Mathematical Aspects of Biomedical Electronic System Design

Professor Chandramani Singh

Department of Electronic Systems Engineering

Indian Institute of Science, Bangalore

Week – 11

Random Variables and Signal Conditioning Circuits

Lecture – 37

E Beam Evaporation System Demonstration

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Hello everyone. Welcome to this session where we are going to talk about a tool which is very commonly used tool in a clean room environment. So, this is a clean room is the plus 1000 to plus 10,000 clean room and the tool the start which is next to my colleague is electron beam evaporator and today in this session we are going to see how we can start the system of electron beam operator and how we can operate it and bring it to the point where we can start the deposition.

Electron beam evaporator is a tool which can be used for depositing metals as well as dielectric on desired substrate. The form of deposition is physical vapor deposition the method comes under physical vapor deposition. Under this technique, we create vacuum when I say vacuum in the chamber to the tune of 10^{-6} millibar. And at that vacuum, we heat up the desired material which is to be coated onto the substrate using electron beam and that is why the name electron beam evaporation.

So, we heat the metal which is placed in a crucible using electron beam so much so that it evaporates and gets deposited onto the substrate and that is why it is called e-beam, electron beam evaporation which means electron beam results in evaporation of the desired material onto the substrate on which we require the material to be deposited. This system leads to very high quality thin films of very high uniformity. So, let us see how the system first can be switched on.

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So, the first step while starting the electron beam impression system is to switch on the chiller. So, chiller as the word suggests is a unit that supplies cool water. When I say cool water it is typically around 18 degrees celsius to the system wherein it supports the crucible which will later see to remain cool. So, after turning on the chiller unit, the next step is to switch on the main switch of the electron beam evaporator.

So, after switching on the main switch, the next step is to we will turn on the system and its display unit. So, now you can see the chamber has been vented which can be seen from the pressure display once it comes to almost the atmospheric pressure and as soon as we open the chamber, the first thing that we can notice when the vacuum chamber is restored to atmospheric pressure is that safety interlock is turned off which means now it is safe to open the vacuum chamber. So, now, since the chamber has been completely evacuated and safety interlock is no not active anymore, the next step is to open the chamber.

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So, this is how we open the chamber. After opening the chamber, the next step is to unload the chuck. Chuck is another name for substrate holder. Substrate here can be either silicon wafer or glass wafer or any other kind of substrates such as glass slides on which we would like to deposit the material. So, now once we have taken the chuck out for loading the samples, let us see before we load the chuck back into the system chamber what exactly and how exactly does a chamber looks like for an electron beam operator.

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So let us now look in detail what exactly is inside an electron beam evaporator vacuum chamber. Main constituents of an electron beam evaporator vacuum chamber are crucible then crystal oscillator, filament and window for observation.

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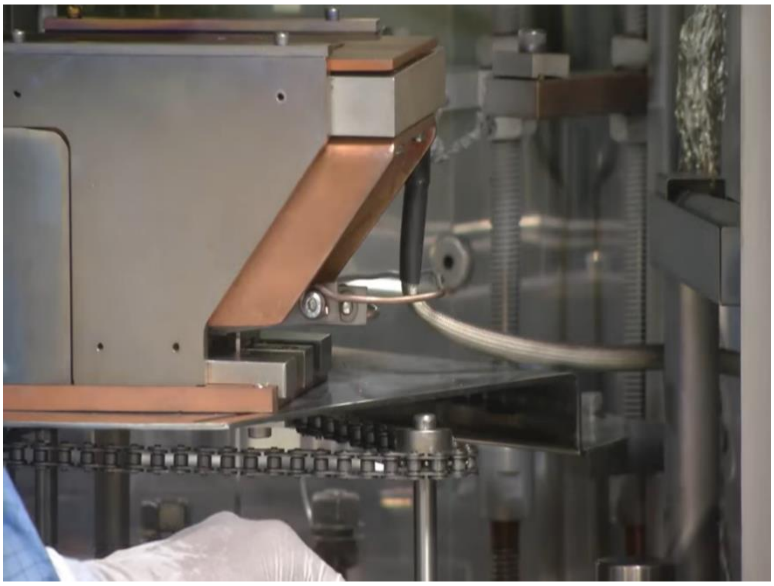

Let us now look these components in detail one by one. So, the particular part that we are looking at his filament. My colleague is showing an indication where exactly the filament is located. Material for a filament is generally tungsten. The idea for using a filament is that when a sufficient amount of voltage is supplied to the filament, it generates electron beam. So, in a way it is a source of electron beam. Typical voltages that we are talking about is 3 to 5 kilo volts which vary from system to system for a unit meant for laboratory research purposes. As we go higher up for commercial usage, the potentials may vary.

