Sensors and Actuators
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Lecture - 33
Physical Deposition Techniques

Hi, welcome to this module. In this module we will be looking at two different technology for depositing metal, insulator and semiconductor materials. Now, in the last module what we have seen? We have seen a thermal evaporation system and I have also shown you two different YouTube videos right that will help you how to understand how the technology works. Like a promise will also show you the E-beam evaporation and thermal evaporation in the clean room. Now, what was the disadvantage or limitation of thermal evaporation right?

If you think about it thermal evaporation is where you have a source, on which you load the material and then you heat that material when the material reaches it is melting point, it will evaporate and it will deposit on the substrate is not it. So, the difficulty here is that if the source material that you are loading on the source, if the source material melting point is higher than the melting point of the source holder, then instead of melting source you will be melting the source holder and that is not acceptable. Because we want to evaporate the source and not this source holder; is not it?

So, that is a difficulty that when the when the material that we want to deposit it is melting point is higher than the source holder then we cannot use thermal evaporation, in that case what can be the alternative technique?

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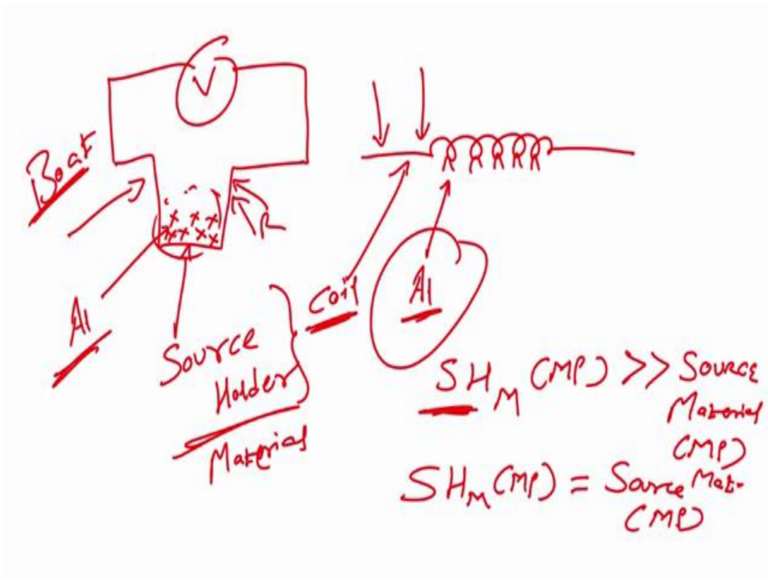

So, if you see the slide what I am saying is, if you have a source this is a source holder; source holder can be also a coil like this right and if I load the material in these source holder which is called by source in this coil we will load the this kind of wires right.

Let us say this wire is aluminum right and this material is also aluminum. Now, the source holder material this is called boat by the way boat B O A T and this is our coil right. So, the source holder material whether it is a coil or it is a boat right. So, I write down the source holder material melting point should be greater than the source material melting point this is source holder the holder that can hold the source. For example, aluminum the coil is also a source holder, it can have aluminum wires loaded onto the coil, is not it? There is a source holder material melting point should be extremely high compared to source material that is your aluminum.

So, if this is the case your alum when you heat this boat by applying a voltage or right higher voltage because this is a resistance. So, the current will flow and because of the current the dual setting I^2R this the material that you are loaded will get evaporated, is not it? However, if the source holder material melting point is close to or equal to source material melting point then what will happen? Then the coil will start evaporating or the boat will start evaporating rather than the material loaded onto the source holder there is a difficulty all right.

So, what can be then alternative to this kind of problem? The alternative is instead of heating this source material or so, this source holder material what we will be doing it. So, instead of heating boat or coil what we will be using is a crucible; crucible again is a holder right.

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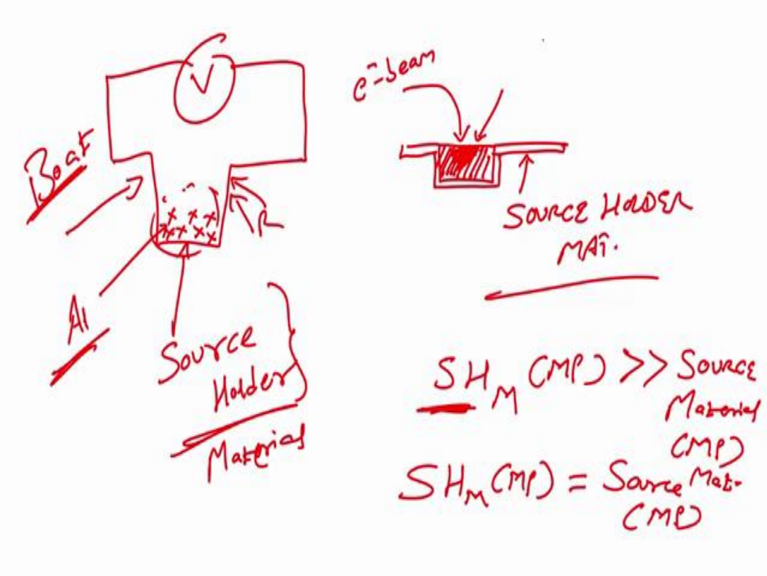

We use a crucible and then we will load the crucible with the material instead of heating the crucible with some you know by applying a voltage or by applying a power what we will be using?

We are using electron beam. Electron beam will be incident will be you know we will electron beam as a source point to heat the source material and evaporate it. In this case your substrate or your source holder need not be conductive. It is fine if it is not conductive. In thermal evaporation we require, the source holder to be conductive all right. So, if I use E-beam then E-beam only heat the substrate sorry source of material and it will melt it and evaporate it all right. So, now you are using electron beam tools you know melt the material instead of heating the entire source holder that is called electron beam evaporation.

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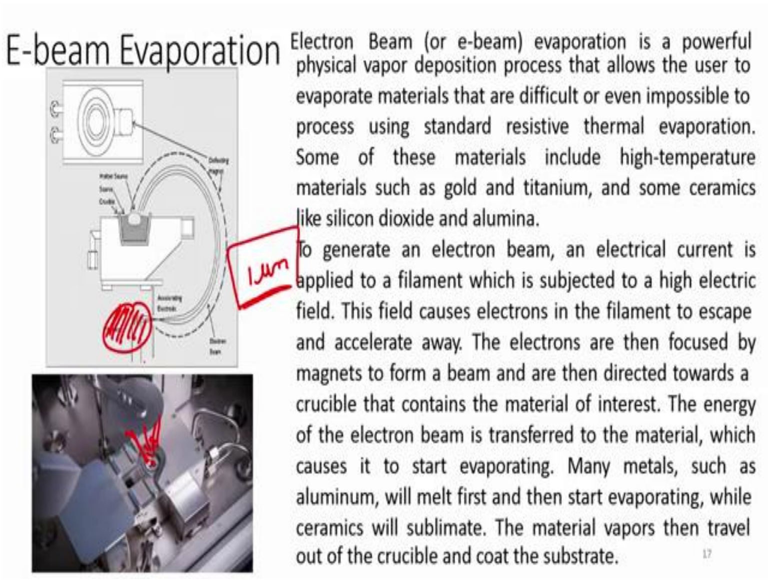

So, let us see in the next slide this is what I was talking about that you have a crucible, you can see you can see here and then you have a source which is write over here and then this is a molten source. Molten source is because electron beam which is generated from the filament it is accelerated to the accelerating electrode and this band through the deflecting magnet and that it is incident on the source.

So, when it is incident on the source it will melt the source and the source will start evaporating. So, that is the phenomenon of electron beam evaporation the mechanism of electron in your patient it is extremely powerful technique, and it can evaporate materials is that difficult or even impossible using standard thermal evaporation technique some of the materials are like titanium or we can also you know deposit silicon dioxide an alumina and then in this case is an actual photograph or the E-beam system this is the source ok.

And the source is loaded in a crucible, and the electron beam will come from here and it will incident on this source like this ok. And because you are heating it the source material will be evaporating this is the shutter. Shutter is to stop the evaporation because when you operate it if you reach let us say you want to deposit 1 micron film as soon as you reach 1 micron you should start you should stop the operation.

But when you stop the electron beam this metal will be at extremely high temperature and still it will evaporate for some time. So, if you use the shutter then the substrate will be the material will not get deposited on the substrate which is above the shutter. What I mean is about this particular shatter there is a substrate alright of course, the substrate size is for like this.

Now, when the shutter is open then the it was depositing material right and when the substrate is closed the material will get deposited on the on this shutter this is a substrate when the substrate is protected by the shutter then the material is deposited on the shutter and not on the substrate thus you can only control 1 micron or even below. So, this is nothing, but a shutter this is therefore, you know in a very easy terms due to understand that you can use shutter to stop the evaporation.

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Now, you see this material here, this is a sink there can be many way of holding this electron be beam evaporation sources one is a single pocket then there can be rotary pocket and there can be linear pocket. So, what is pocket means? This here this one is a pocket right this is a pocket. If the pocket can only hold one source single pocket if it is rotary; that means, that there is 1, 2, 3, 4.

So, this one here is a rotary system, this is one is here, second source will be here, third would be here fourth would be here. So, you can deposit multiple source using the rotary system. Then there is a linear pocket where the sources the pocket for holding the source is in linear fashion like this right that is what the evaporation sources holder means. So, this is the for the single pocket, this is for rotary pocket and this is for linear pocket all right.

