reacts with oxygen it from silicon dioxide right as simple as that ah of course, we have a dry oxidation and wet oxidation ah, but right now we are just taking the example of dry oxidation where only oxygen dry oxygen right is passed through the quartz tube at a high temperature and there is a reaction between silicon and oxygen forming silicon dioxide. Now ah this is same thing is written ah in this particular ah slide that chemical gas sources are thermally optically or electrically activated to react with a surface ah to deposit the layer and the byproducts are pumped out from the chamber right. In a simplified model as you can see in this particular slide as gas flows over the substrate when the growth is determined by the adsorption and reaction rates. So, now, you see this particular ah schematic what is that there is a substrate and then when this gas phase reaction occurs with the with the substrate there can be multiple things one is the nucleation and island step growth which will occur here second one is there is some desorption will occur then third one is that when the gas reaction occurs it goes to the ah substrate adsorption occurs surface diffusion occurs and re adsorption occurs right.

So, there are many things that can that occurs when the reaction is ah there within the chamber and and this is nothing, but like in a bigger chamber you see like this right. So, when a gas main flow main gas flow region is here and how the reaction occurs and what can be the possible solutions one is that the film is deposited by nucleation and island growth second one is that there is a adsorption re adsorption then last one is a deabsorption. So, the ah reality deposition rate is affected by distance from the gas inlet specifics of the reaction and radial variance right. So, if I if I have a slide so, if if I kind of ah have a angle right at which I am putting the wafer what will happen is that the ah wafer that the inlet is here right. So, the as you go towards it right the if you have this one and you see that the gas is like this over a period of time the concentration of the gas here will be lesser than the concentration of gas here as it passes through is not it.

So, if I tilt it if I tilt the entire ah substrate holder like this then what will happen is the reaction even the concentration of gas decreases the reaction rate will not decrease significantly. So, that is why we can this radial variance is important factor when we talk about the ah CVD. The last thing is the tricks to improve ah so, when I say ah when I say that ok let us tilt the substrate that is what I meant that when you tilt the substrate the ah rate of deposition or uniformity also improves ah not really rate of deposition, but more like uniformity. So, that all the substrate within the CVD ah will be uniformly coated ok. So, one is you tilt the substrate in the flow like I have just drawn right increase temperature along the substrate and single wafer processing single wafer is there no issue.

The multiple wafers are there then you need to make sure that the all the wafers are uniformly coated ah with the material of our choice, but when we talk about why ah CVD is not so, common in ah the laboratories right it requires a specific way of treating the hazard which is a byproduct. So, even for the lab that we have recorded this thermal evaporation EBMOS pattern we do not keep CVD, but we have CVD as a ah as one of the deposition techniques in the central facility of our institute. So, the the advantage are many, but then limitations or the way to handle the gases are extremely important. So, that is the main reason that the safety is an issue when we talk about CVD in common labs ok. However, it is an extremely important deposition technique.

So, many gases using CVD systems are toxic when you say toxic they are hazardous to humans then it is corrosive in nature then ah particular causes corrosion to stainless steel and other metals. It is flammable that means, when burns when exposed to ignition source and oxygen source explosive and or pyrophoric. So, spontaneous burn or explode in air moisture or when exposed to oxygen. So, so what are the gases generally used in CVD? So, the gases are listed here right from ammonia, silane, arsine, phosphine, hydrogen, nitrogen oxide, hydrogen chloride, diborane, dichlorosilane. What are the hazard ah levels? So, it is from toxic to corrosive to flammable to oxidizer to ah you know ah corrosive and toxic both right or combinations of of this.

The limits also are given exposure time is also given because if you are you are exposing more than this like parts per million more than 25 parts per million of ammonia if you expose it is hazardous to to health 0.5 of silane 0.05 of arsine. You can see the how low we are talking about and this parts per million. So, it goes to almost parts per billion when you talk about 0.05 ah 0.015 right ah and then flammable limits also you see ah it is pyrophoric. So, it is spontaneous burn right. So, you to be very careful when handling this kind of a gases. So, that is a limitation of why we generally do not go for the ah chemical repar deposition techniques generally in the common lab, but we definitely use this thing and I will show it to you how physical reparition techniques and CVD are used to fabricate these devices.

So, this is the last slide for our ah lecture. In the next lecture what we will look into is ah how the micro sensors how to make the micro sensor implants and starting with the photolithography ok. So, this will be the next lecture ah for our course. Till then you take care ah I will see in the next class. Bye for now.