Fabrication Techniques for Mems-based Sensors: Clinical Perspective
Prof. Hardik J Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture – 06
Physical Vapour Deposition

Hi, welcome to this particular module. So, here what we will be learning today is what you mean by Physical Vapour Deposition. If I want to deposit a metal on a substrate right, for example.

(Refer Slide Time: 00:38)

Let us say we want to form this pattern; from this pattern on a substrate which is my silicon wafer right or.

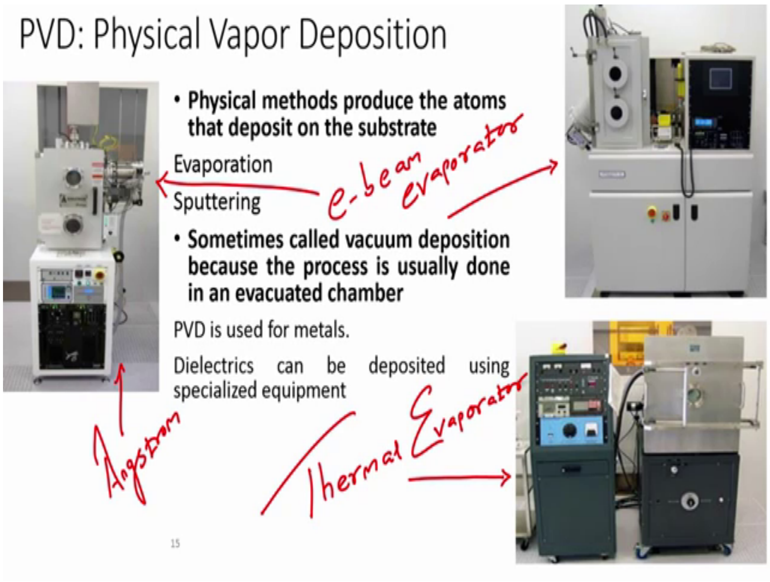
(Refer Slide Time: 00:57)

I want to form this pattern on my silicon substrate or oxidized silicon substrate. So, this pattern is formed using photolithography, but first point is how can I deposit this metal this is gold by the way. So, how can we deposit this metal how can we deposit an insulator, how can we deposit a semiconductor. So, the answer to the question is by using techniques which is physical vapour deposition. So, as a name suggests we are using physical technique to vaporize the material and deposit it on the substrate.

Now, when we talk about physical vapour deposition then within physical vapour deposition, there is thermal evaporation, electron beam evaporation and sputtering. So, we will today look at all three techniques to understand how can we deposit a metal semiconductor and insulator on the substrate. And as we know substrate can be glass, substrate glass is what insulator substrate can be semiconductor which is silicon or germanium or gallium nitrate or silicon carbide. It can be anything that you can that you are using as a base it can be metal substrate as well alright.

So, let us start with thermal evaporation and what do you mean by thermal evaporation? Thermally evaporating something right. So, what is that something we will we will look at that things it can be we will take an example of a metal and we will see how we can evaporate the metal is in thermal operation.

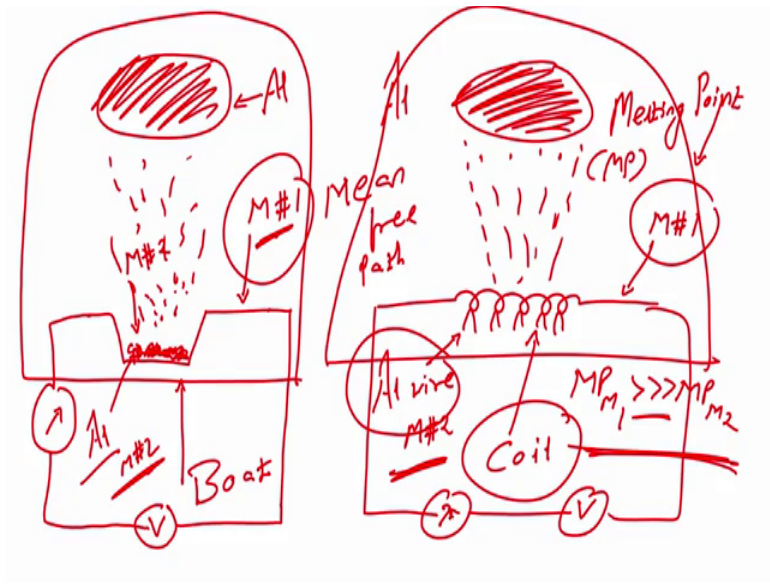
(Refer Slide Time: 03:25)



So, if you see the screen physical vapour deposition the physical methods produce the atoms that deposit on the substrate. Two techniques; first one evaporation, second one sputtering sometimes physical vapour deposition are also called as vacuum deposition, because the process is usually done in an evacuated chamber.

