Biomedical Ultrasound: Fundamentals of Imaging and Micromachined Transducers

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Lecture: 24
Sputtering lab demonstration

Welcome to this lab video. This lab video is on sputtering. Sputtering is one of the three physical vapor deposition techniques. In sputtering we introduce argon gas and there is a creation of plasma. Depending on what kind of sputtering you are using, be it DC sputtering, RF sputtering, DC magnetron, RF magnetron, this argon ions will hit the source material, dislodge the atoms and will deposit onto the substrate. Let us see how it is done in real time. So we will see the sputtering tool, how the vacuum is brought in sputtering tool, where is the source loaded, where is the target/substrate loaded, how we are creating a plasma, how we are adding the argon gas so on and so forth. So, look at the video if you have any questions please feel free to ask it using our NPTEL forum.

Welcome to the lab demo. Today we will focus on sputtering and we will see how this tool works and how we can deposit our desired material using sputtering. The three different fabrication steps involved in fabrication are additive, subtractive, and patterning.

In additive step we are adding some material onto our substrate or a wafer. That material can be a metal or oxide or active layer. Depending on which material will be deposited, we will go with the tool required. In physical vapor deposition, we are physically either melting the material or we are bombarding some gases and the dislodged target atoms are coming and depositing onto the substrate. In this process, we require the chamber to be under vacuum. Vacuum is required because we want to increase the mean free path between two atoms as in when the material is melting, and are going up and condensing on the substrate. We want it to follow a molecular regime wherein one particle is not able to see another particle and without any collision, it is directly going and condensing onto the substrate.

In physical vapor deposition, we have three basic tools. The first is thermal, second is ebeam and third is sputtering. The disadvantage in the thermal and e-beam is that the melting point of the source holder material should be higher than the source material. Metals like tungsten have very high melting points and if we try to deposit it using e-beam or thermal, it will not reach to its melting point with the resistive heating. For the dielectrics or oxides, whose melting points are really high we use another technique, called sputtering. In sputtering, we have the target/source material and we bombard argon atoms to this target. So we have a very high electric field near the vicinity of the target and whenever these argon atoms are coming inside the vicinity of this electric field, these

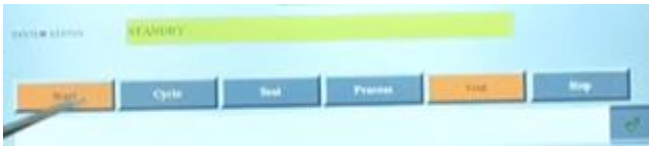
argon atoms get ionized. Since my target is at a negative potential, these positive argon atoms will come and hit the target. Once it hits the target, it will dislodge or knock out the target atoms from the base material or target material and this knocked out neutral atoms will come and get deposited onto the substrate. This is the basic theory for the sputtering.

Now, we'll see how to operate this sputtering tool. For this, I will press Start or IO. Every time I press Start, I'll press Reset. This is a hardware reset. It will reset all the electronics and we can start the tool. All the safety interlocks and water cooling will be checked at the point when I press reset.

I will login using my credentials This is the main menu. Now there are options to choose from.

The most desired tabs to look for is the system control and the source control. In these two, I'll go to my system control. And now you can see a display wherein I can monitor all the pressures inside the chamber.

The roughing wall pressure and the backing pressure is visible in the system control menu. The backing pressure will come into picture when the chamber pressure will go to 10^{-3} millibar because the penning gauge which will give me the reading of the backing pressure will come into picture or it will start showing the reading after 10^{-4} millibar. Now to start the tool I have two options either to start or vent.



I need to start the tool. What this start will do is that it will start my turbo molecular pump. Turbo molecular pumps works on very high RPM speed and it requires at least 5 to 10 minutes of time to come into its full speed. To save that time or to give that time to the turbo I will press start.

This start doesn't mean that I have started evacuating my chamber. It is just a start for my turbo pump to start accelerating. And you can see the prompt that turbo pump is accelerating.

This will take 5 to 10 minutes of time. Meanwhile, I'll show you other displays of the tool.

This is the emergency stop button. If there is an emergency, like if you see smoke coming out from the tool, then you should press this Emo button.

This panel is the temperature control wherein if you want to increase the substrate temperature then you can set the temperature and decrease or increase the temperature using this buttons. And once you enable from the display panel, the substrate will start heating and it will reach to the set value which is displayed here in green. And the value displayed here in red is the actual value or the actual temperature of the chamber.

The meter on the right to the temperature control is the digital thickness monitor. Here we will see the rate of deposition and how much thicker film has been deposited to a particular point.