So, if you go in detail then a water cooled copper block is bored out of how to have a pocket in the shape of inverted truncated cone which is right over here right this is water cooled. So, as to keep the other area of the material at lower temperature except the electron beam area which is here where the source is loaded source material is placed within this pocket. So, where is the source material is placed within this pocket. So, when I say within this pocket where it is? It is here.

If you see here this one is a source right. So, this is loaded with in the pocket. Now, the crucible has a smaller or similar pocket within it a magnetic structure consisting of permanent magnet two pole extensions are located around the block such that it is fields lines around run to side of the pocket. Such that when the electron beam comes it will only incident or in this area and not some other area on the same slide of the block is a filament which produces electrons by therma thermionic emission and it is formed into a beam this is called emitter assembly. So, this goes all the way down you do not you cannot see anything which is emitter assembly, when you open the system like here you cannot see anything which is below this guy correct.

So, this is the what is it done here, the electron beam is steered by this fields in a 270 degree arc to impinge on the center of pocket, the electron beam energy is controls as that magnetic field will bend it is precisely into the center of pocket all right. Then the addition is that an electromagnetic coil known as sweep coil is employed to effectively raster the beam around the surface. So, what happens is, if you have the source if I just incident the electron beam only in one area this area will get melt, but what about other area what about this one this one right.

So, instead of that we if we have the raster scanning of electron beam on this particular source, then it will scan like this right also depending on horizontal screening or vertical scanning or raster scanning. So, the raster scanning is possible if we use the electromagnetic coil and it can sweep in x y direction. Variety of sweep patterns are used in control program for electromagnetic coil, materials with high performance high melting point require X Y sweep to prevent the E-beam from boring a hole. See high melting point means you are to this is a material right loaded onto the sub source holder.

If I just keep on focusing electron beam on single spot. Because the melting point of this material is extremely high, it will start like making after it evaporates it will start making a hole into the holes into the it will from a bore right from a boring a hole into the melt this is a melted area right and subsequent spitting which creates large nodules of source materials in growing thin film.

So, what happens is, when you when you let me let me read it when you have a source and if you have a single spot of E-beam rather than raster scanning what will happen this? This is start melting these source and any such melting because multi means so, high what will happen the chunk of this material will also get melt and in the substrate instead of having a cools uniform thin film what will get is, a substrate with some chunk in between. Film will be there, but it not be uniform and some chunks are available why because here the (Refer Time: 13:44) is non uniform all right this will happen when you do not use the xy sweeping. When you do not use express shipping then the difficulty is with the large modules of source material depositing when you are growing the thin film all right.

Now, if we talk about the rotary pocket instead of single pocket, if I use rotary pocket then the electron beam source has all the same parts as a single pocket unit except the water cooled copper block is essentially a turret of multiple pockets each of which can be extended into position. With this design a number of different materials can be evaporated because you have four source.

So, you can have aluminum, you can have chrome, you can have gold, you can have titanium there can be multiple sources possible to evaporate at a single time only one source is available for you to evaporate all right, but you can load multiple sources that is advantage of rotary pocket. Now, with this design number of materials can be operated sequentially not simultaneously sequentially from a common magnate emitter sweep called structure; obviously, this is a design includes shielding to prevent the cross contamination of the source.

So, this is a shield this is a shield right and exactly this rotary pocket is in here right see this is the system with rotary pocket is not it? So, rotary pocket this is a shield so, that you can prevent the when this gets evaporated it will not deposit on the other sources do not deposit on other sources. So, you can also act as a shield to prevent the cross contamination ok. The final pocket or evaporation sources is linear pocket a liner pocket a beam source is similar to rotary pocket except that the it is pockets are arranged the line are index into position in a linear fashion with a common magnet into coil structure.

So, this is like whatever you want to evaporates this guy will go in this direction and here is the e beam. So, once it is there you can just move it. So, this bar can move all the way here right. So, it is just only this area is exposed, if you wanted you can pull it on this way or you can pull it in this way right. So, this bar can go here or can go here, depend on the source that is exposed to E-beam we will get the material deposited onto the substrate.

Substrate is what? Substrate is silicon wafer or any material in which you want to design or fabricate the sensor. So, let us see the two videos about introduction to introduction to E-beam and then detailed about that.

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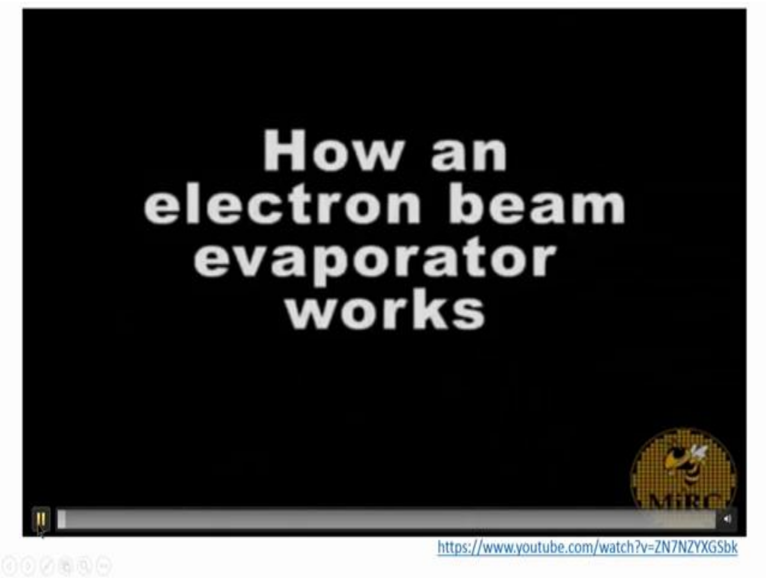

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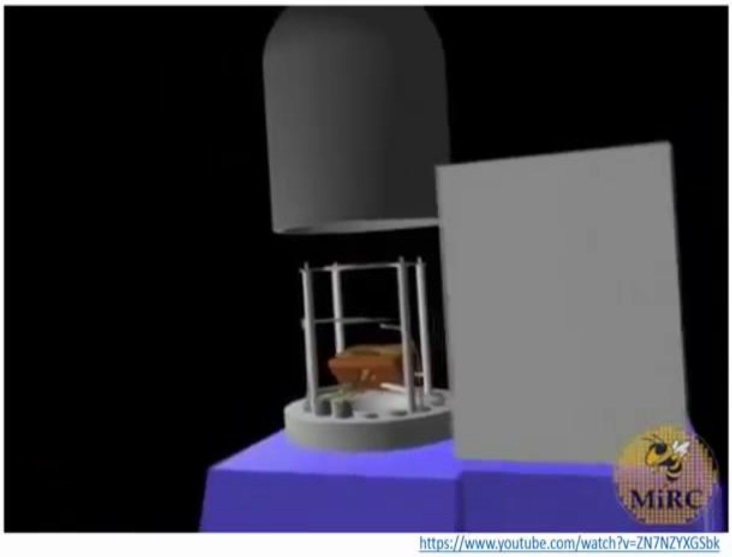

So, let me play the video. An electron beam evaporator a type of physical vapor deposition tool is used to coat one side of a sample with ferrous metals commonly use metals on this machine include aluminum, platinum, gold, chrome, nickel, copper.

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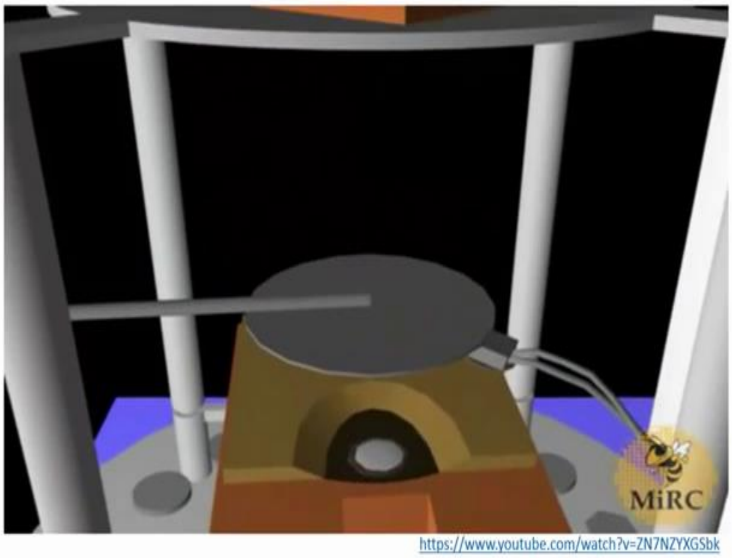

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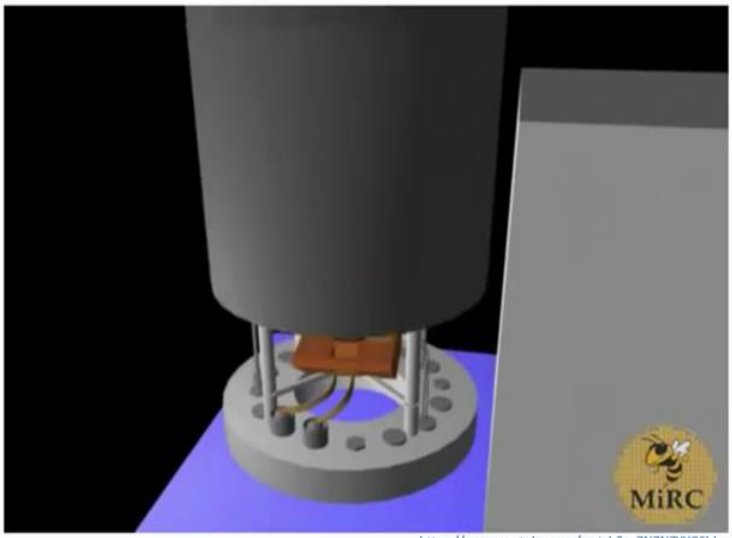

https://www.youtube.com/watch?v=ZN7NZYXGSbk

Once a sample has been loaded the chamber will be closed, the chambers then pump down to a very low pressure.

