Microsensors, Implantable Devices and Rodent Surgeries for Biomedical Applications
TA: Anujkumar D Prajapati, Course Instructor: Dr. Hardik J. Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore
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Welcome to this class. Here, again, we have a lab for you. In this lab, we will show you how electron beam evaporation works. If you recall, the E-beam is a technique that falls under physical vapor deposition. Now, physical vapor deposition also includes thermal evaporation and sputtering, right? So, today we will see how the electron beam evaporation system works and how we can achieve vacuum conditions. After achieving vacuum conditions, how can you use the electron beam to deposit materials onto the substrate? These materials are the materials that cannot be deposited using thermal evaporation because these materials that we can use in the E-beam evaporation system have a higher melting point compared to the source holder, right? In thermal evaporation, we have a source holder. We heat the source holder, melt the material within it, and then deposit it. However, in the case of E-beam evaporation, we do not follow the same process.

Here, the electron beam will heat the material loaded onto the crucible. Depending on the point source or scanning source, the electron beam will melt this material, and the material will get deposited. So, you will see how the chamber looks like. We will show you where you can load the substrate, which is the substrate holder, and where you can load the source, which is a crucible from where the electron beam will come. There is always a quartz crystal monitor to understand the thickness of the film that we are depositing, right? So, please see the lab component, and I hope you enjoy it.

As in the coursework, we have already seen the building blocks of any microfabrication process, which are deposition, lithography, and etching. So, let us start with deposition, which can be of two types. Either you can have physical vaporization deposition, that is PVD, or chemical vapor deposition, that is CVD. We will be focusing on PVD for now. In this PVD, the first tool that we are going to see is the E-beam thermal evaporator. So, what happens in PVD is that the molecules of the desired material physically come out of a source and stick to your sample or substrate. In comparison to CVD, where the precursors flow into a chamber and undergo a chemical reaction with the desired substrate or sample under favorable conditions such as pressure and temperature resulting in deposition.

So, starting with this tool, the E-beam thermal evaporator, what happens here is that the desired material will be heated and melted, and its vapors travel upwards. On the substrate holder, which is at the top, you will have your substrate or sample, whichever you call it, and these vapors will come and get deposited. Now, this can be done in two ways. Normally, we would go with a resistive kind of heating, where there will be a heating coil on which there will be a sample (sorry, the desired material), and as a current is passed through this resistive coil, the desired material melts, and the vapors are formed. An advanced version of this would be the E-beam evaporation, where an electron beam is directed towards the crucible holding your sample, the desired material, and the vapors formed will go and get deposited on the substrate. So, let's get started with this tool.

This is one of the PVT systems, the E-beam thermal evaporator, that we have in our lab. It is an HHV auto 500, manufactured by an Indian company, Hindhai Vacuum. Now, let's start with the chamber first. As we might have covered in the theory class, for thermal evaporation or E-beam evaporation, we need a very high vacuum, that is 10 to the power minus 6 millibar. But why do we need this vacuum? When you are evaporating the required material, if the pressure is too high or even at atmospheric pressure, there will be a lot of other molecules between the source and the substrate. This results in a lot of collisions, and this collision means that the mean free path between two subsequent collisions is very low. If the mean free path is very low, this source molecule can't reach the substrate molecule without any interruptions. The mean free path lambda is inversely proportional to the pressure. So, if we have a very low pressure, the mean free path increases, and there is no interruption between the source and the substrate. This chamber is capable of reaching a pressure of up to 10 to the power minus 7 millibar, but we usually operate in the range of 10 to the power minus 6 millibar.

There is this viewport from which you can move the shutter, the viewport cover shutter, and see what is happening inside. This is the handle that you use to pull out the store. There is a water jacket for cooling because, since it is a thermal evaporation, the temperature inside would be quite high, and if a user accidentally touches it, there will be physical damage to the user, of course. So, to avoid that, the chamber's outer wall is water-cooled; these are the ports for water cooling.

Now, we can move to the next part, which is the user interface panel. This is the monitor where you can see what is happening, what all processes are happening, and also it takes user input as it is a touchscreen. This is the power button, the reset button for all the peripherals. This light ensures that all the safety interlocks are on, the water cooling is on, and the source is enabled for the E-beam. The most important part is the emergency stop button. In case you find that anything is going wrong with the tool, you can simply pull and turn this off. All the processes will cease at the exact time, and the expert can come for maintenance later. The next is the source control.

