Neural Science for Engineers
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Lecture - 50
Microengineering devices for Neural Signal Acquisiton

Hi, myself Hardik Pandya. And I am a professor in Department of Electronic Systems Engineering at Indian Institute of Science, Bengaluru. So, as a part of this particular course, on neural science for engineer's, I thought of taking 2 TA classes. So, that the engineers, who are taking this particular course would understand, how the fabrication or the process for fabricating several micro devices can be used to understand neural signals right.

Now, we have already seen through the course instructor Dr. Vikas, who is also a neurosurgeon that, how the brain works. And what is the anatomy, we have also seen some of the signals and how the processes are made.

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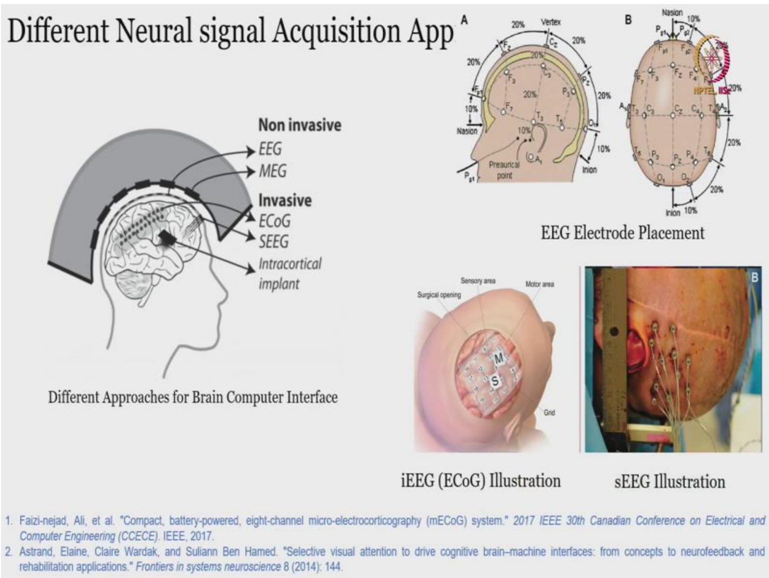

Now, in this work what I want to show you is, what kind of different neural signal acquisition approaches are there. So, you already know about ECG right. What is ECG? ECG stands for electrocardiogram. But when you talk about EMG, it stands for electromyogram. So, ECG are basically the signals that are originating from the heart muscles.

So, it is ECG that we generally see in a daily basis in movies or in your serials, there is an ECG echocardiogram. Then there is an EMG like I said it is a muscle moment. So, if I move my muscles, if I put an electrode, you will see a potential generating from the muscles.

But when it comes to brain in particular then, we look at several, one is you are EEG and secondly is MEG. So generally, you will see the term EEG, which stands for electro encephalogram. But that is outside; that means, when we take the signals from the scalp right then, you get the EEG. So, the voltage value the amplitude that you find in the EEG signal is way lower than, the amplitude of ECG or EMG.

ECG and EMG the voltage range is of millivolts. EEG the voltage range is of microvolts. So, that is where the difference is, but the first question that will arise is, why EEG is having lower voltage or lower potential than ECG and EMG. And the reason is that the impedance provided by the skull would reduce the signals that is originating from the brain.

But also, the muscle moment of our heart. So, that is way higher compared to that of brain. So, the signals originating in the brain are of lower potential. Now, I am putting in very easy terms for you to understand, not really into the bookish term.

So, that we understand how to measure those signals and what kind of different devices that we can fabricate. So, we can divide the approaches for brain computer interface, which is BCI into 2 particular modalities. One is a non-invasive technique to measure this EEG signal or the signals arising from brain EEG or MEG.

That means that noninvasive is without invading. So, you may have seen the terms invasive, open-heart surgery is invasive. Minimally invasive blood glucose monitors, minimally invasive you know through urine we test pregnancy.

So, it is minimally invasive. It is not actually minimal invasive, because there you are not invading something. But blood glucose for sure because you are putting a needle right. When it comes to invasive; that means, you are actually invading means you are going inside. For example, if you open the skull and understanding the signal from the brain or acquire signal from the brain then, it becomes invasive.

Third thing is, one is noninvasive without invading, it can be your breath analyzers that you just have to measure the signatures of the breath or EEG measurement like 10-20 system you may have seen. And when, it comes to minimal invasive I have given example of a blood glucose monitor. When it comes to invasive then, there are several different techniques. In this particular course, let us keep ourselves limited to ECOG, SEEG and intracortical implants.

Now, again to make it simpler, when we take the signals directly from the brain it is electrocorticography. So, when you see this one, this particular image that we have taken from 30th Canadian Conference on Electrical and Computer Engineering. And also, we have taken another paper from frontiers in system neuroscience, which we a have acknowledged on this slide. What we see here is that, how the EEG electrode placements are done.

Now, you can see very clearly in this particular slide, I will just put a laser pointer. In this one, what we see is, there is a 10 20 system right. This is a 10 20 system based on that, where to put the electrodes and how to measure the or how to acquire the signals. Simplified way this F stands for frontal, frontal is front. T stands for temporal. C stands for central and O stands for occipital, alright easy, frontal F central C occipital O temporal T.

This much is easy. Now, if I place the electrodes in this given fashion, what will happen is that we can get these EEG signal and that EEG signals that we record has lot of application also to understand in several domains. Let me take an example of seizure, it is epilepsy. So, if you if somebody wants to understand whether the epilepsy is focal to a certain point let us say, it is just on C z or C4 or it is a generalized epilepsy.

Where it is in most of the electrodes or it is focal to generalize that mean, it started at some point and then it is spread over different electrodes. Then one can easily understand alright. Now, when we take talk about the ECOG that is electrocardiography as I said it is a signal again the brain originating from the brain.

But we are directly placing the electrodes or a flexible implant implantable chip on to the brain. Now, so for that, we need to open the skull of course, when I say, we is not you and me, its neurosurgeon like Dr. Vikas. So, he can open the skull or a neurosurgeon can open a skull, then there is a dura and then there is a brain.

And in the CSF, when you place a device on this particular brain and you measure a signal, we know whether it is sensory area we are measuring or whether it is the motor area where we are measuring right. And that particular data that, we get is called ECOG alright. And then, there is a SEEG illustration, which is over here right.

But the point is let us restrict ourselves to ECOG and EEG. So, I hope that in this from these 2 slides, what we understood is, what is the difference between this EEG signal, which is electro electroencephalogram versus electro electrocorticography right. Then let us go to the next slide.