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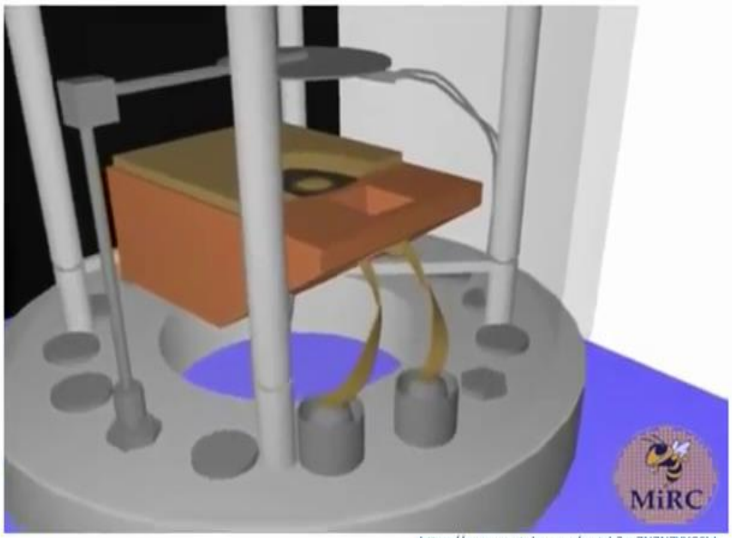

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The machine that releases electricity through a filament.

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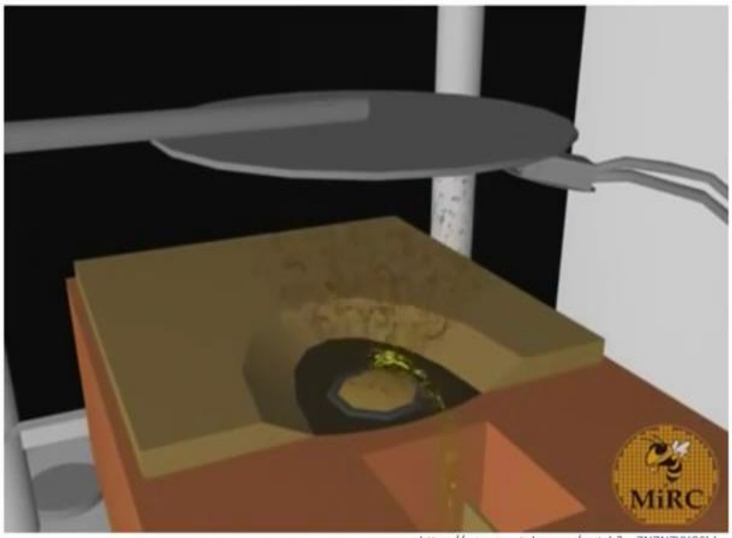

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Several magnets are used to direct the electron beam from the filament to a crucible containing the target metal. The metal then heats up and begins to evaporate onto the shutter, this process can take several minutes.

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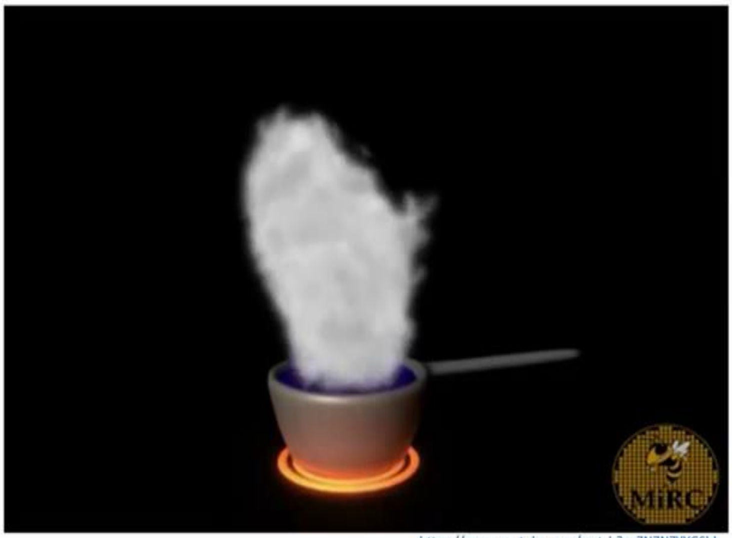

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This is similar to a pot of boiling water a hot stove.

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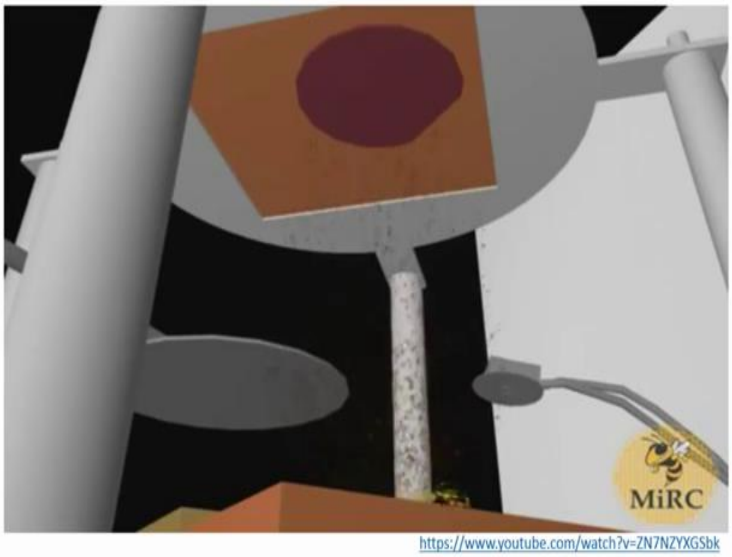

A sensor within the chamber is used to determine the current rate of evaporation. Once the desired rate has reached the shutter is open and the sample is exposed to the vibrating middle. The desired rate of evaporation and the amount of metal to be evaporated can be set under the deposition controller.

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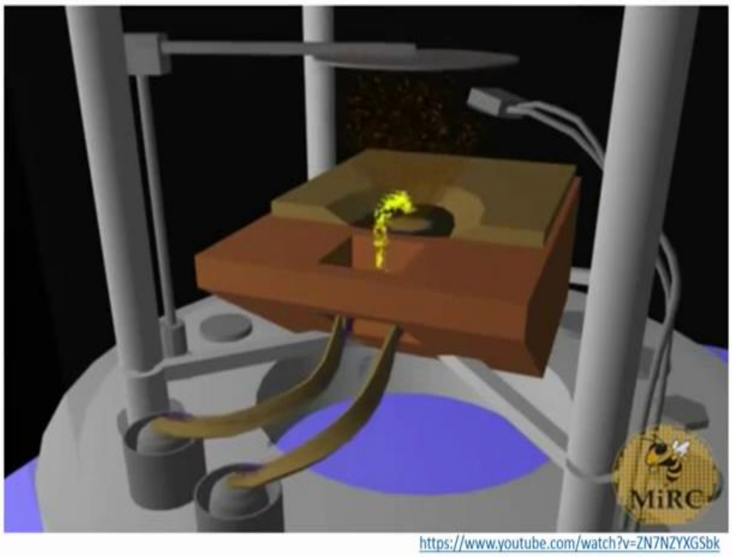

Once the desired amount of metal has been evaporated shutter is closed, the pressure inside the chambers and increased atmospheric pressure and the chamber is opened. Ok you have seen the first video right let us see in the second video as well.

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This is E-beam, it is used to deposit metal within the source (Refer Time: 18:04) dioxide or onto your substrate result is a uses a electric gun into (Refer Time: 18:12) sample material and that will evaporate into your substrate in the sample of here. So, before you use a machine you need to be trained and qualified and once you get those two things accomplished you will get a council login.

So, when you come to the system you want to make sure nobody else is using it the system not down those are all fine and you come in and login once you have logged into the system you want to write them to the logbook. So, the logbook you would write your name, you are timing using it the material, you are depositing the base pressure and then once you log in they are all ready to start a loading a sample for the substrate. This is the phase of loading your samples into the E-beam.

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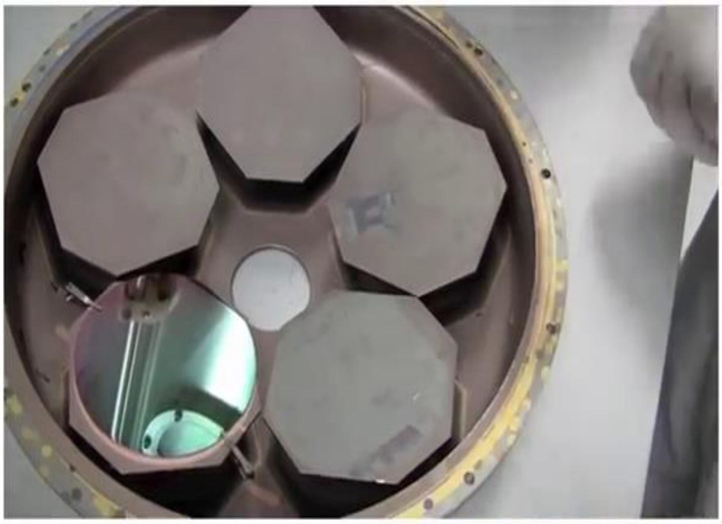

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There are two types of substrate holders, this one this whole wafers well there is another over here.