Once you switch on the E-beam, you can control the voltage and current from here, and there are some indicators as well that will tell you whether the vacuum, power, and rotary drive are functioning or not. Next is the sweep control. When you have an electron beam, it will fall on a single point. What happens if you want to cover the entire area of the crucible? So, what we can do is give a sweep in the x and y directions, which ensures uniform heating on the surface. The electron beam falls uniformly over the entire surface. This control is for that purpose.

Next is the turret control. If you look, there are 1, 2, and 1, 2, 3, and 4, and you can control it with this knob. These 4 correspond to the 4 materials we have: platinum, gold, aluminum, and titanium. Next is the DTM, which is the digital thickness monitor. It gives us an idea of the rate of deposition right now and how much film has deposited. This is just the indicator display; the actual mechanism I will explain in a few minutes once we open the chamber. Next is the control for the DTM.

This is the control for switching off and on the DTM. This is for switching on and off the shutter. When the E-beam starts to fall on the source and starts evaporating, we place a shutter just above the source. This ensures that whatever deposition is happening occurs on the shutter and not on your substrate, giving us more control over the thickness.

This control is for the rotary drive. Your vapors are coming from one particular point, and it might happen that the entire chuck does not get a uniform coating. If you have a rotary drive, it ensures that your sample is rotating, ensuring a very uniform deposition. This knob controls the speed of the rotary drive, and these knobs and indicators are for low thermal deposition. When we are not using the E-beam, we use the resistive coil heating method; these indicators are for that.

Here is the control for the E-beam transformer. Now, I think we can start with the process. First, I will turn on the chiller unit, which ensures that this water jacket always maintains the temperature around 23 or 25 degrees. Next, I will turn on the main supply for this tool. Next is this power button, as discussed.

Now, you can see that the safety interlocks and water cooling are functional. That means we can move forward now. Let us have a closer look at this panel. If you see, the system status shows "standby," the chamber pressure is in the order of 10 to the power minus 1 millibar, and we have some options here: start and vent. There are other options as well, but they are not highlighted, which means they are not available at the moment.

It depends on the state of the system, and accordingly, you will have some options. Right now, the only options available to us are "start" and "vent." "Start" will turn on both the pumps, which are the roughing pump and the turbo molecular pump. I will explain to you the function of these two pumps. Let's first start the pumps.

Meanwhile, I will explain the schematic diagram to you. If you can see, this is the roughing pump, and this is a turbo molecular pump. The function of the roughing pump is to take the chamber from atmospheric pressure to a high vacuum, which is 10 to the power of minus 3 millibars. Once a high vacuum is reached, the turbo molecular pump takes over, and its function is to transition the conditions from high vacuum to very high vacuum, from 10 to the power of minus 3 millibars to 10 to the power of minus 6 millibars. There are some walls here, as you can see, and this is the actual chamber. So, once 10 to the power of minus 3 millibars is reached, this roughing pump also bypasses. Right now, the chamber is directly connected to the roughing pump via the roughing valve. This setup allows the chamber to reach 10 to the power of minus 3.

Once this condition is reached, this valve will close, and the entire system will switch to the turbo molecular pump from the roughing pump. Now, you can see the status is "turbo acceleration," which means the turbo molecular pump is accelerating. Once it reaches full speed and the pressure inside is 10 to the power of minus 6 millibars, the turbo molecular pump will take over. Meanwhile, we can vent the system, and I will show you what is inside the chamber. If you listen closely, there will be a small hissing sound, indicating that air is entering the chamber.

Now, the chamber pressure is 10 to the power of 3 millibars, which means it is at atmospheric pressure, and we can now open it. Let me just seal it. So, let's open this chamber and take a closer look at all the components inside. The first and most important component is this chuck. This chuck is where you load your sample or substrate.

This sample or substrate is where you actually want the coating. Next is this entire system, which consists of a source from where the E-beam originates. This E-beam comes through this window or port and falls onto this crucible. There is a crucible set to aluminum right now, and there is also this shutter that I mentioned earlier. Once it starts evaporating after melting, this shutter gives us control over the thickness we are aiming to achieve.

Next is the digital thickness monitor (DTM) and how it actually works. It is called a quartz crystal monitor (QCM). There is a quartz piece, and as deposition occurs and more material is deposited on this quartz crystal, its thickness increases, causing a shift in frequency. The DTM calculates the thickness based on this frequency shift.

At the back, you can see a spring-like structure, which is a board for low-temperature heating. It operates on the resistive heating principle. As current passes through it, it heats up. This board is made of tungsten. If a material with a low melting point is placed on that board, it will start melting and evaporating. For the same purpose, there is a shutter that controls its thickness. Okay, I can now show you how these components work.