PVD is used for metals in general not limited to metals however, and dielectric can be you can be deposited using specialized equipment. So, this particular system is a thermal evaporator, thermal evaporator this and this system this both are e beam evaporator ok. So, what is thermally evaporator and what is e beam evaporator we will see. this system is from a company called Angstrom company name is Angstrom.

(Refer Slide Time: 05:42)



Now, let us see how thermally evaporation can be done. So, this is called boat and this is your coil this is boat and another one is your coil. And these are used to hold the, these are used to hold the materials of our interest that we want to deposit. So, what do you mean by that let us say I have aluminium chunks of aluminium loaded on the boat or I have aluminium wires loaded on the coil. Now how to deposit this aluminium either in the wire formed aluminium wire or aluminium chunks onto a substrate.

So, this is metal and let us say metal number 1 aluminium is our metal number 2. Same way this will be our metal number 1 and aluminium wire will be metal number 2. Now, if I heat this metal 1; so, since it is metal it has extremely low resistance right. So, if I apply a voltage because of the low resistance there will flow of current there will be flow of current. And there will be extremely a high current flowing through the boat; extremely high current flowing through the boat, because of extremely high current flowing through the boat. The boat will start heating because of the I square R effect also called as joules heating.

And the metal within the boat will start melting will start melting. If I keep on increasing the power what will happen this metal will start evaporating, metal will start evaporating vaporizing and evaporating alright.

Same thing goes for aluminium as well same thing goes for aluminium as well. What I mean by aluminium as well aluminium wire as well, because aluminium wire it will also melt and vaporized. When I apply a very high power to my coil which is my metal 1 and the metal will start evaporating by melt first is melting followed by vaporization melting followed by vaporization. So, finally, we will have metal on the substrate we will have metal on the substrate which is our aluminium right.

Now, sorry we have to have this entire system on this system in a chamber why we need to create a vacuum why because we need to create a vacuum.

Now, what is the role of vacuum why we have to create a vacuum here, why we have to create vacuum because we want to have very high mean free path mean free path. If the mean free path is higher we will have a better deposition with less collision when between the atoms when they are getting deposited from solid to vapour to solid to melting point that is your melted version that is your liquid. Or semi-solid or semi liquid to vapour and finally, decaying deposited on the substrate.

So, if the mean free path is higher then I have less collusion between the atoms and a better deposition. That is the role of vacuum and that is why e beam evaporator or thermal operator or sputtering is generally carried out under the vacuum.

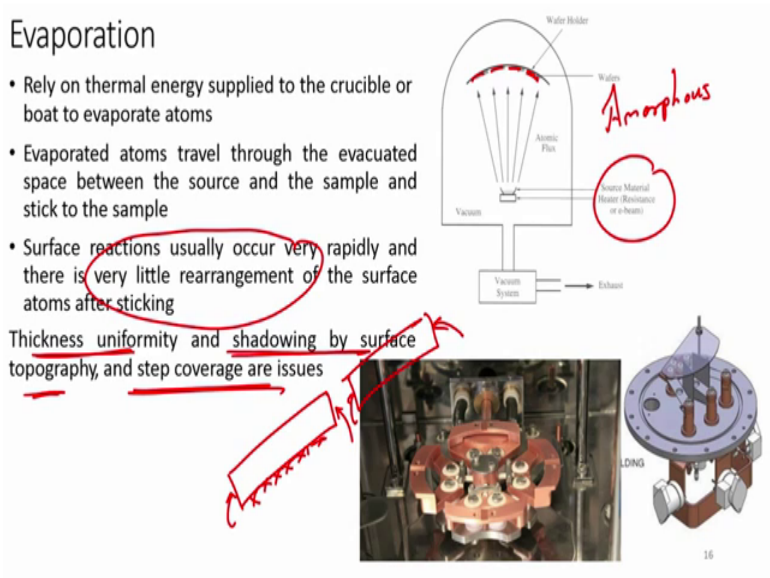
Now, the very important point that you need to remember in this particular example, is that when I am heating metal 1, my metal 1 is not getting evaporated only my metal 2 is getting evaporated correct. My metal 1 is not affected only my metal 2 is affected if this aluminium is by metal 2. That means, to have a good deposition or to have to evaporate a material of our interest that is material which is loaded on the a boat or coil. The melting point, let us say melting point we denote by MP.

So, melting point MP of metal 1 should be very higher than melting point of metal 2 you got it. Melting point of metal one should be extremely high compared to melting point of metal 2. That is the melting point of boat and coil should be extremely high compared to melting point of aluminium. And that is why when we have when we want to deposit a material which of which melting point is extremely high for example, silicon dioxide the melting point of silicon dioxide is very high and we cannot use thermal evaporation.