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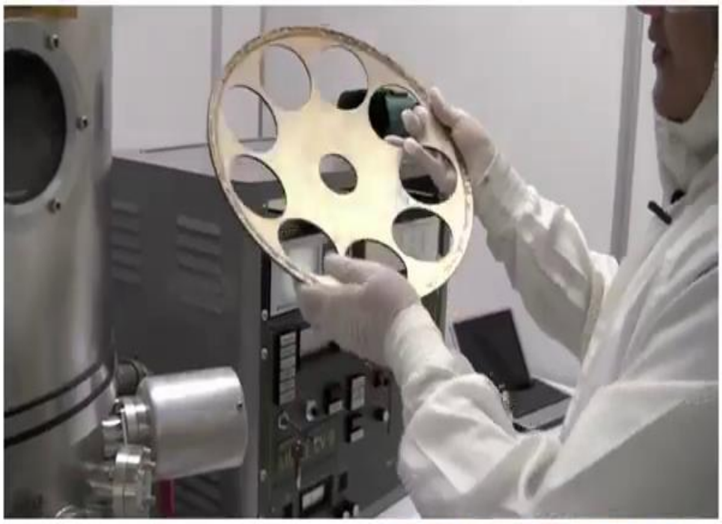

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Where we can put smaller or pieces of wafers as well you can actually not the whole (Refer Time: 19:12) as well. So, if we look at this sample holder you put the wafer near and we going to keep it on together because actually this whole thing is inverted in the machine. So, you do not want it to form, a sample to form I use clips.

But you can also use the thermal (Refer Time: 19:31). So, once you have melted your wafer and you want to put it in the system, you would need to invert the system because right now it is a high vacuum. So, what we are going to do is now we are going to (Refer Time: 19:47) the system. So, now, that we may run to the system into the pressure has reached 7.4 to 10 to plus 2 at ATM we can actually open the chamber. So, to that we would turn the vent off and raise the tray means the chamber over the toggle valves.

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You push it back because there is two pins right here right here look good. So, we know how far back to pushing.

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So, once we have our sample the system loaded up here we want to actually load and possible that the name contains the metal that we want to evaporate. So, the system actually has four pockets that you can put this in.

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https://www.youtube.com/watch?v=T2FXGL-d0sQ

So, to fill the right pocket, we will need to first use gold as a reference, system we are doing to tighten titanium we want to be wonderful gold.

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So, we have gold we look for gold and then we will not if the system with this knob here and we will not see the open crucible for titanium and that is where we put it. So, we will do it now we will open the shutter. So, we can see a samples.

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So, we can turn this till we find gold.

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So, we look inside. So, we can keep turning it, then gold is right there. So, we went out as one after the gold. So, we know this is the slot for titanium.

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So, we put in to here, make sure it is (Refer Time: 21:41) and then we close our shutter, it is also good to look at these two mirrors. So, these mirrors help you to be a crucible when you depositing. This mirror let us you see a crucible when the shutter is closed and then this mirror let us you see the shutter the crucible when the shutter was open.

So, you put your head about this height and to make sure you can see the mirror there when the shutter is open, and then the mirror there it look sample the crucible the shutter is closed. So, I guess see the crucible there when it is closed, and then I can see the crucible there it is open. So, my mirrors are in the right position. So, now, that the sample is closed and the substrate is there and the shutter is closed a mirror is in the right position we have a sample up here mounted securely we can bring a chamber down and put it to back into high vacuum.

So, we are going to do that now it is like a load the chamber. So, now, that we have close the chamber and our samples are in there and that crucible is there and the shutter is closed, we can begin to pump down process. So, right now the system is in atmosphere normal atmosphere. So, we want to bring it down to the high vacuum, but we cannot just chop there. So, we need to work it through the kind of a pump. So, the first thing we are going to do is turn the mechanical pump on which is called a roughing.

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So, it is a roughing valve here, we just turn it on. Make sure the high the vent is off.

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So, we turned a dropping on and you should see the pressure decrease. So, we wanted to make this to make sure that the pressure is less than 7 times 10 to the minus 2 before we turn the high vacuum, but you can go a little even lower than that. So, we will wait a little bit for the pressure to drop. So, after they are roughing about roughing the pump has brought the pressure down to below 50 millet or we can switch the mechanical pump off for the roughing and turn on the high watt.

So, what we do is we look at the pressure it is under 50 minute and now we are going to turn off, and once we turn it off we wait a little bit for the actuation of medical valve to make sure it is closed and then we turn the high back on. So, when we turn the high back on can we turn us on we should see no pressure drop. So, let us turn the high back on, you can see the pressure drop fast. If the pressure does not drop there might be a problem with the cryo pump they might have been dumped to verify that we would look at the cryo pump which is located behind the system.

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So, we want to make sure there is no moisture on top of the pump. If there is moisture; that means, the cryo pump has been dumped. So, we want to abort the process. So, to abort the process, we will make sure to turn the high vacuum off and then go to the chase and turn the compressor off. In case the cryo pump has been dumped, you want to make sure you turn. The pressure off the compressor is found in this chases room 237. And before you go on you want to make sure there is no odors or chemical spills if there is, then you would notify staff it looks like it is fine to go in. So, we are go in and turn off the compressor.

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This is the compressor for the E-beam one cryo pump. So, if they have all E-beam 1. So, it is part of one and if the cryo pump is dump you need to try to switch off.

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Switch is located here and you turned this off if the cryo pump is dumped. After this turned off would you know the (Refer Time: 25:51) know the system has been dumped. So, we are going to wait to the high vac, goes in to the bigger four range because we are going to negative (Refer Time: 26:00) range (Refer Time: 26:02) on. So, we will wait for. So, high vac to pump down what the pressure of the thermal couple (Refer Time: 26:16)? So, we turned it on to see the pressure is 6.8 to 10 to the minus 5. So, we watch the system and we are going to make sure that it is still high vacuum (Refer Time: 26:33), now we can read the (Refer Time: 26:34) comeback after about 2 hours (Refer Time: 26:36).

So, what you understood? You understood that how the E-beam evaporator would work? What are the sources within the E-beam evaporator? What is the advantage of E-beam evaporator over thermal evaporation right and what are the different kind of pockets available if you want to have multiple sources is not it?

Now, this E-beam evaporator or thermal evaporator both are based on the heating and that is why it is a bigger umbrella is thermally the thermally evaporating or electrically heating the material. Because in both the cases either in this electron beam or heating the source holder we are using a electric energy right. So, electric either we are heating it up with the help of a power source or we are using electron beam and in both the cases we are melting the material and then evaporating it. There is one more you know technology that that is used for depositing this film and that is called sputtering. Sputtering is a mechanical way of dislodging the atoms from the source and depositing on to the substrate.

Now, if you have seen when there is a metal roof and if the rain falls drop by drop did sound that comes if it is tak tak tak right this is sputter. So, that is why from that phenomenon it is called sputtering because here also it feels like a raindrop, but in instead of raindrop we are using atoms to dislodge the. So, the gas is used to dislodge the atoms and atoms fall onto the substrate and deposit a film. So, it is like one, second, third, fourth, fifth, sixth, seventh, eighth and so, on.

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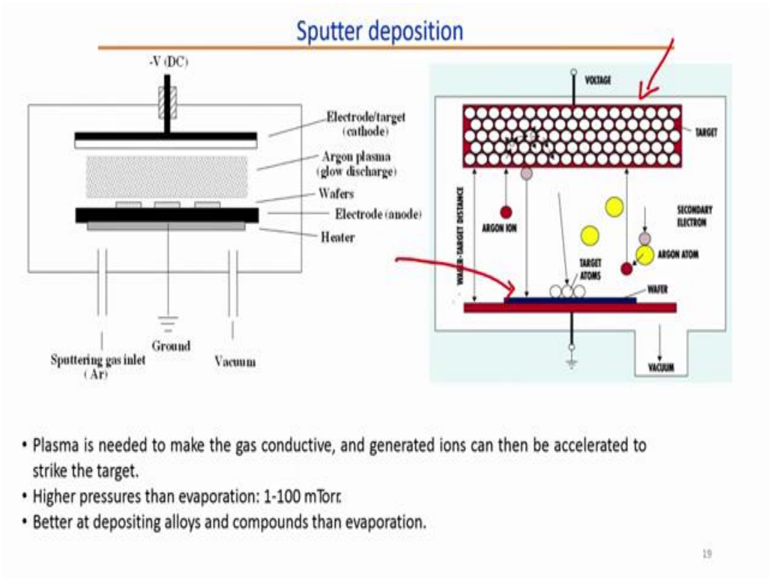

So, let us see the sputter deposition you can see here sputter deposition system. The these sources you know on the top and the substrate is on the bottom all right and what happen is, that when you have a vacuum and you introduce argon then argon ions will dislodge the atoms from the target and this atoms which is target atoms or you can say source atoms will get this large mechanically.

Because argon ion will heat it and when the target atoms are dislodged it will move towards the substrate or subsidies a wafer right. So, every time when you have a high vacuum this phenomenon occurs under introduction of argon, there will be plasma generated and this argon ions will dislodge the target atom and this target term would travel towards the substrate or a wafer creating a film. The advantage of this particular system is that, we can deposit alloys and compounds better than evaporation technique better than E-beam evaporation as well as the thermal evaporation.