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Another important part of the vacuum chamber of an electron beam evaporator is shutter. The middle shutter plays a very important role of preventing any kind of deposition onto the substrate unless desired. The idea is until a particular optimum current beam is falling on the substrate holded by the crucible, the material which is holded by the crucible and it is totally melted till then we do not want any deposition to start on our substrates such as silicon wafer or glass wafer, because if it happens, it may lead to non-uniformity in the deposited film.

So, this is what is the role of metal shutter. The control for metal shutter is outside the chamber and just by pressing a knob we can open or close the metal shutter. As we can see, my colleague has now opened the metal shutter by pressing a knob. In a similar way, we can press the knob again to close the metal shutter. This can be done while the process is going on and the chamber is under a vacuum.

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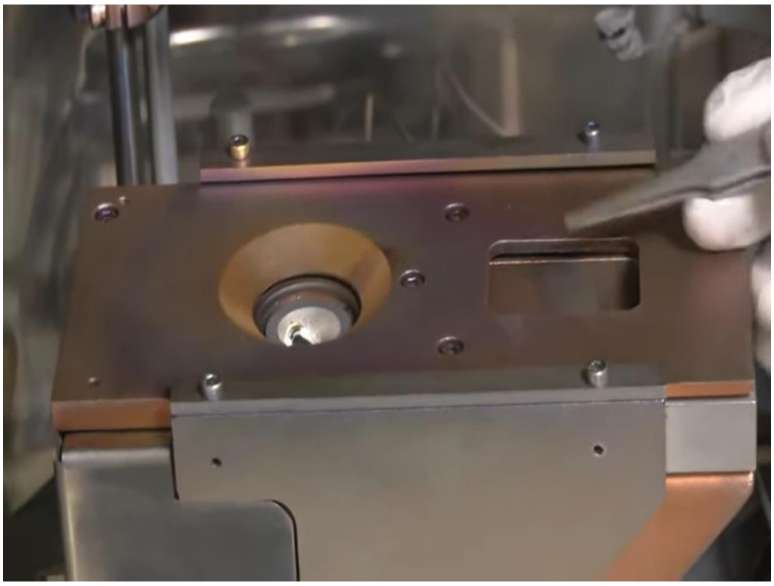

So, now we will have a look at the most important part of any electron beam operation system which is crucible. This is a target crucible which means the targeted, targeted material is loaded onto that crucible. We will now see how does the crucible look like and where is it loaded. So, what we are looking at here is a crucible.

As my colleague is pointing out using a tweezer there is already a material loaded onto the crucible and the current wave is generated to the right of the crucible and by applying a magnetic field which is located on the sideways of the filament we can direct the electron beam thus generated and focus it only onto the crucible.

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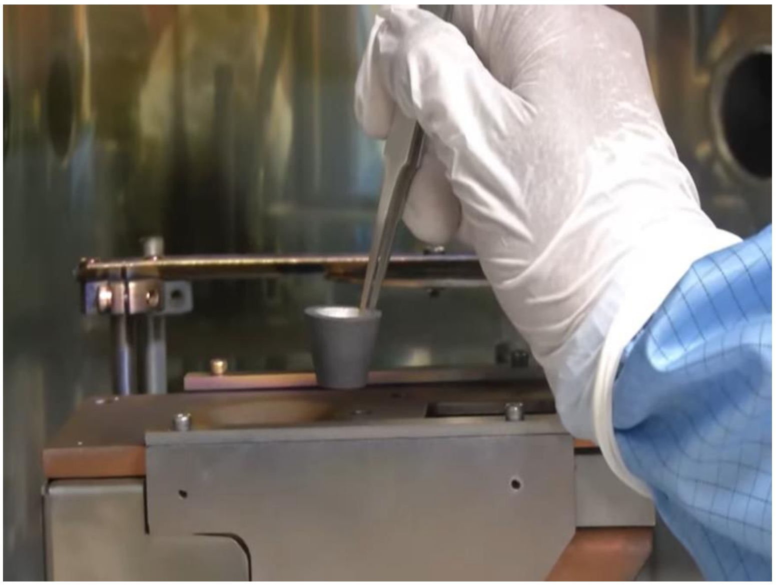

So, now let us see how does the crucible look like. So, this is a typical crucible. The size and shape of the crucible may vary from system to system, but materials which are used for crucible are generally graphite, tungsten or molybdenum. These are used because of their very high melting point.