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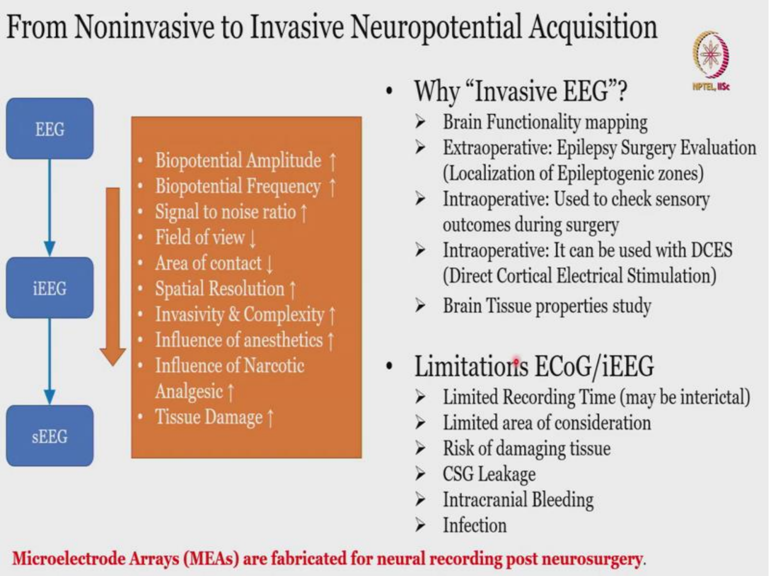

So, from noninvasive to invasive neuro potential acquisition. So, like you see here, when we go from EEG, which is noninvasive to IEEG to SEEG.

Actually, the changes happen particularly, what we have to understand is that what exactly happens when we go from noninvasive to invasive. First and foremost is that the biopotential amplitude would increase. The biopotential frequency would increase, signal to noise ratio would increase right. And that is good, because now directly we are touching the brain right. Then field of view decreases right.

Of course, depending on what kind of craniotomy surgeon operates. The area would change, the special resolution increases invasivity and complexity increases, because now we are opening the most delicate and kind of unknown region of the human body right. Still lot of research is going on in the area of brain.

So, invasivity and complexity increases. Influence of anesthetics also plays a role, because when you want to go for that kind of surgery you have to anesthetize the patient. Influence of narcotic analgesic also increases. There is a chance of tissue damage and that is why when we use implants, we also go for something called toxicity studies.

So, if you use the implant and depending on what kind of material that you use in the implant, is it a biocompatible material? If it is a biocompatible material, what is the material made up of? And once you implant that device into the brain then, what kind of toxicity effect it may have. So, all these things one has to see, when we move from noninvasive to invasive neuropotential acquisition.

Next is let us understand, why we want to go for invasive EEG or IEEG. So, brain functionality mapping now, we know what kind of signals are originating from different regions of the brain and from that, we can map the brain. It is an extra operative or epilepsy surgery evaluation sometimes the drugs.

So, when there is epilepsy, it is also called seizures. A person has is generally advised or administered different kind of drugs that are called anti-epileptic drugs. But there is a there is one single kind of epilepsy, in which it the surgeon has to operate the patient alright. So, for that one, we need to understand or check the sensory outcomes during surgery.

We need to understand, whether it can be used with direct cortical electrical stimulation. And we can also understand brain tissue properties. So, that means, that if I want to use the same kind of device or a deep brain stimulation electrode for treating Parkinson right. What kind of signals are required, where to implant this electrode, how long the electrode should be implanted, whether you implant the electrode, what kind of toxicity effect will be there?

Whether there will be any tissue damage. So, all these things one can understand, when we go for IEEG or invasive EEG. But if there is an advantage then, there are certain limitations. And the limitations of electrocorticography or IEEG are limited recording time, second is limited area of consideration, third is risk of damaging tissue, next is CSG leakage, next one is intracranial bleeding and final is infection.

So, what we are focused on is that as an engineer and if you know as a process designer for designing different microchips or implantable flexible micro devices, can you design a microelectrode array? And if you are designing that one then, can you record those signals arising from the brain post neurosurgery.

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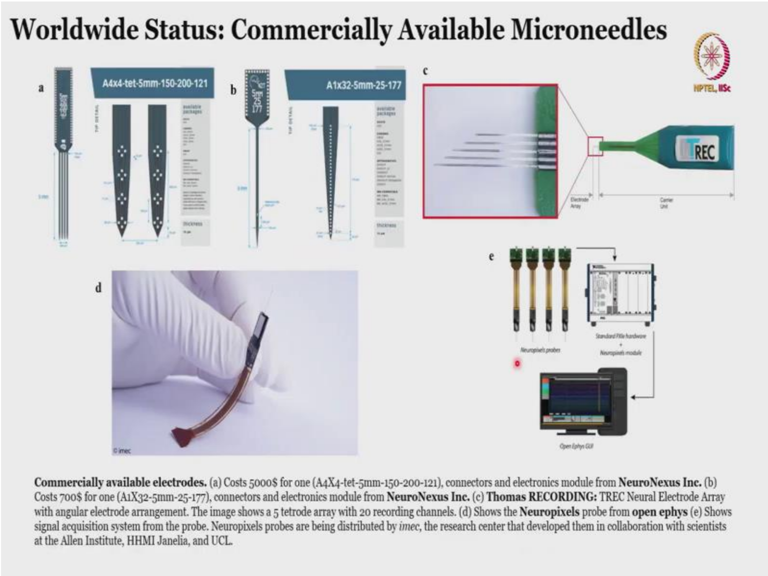

But also, when you implant this electrode, what kind of signals are originating, can you acquire those? Now, the question is like if we want to go into this particular research domain, first question would always be, why? Right, why we need to do this? Are there already existing products? What are we talking about? And what forces us or compels us to go in that particular direction or fabricating our own devices alright.

So, if you understand the commercially available electrodes then, it cost about 5000 dollars for 1 A 4 X 4 5 millimeter 150, 200, 121 with connectors and electronic only from neuronics incorporation. This one, it is costing how much? 5000 dollars right.

Now, if you go for a b, which is this one, it will cost some 700 dollars right. Then, if you go for the c one right with this one it is from Thomas recording. There is a track neural recording array right. Then, there is a neuro pixels probes are being distributed by imec right like neuro pixels probes are here.

So, the point is that, are we ready to invest this amount of money to study different brain signals. And now there are multiple questions. Yes, we can if it is useful, and it is affordable. Second is how many of these devices you can procure? This procurement of these devices; that means, we are loading the import. How to reduce the import? How to how to improve the export?

So, can we fabricate these devices here in our country. If that is the first question, if yes then, what are the process flow to fabricate it right. That is the second question. And what will be the affordability point of view or margin that, we can bring it that is a third point. Fourth point is, whether those electrodes will work or have the similar efficiency like the existing commercially available devices.