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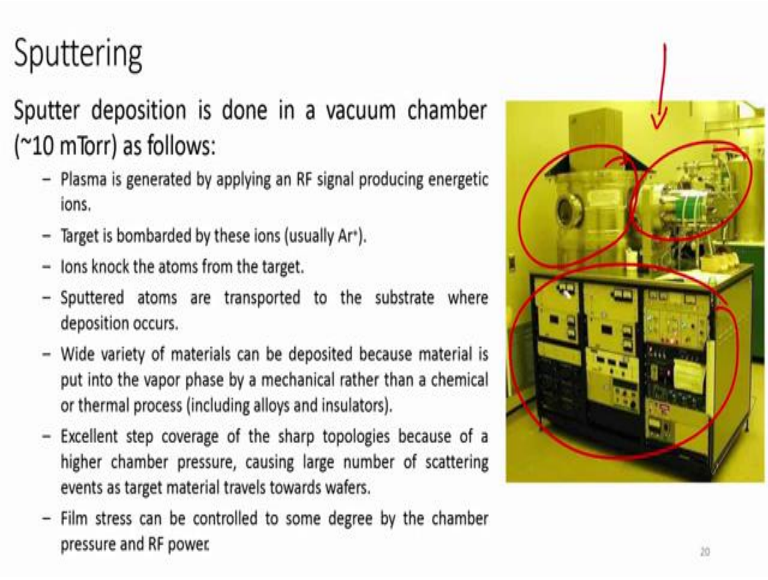

So, this is an actual system of a sputter unit, this is the chamber where the things happens, these are all the controls which has electronic control, and this is a vacuum system that will create a vacuum. So, this is how the sputter system looks like and the plasma is generated by applying RF energy or RF signal, target is bombarded with argon ions, we already discussed this iron knocks the atoms up from the target, sputtered atoms are transported to the substrate wide variety of materials can be deposited.

Because material put in the vapor phase by the mechanical rather than a chemical or thermal process though this is like mechanical dislodging or mechanical way of depositing their film the advantage other. Advantage is that there is a excellent step coverage of the sharp topologies causing large number of scattering events finally, film stress can be controlled to some degree by chamber pressure and RF power.

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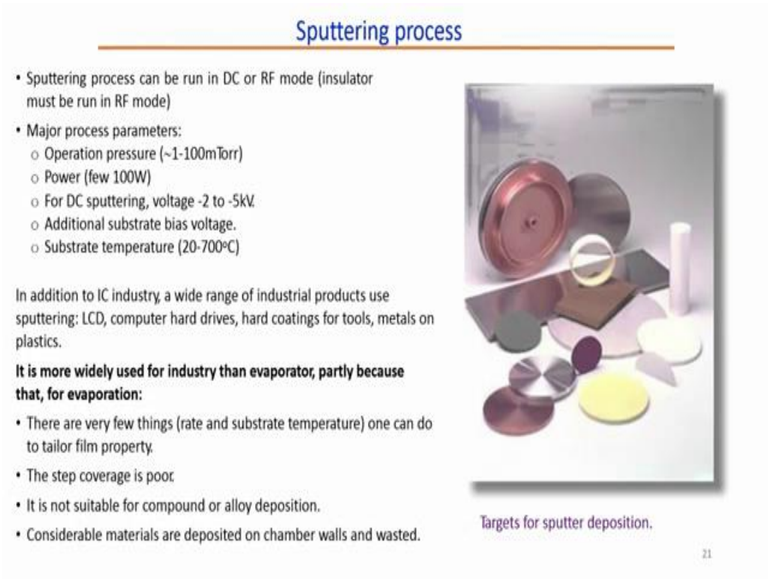

Now, what are these sources or a for sputtering? Sputtering process can be done in two modes one is called DC sputtering another one is called RS sputtering; sputtering can also be magnetron. So, if it is a magnetron sputtering that you can say DC magnetron sputtering and RF magnetron sputtering. Major process parameters are given over here right.

The sputtering is one of the most used equipment in thin film deposition, in addition to IC industry several other industrial products use sputtering whether it is computer devices or hard drives hard coating for tools, metals and plastics LCD and the advent and the reason of using it widely then evaporator is because, there are very few things one can do to tailor the film property this step coverage for the evaporator is poor it is not suitable for compound or alloy when you talk about evaporation unit and finally, consider materials are deposited on chamber walls and wasted while in case of sputtering it is not.

So, these are few targets that are used for inside the sputter system. So, let us see again two different videos to understand the sputtering system and then we will compare the air wherever and the limitations of this sputtering system and you play the first video.

The use of thin layers of materials is a crucial need in many industries. Architectural glass displays and touch panels or solar cells all contains thin films. The most important coating process to produce these layers is called sputter deposition. How does it work?

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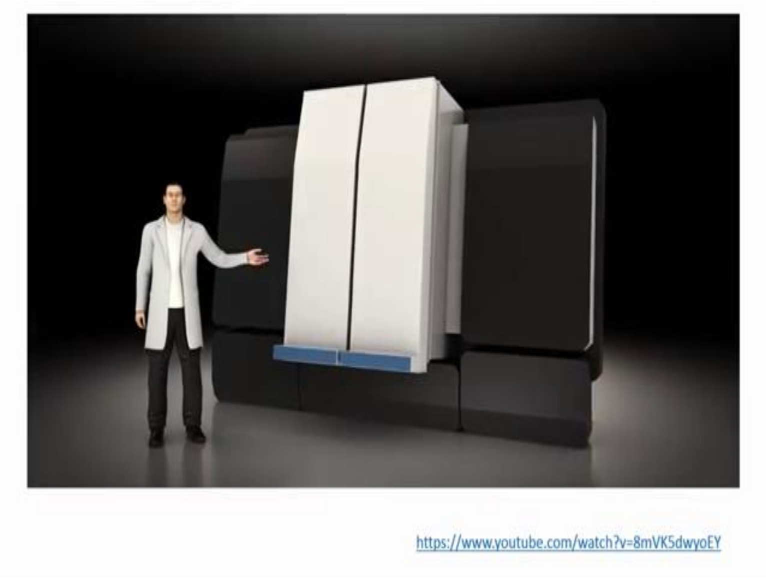

Sputtering deposition is done in a vacuum chamber, the most common substrates for the thin layers is glass the sputter system can have different sizes depending on the application.

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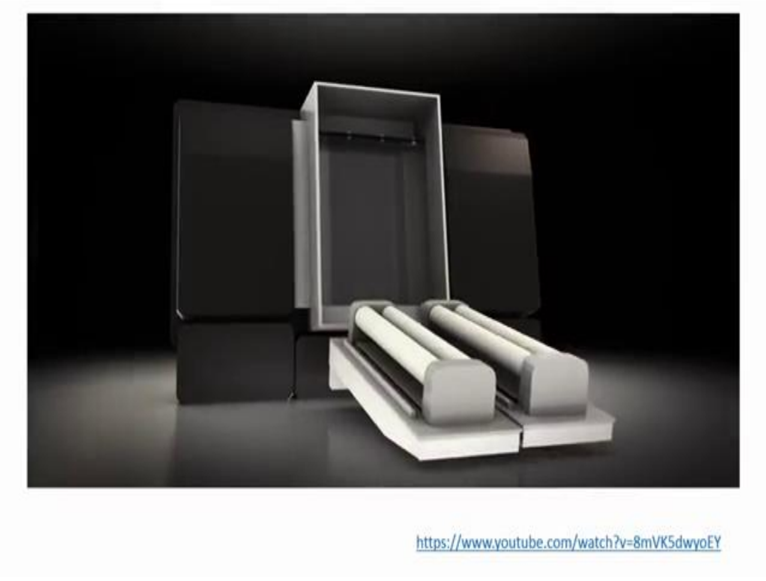

The source of the thin film material is a planner or rotary sputtering target of metal ceramic or even plastic molybdenum targets. For example, are used to produce conductive thin films in this place or thin film solar cells.

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At this point the process starts, air is continuously removed by vacuum pumps. The base pressure in the vacuum is around 10 to the minus 6 millibar which equals about a billionth of the atmospheric pressure.

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Argon gas is introduced continuously to achieve a low pressure argon atmosphere. A magnet array inside the cylindrical target generates a magnetic field. The target is filled with cooling water which will dissipate the heat generated during the sputtering process.

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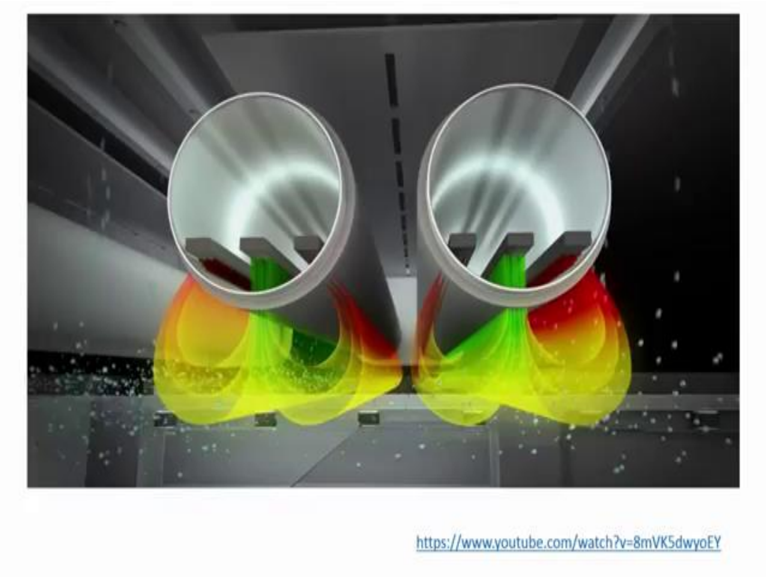

The targets are rotating so, that the material will be utilized uniformly. A high voltage is applied to the molybdenum target; it creates a plasma which is concentrated along the magnetic fields.