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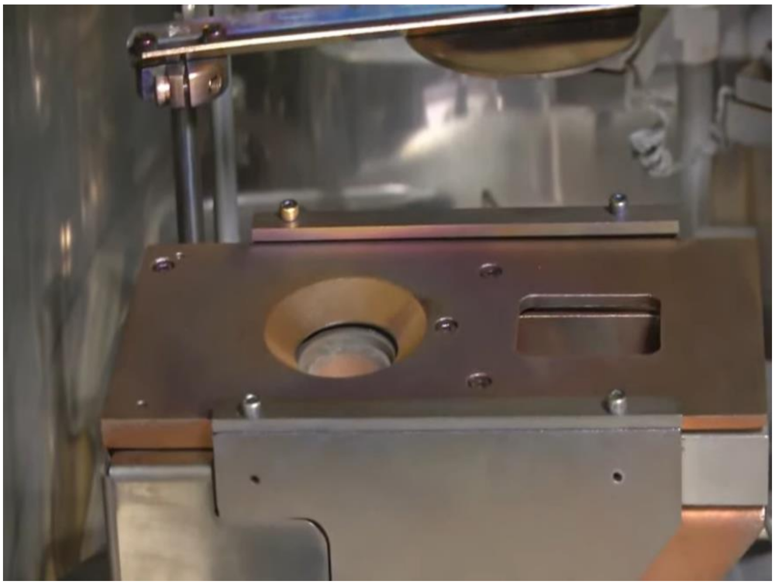

So now, we will see how a crucible is loaded onto a crucible holder. This is how a crucible is loaded and one other feature of any electron beam evaporator is that there are multiple metals with multiple crucibles dedicated for individual metals available in different slots. So, as my colleague will demonstrate how by using a control operation from the system electronics part, we can change the crucible containing a different metal. For example, the Crucible which you saw previously contained titanium and the crucible which now you are seeing is gold.

So, similarly, there can be many such crucibles depending upon the system capability and intended application which can be used for multi-layer thin film deposition or adhesion and then final metal deposition. For example, gold does not have a very good adhesion on most of the substrates and that is why chromium or titanium are used as adhesion layers. So, in order to deposit gold, one has to first deposit titanium or chromium and then gold without breaking the vacuum.

So, this is another advantage of using multiple crucibles which can hold multiple metals. But one important caveat here is each metal will have its own melting point and therefore, the currents have to be optimized for each type of metal to be deposited.

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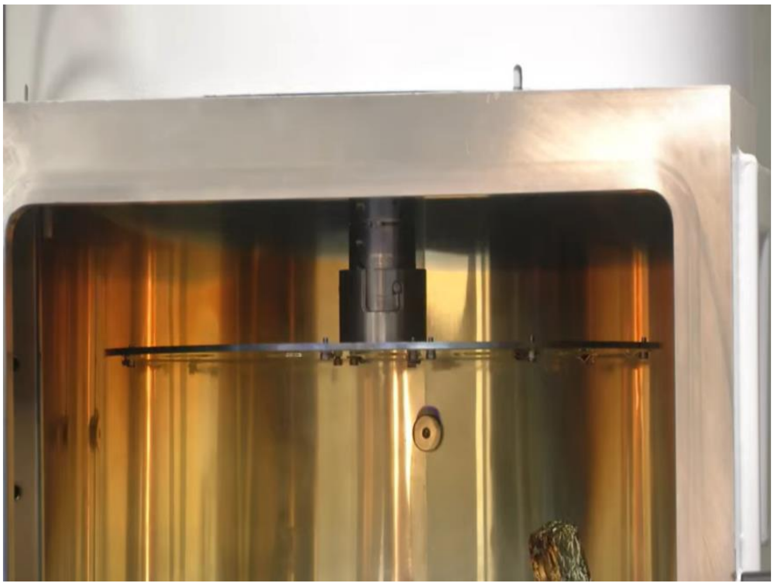

So, now that we have seen what are the components inside an electron beam vacuum chamber, let us now see how we can load the chuck which is loaded with the sample. So, here we have loaded some four glass wafer pieces which are adhered by Kapton tape. The adhesion can also be done or the sample hold can also be holded using screw and clips depending upon the requirement. So, now we will see how this chuck loaded with samples can be inserted inside the vacuum chamber and be loaded at the desired slot.

So, as my colleague is showing, the chuck is being loaded into the vacuum chamber at the desired slot. Now another important feature of an electron beam evaporation system is rotating chuck. Rotating Chuck allows us to have uniform deposition when we have multiple substrates loaded onto the chuck.

So, let us say one has to deposit titanium gold on to 4 silicon wafers or 5 silicon wafers in the chuck, 3 in silicon wafers, then if do not rotate the substrate, then the electron beam evaporated metal will not be falling uniformly on all the wafers. To make it fall uniformly on all the wafers, we can control the rotation of the chuck and hence, obtaining very uniform layer for all the 5 substrates or any number of substrates.

So, now my colleague will show how the chuck rotates and how it can be controlled. So, after pressing the knob as you can see, the chuck starts rotating. This process can be done without breaking the vacuum.

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So, now we have loaded the chuck and the sample therein. Next step is now to close the chamber of the vacuum chamber. Close the door of the vacuum chamber. We will now start the pumping sequence.

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So, now, we will see the sequence of how we can initiate the pumping and reach the and help reach the system to a state where we can start the deposition. So, before we begin, let us look at what is shown in the display. The first thing that is shown in the display system status standby which means there is nothing moving inside the system. There is no operation whatsoever being running inside the system. System is in total standby.