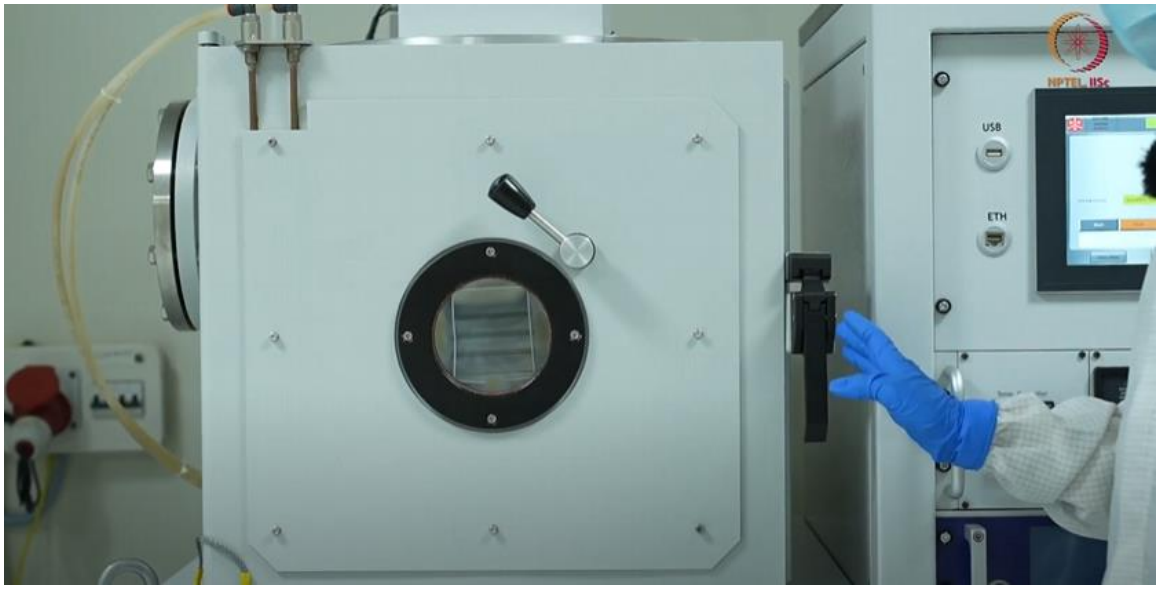
This upper panel in figure below is for RF sputtering, and the lower panel in figure below is for DC sputtering. This tool can be used for RF sputtering and DC sputtering.

The difference between RF and DC sputtering is, suppose we are hitting argon atom to a target which are ionized. The argon atoms are ionized. Now this argon atoms to go into neutral state, it will need one electron. When we are depositing any metal, since metal has a lot of electrons, the argon atom will easily get one electron from the metal which we are depositing and it will go out of the system. But in case of oxide or dielectric wherein the free conducting electrons are very less, the argon atom will not find that electron to neutralize, which can be compensated with the RF signal. So, RF signal is a pure sinusoidal signal. In first half of the cycle, the plasma will strike and in second half cycle the negative charge will be provided by the RF signal and the argon ion will neutralize and will go out of the system.

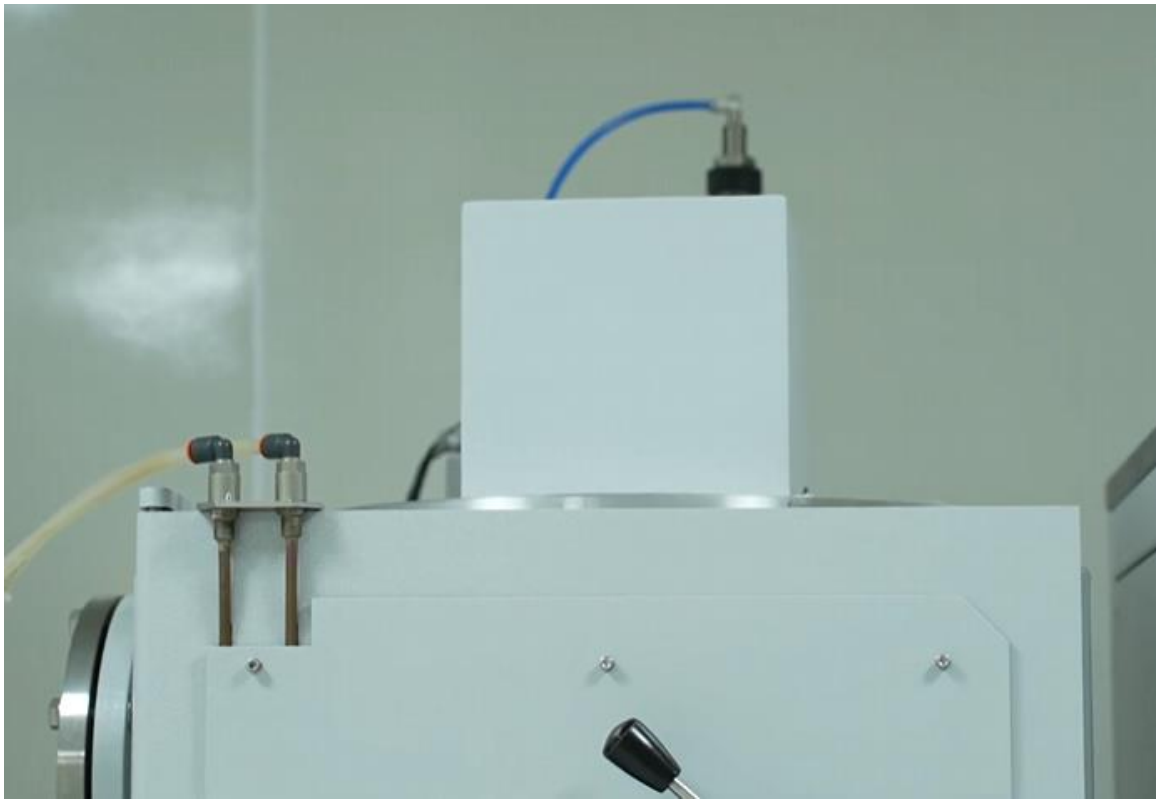
Now you can see on the prompt that turbo is ready and that means that turbo has reached to its maximum speed and now we can vent the chamber because we need to place our sample for the deposition.