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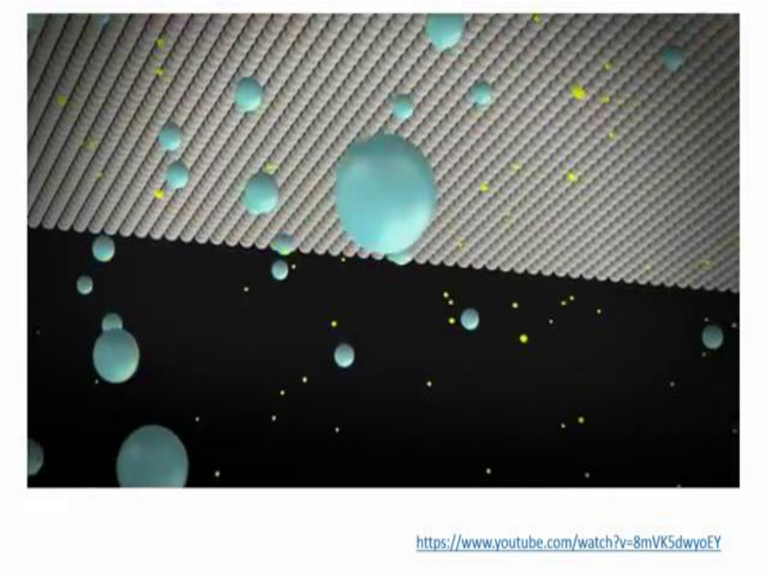

The plasma consists of argon atoms positively charged argon ions and free electrons.

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Positively charged argon ions are continuously generated by electrons hitting the argon atoms. Sputtering target is negatively charged therefore, the argon ions are attracted towards it is surface let us see what happens.

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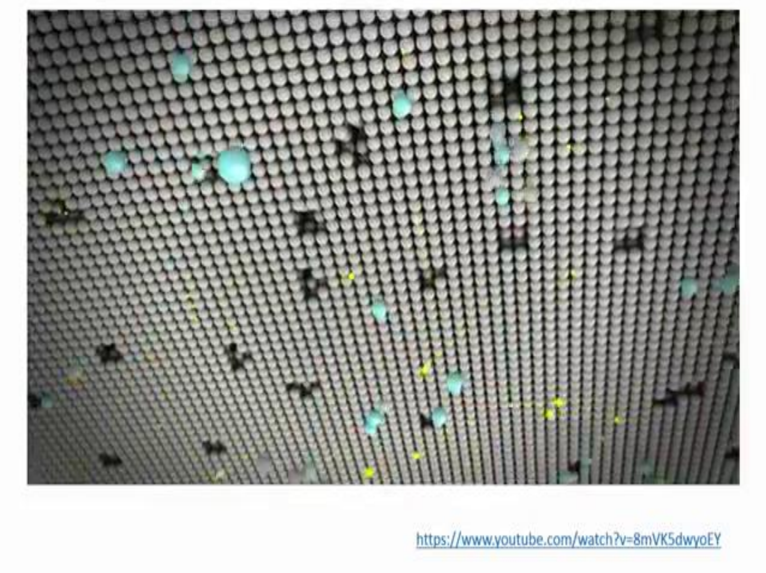

The argon ions collide with the target and eject molybdenum atoms from it is surface, this is what the sputtering process is all about in a way it resembles a game of billiards, do not you think?

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https://www.youtube.com/watch?v=8mVK5dwyoEY

Layer by layer dejected molybdenum atoms are deposited onto the glass substrate opposite the sputtering target.

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https://www.youtube.com/watch?v=8mVK5dwyoEY

But let us go back to the target material, no metal can be made 100 percent pure. Iron or chromium impurities in molybdenum targets are critical, why is that? Argon ions do not distinguish between molybdenum and impurities; impurities will also be sputtered and incorporated into the thin film.

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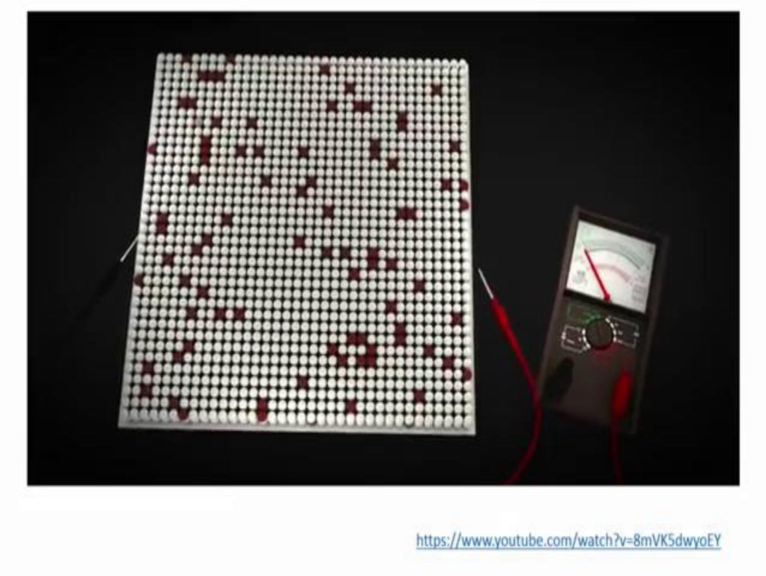

Nobody wants that. Impurities can negatively influence the thin film properties the electrical conductivity for example, only highly pure sputtering targets can ensure high quality thin films.

And that is what (Refer Time: 35:19) we are the only manufacturer to supply molybdenum at a guaranteed purity of 99.97 percent. Typically the material is even pure, it is this purity that our customers rely on to create the best products in the market.

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Let me also play the second video also, here you will see how this sputtering occurs and in detail here you will be able to see in the second video you are able to see that what are the these subsystems within sputtering and that is why I particularly have selected this video. So, that you can see the internal parts of this parting unit ok. So, there is an advantage of this one.

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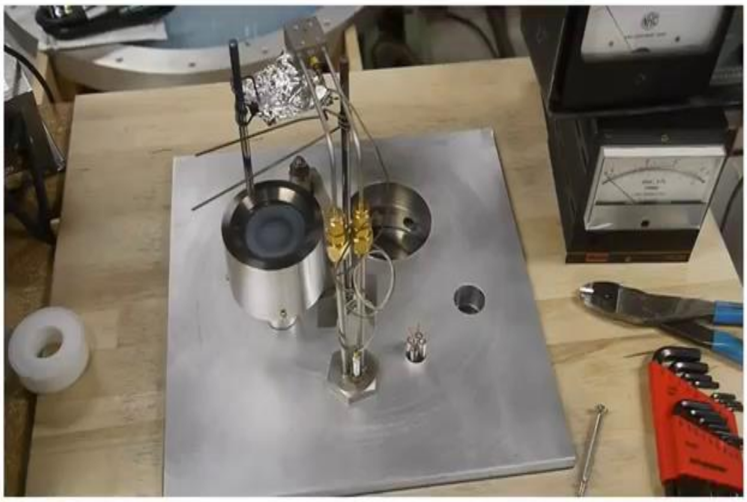

https://www.youtube.com/watch?v=9OEz_e9C4KM

Hey everyone, I was finally, successful in depositing a clear conductive layer onto a microscope slide.

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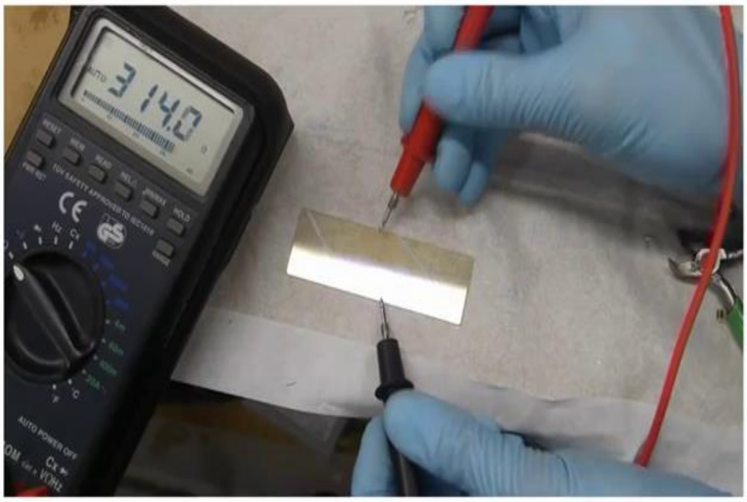

https://www.youtube.com/watch?v=9OEz_e9C4KM

So, this will be the basis for a lot of my future experiments in leds and other display technologies. So, let me show you how I did it. The device that is actually doing the depositing is called a sputter gun and I machined mine from basic pieces of metal and I am going to unscrew it here like this and eventually the whole thing just comes off like so.