The next thing is chamber pressure. Chamber pressure as shown by pirani gauge, this gauge aspect I will come to it after some time. It is showing it to be 10^3 millibar. 10^3 millibar is roughly equal to one atmospheric pressure which means chamber is at the same pressure as the atmospheric pressure.

Also, among the display buttons that you can see which are total of 8 of them, only 2 display buttons are highlighted, either start or vent. So, these are the only two operations we can do. However, we have already vented the chamber, we have gone through all the sequence of venting the chamber, taking the checkout, loading the sample on a chuck and then loading the chuck along with the samples. Now the next step will be to start pumping. So, let us see the next sequence of pumping.

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So, as soon as we press this start button, the first thing that comes to the display as part of system status is that backing. What does it mean? Backing valve is closed and roughing wall is open which can create the base pressure for the turbomolecular pump. All these terms we will discuss it now. So, in electron beam evaporation system, there are two chambers. There are two pumps. So, now as you can see, system status has changed to turbo acceleration which means the turbo molecular pump has started accelerating.

Typical speed of turbomolecular pump is around 13,000 RPM. The process of turbo pump evacuation and turbo pump being ready takes around 15 minutes. So, let us till then understand what are the different components which are hidden inside the casing of the electron beam system that you are looking at. So, electron beam system, the two most important component which result in creation of very high quality.

So, now let us see what is the system status. As we can see system status says that turbo pump is ready and however, the chamber pressure is still 10^3 millibar which means we need to start the rotary pump. In order to start the rotary pump, the next sequence of the event is to press the highlighted button cycle. Cycle will start the pumping cycle and as we can see, the system status has changed to cycle sequence roughing which means roughing valve is open and running pressure has been created using rotary pump.

As we will see that the chamber pressure will also start changing after some time. As we can see here, the chamber pressure has now dropped from 10^3 millibar to 4×10^2 millibar and it will quickly lead to 10^{-3} millibar. The time it typically takes to reach there is up to 5 minutes. Now, as soon as the chamber pressure reaches a particular value which is typically 10^1 millibar, you can see that the safety interlocks which was earlier off, the indicator for safety interlocks is now turned on. It is highlighted green in color.

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Another important part of the electron beam evaporation system or for that matter, any such complex system is emergency stop button which can be seen here. This emergency stop button comes very useful when there is any kind of system issue such as vacuum is stuck or there is limited power supply through UPS in case of certain interruption of regular power supply.

In all such cases or in any other cases which are not considered in usual routine runs, emergency stop button helps to completely shut down the system to prevent any further damage to the chamber to the system, electronics as well as to the user resulting in any kind of shock or fire prevention as well.

This emergency stop button is to be used only for emergency cases as the name suggests. So, as you can see, the vacuum has now dropped to 10^{-1} millibar. So, now we can see that the chamber pressure has reached 10^{-4} millibar. And that is why the system status has now changed to cycle sequence fine pumping.

Fine pumping here refers to the pumping which is executed by a turbo molecular pump which means now the backing valve was open, venting valve is closed and turbomolecular pump has now started working to evacuate the chamber to the desired vacuum which is around 3223×10^{-6} millibar. This process in this particular unit takes around one hour.

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We can see that the vacuum has reached $1.94\times e^{-6}$ millibar. Generally, we can start the deposition process once the vacuum reaches $3\times e^{-6}$ millibar or anything less than that. This is to ensure that the mean free path or the total distance travelled by the charged species from one end to the other end this maximum and it does not collide in between to any kind of impurities.

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So, now we will turn on the electron beam gun. So, now we will turn on the mains of the electron beam gun control. So, as we can see he has turned on using the MCB switch. The second step will now to turn on the transformer. So, as we turn on the transformer, we can see here, the MCB control will start the process of electron beam control being on. So, after turning on the transformer MCB, the next step is to start the vacuum button.

So, we will press the seal button. So, now the chamber is sealed and after the chamber is sealed, the next step is to start the process. So, as we can see, the process button is clicked now and the chamber is sealed. So, once the process button is pressed, we need to wait till the chamber pressure reaches again around less than $3 \times e^{-6}$ millibar. After that, we need to turn on the transformer by this push switch. As we can see, once the display stabilizes to 01 display, the next step is to push the gun button. This means electron beam gun is now on.

Next step now is to turn on the amplitude. Amplitude means the current amplitude, this also defines the shape of the electron beam that is going to be incident on the material supposed to be deposited. It can either be a spot beam, sinusoidal or square beam. These kinds of functions are given in the control panel here. Next step now is to gradually increase the current. So, there are two checks which are supposed to be made here.

One, final check to see if the boat or the crucible in which the material is loaded is glowing active or not. In this case, titanium is supposed to be deposited as an example. And so, we have noted titanium in crucible number 3 and that LED corresponding to crucible number 3 is glowing. So, this is further confirmation.