So, I will ask my colleague to turn on the rotary drive, and you can see that the chuck starts moving. On this chuck, the sample will be loaded, and it will also move along with this chuck. The speed can be adjusted, but we usually keep it around 5 rpm. Next is the shutter. I will ask my colleague to turn off the rotary drive and turn on the shutter.

You can see the shutter has moved, and now the vapors from this source will directly hit the substrate. You can close the shutter. Now we can see the rotary drive here. Okay, we can turn the shutter and see the rotary drive.

We can switch it to 1. I can see that the drive is moving, the turret is moving, and the crucibles are changing. Yeah, so we have reached crucible number one, which is titanium. Oh, my bad, this is crucible number three, which is platinum. Okay, now we can close the shutter. Now what I will be doing is I will take out the chuck and load a glass slide on it, and we will demonstrate the deposition process.

So I have taken out this chuck. It is a 12-inch chuck, and I have fixed a glass slide on it, as you can see, on which we will be depositing aluminum today. So let us place it inside. Ensure that while opening the chamber, it is sealed, which we have ensured. Close the door, and now we will start the vacuuming process. As you can see, certain options that were grayed out are now available.

Right now, I will start the vacuuming process, which is cycling, and now the cycling sequence has started. If you can hear, this is the sound of the roughing pump. Like I said, the roughing pump will take my chamber from atmospheric pressure to a high vacuum, which is 10 to the power minus 3 millibars. Once that is reached, the turbo molecular pump will take over and reach 10 to the power minus 6 millibars. So let us wait for it.

So now it has been around 40 to 55 minutes since we started the vacuum, starting from atmospheric pressure, which is 10 to the power plus 3 millibars. Now we have reached a very high vacuum, which is 4 times 10 to the power minus 3 millibars. As I explained earlier and we have seen, a lower pressure or a high vacuum or a very high vacuum means that the mean free path of the molecules is very large. That is, the particles or molecules from the source can reach the target with minimum collisions with each other.

Keeping that in mind, we have a very high vacuum, and now we can start the process. So, the first thing I will do is switch on the electron gun. Now I have turned on the power to the e-beam gun, the main power. Now I will switch on the transformer. Now that the e-beam is on, let's see what options are available to us in the control panel. We see right now we have seal and vent. We won't be venting; we vent when we want to load or unload the samples. So the only option is seal. Once we seal the chamber, then we can start with the process.

Now I have pressed seal. The available options are stop, cycle, vent, and process. Like I said, we'll be starting the process because we don't need to cycle again; the vacuum is already holding. Now the process sequence has started. Once it is complete, we can start with the deposition. So now the process sequence is going on; meanwhile, we will turn on the source control.

The first display is for the voltage, which is maintained around 5 kV, and the second is the filament current, which we can adjust. I'll turn on the gun. As you can see, the voltage is 5 kV, and the current here is almost 0.0 milliamps, which we will be adjusting. Okay, and next, you can see here is the sweep control. Sweep control is like when you have, as I have already talked about it, the electron beam falling off at a point. But if you want uniform heating throughout the surface, we sweep this beam so that it covers the entire surface area of the crucible.

With that, we will be using the XY and these waveform controllers. The next one is the turret controller. As we have seen, we have four metals that we can deposit using the E beam. So, the current turret is at number three, and we need to deposit aluminum, which will be at four.

So I'll just switch it to four. It takes some time because the mechanism is a bit slow. Now you can see the LED at number four is glowing, which means we have crucible number four loaded, and you might have also seen that when I switched from crucible three to four, this display went off, which is a safety mechanism so that your E beam doesn't fall somewhere in between and always falls on the crucible. Now we can see here we have some options, the DTM. Now we can see we have some options here.

We'll check the DTM. When we turn on the DTM, it starts; we just have to reset it, and now it's showing zero. So like I said, the deposition here is something that we control; the thickness needs to be precisely controlled. So we have this DTM or the digital thickness monitor, which is paired up with the crystal oscillator, the quartz crystal oscillator that we had seen inside the chamber previously. This is the E beam gun shutter, which I'll be using to start and stop the deposition process. See, the E beam, the electron beam, will be falling on the source at all times, the crucible at all times, and continuously this material will be evaporating.

But when we have the shutter, the material doesn't reach your substrate, so it is quite so in this way we can control when we start the deposition and we stop it. So, I think we can get started. We'll slowly increase the current to 10 milliamps. It's okay, it's 11 milliamps, doesn't matter.

We'll have this for one minute. So it has been one minute, and we have preheated the crucible at 10 milliamps. So now we'll switch to 25. Again, we'll preheat at 25 milliamps for some time, and then we'll increase to 35. So, meanwhile, I'll show you about this.