Fifth point, can we acquire those signals and record it with the existing electronics that, is available commercially. So, there are several things that one has to take care of it. How many devices you can fabricate? And what kind of fabrication process are there?

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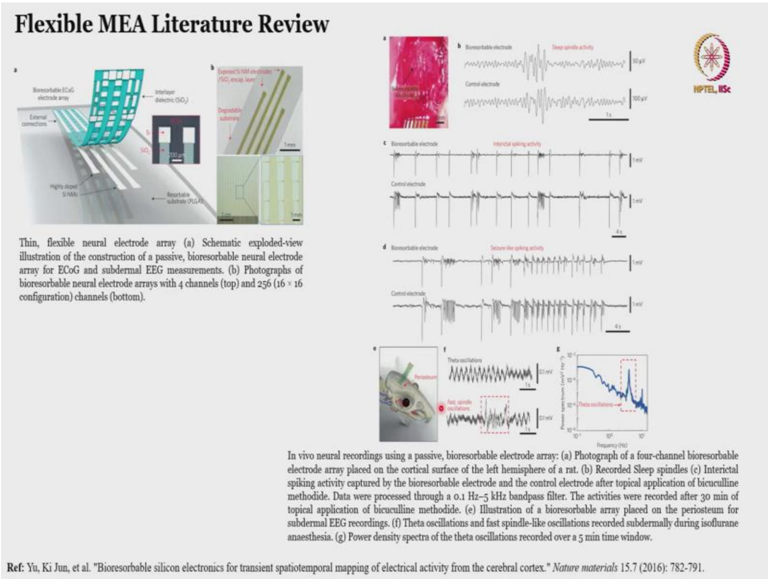

So, taking all this into consideration, we can think about what are the process flows and what can we what can we do from the micro engineering fabrication process point of view.

The second thing that is of interest is of micro electrode array. And this electrode array is on the surface of the brain right. See the one that you are looking at are kind of a needle, what we call is a micro needle or some people call this a probe right. So, this needle can be implant implanted deep inside the brain, it goes deep inside the brain.

But when you want to know the surface, what kind of signals are originated from the surface of the brain. Then, there are several ways to fabricate, flexible microelectrode array. And from the literature, what we found is that, on the left side what you see is a bioresorbable ECoG electrode array. There is an external connection and then there is a highly doped silicon nano nanomaterials, we use nanoporous silicon also. And then, you can also see that this is a bioresorbable.

What do you mean a bioresorbable versus biocompatible? Biocompatible is that a device is compatible with the human body right or an animal body, depending on whether, we are using on a Rodent model or on monkeys or humans. So, that is bio compatible. Second is bioresorbable, resorbable means it will dissolve in the brain, it will dissolve inside the body.

So, once you implant it, you do not need not to take it out again, because it will dissolve. There is an advantage of using bioresorbable over biocompatible. Of course, bioresorbable is also biocompatible, because otherwise it will form toxins. So, this example like you can see here, there is a silicon dioxide, which is insulating material, there is a silicon.

This is a PLGA material, this is a degradable substrate and these exposed silicon electrodes or SiO_2 encapsulation layer. We have schematic of exploded view, which is right over here. And then you have photographs or bioresorbable neural electrodes with four channels, which you can see here. Then you can see, in this particular thing. So, since there are 4 different channels and you have different electrodes, you can also measure that, what kind of ECoG signals are arising.

Now, why I am not talking about ECoG and not EEG, because you are implanting this electrode onto the brain of the Rodent model or on the rat’s brain. And you are measuring electrical signals. Now, you can see that, in the right side the slip spindle activity is about 50 microvolts or 100 microvolts right. Control electrode and bioresorbable electrode.

So, you have the difference of 50 microvolts, but at the same time if you create an epilepsy by using epileptic inducing drugs then you can see, there is an interactive spiking activity and the range here suddenly becomes 1 millivolts. So, the range changes from few microvolts to 1 millivolt; that means, there is a seizure right.

Same thing if you see, this is spiking activity. Then this is the seizures right. So, you see the seizures clearly you can see, in this biological electrode versus a control electrode. And the seizures are also of very high amplitude. The next one is there is a theta oscillation as you can see here. And then, there is a fast spindle oscillation as you can see here.

The point that I am making is that, using this flexible bioresorbable 4 channel electrode arrays placed on the cortical surface of the left hemisphere of the rat the authors were able to like Yu Ki Jun et al.

Which is, this work is published in nature materials in 2016, they were able to understand what kind of electrical signals they can measure using a bioresorbable electrode. And how the performance of bioresorbable electrode is different compared to the control electrodes. Also, to understand whether the electrodes, whether it can pick up the activity like interactive spiking activity or seizure like spiking activity, they did further experiments and they were able to measure it.

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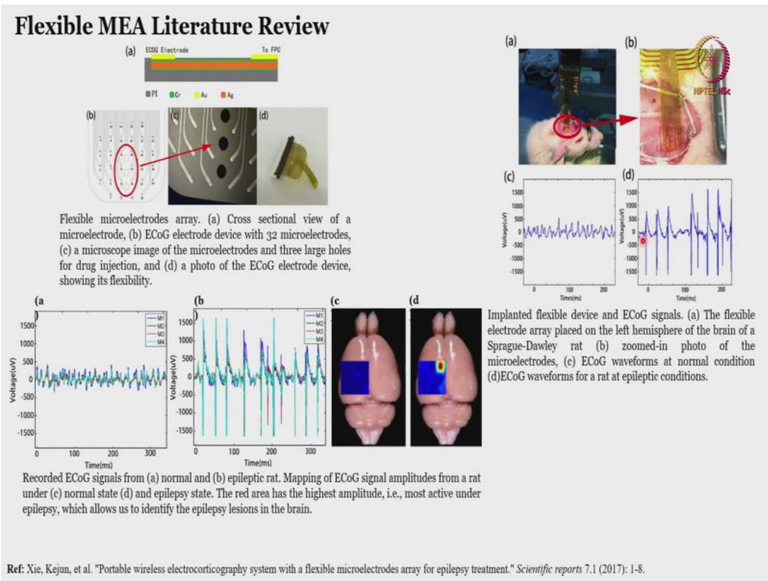

Now, this is about the micro electrode array literature, that was the first paper. The second paper that I am showing it to you is by Xie and Kejun et al and it is published in scientific reports in 2017.

And here, what they have done is, they have again fabricated ECoG electrodes on a flexible substrate. And then, there are three holes in this one to load the drug right when the chip is implanted onto the animal brain. And you can see, the flexible electrode array cross sectional view of a microelectrode which is right over here, which is this one.