Currently the chamber is in some vacuum. So I will press vent and I will wait for couple of minutes for the chamber to vent.

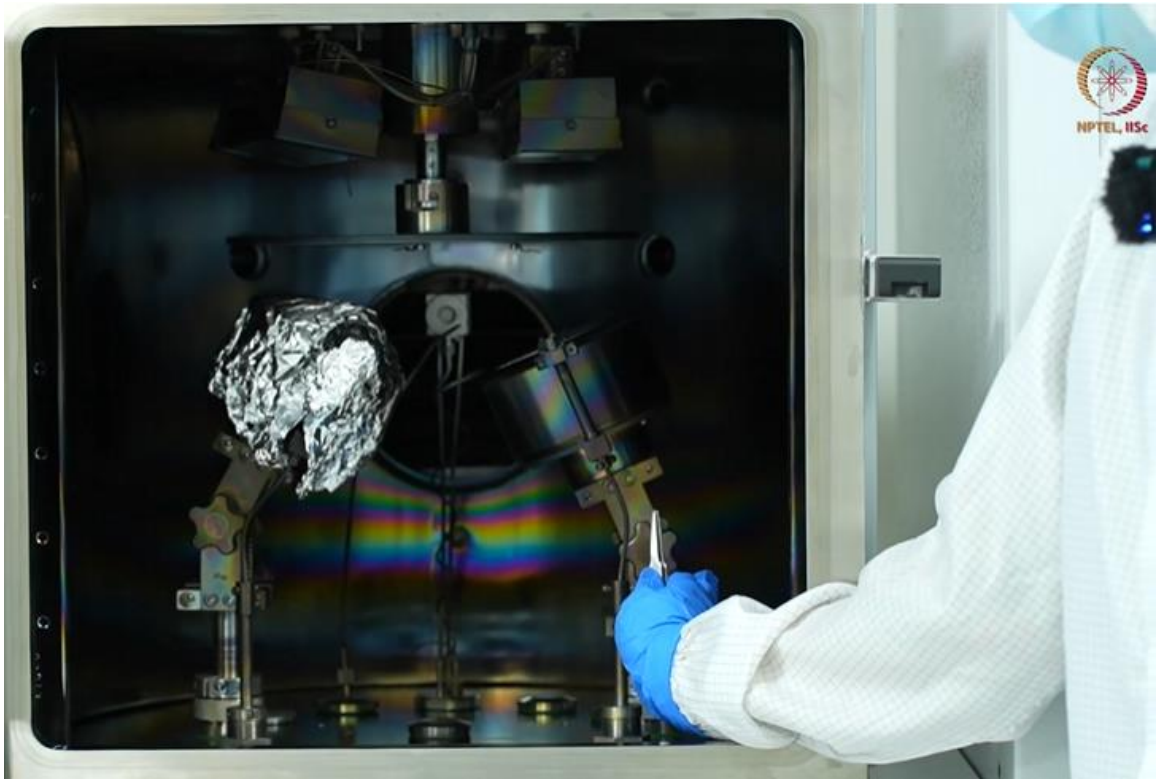
The chamber has vented and it is safe to open the chamber. Before we open the chamber, I will give a brief of about the chamber. This is the viewport wherein if you want to see whether the plasma has struck or to see how much deposition has happened, or to see if the substrate is rotating or not, this is a viewport from where we can see.