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The next step to check is the rotation of the chuck is on or off. Why it is important? It is important because switching on the rotation of the chuck ensures uniform deposition of the material, it can either be metal or a dielectric on the desired wafer or substrate. Once that is done, the next step is to switch on the quartz crystal monitor.

As we can see here, the quartz crystal monitor functions to measure the deposited material and gives us an idea how much metal, how much thickness of the metal has been deposited. Now, once these checks are done, the next step is to gradually increase the current. Now, before we increase the current there are some things that needs to be clarified.

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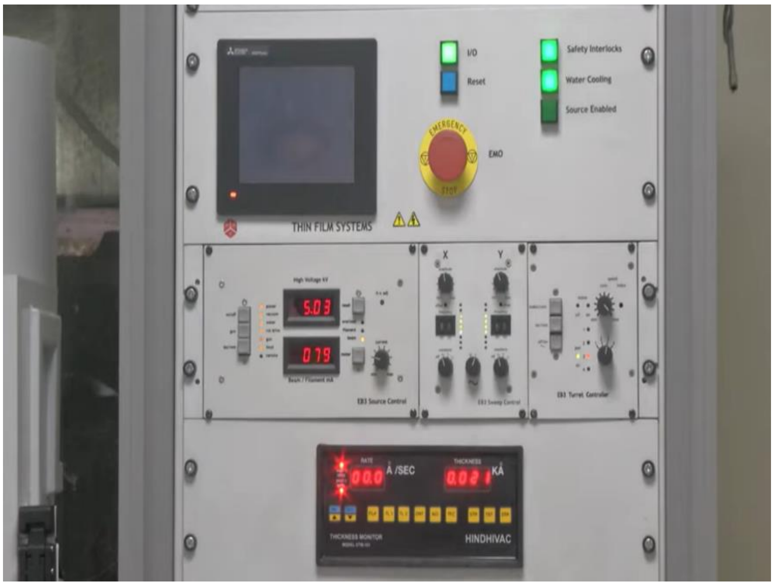

Now, the next step is to gradually increase the electron beam current. This has to be done very carefully because sudden increase in current can lead to thermal shock or even damage of the filament. Now while increasing the electron beam current, there are two aspects in terms of time for which we are increasing the current and then keeping that current for some time so that the gun becomes stable and there are no thermal shocks received at the crucible.

These two times which is increasing the current up to a certain level and then keeping that current constant at that level is called as rise time and soak time respectively. So, rise time is the ramp up time which means you increase the current up to set point and then at that set point, you maintain the current level for a desired time which is obtained after several optimization cycles. This helps to uniformly heat the crucible and avoid any kind of focused heating. Depending upon the material that is supposed to be deposited, we can have several such steps of rise and soak time.

So, as we can see, now, we have given the first set point at 25 milli ampere and we are now soaking which means the current is allowed to be there for some time. The time ranges from few tens of seconds to a minute depending upon the process parameter. Again, I would like to repeat that increasing the current gradually is the key here. Now, we have reached the second set point after going for another rise and now it will be kept for soaking for next few seconds. So, now we are increasing the current further for the next rise and soak cycle.

The first reason and soak cycle was at 25. The second was at 50 and now third is that 70. All these values have been optimized after several such deposition cycles. So, now we are going for the final rise and soak cycle. Final rise and soak cycle means after this cycle, actual deposition will come.

One important thing that needs to be kept in mind is that all this time when rise and soak deposition, rise and soak is going on we need to make sure that the shutter, the shutter which prevents any kind of metal deposition on the substrate is closed. If we do not do it, we will find different kinds of spots on our substrate and non-uniform deposition.

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So, now we are done with the final rise and soak time and the time has come to open the shutter and allow the deposition to start. So, as we can see the knob when pressed on the left side will open the shutter and the deposition will start now. The deposition has started.

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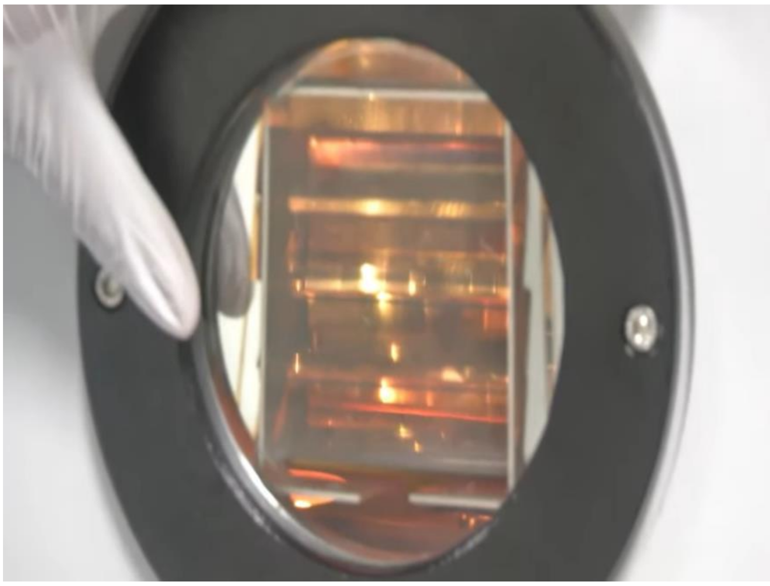

So, now we can see that once the deposition is started by opening the window, we can check the bright spot which is visible here. And this is something where the metal is melted in a crucible. So, the metal is still being deposited.