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https://www.youtube.com/watch?v=9OEz_e9C4KM

And down in the hole here is a spark plug and it is facing up towards us. So, on the underside there is the rest of the spark plug of course, and then right next to it there is a needle valve with a hose coming off and the hose runs to my argon cylinder. So, I can control how much argon is getting into the chamber through the needle valve and I can get high voltage into the chamber through the spark plug.

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https://www.youtube.com/watch?v=9OEz_e9C4KM

And the underside of the sputter gun has a rod in here that contacts the top of the spark plug. So, I have sort of a shielded entry into the chamber a sputter gun itself is relatively simple in construction. So, let me just take it apart and show it is inside and then describe how the whole process works. So, the very outside is called a ground shield and it slides off like this and the purpose of this is just to keep the things that you do not want to sputter inside this. So, in the shield is on the only thing that is exposed to the chamber is the surface of this disc here, which is the thing that we want to sputter to send off onto the microscope slide.

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https://www.youtube.com/watch?v=9OEz_e9C4KM

So, if we take that off the rest of it is built like this and between these two layers is an insulator. So, we will take this apart and currently there is some changes that I am going to make to this these are nylon screws and nuts holding it all together in nylon is not really a great vacuum chamber material. So, eventually I am going to upgrade this I am not quite sure what I am going use instead.

And so, this part is at the vacuum chamber case potential let us just call it ground and then the inner part here this is where it touches the spark plug. This is all at a negative high voltage let us say a 1000 volts negative. So, inside here we have got a very high potential between this outer shell and the inner shell, but there is a few other tricks here that allow us to sputter just the target material and not sputter the rest of it.

So, I will open this up and as you can see I am missing quite a few screws because I have not got the right ones in yet and I just wanted to test this quickly. Inside here is a magnet a ring magnet neodymium ring magnet and an a steel pole piece that I turned on the lathe and so, the idea here is that when the magnet is inserted into here like this there is a nice magnetic field on the top here and you can even see one that I cracked my disk unfortunately.

So, I am not going to undo the top layer just yet, but also that there is a ring pattern where the disk has been eroded by the sputtering. I have also got some holes in here for a cooling system which unfortunately I did not have running yet that is hence the cracked disk.

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And the idea with that would be this is a sort of a Teflon hose, it is actually called a plastic called pfa with a within a o ring on like this, the hose can be sealed up to this and then within an O ring in the right spot, here this whole thing closes up and I can actually pump water through the copper block.

So, a lot of sputtering systems say they require water cooling and I always you know thought that only applied to like systems that ran for you know 8 hours a day I figured that the thermal mass that this block would be enough to keep me safe for a you know a 5 minute run, but as it turns out not quite. I am not sure if this was due to my clamping or you know too much power or something, but I think water cooling is kind of a necessary thing if you want to sputter stuff at any reasonable rate ok.

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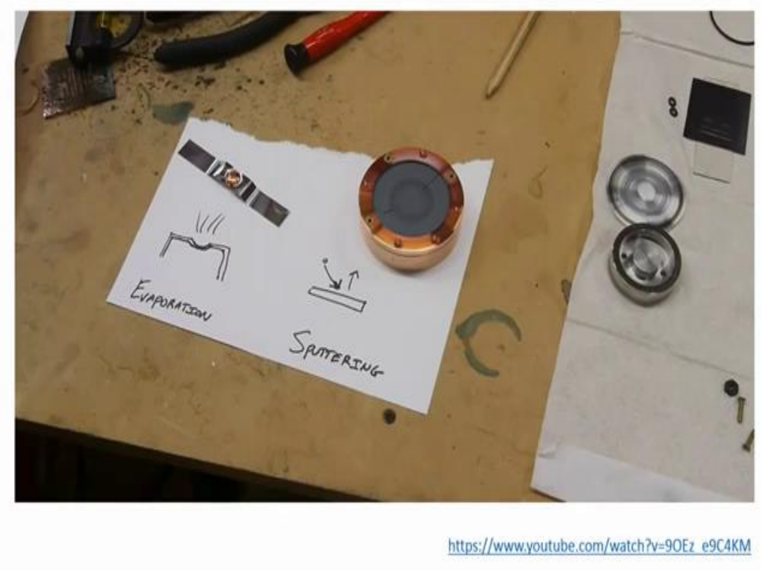

So, let me tell you how this thing actually works. So, if you want to make a nice uniform coating on something say like a microscope slide, you have a few different options and two of the most common ones or evaporation and sputtering. So, in a previous video I described the evaporation process, and this entails heating up the material that you want to coat. Sorry heating up the material with which you want to make the coating and typically that is done in a metal boat like this. So, what we do is pass a really high current through here this thing becomes very very hot, white hot even yellow hot and material here evaporates and then condenses on the thing that you want a coat.

So, this is you know roughly analogous to boiling water in the kitchen and then noticing water droplets condense on a cold window. The downside with this is that you have to heat up the material to that yellow hot temperature. So, if your material cannot take it for whatever reason or if it changes into another material at that temperature, then this is not it going to work and when we are talking about making conductive ITO coatings this is definitely the case where if you heat IT IO up in a vacuum as far as I know it reduces itself back down to base metals and it does not work.

So, an alternative process is called sputtering and this works by accelerating gas molecules and slamming the gas molecules at very high speed into the surface of the material with which we want to make the coating. And when that happens it is just the right energy levels, it actually chips off a few molecules of the surface of this material and they go spraying off into the chamber and eventually they will land on the thing that you want to coat.

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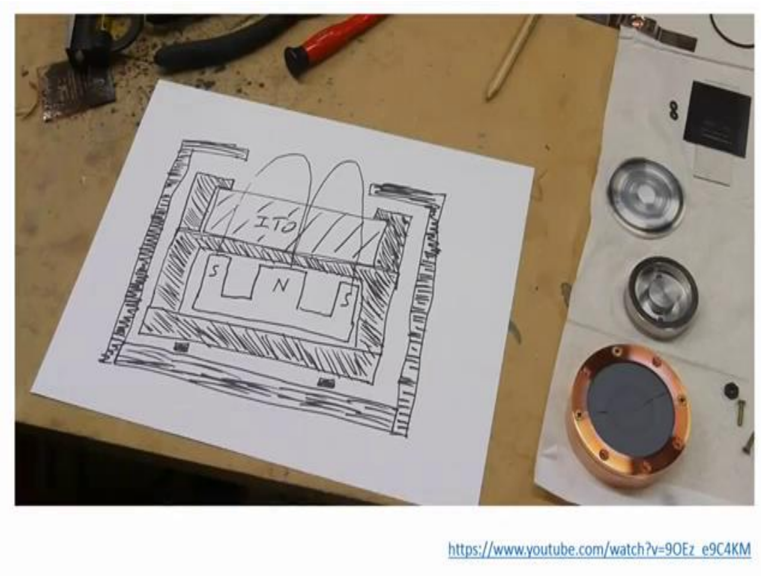

So, here is a cross section view of the sputter gun, the I to disc is the thing with which we want to make the coating and then we have got our magnetic pull piece here with north and south poles it does not matter, which is which I do not think the idea with the pole piece being that the magnetic flux goes through the steel and then back up you know through here. So, the magnetic field lines look like this; this whole intersection here is at about negative a 1000 volts and the outer section is at 0.

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So, when we pump down the chamber to a very low pressure and put our 1000 volt potential difference on here the remaining gas molecules in the chamber will ionize, Au basically just like they do in a neon sign and the trick with the magnet is that it concentrates all of the electrons in this area. And it does this because the electrons are relatively lightweight and they have charged. So, the moving electrons are affected by these magnetic field lines in fact, they actually spiral around the magnetic field lines, we have concentrated all the electrons in this area.

However, it is not the electrons that are actually doing the sputtering for us what happens is these sputtering fast moving electrons end up ionizing more gas molecules and it is actually the gas molecules that are attracted to this negative potential and hit the surface and cause the sputtering to happen, which is why this is negative and the shield is relatively positive for at 0. This negative voltage attracts those positive gas molecule ions and that is what causes the sputtering. The reason that we use argon is because we do not want an incoming gas molecule to react chemically with our material here.

So, for example, let us just say we were sputtering aluminum and we had oxygen up here, what might happen is a really energetic oxygen molecule might hit this and create aluminum oxide it might not actually sputter the material it might react with it. And sometimes that is desirable volt depending what kind of process we are doing, but generally you want to control those gases very carefully. So, for a lot of sputtering we just use pure argon. The exact pressure at which this whole process works is very critical to determining the success of your coating. So, if you have no gas molecules up here; obviously, the process does not work at all because there is nothing to cause the sputtering that is at a really high vacuum.

And really poor vacuums if you tons and tons of gas molecules up here, it is true you will certainly they will just slam them into the surface; however, the high pressure is such a good conductor because there is so, many ions, it is tough to get the voltage high enough. So, that the incoming ions are going too slow to cause the sputtering to happen you will have a nice glow discharge and things will look like they are working.

But you just cannot get the voltage high enough without you know blowing everything up basically another problem is that if you have tons of gas molecules up here when you eventually do sputter off a piece of the material it is going to interact or it is going to hit those gas molecules and that may or may not be a good thing depending how your setup is configured.

So, if your surface that code is kind of up here, you generally want these sputtered molecules to have a fairly clear path toward it. If there is so, many gas molecules up here that a lot of the sputtered material interacts with the gas and kind of starts flowing, that may be a bad thing because they are going to escape and coat other things on the surface of your chamber. It seems in the literature that most people prefer 10 to 100 ml of Tor for proper sputtering pressures.