And then you can see, the bottom material right, the substrate is PI, which is flexible in nature. Then, you have your chrome, you have your Ag and you have your Au. Finally, gold is used to acquire these signals or record the signals ECoG electrodes device with 32 microelectrodes as you can see the numbering from here.

So, last is last paper right, what we saw is about 4 electrodes, here there are 32 electrodes. Also, microscopic image of the microelectrode and 3 large holes for drug injection. So, you can inject different drugs using these 3 holes right when the device is implanted onto the rats brain. Finally, you can see, the actual photograph of the fabricated device.

So, what we see in this particular case is that, when there is a normal signals ECoG signals, which are normal you can see, this amplitude range and it is a voltage in microvolts. And when it is epileptic red; that means, when we can create epilepsy then, you can clearly see the spiking activity right. And the amplitude increases many folds compared to the normal ECoG signals.

Next one is the red area has a highest amplitude. So, they have also mapped it and the done the analysis to understand that which area shows a maximum amplitude. And most active under epilepsy, which allows to identify epilepsy region in the brain. So, when you create an epilepsy if it is a focal epilepsy or a cert epilepsy generating only in the certain area, we can easily understand using this kind of flexible device.

Now, the next one here is the flexible electrode array placed on left hemisphere of the brain, zoomed in photo of the microelectrodes and ECoG normal. So, this is again the normal end, when there is a epileptic conditions.

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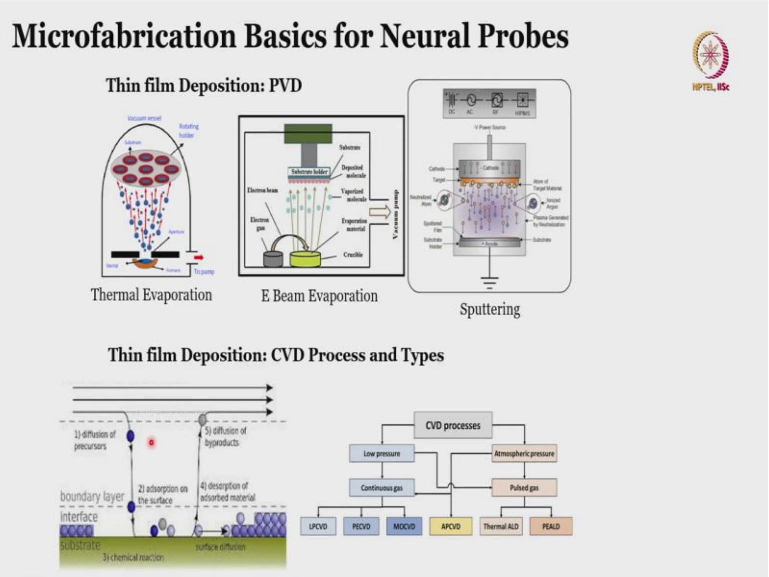

So, the point of showing you all this particular literature is to make you understand that there is a possibility for people, who understand fabrication process, micro fabrication process to fabricate these kind of devices.

It is not too difficult once you understand it becomes very easy. But to understand, how we can deposit the different material whether it is a metal or whether it is an insulator or whether its semiconductor, we need to understand something called PVD. PVD stands for Physical Vapor Deposition.

So, you can see here in this particular slide, thin film deposition, which is PVD, we have thermal evaporation in which you can see that there is a boat then, e-beam evaporation and then there is a sputtering, but in let us start with thermal evaporation.

So, thermal evaporation as its name suggests, we are heating a material, which is kept on a source. You can see here there is a source holder on which the material is kept, which is blue in colour. And then, when we heat this source holder, which is also called boat. When you have a boat; that means, a source holder.

It is made up of a metal. So, if you apply a voltage, what will happen? Because of the resistance of the metal the current will flow and there is a generation of I^2R heating which will heat or melt the material loaded onto the boat, onto the source holder. And because of the melting of the source material, it will start evaporating.

That evaporation is caused because we have thermally evaporated the material that is why the name comes as a thermal evaporation. Now what are on the top this one. This is a substrate holder which is holds several substrates. And this is a rotating holder, rotation is to make sure that the uniformity of the deposited film is intact. And finally, there is a vacuum chamber or vacuum vessel.

So, what will happen is that, at a single time you can deposit one after other materials, but the same material you can deposit on several wafers on in a single time. And that is the advantage of using this thermal evaporation. What is a disadvantage? The disadvantage is that, when the source material has a higher melting point compared to the source holder.

Here they call furnace, but the right term that or most of the paper most of the papers or the books that you will find they write this as a boat or a source holder right. And this as a substrate holder, the top one is a substrate holder the bottom one is a source holder. So, when the melting point of the source that is a material that we want to deposit is way higher than the melting point of the source holder.

Then, we cannot use thermal evaporation. And then in that case, we need to move to the electron beam evaporation. Now why to use this vacuum. So, this is also called vacuum-based evaporation. So, the reason of using vacuum is to improve the mean free path. Now what is mean free path? The path before, which these atoms will start colliding with each other.

So, how long this can travel without colliding with each other that is a mean free path. Higher the mean free path right better it is for us, for getting the deposited film. Also like I said rotating the holder will improve the uniformity of the film. But in the case, where their source is having very high melting point compared to source holder we go to a second system, which is called electron beam evaporation.

In electron beam evaporation you have a crucible, which you can see here then you have electron gun, which you can see here. And then electron beam comes and it can be incident onto this crucible, where the source is loaded. So, when the source is loaded, when the electron gun comes, and it is incident on the crucible this will start melting.

It will start melting. And when it starts melting, it will evaporate and when it evaporates it again gets deposited onto the substrate. This substrate is attached to the substrate holder. Now here we are not heating the crucible. Crucible is made up of a material which has a very high melting point compared to any source that is used inside the e-beam evaporation.

So, for example, graphite that is one of the materials that one can use for crucible. The idea is that using electron beam you heat or melt the source and the crucible we are not heating that is why this is an electron beam evaporation. You are using electron beam to melt this source material, which is loaded onto the crucible, which is a source holder and this material will evaporate.

And it will get deposited on the source, on the substrate and this substrate is attached to the substrate holder. So, again this is using the vacuum right. So, vacuum is used for increasing the mean free path remember. The next one is the sputtering unit, sputtering unit in this one, we are not actually melting it.

We are not melting the source material, but what we do is, we dislodge the atoms, we use argon and neutralize atom. We use argon to heat this cathode. And the anode is where the substrate is there. Now, when we heat this cathode with argon in presence of plasma, what happens is that the atoms from this target material will get dislodged.

And when it gets dislodged, it will start moving towards the substrate. You can see, this one in this particular direction. And when it starts moving towards the substrate it will start depositing on the substrate. This deposition if you have seen, how the rain drops you know, when there is a rain and raindrops falls on the roof, which is made up of metal you will hear a sound and that sound is similar to the sputter sound.