This is the motor control for the substrate holder to rotate.

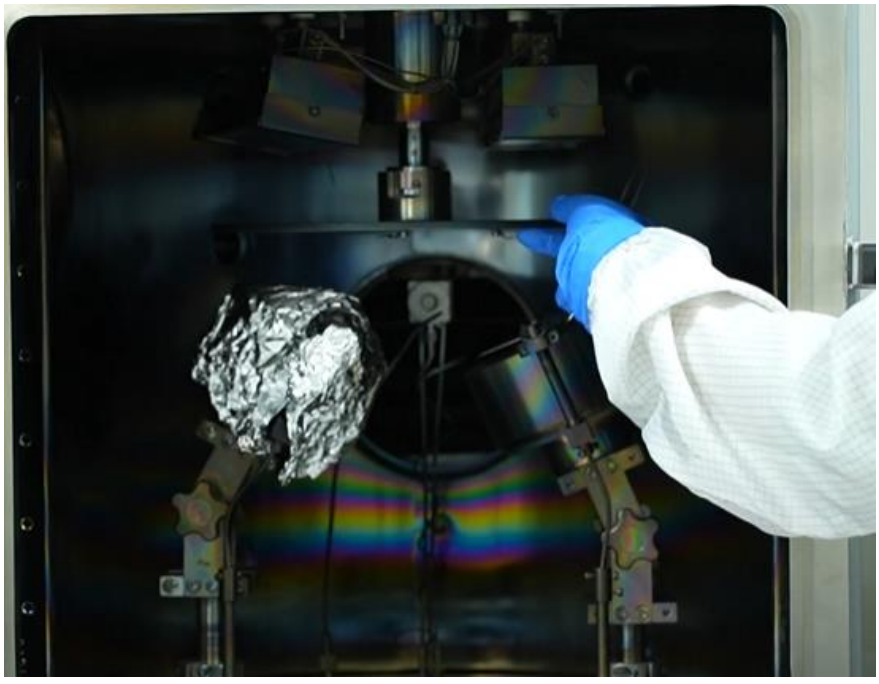


Now I will open the chamber. Here, there are two magnetrons. The left side magnetron is dedicated for the RF sputtering and the right side magnetron is dedicated for the DC sputtering. In today's deposition, we will be depositing tungsten using DC sputtering.

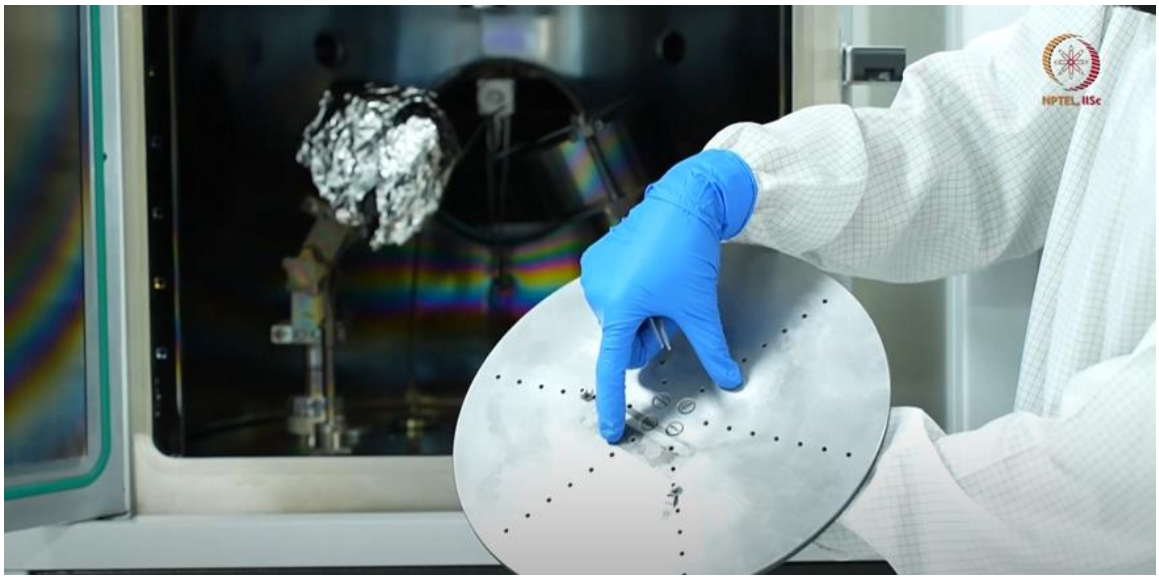


So we have placed our target and we have covered the RF sputtering with the aluminium foil so as to eliminate any contamination while the tungsten is getting deposited.