But it is also very common to use the diffusion pump anyway and pump the chamber way down as low as you can get it basically just to clean everything to get the water molecules and everything to evaporate of the surface, and then backfill it with argon back up to the pressure that you want.

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https://www.youtube.com/watch?v=9OEz_e9C4KM

In my first few experiments, here I have noticed that controlling the pressure is actually surprisingly difficult and also as the literature says has a pretty profound an effect on how the sputter process is going.

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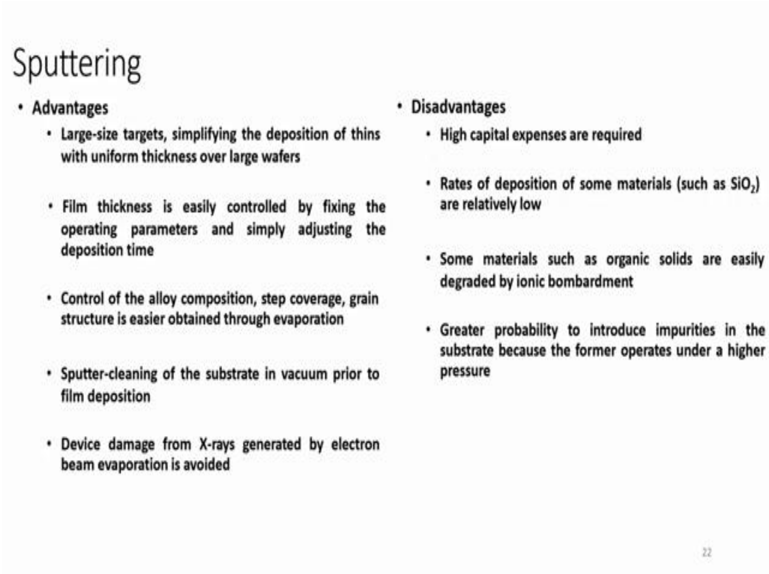
https://www.youtube.com/watch?v=9OEz_e9C4KM

I have been using an electrophoresis power supply for my first attempts here. And it turns out to be a very non ideal power supply for this purpose, besides all the stupid safety interlocks that are making it difficult to use, the supply goes into it is current limit condition kind of too quickly and it is hard to get a consistent voltage current out of it. It is nice that it has a constant power function. So, you can actually set a desired wattage and then play with the chamber pressure and it will balance the voltage and current without exceeding that power limit. However, I think for future experiments, but I am going to use is just a microwave oven transformer with the standard diode and control it with a very (Refer Time: 47:31). (Refer Slide Time: 47:45)



Now, let us come to our second last slide for the today's module and if you see the slide the sputtering has advantages and limitations. So, what are the advantages? If you can focus on the slide you will see that, the advantages of sputtering system are large size targets, simplifying the deposition of films, uniform thickness. Second is film thickness is easily controlled by fixing the operating parameters and simply adjusting the depletion time.

Then the third advantage is computed control of the alloy composition, along with good step coverage grain structure is easily obtained through evaporation. Sputtering cleaning of the substrate in vacuum prior to film diversion, this is very important because every time if you want to clean the system before a deposition it is very easy to use sputter compared to the E-beam main thermally evaporation.

Finally, damage the device damage from excess generated by E-beam is avoided; in case of E beam the secondary byproducts are X-rays which are which will cause damage when you create MOSFETs in particular another transistors and that is why the device damage if you use patterning would be minimal. While when you can talk about the disadvantage or limitation of the sputtering system there are several such as high capital expenses, rates of deposition of some materials such as SiO2 are relatively low, some materials such as organic solids are easily degraded finally, greater probability to introduce impurities in substrate because formal operations are a high pressure. So, these are some of the limitations.

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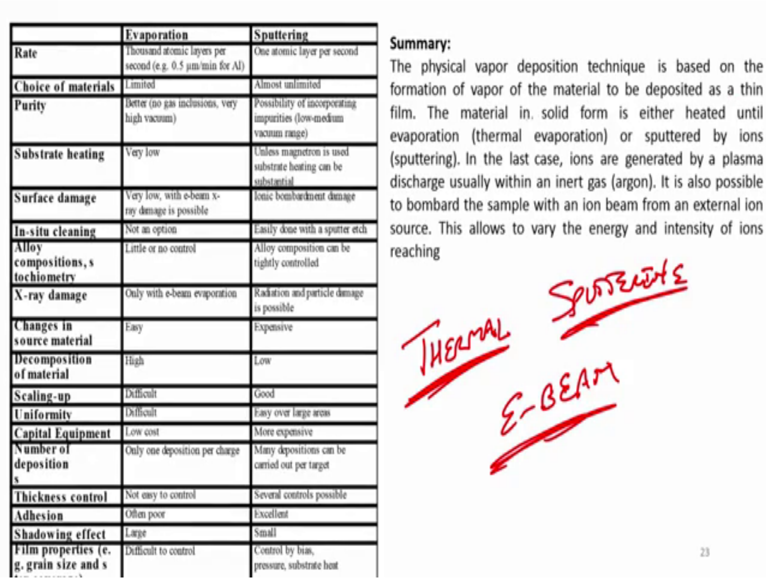

	Evaporation	Sputtering
Rate	Thousand atomic layers per second (e.g. 0.5 μm/min for Al)	One atomic layer per second
Choice of materials	Limited	Almost unlimited
Purity	Better (no gas inclusions, very high vacuum)	Possibility of incorporating impurities (low-medium vacuum range)
Substrate heating	Very low	Unless magnetron is used substrate heating can be substantial
Surface damage	Very low, with e-beam x-ray damage is possible	Ionic bombardment damage
In-situ cleaning	Not an option	Easily done with a sputter etch
Alloy compositions, stochiometry	Little or no control	Alloy composition can be tightly controlled
X-ray damage	Only with e-beam evaporation	Radiation and particle damage is possible
Changes in source material	Easy	Expensive
Decomposition of material	High	Low
Scaling-up	Difficult	Good
Uniformity	Difficult	Easy over large areas
Capital Equipment	Low cost	More expensive
Number of depositions	Only one deposition per charge	Many depositions can be carried out per target
Thickness control	Not easy to control	Several controls possible
Adhesion	Often poor	Excellent
Shadowing effect	Large	Small
Film properties (e.g. grain size and s	Difficult to control	Control by bias, pressure, substrate heat

While we compare the E -beam and sputtering then we can see that if you compare the rate choice of material purity substrate rating and several other parameters, then you will find that the sputtering is way better in a lot of applications, lot of parameters compared to evaporation. However, depending on the application a person will select or a scientist should select or researchers will select a type of technology, if I just want to create a contact layer of aluminum I will rather go for evaporation then for sputtering.

But if I want to go attempt by late atom layer, then or one atomic layer per second then we can go for sputtering because internal evaporation is not possible. Also if I want to see any source then I can use for sputtering compared to thermal evaporation, where the source melting point is very important. When talking about purity, the purity of the evaporation is little bit better than sputtering while the substrate heating in the evaporation is less and in a sputtering if you use magnetron, the subtracting would be less but if you do not use magnetron the substituting would be substantial.

Then we talked about surface damage, then adding embodiment damage in sputtering is possible while in the case of evaporation you have a very low, but there is a generation of X ray. In-situ cleaning which is possible in sputtering it is not possible in evaporation; alloy composition to sociometry we have little or no control in case of the evaporation while in case of the sputtering it is tightly controlled X-ray damage like I said only in E-beam evaporation were radiation with particle damage is kind of possible. In sputtering decomposition of material is high in evaporation compared to sputtering changes in source material.

This is very easy in case of spot evaporation well in sputtering you are tio it is very difficult as you can see as you have seen from the video. Scaling of the system is good in case of sputtering, but while a case of evaporation it is difficult uniformity also is better in case of sputtering when you talk about large area, capital equipment is also more expensive, sputtering is more expensive than evaporation number of deposition many deposition you can do it can be carried out for target while only one deposition for change or per charge; thickness control is possible in sputtering with several control is possible when in case of evaporation it is not easy.

Finally we have addition, addition and sputtering is excellent and that is why when it is about the metal edition people prefer sputtering over the evaporation. However, this shadowing effect is also less or small in case of sputtering and you are compared to evaporation that is why you have better uniformity of the film also step coverage. Finally, the film properties such as grain size and other parameters is difficult to control in case of evaporation, while in the case of sputtering is very easily controlled.

So, if I want to have a summary, summary is physical vapor deposition consists of three techniques one is called thermal evaporation, second is called sputtering and third one is called E-beam evaporation right thermal evaporation, E-beam evaporation, sputtering. So, is a technique based on the formation of vapor on the material to be deposited as a thin film, the material in solid form is either heated until evaporation right or sputtered by ions. While in the last case ions are generated by plasma, which is the sputtering case right with an with inert gas it is also possible to bombard the sample with an ion beam from external ion source, and this will allow to vary the energy and intensity of the ion reaching to the substrate.

So, this is the last slide for today's module, and I hope that you understood the process of how this sputter system works and how the E-beam operator works. In the next classes we will be looking at the lithography system in some of the videos on lithography, and then will actually start fabricating or process flow of fabricating several sensors and transducers or sensors and actuators.

So, till then you take care look at the this particular module, understand the technology right the idea of you of me showing these things to you is to make, you familiar with the technologies available for depositing several films whether it is metal or semiconductor or insulator all right. So, till then you take care I will see you in the next class bye.