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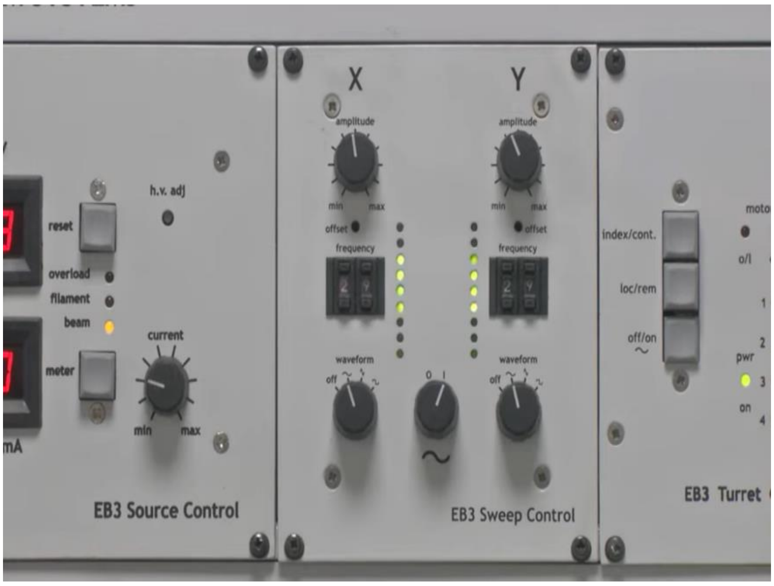

Meanwhile, we can also check that what is the meaning of this electron beam speed control. As we had mentioned that there are two different kinds of beam which can be used either it is a spot beam or a shaped beam, the shape can either be square or sinusoidal. Now, in either case, the shape can be changed in terms of its amplitude in either x direction or y direction.

As we can see there, there are two different knobs wherein x direction and y direction amplitudes can be changed. All these parameters are there to tune the amplitude, they can also tune the frequency in x direction as well as y direction. Overall, it gives us more degree of freedom in tuning the beam parameters. This is one of the beam sweep control and which can help us optimize our process and get the desired thickness with uniformity.

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So, now the deposition time has lapsed, the first thing that we need to do is to turn on the shutter and then we need to turn off the current very gradually.

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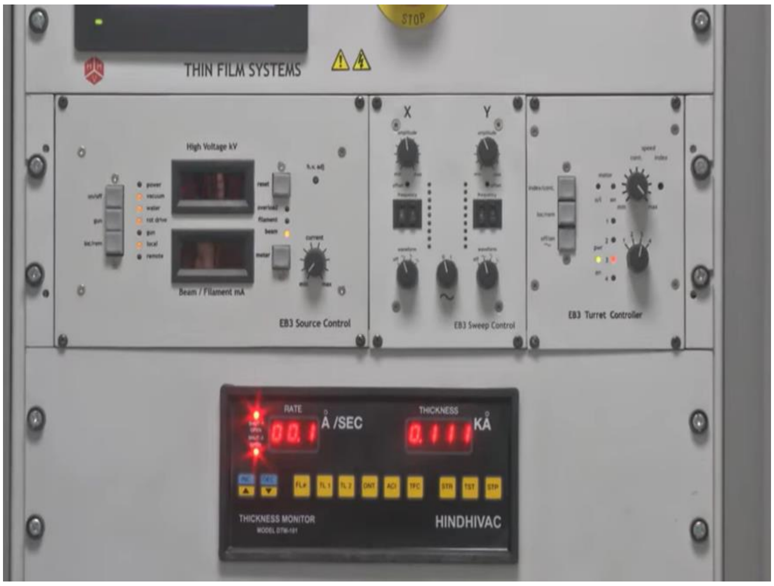

Now, we can see that we need to rotate the knob very slowly. If we do not do it, there will be a thermal shot at the crucible and it can damage the crucible leading to formation of cracks. Now one would question that why we need to turn off the shutter. The reason is, if we do not turn off the shutter, the current has an is going to be decreased.

And if we keep on decreasing the current, the rate of deposition will gradually come to almost 0 which will lead to formation of puddles or spots on substrate and whatever deposited material will be there, the quality of that material will be lost. After we bring the current down to zero, the next step is to reduce the amplitude knob to zero position. Then the next thing is to turn off the gun by the push switch followed by turning off the transformer and then turning off the crystal.