This is the substrate holder and I can remove it.

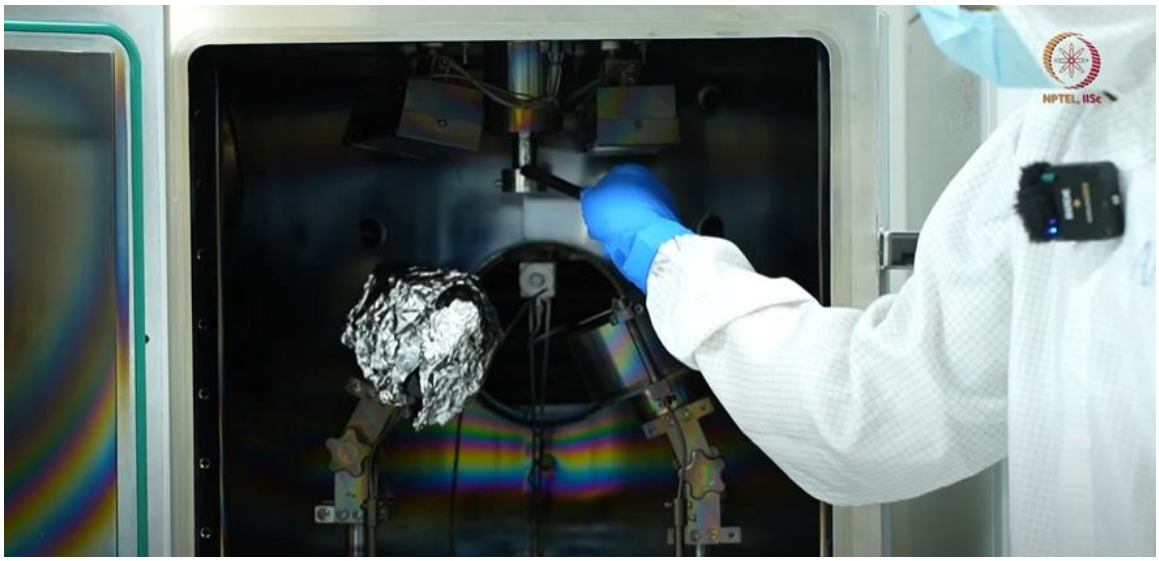


The substrate holder can be removed, and we can place our substrate onto it. As you can see the magnetron is at some angle. So the ideal position to keep the wafer or the sample is at the center of the chuck.

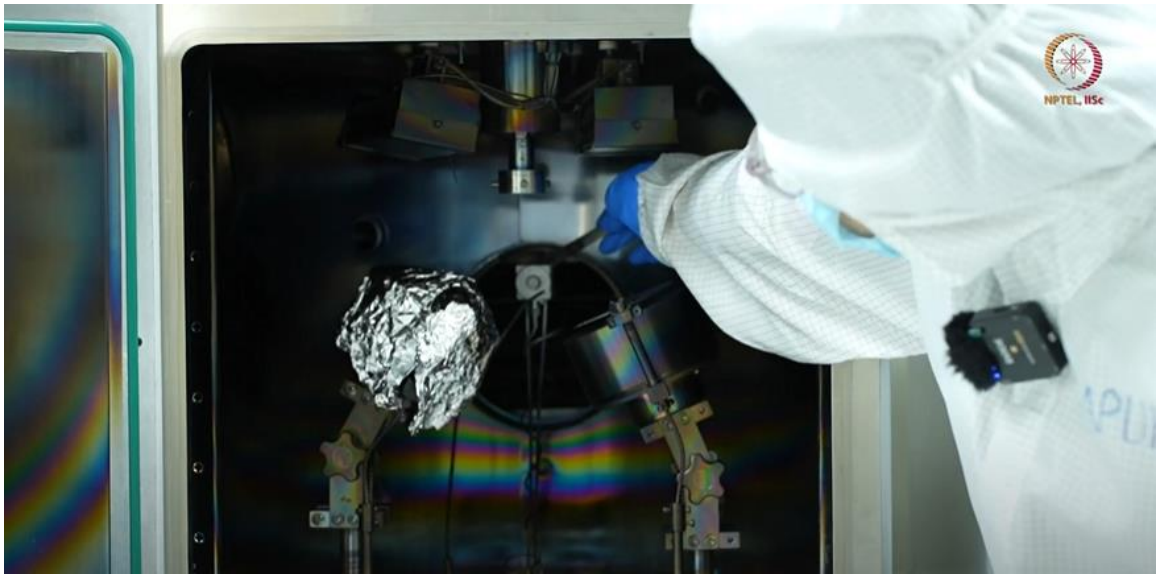


In the figure below, you can see the halogen lamps for substrate heating. It will heat the substrate using radiation heating.