The rain drops falling on the metal roof if you hear it carefully that is how the sputtering works. So, the sputtering names comes from sputter and sputter is similar to rain drops. In this case there are no rain drops, we are talking about the dislodging the atoms from the cathode or from the target. And this will move towards the anode on which there is a substrate and the deposition occur.

So, this is a mechanical way of depositing a film. The thermal evaporation and e-beam evaporation is, we are heating it, we are using electrical energy right to heat the material, or electron beam. In this case, we are mechanically dislodging the atoms right. Now, this is called physical vapor deposition.

Because we are physically evaporating the material and we are creating into vapor and depositing it onto the substrate. But there is a chemical vapor deposition and chemical vapor deposition as you can see on this particular slide, which is right over here. what happens is that you create you a chemistry, where the chemical or the gases that forms this particular layer can be passed through the chamber and those gases will react with the substrate, which is called as a diffusion of percusses. It goes inside and it reacts, which is either it is absorption or desorption. And then, that reaction occurs, which is we called as a chemical reaction. Then there is a desorption and then there is a diffusion of byproducts.

So, whatever the byproducts are there will come out of the chamber. Here we are using chemical as a medium to create the film, that is why we call this a chemical vapor deposition right. So, saline is used, and several other materials are used to create a different kind of films. So, again if I repeat it then, we have a diffusion of precursors then it goes as an absorption on the surface of the substrate.

Then there is a chemical reaction it forms the film; a certain material will get desorbed. And finally, the byproducts will come out of the chamber, this is known as chemical vapor deposition. Again, I am talking from a very peripheral point of view. So, that you do not get confused. Now, so in general, what we understand is PVD versus CVD, but in CVD there are several types, like in PVD there are 3 types; thermal evaporation, e-beam evaporation and sputtering.

In CVD also we have several types one is a low-pressure CVD, second is atmospheric pressure CVD. And then there is continuous gas is supplied, where you have LPCVD. Then you have PECVD and then you have MOCVD. Then you have atomic layer CVD, which is ALD, then you have thermal ALD, then you have atmospheric pressure CVD, which is APCVD, you have low pressure CVD LPCVD, you have plasma NNCVD PECVD and so on.

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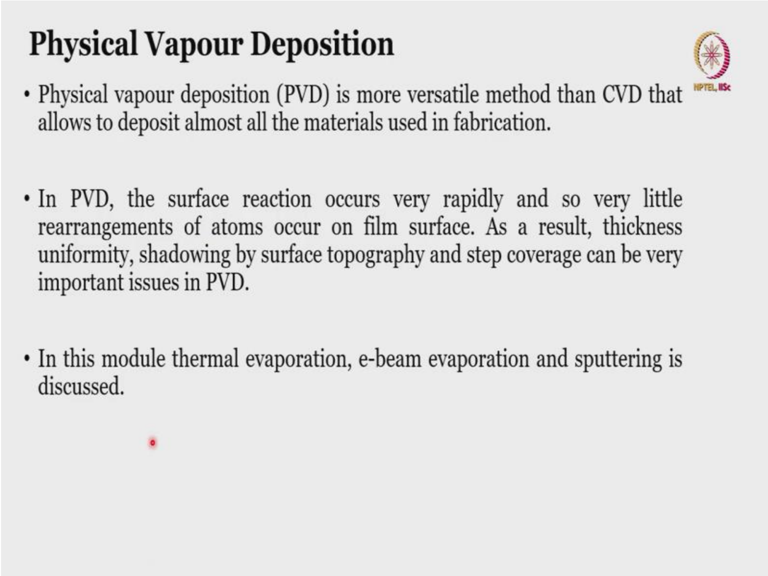

So, several types of CVD. So, as you have noted that physical vapour deposition is more versatile method than CVD since it is allows to deposit almost all the materials in fabrication. But at the same time PVD has a limitation that, we cannot get a good surface coverage and step coverage in particular. So, as you can see, the shadowing effects causes the step coverage to be poor in PVD.

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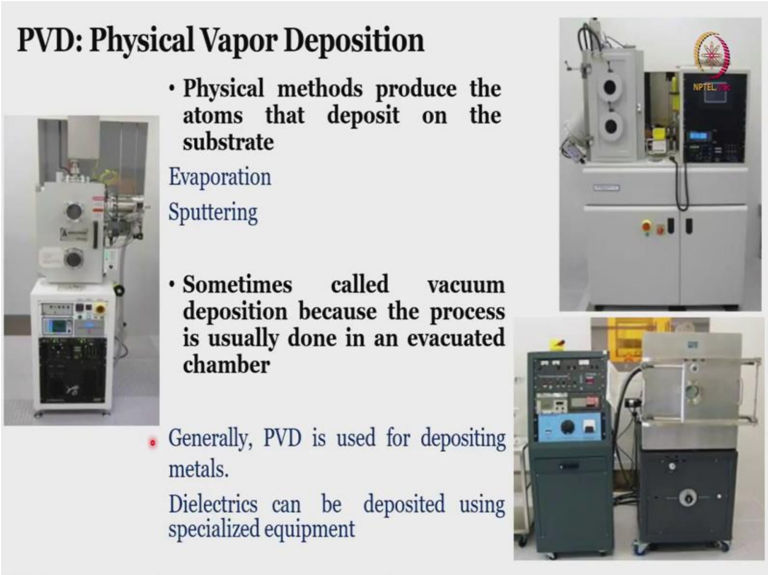

Now, in this module let us understand PVD, NCVD a little bit more in detail. So, in the left side, what you can see is a e-beam evaporation system this particular one in the right side you can see thermal evaporation system, which is right over here. This is also thermal evaporation system. So, physical methods produce the atoms that deposit on the substrate it is evaporation on sputtering.