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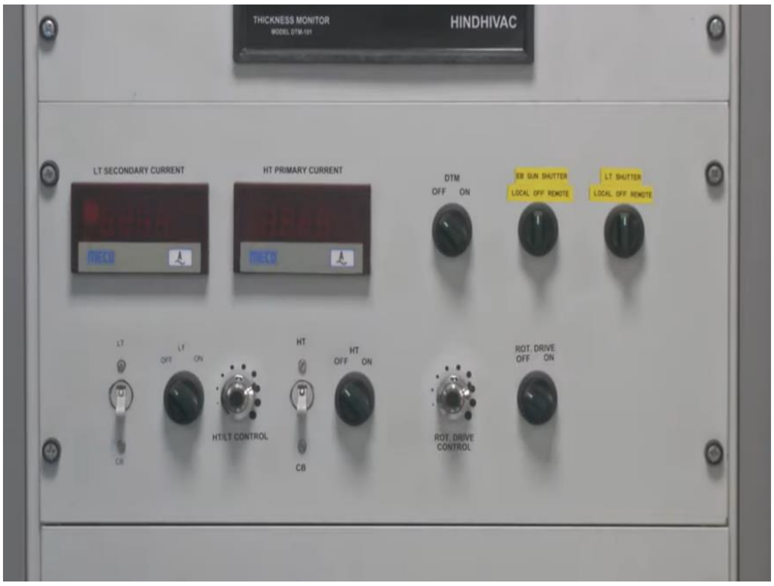

Then next one is to turn off the crystal monitor followed by the rotation drive. So, now the chuck is not rotating.

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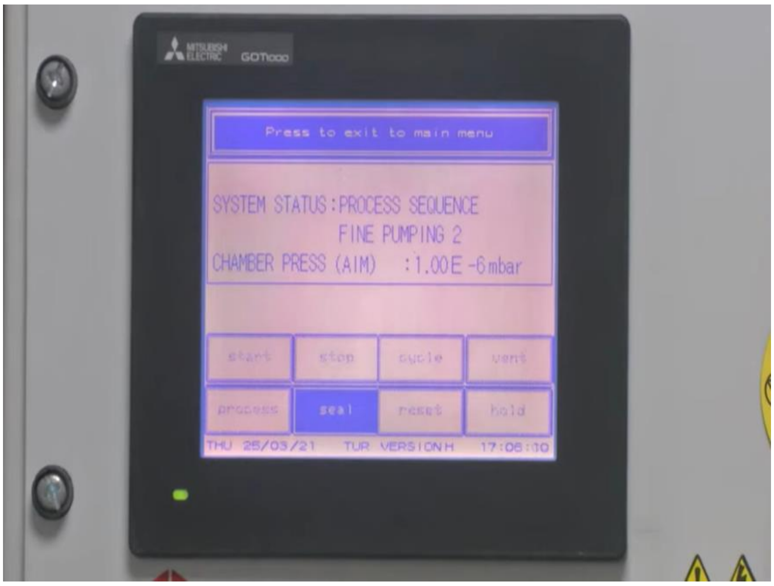

Then we turn on the transformer mains which was responsible for electron beam generation and finally, turning off the main MCB related to electron beam gun power generator.

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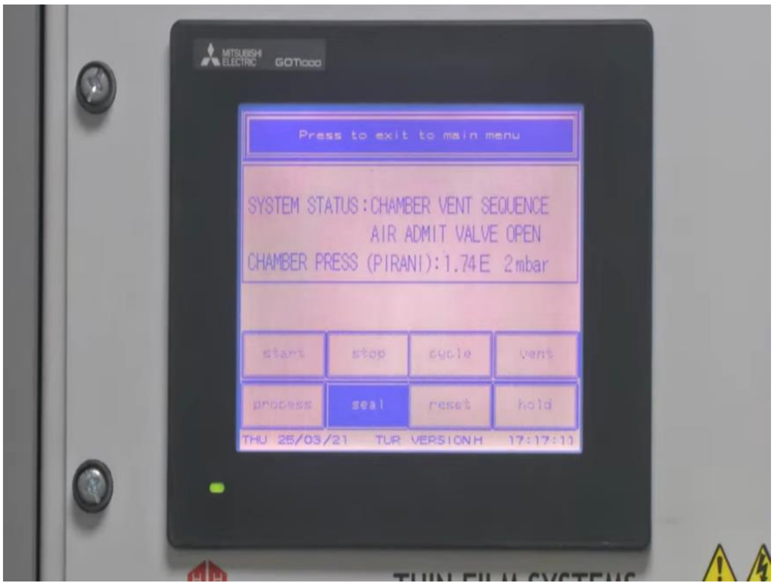

So, now once we have turned off the electron beam then power, the next step is to break the seal of the chamber. So, we can press the seal button and then we can stop. So, now we have stopped the pumping from the chamber the evacuation has stopped but turbomolecular pump is still on. So, before we go for venting, we need to allow some time for the turbomolecular pump to gradually come down to its lowest speed and eventually turn off. Only when it is turned off to its lowest possible speed, only then we can press the vent button.