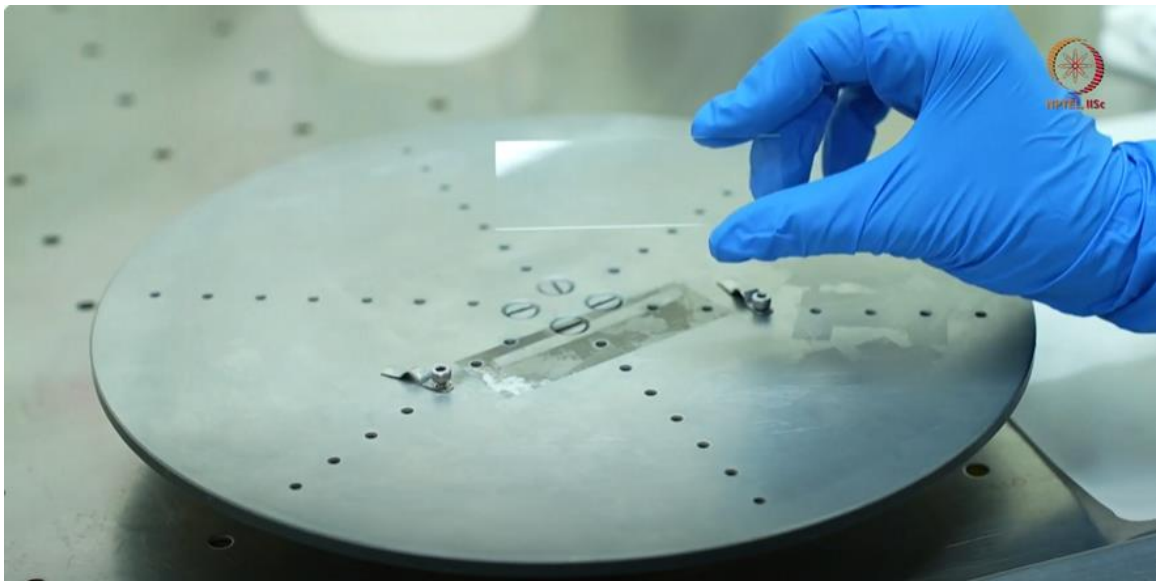
This is the spindle to rotate and place the substrate holder. It will rotate as and when required.



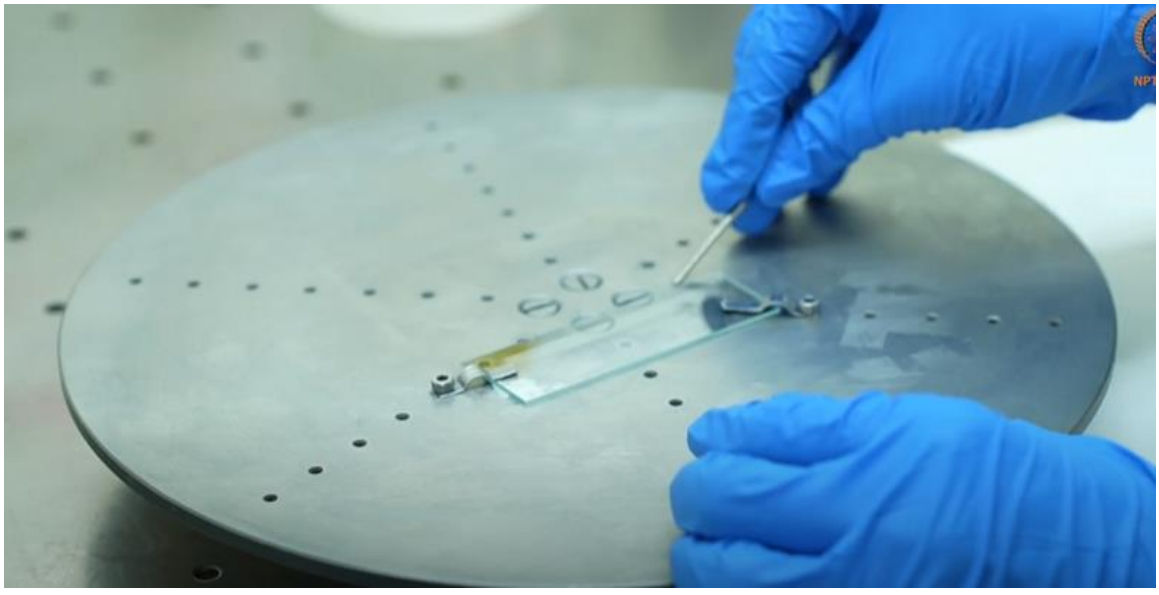
In the image below, you can see the QCM. It is a quartz crystal monitor. It has a quartz crystal which has its own resonant frequency. Once some mass is getting deposited onto the quartz crystal, its frequency will change. The change in frequency will be calculated in to the amount of deposition which has happened.