Sometimes it is called so called vacuum deposition, because the process is usually done in an evacuated chamber. So, generally the PVD is used for depositing metals and dielectrics can be deposited by specialized equipment

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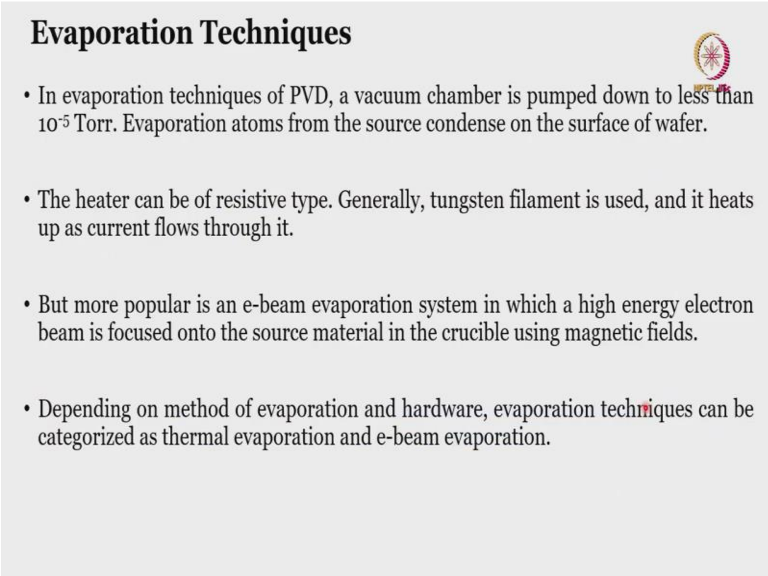

The evaporation techniques of PVD, we use a vacuum chamber. I told you to improve the mean free path and generally the vacuum is pumped down to less than 10^{-5} Torr.

The heater can be of resistive type, generally, tungsten filament is used and it heats up and current flows through it. But more popular is an electron beam evaporation as I told you, because where the material that you are using if it has high melting point it cannot be evaporated using thermal evaporation.

But we can use the e-beam evaporation. Again, depending on the type of the evaporation and the material that you want to evaporate, you can either categorize it as a thermal evaporation and evaporation and take that particular technique to deposit the material.

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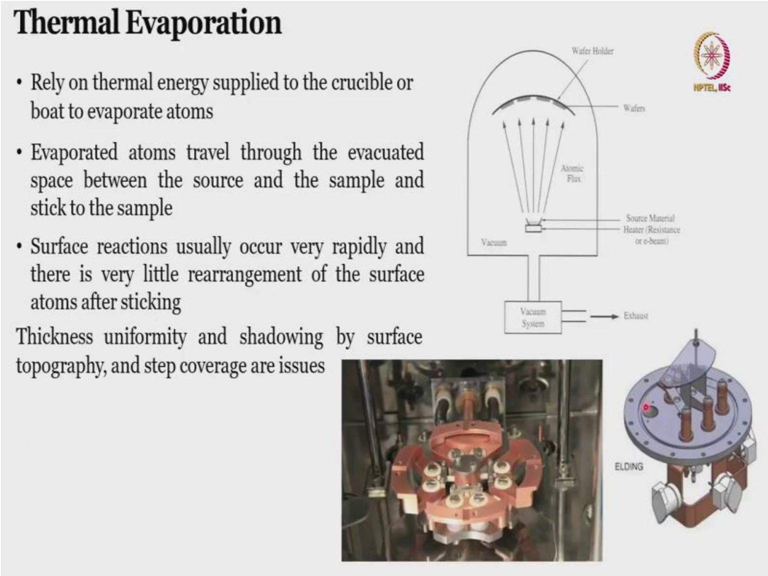

This is again a similar thing in a different form, a very dear friend of mine has given me this image. This is a source holder, you can hold different boats or a source holder and whenever it connects with this particular electrode it starts heating, because the power is given to this particular source holder.

Then, you can rotate this, and you can connect this one. Then you can again rotate you can connect this one. So, you can deposit 4 different materials inside the vacuum chamber. This is a vacuum system, there is a source material or a heater, there is a wafer holder with wafers and the thermal evaporation as we have discussed earlier relies on thermal energy supply to the crucible or a boat to evaporate atoms.

Evaporated atoms travel through the evacuated chamber and reaches to the substrate. Surface reaction occurs very rapidly and that is why there is a very little time of rearranging the surface atoms after sticking. And that is why when we see the depositor film generally, it is amorphous in nature. You may know, what is amorphous, what is polycrystalline and what is single crystal.

So, the question is, how we will know whether the film is amorphous or film is polycrystalline? Why is this very important? Because certain times you need to fabricate devices like piezoelectric device. Now, what is piezoelectric? Piezoelectric is a material or is a property, where you apply your pressure there is changing voltage and vice versa, when you apply a potential there is a change in the pressure.

So, for those kind of material for example, if you use pzt, lead zirconate titanate. Then, we need to know that the crystals are oriented in a certain fashion. And also, polycrystalline film shows a better sensitivity if you go for a gas sensors and some of the other sensors. But when we go for thermal evaporation since there is a very little time of rearranging of atoms.

Most of the time the film that, we get is amorphous in nature. How to get a polycrystalline film. So, there are 2 ways one is that you can heat the film during the deposition; that means, that if your wafer holder or a substrate holder has a heater. We have seen earlier that there was a heater indicated onto the substrate holder then the rearrangement of the atoms can be made better.

Second is that, if you take out the film, the deposited film, you take it out and you anneal it in a chamber and you heat it in a chamber then you can again see that it has a polycrystalline nature. How you can measure this polycrystalline and amorphous, using a technique called X-ray diffractogram, that is a material characterization technique.

So, thickness uniformity and shadowing by surface topography and step coverages are the issues.

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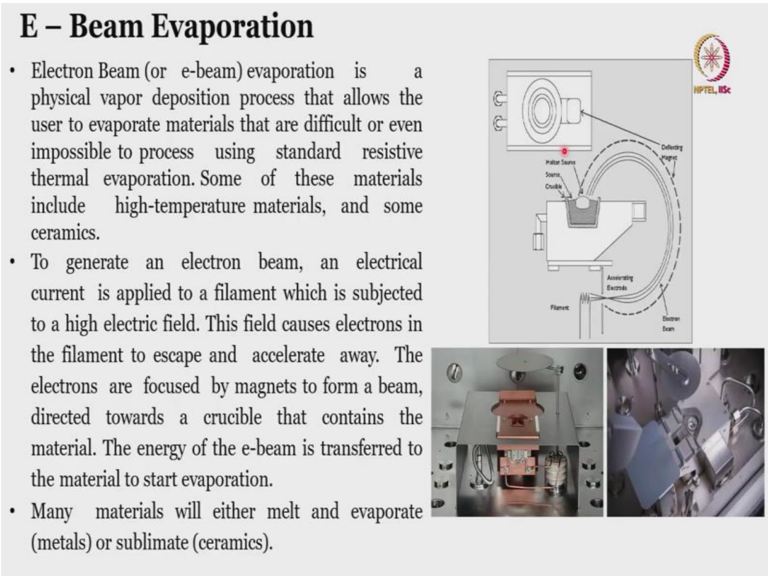

So, one can go for e-beam evaporation. Again, there is a photograph of this e-beam evaporation, there is a schematic here and you can see there is a crucible then, there is a source and there is molten source. Molten sources because there is a filament here.