So, the time required for this process is generally between 10 to 15 minutes. If we do not wait for this much time and we immediately turn off, it can damage the turbomolecular pump with and it can lead to damage to its blades. And as we all know, turbomolecular pumps are very expensive and that is why and they rotate at very high speed. So, in order to bring that very high speed to very low speed, we need this much of time.

So, as we can see now the system status from turbomolecular pump down has changed to turbomolecular to standby and once it reaches the standby status, the vent and start button both are activated. This means either we can start the pumping cycle or we can vent the chamber. Since our deposition processes done, we will click the vent chamber. Now as we can see, as soon as we press the vent chamber the vent sequence started and air admit wall which releases the vacuum has been opened.

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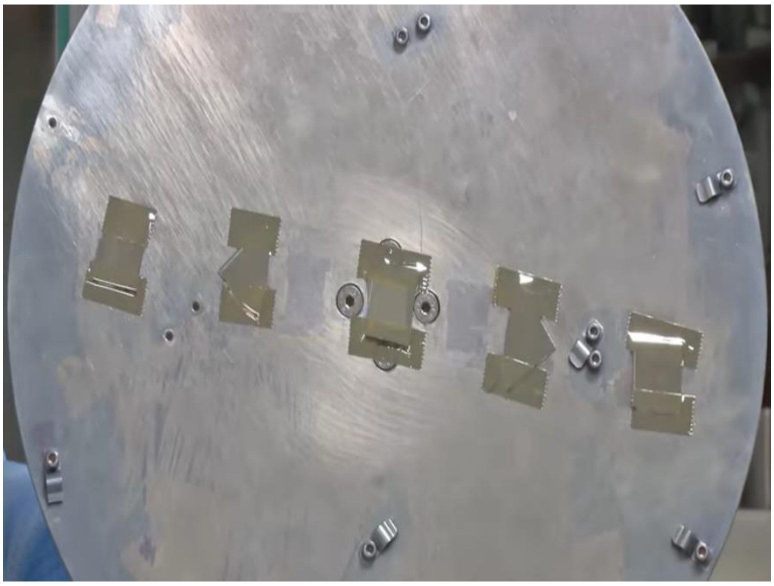

So, now the chamber will be open. This process typically takes 10 to 15 seconds and once the chamber is at the same pressure as that of the atmosphere, the chamber can be opened. Once the chamber is opened, the next step is to remove the chuck on which substrates are loaded. So, as we can see, the chuck is being removed carefully and as we can see the metal has been deposited. As we can see the samples are having shiny surface which says that metal has been deposited using the process of electron beam evaporation.

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Now, once the chuck has been taken out, we will close the lid, unload the substrates and then keep the chuck back. So, we have removed the samples and now, the chuck is placed back into the chamber. Once the chuck is placed back into the chamber, the lid of the chamber needs the door of the chamber needs to be closed properly.

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The chamber should never be left without any kind of vacuum. And that is why as we can see, the start button has to be pressed to keep the chamber in some finite vacuum. As we can see, as soon as we press the start button, the system will change to backing. So, as we can see the safety interlock indicator is off because there is no vacuum. And now that turbo pump is accelerating after the roughing pump has created a base vacuum.

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So, now we can see the display on the screen has changed. The system to status now shows turbo pump is ready. Once the message is shown the turbo pump is ready, we can press the button cycle. Now, as we press the button cycle, what we can see is the roughing wall has started. Roughing wall as we can as we have discussed previously creates the base vacuum. Once that base vacuum is created, then the backing wall opens and gives access for turbo molecular pump to evacuate the chamber to the base vacuum.

At that base vacuum, we can keep the system and turn the system off. So, now as we can see the chamber is in some vacuum and that is why the safety interlock indicator is on automatically. So, as we can see the chamber vacuum shows $5e^{-5}$ millibar around and this vacuum is sufficient to keep the chamber under vacuum conditions. So, since it is sufficient, make it now seal the vacuum at that vacuum level and then we can stop the pumping.

After stopping the pumping, we can see that turbo decelerating message has been updated in the system status which means that turbo pump is now decelerating. Once it is decelerated to its lowest possible speed, then we can safely turn off the system. So, now as we can see on the display, the system is showing standby which means that our molecular pump has been completely slowed down. So, now it is safe to turn off the system.

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To turn off the system falling is a sequence a first press the I/O button. Once we press that, we will next turn off the mains MCB. So, now as we can see, on the left hand side, the mains MCB this is the mains that supplies the power to the electron beam system, evaporator system and now we can turn it off. So, now the system is turned off. The final thing is to turn off the chiller. So, the switch over there is further chiller vent. So once that once the system is turned off, then we can turn off the chiller.

This completes the deposition process and system switching off process. So now, as we have turned off the mains as well as the chiller, it completes the system turning off and deposition process in complete sense. Thank you.