This is the control for the rotary drive. As I had explained previously when I opened the chamber, we saw that the chuck keeps on rotating to ensure a uniform deposition. Now the chuck is rotating inside. So I think it has preheated for some time now. Now I'll increase the current to 35 milliamps. So now we'll increase the current to 50 milliamps and wait for some more time so that the desired material which we are going to coat as a deposit is uniformly heated.

The next step would be to increase this current to around 70 milliamps and we'll carry out the deposition from there until we have a uniform coating. Now one minute is over, and we'll increase the filament current to 70 milliamps and now open the shutter. So now the shutter is open. The vapors from the crucible will directly come and stick to the sample. Now we'll wait for some time until we have a uniform deposition, and then we'll take out the sample.

So now we have carried out the deposition for like around 15 minutes, and we can also see that there is some sort of deposition through the viewport. What we'll do now is we'll stop it using this E-beam shutter. Now the shutter has come over the source. So now whatever deposition is happening, whatever vapors are coming, they are just sticking on the shutter and not our samples.

I'll slowly decrease this current. Okay, now the current has reached almost zero. I can turn off the gun, wait till the voltage also falls to zero, then turn off the supply. Next, I'll turn off the DTM and also the transformer which I had earlier switched on for the E-beam. Okay, now all the systems are off.

We are ready to take out our samples. For that, first we'll need to break the vacuum. Oh, and my bad, I forgot to turn off the rotary drive. Okay, now we'll just break the vacuum. For that, we don't have any other options other than seal.

We'll quickly press on seal and now vent the chamber. If you can hear the slight hissing sound, that means that air is entering the chamber, and the vacuum is being broken. Meanwhile, I'll just turn off the main supply for the E-beam. Okay, now we can see that the chamber pressure has reached 1 into 10 to the power 3 millibars.

That is the atmospheric pressure. Now the chamber is vented. It is safe to open the chamber and take out the sample. I'll just seal it and take out the chuck carefully. While taking out the chuck, it is important that you don't touch any of your samples. Now if you can see closely, there is a very uniform deposition and a mirror-like finish of aluminum. I'll take out the sample from this tape, and then you can appreciate that the part which was covered by this Kapton tape will still be transparent, and the rest of the part will have a mirror-like finish.

Now if you see the chuck, you can clearly see that the area where we had that Kapton tape and the glass slide, the sample is still having that golden and a dark grayish color while the rest of the chuck or the substrate holder looks sort of like aluminum. So I'll show you the sample which we have deposited in a minute. Meanwhile, I'll place the chuck back into the chamber and put it in a vacuum. So now we have taken out the sample and placed the chuck. You can see in the center there is an aluminum finish, while at the edges where we had this Kapton tape, you can see it is still transparent.

Now we can zoom in and have a really close look at our sample. You can notice that at the edges, a transparent glass slide is visible, while the uncovered area in the middle has aluminum coating and a mirror finish. So now that we have kept the substrate holder back into the chamber, the next step would be to take the chamber back to its vacuum condition. It is not a good idea from the point of view of the tool's lifespan to keep it and leave it at atmospheric pressure. So what I'll do is I'll just click on cycle, which will start the vacuuming cycle. Once it has reached the required pressure, somewhere around between 10 to the power minus 4 or minus 5 millibar vacuum, we can then switch off the tool.

So at that time, I'll just press stop, which is not available right now, and once it is at stop, I'll wait till the turbo molecular pump goes into standby mode, and then we can switch off the main supplier, that's it. Thank you. So I hope you enjoyed the video and you have seen that again we need to follow the protocol. That's why the first video of the lab was on how to gown and how to enter the cleanroom facility. Once you know the next thing is when you want to operate a system, what are the processes to operate the system, as you have already seen that before we get a high vacuum like 10 to the power minus 6 or minus 5 torrs, initially we had to get a base vacuum which is close to 10 to the power minus 2 to 10 to the power minus 3 torr. To get the base vacuum, we use a primary pump, and to get the high vacuum, we use a secondary pump.

In this case, you have seen the turbo molecular pump. There are two gauges for understanding the vacuum or measuring the vacuum. One is called a Pirani gauge, and the second is called a Penning gauge. The Pirani gauge is used to measure the base pressure, and the Penning gauge is used to measure the high vacuum, which is about 10 to the power minus 5 or minus 6 torrs. So here you have also seen that we are depositing a metal onto the substrate. This is an EB mu operation system. Now in the next class, we will see one more system, which we call sputtering. Till then, take care. I will see you in the next class. Bye for now.