And the filament will generate an electron, which will pass through the accelerator electrode it will bend, because of the deflecting magnet. And you can incident those electrons on a given surface. So, e-beam evaporation is a physical vapor deposition technique, because here, we are physically evaporating the material and depositing onto a substrate.

And that allows the user to evaporate materials that are difficult or even impossible to process using standard resistive thermal evaporation. Some of these materials include high temperature materials and some ceramics. So, to generate the e beam, an electrical currently is applied to the filament, which is applied over here.

And then, which is subjected to a accelerating electrode this accelerating electrode with helps to accelerate the electrons further and to escape the filament. The electrons are then focused by the magnets to form a beam you can see here, and the laser pointer directed towards a crucible that contains the material, this is a crucible with the material.

The energy of e-beam is transferred to the material and the material will melt and will start evaporating. Many materials will either melt or evaporate or sublimate depending on the material property.

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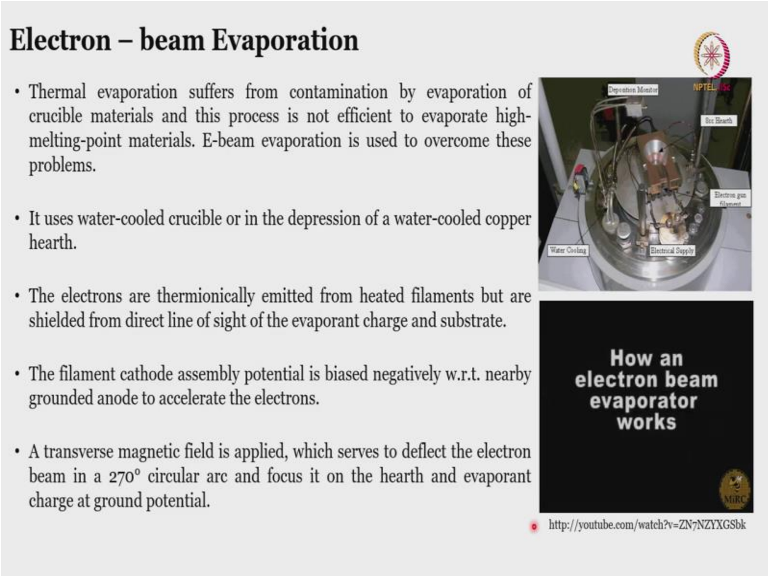

So, this is the e-beam evaporator, this is a shutter right. So, until the material is properly melted, we do not open it.

And then, how to measure it? So, there is a QCM, which is called quartz crystal monitor. It is used to measure the thickness of the material. So, when you start evaporating the material you do not open this shutter, above the shutter there is a substrate holder somewhere here the substrate holder will be there this is a shutter right. It will shut off the deposition.

So, it will not allow the material to get deposited onto the substrate until we remove the shutter from the path from, which the atoms are evaporating and depositing onto the substrate holder. So, somewhere in this chamber there is a quartz crystal monitor, this quartz crystal monitor as you know quartz is piezoelectric it is used to measure the thickness of the film.

So, when we get the right thickness, right rate of deposition rather than thickness, we can open this shutter and start and allow the material to get deposited onto the substrate holder. So, the role of shutter is to shut off this particular deposition until, we get the rate of deposition that we desire.

So, then there are different kind of source holder I will talk about it later. So, here you can see, that this QCM, which is also called deposition monitor or quartz crystal monitor as I said it is there to understand, what is the rate of deposition?

Then there is a hearth there is an electron gun and the electrical supply and there is a water cooling. Why water cooling is given in the back, because to reduce the heat effect that happens because of the electron beam incident onto the substrate onto the source holder.

This source holder is crucible is a graphite material, but we need to keep it at a lower temperature by using water cooler. So, water cool crucibles or are used in deposition or in the depression of the water-cooled copper hearth. It is a water-cooled copper hearth in the backside the water will come, which is which will help it to maintain the temperature or not rise temperature beyond certain value.

So, the electron beams are thermionically emitted from heated filaments, but are shielded from direct line of sight, the evaporant charge and the substrate. The filament, which is a cathode assembly point is biased negatively with respect to nearby grounded anode.

And finally, a transverse magnetic fill is applied which serves to deflect the electron beam in 270-degree circular arc and it focuses onto the hearth and evaporant charge at ground potential. So, this video let me see, if I can play it if not yeah just quickly see.

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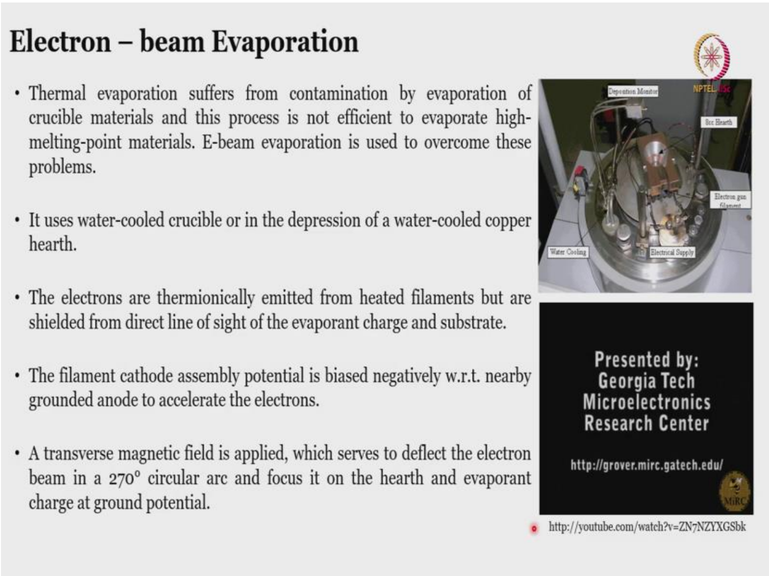

How the electron e beam evaporator works.

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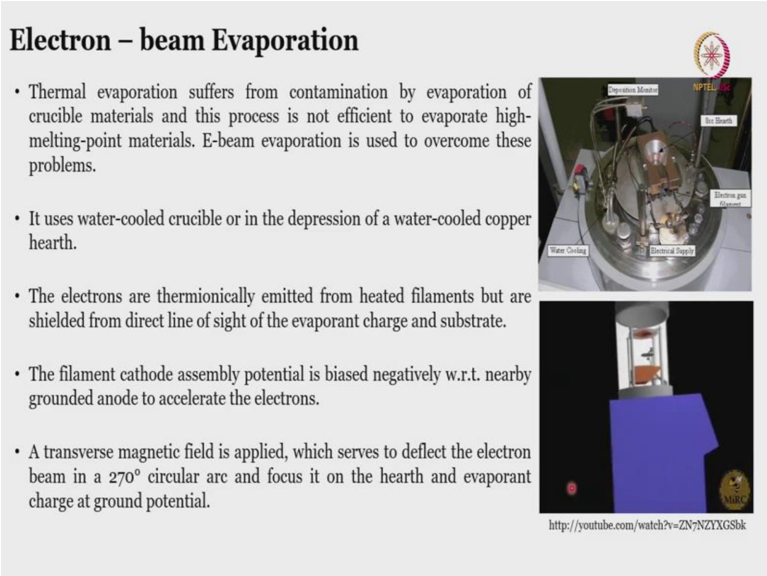

It is from Georgia Tech Microelectronics Research.