Now we will load our sample on the substrate holder and we will keep it back on the spindle and keep the chamber for cycling. So this is a glass slide on which we'll be depositing the tungsten. And as you can see, it is a transparent slide and I have cleaned it using IP acetone and DI water. And I have given a nitrogen blow to it so as to dry the slide.



Now it's time to load this slide. I will be using the clamps to hold my sample. It is the safest option to hold this sample. We are doing this because the substrate holder is placed upside down and we want to make sure that our samples stay intact and it should not fall while we are placing the samples in the chamber. Now we have tightened the screws and we will check whether our slide is moving or not. It is not moving so we are okay to take this substrate holder to the vacuum chamber.



Chamber is already in the vent condition. I will open the chamber and I will place this substrate holder.

Now the chamber is in atmospheric condition. I want a connection between my pumps which is already running and chamber. To do that, I will press cycle.

So now you can hear that rotary pump has started and it will take down the chamber pressure to 10^{-3} millibar. Once that is done, turbo pump will come into action and further pressure will be reduced from 10^{-6} or the desired vacuum pressure required for the deposition. To get a closer look into the details of the pumps and the walls, I'll go to the system view. And here is a mimic diagram of the whole system. We can see the chamber and the two magnetrons. And there are two lines going. One going through the turbo pump and one is directly connected to the rotary pump.

When I press start, the turbo molecular pump start accelerating and reaches to its maximum speed and there is a vacuum generation or the line evacuation of this line. Once I press cycle, the air inside the chamber will be sucked out through this line using rotary pump first. Once the chamber pressure reaches 10^{-3} millibar, the high vacuum valve will open and the evacuation will happen through the other line. Right now the chamber pressure has not reached to 10^{-3} .So you can see this valve is closed.

We will now go back to system control. and we'll wait for one and a half hours for our vacuum to reach and we'll come back once the desired vacuum has reached and we'll resume our deposition process.

After waiting for one and a half hours we have reached to the desired vacuum level of 3.2 10^{-6} millibar. So this is our desired vacuum level. Now we can start our deposition.

To go into deposition mode there are three options available with me: either seal, process or vent. To go into deposition mode I will go into process mode So once I have pressed the process, the backing valve which was sucking out the air from the vacuum chamber has partially closed. This is because for this deposition we will be using argon gas and there should be some gap in the valve through which the argon gas will go out of the chamber. Now I will go to the source control .

Since we will be doing dc sputtering, I will enable the DC supply. Once the DC supply is switched on, all the display will be highlighted.

The first one is the knob for voltage. I'll increase my voltage to 600 volts. Second is the power knob. I have already set my power to 300 watts, and the third is the current knob. When I want to start the deposition, I will start increasing the current

This is the argon flow. I will open the valve for the argon flow.

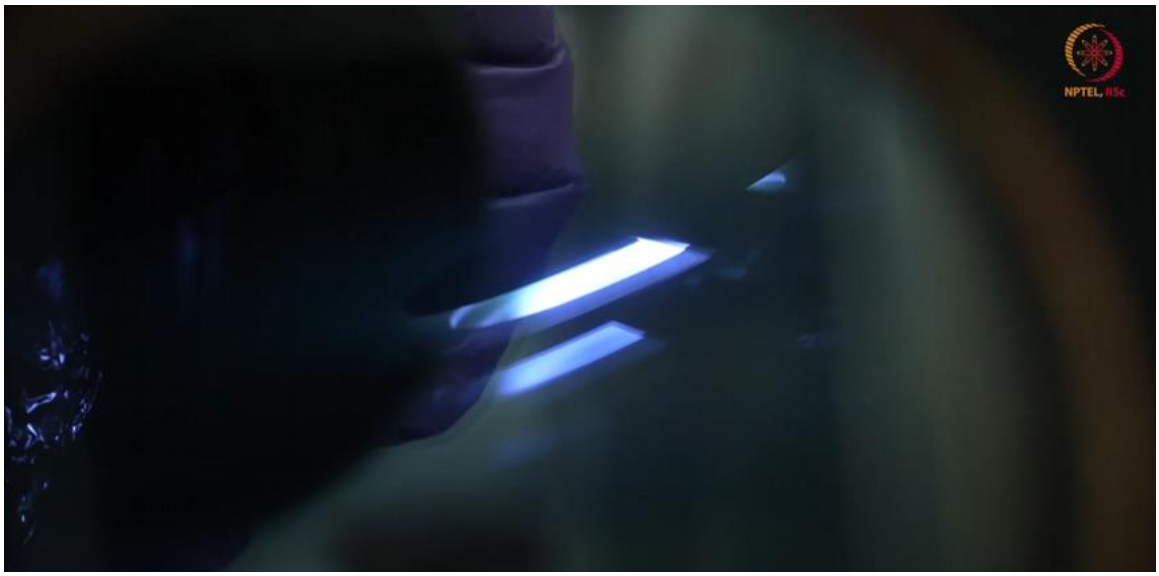
Now, I want to increase the voltage to 600 volts. First I should set the toggle button to the set mode and I will set my voltage to 600 volts. Once my set voltage is 600, I will move the toggle button to read mode.