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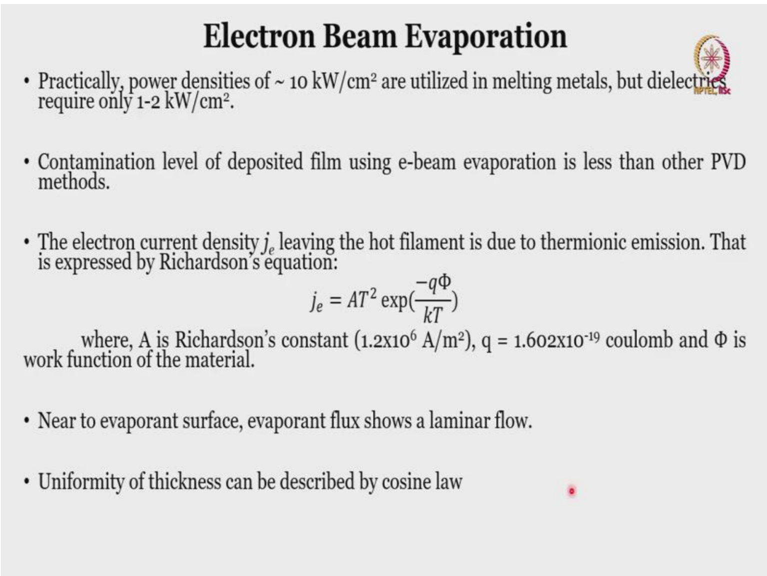

So, I hope you have seen the video right. Now, we will talk about e-beam evaporation in, which we practically, what is the power that is used. What power densities? The power density is about 10 kilowatt per centimeter square. But for dielectrics it requires 1 to 2 kilo volt per centimeter square. So, contamination level of the deposit film using e-beam is less than other PVD methods this is the advantage.

Also, the electron density j_e leaving the hot filament is due to thermionic emission, we know that. And that if somebody wants to calculate then, they can calculate using Richardson's equation, which is given over here. And the near to evaporant substrate surface evaporant flux shows a laminar flow.

And uniformity of thickness can be described by cosine law. So, you will know that, where is a substrate holder? Substrate holder if you have seen is perpendicular to the source material. And the reason of having it at a certain degree is, when you understand the cosine law you will understand it better.

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Now, when we talk about the e-beam evaporation, we also have to understand that what kind of different evaporation sources are there. So, one is a single pocket source as you can see on the left side here. Then there is a rotary pocket, which is over here. And finally, there is a linear pocket. In single pocket as the name suggest, you can only have one particular source material.

In rotary pocket you can have 4 to 5 different rotary source material because you can see 1, which is exposed here, second would be here, third would be here and fourth will be here. So, suppose you want to deposit chrome and then after chrome you want to deposit gold you can use this chrome deposit it then, turn it. So, the gold the substrate the source holder that will have gold we will come into this particular region.

And then, we can again deposit gold using e-beam evaporation. Then there are linear pockets, that means, that on 4 pockets whatever the whatever the material you want to deposit you have to bring that particular source holder, where you can incident the electron beam. So, linear pocket e-beam is similar to a rotary pocket source except that the pockets are arranged in a line and are indexed into a position in a linear fashion. A rotary pocket has all the same parts as a single pocket like here.

Except that with water cool copper block is essentially a turret of multiple pockets. You know turret means, if you have seen or use microscope there are different lenses. So, you can change the lenses that holder is called turret. So, is essential turret of multiple pockets with this design a number of different materials can be operated sequentially from a common magnet, emitter, sweep or coil.

Obviously, this is then includes additional shielding to prevent cross contamination the pocket in position is chosen via motorized rotary indexer. So, generally, when we go for e-beam you will see that most of the e-beam will have the rotary pocket, because of the given advantages right over here.

Here if you talk about single pocket a water-cooled copper block is bored out to have a pocket in the shape of an inverted truncated cone, which you can see here. And in this, we can place the source material. Source material is placed within this pocket or within a crucible, whose exterior fits squarely with the pocket the crucible has a smaller pocket within it.

So, you can load the crucible and then in the crucible you can put this source right not directly in the pocket. So, do not understand differently, you have a crucible, which you have loaded into the pocket in which there is a source material. Before we go to sputtering let us understand that the thermal evaporation, we have seen has 2 different types sorry the PVD technique that we have used has 2 different types.

One is thermal evaporation and second is the electron beam evaporation. We have seen, how thermal evaporation works, we have seen how e-beam evaporation works, we have seen CVD techniques. And all these things are useful for us to fabricate the devices that, we have seen earlier.

So, with that I will stop the module here. And we will see, what is the way to deposit sputtering, what kind of different techniques are used to sputter, what kind of different sputtering techniques are there. So, one is that PVD technique, there are 3 thermal e-beam and sputtering. But within sputtering there are further subdivision. So, we need to see how those works. The idea of showing you this particular module is to make you understand that the material that one uses for designing this micron needle or surface microelectrode array, like gold or silicon dioxide. We can use this PVD technique, the idea of showing you CVD is that we can deposit insulating material like silicon dioxide. Now, we understand that if I have a material already deposited onto a substrate and the melting point of that material is below the melting point of silicon dioxide that gets deposited.

Then it cannot work and that is why we will talk about a technique called PCVD plasma enhanced chemical vapor deposition, which is used to shield the metal and deposit the silicon dioxide at a lower temperature. Lower temperatures can be 100 and 200 degrees centigrade, which will not affect the metal below it; that means, gold will not get affected.

But LPCVD goes for very high temperature about 900 degrees centigrade. So, we cannot use LPCVD, we have to go for PCVD. Now, I am bringing all this thing into your understanding or knowledge so that we can see that, when we fabricate a device a process slow, I will show it to you how different methods that we are learning here can be utilized to fabricate those devices right.

So, with that let us complete this class. I hope you understand a bit on PVD techniques, a bit on CVD techniques, a bit on micro electrode array and a bit on micro needles. We will see, how we can fabricate those things in the next class. Till then take care, bye for now.