After this, I will give the argon supply as 5 scm. At the same time, I will monitor the sputtering pressure because this plays a major role while deposition. Then, I will increase my flow to 8 scm. Right now, the read power is zero. Once the plasma strikes this power will change and you will see some value.

Now the argon flow is 8 and the sputtering pressure is 3.7 e-3 mbar. I will increase to 10. Once I did this I will set my current to 0.5 amperes. As I am increasing my current, there are chances that plasma will strike with the 10 scm gas flow. But it might happen that the argon atoms inside the chamber is not sufficient and the plasma is not getting striked. So once I go to 0.5 mA, I will increase the gas flow as well. now it's 0.45 and I will increase my argon gas flow to 12. Now the current is 0.5 amperes and my argon flow is 12.

So maybe the argon atoms near to the target is not sufficient. So I will now open and close the shutter. Now as you can see, the power increased from 0 to 150. That means plasma has striked.

Now we will have a closer look at the viewport. And if the plasma is there, you will be able to see a glow discharge when I open this viewport. So as you can see a light bluish color plasma has strike that means the argon atoms are getting ionized and it is getting bombarded on to the target.



You can see there is a shutter which is stopping the deposition to happen on our desired substrate. Once I open this shutter, deposition will start happening on the substrate. Now

we'll switch on the DTM as well. And I'll press stop. Now as you can see my read voltage has decreased to 500. That means my current is not sufficient as well as my argon flow is also not sufficient.

So what will I do? I will increase my argon flow to 15 and I will increase my current to 0.55 amperes. Now it is time to open the shutter so that the deposition will start happening onto the substrate. Also we need to rotate the substrate holder so as to get the uniform deposition. So I have enabled a rotary drive and I am setting the RPM to 10 rpm. Once again I will go back to the source control and I will open the shutter. And I will press start. So whatever the change is happening in the DTM on the right hand side is the thickness which is getting deposited and on the left hand side is the deposition rate.

So right now it is getting deposited 27 or 28.4 Armstrong per second and the deposition till now is 70 nanometers and it is going on. To increase the power, we can increase the argon flow if required, but I feel this is a sufficient power for the deposition to happen. I will deposit for around four to five minutes, depending upon how much thickness I want. Here the deposition rate is really high.

Now my desired thickness has been reached. And to stop the deposition, first I will close my shutter. I will decrease my argon flow to 10. I will decrease my current slowly to 0. and the power is decreasing. That means we are not supplying sufficient power for the argon atoms to get ionized. Once the power is zero, I will decrease my argon flow to five. And then all the way back to zero and I'll close the gas valve as well. Now I'll move the toggle to set voltage and I'll decrease my voltage all the way back to zero. Meanwhile I will stop the rotation once my read voltage is below 50. I can switch off the DC supply also and the DTM as well. Now I will go back to the system control. Where I have the option to seal or vent. The ideal practice is that I first cycle it for a few minutes and then I vent the chamber.

So to do that, I will press first seal. So the valves has come back to its normal position and then I'll press cycle. Whatever argon was present inside the chamber, will come out when we press cycle. We will keep for cycling for a few minutes and then we'll vent.

To see the deposition, I will press seal which will isolate the chambers from the pumps and then I will press vent. Now you will hear a hissing sound that means atmospheric air is coming inside the chamber and bringing the chamber pressure to atmospheric pressure. We will wait till the chamber pressure becomes same as atmospheric pressure.

As you can see the glass slide which we have kept at the time of the vacuuming is nicely covered with the tungsten and the glass slide which was initially transparent is now shining and nicely coated with tungsten.

Now I will remove this glass slide and put back the chamber into vacuuming. This is because ideally this chamber should always be in vacuum condition. So as the chamber is now in the atmospheric pressure, I need to put it back into cycling.

So again I will press the cycle button. Before that, I have to again isolate my pumps and the chamber. For that, I will press seal and I will keep my chamber for cycling. Sufficient vacuum has reached so that we can stop the tool. Now, we will stop the tool and that is all for today's lab session. Thank you.