Also some sub some material some metal we cannot use thermal evaporation. Because the melting point is high it we do not have a substrate or. So, we do not have a source which has a similar melting point like the material that we want to deposit that is we do not have anything which is MP melting point M 1 greater than greater than MP M 2.

Because if the melting point is close to the melting point of the material that we want to evaporate then the metal 1 will start evaporating as well instead of getting a single metal film will have a alloy understood. So, that is the drawback you can say or limitation of thermally evaporation. Thermal evaporation cannot be used when you want to deposit a material, which has a higher or high melting point which is close to the melting point of your boat or your coil. So, in that case what we can do? So we will see that we will see that in the later part of the this module.

(Refer Slide Time: 14:47)



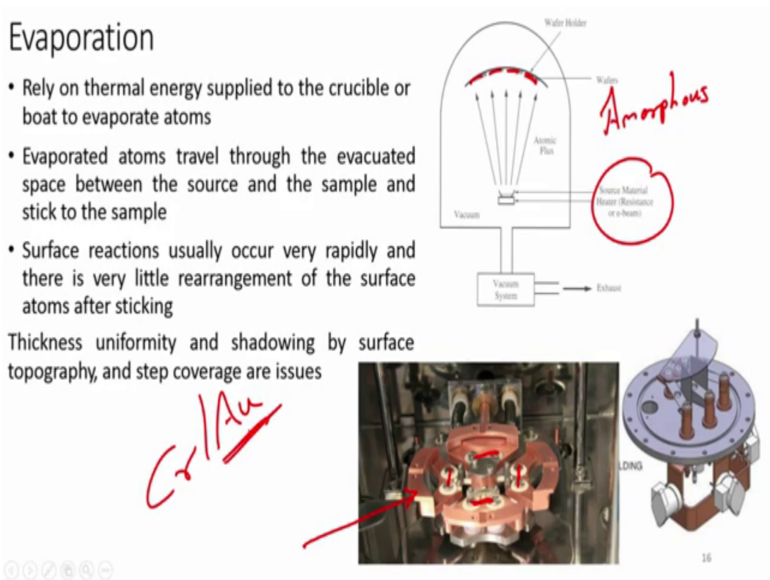
Right now let us see quickly the evaporation that is thermally evaporation rely on thermal energy supplied to crucible or a boat to evaporate we know it right; boat or crucible to evaporate. Evaporated atoms travels through the evacuated space between source and the sample and stick to the wafer stick to the substrate here, 1, 2, 3, 4 we have noted 4 wafers.

Surface reaction usually occurs very rapidly and there is very little time or rearrangement of the surface atoms after sticking. So, because there is very little rearrangement time most of the film that we deposit would be amorphous in nature. Most of the film that we deposit would be amorphous in nature.

Thickness uniformity and shadowing by surface topography and step coverage's are the issue. Thickness uniformity we cannot obtain there is a shadowing effect by surface topography and step coverage. So, if I want to deposit let us say these are my wafers right. This will be deposited correctly this surface, but what about this one steps would not be covered properly that is what you mean by surface topography or step coverage.

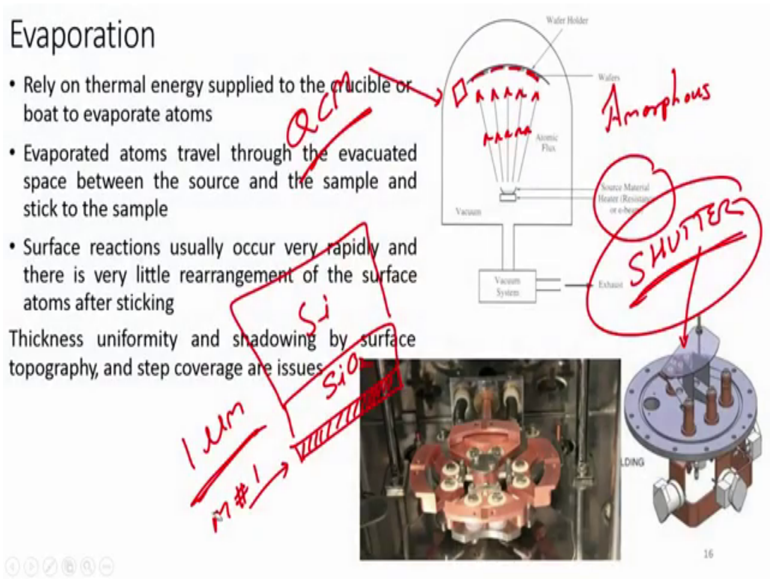
Now, the one that you see is an example of force source evaporation. At same time you can load source one here, second source third source and fourth source. Four source you can load at the same time and you can heat one at a time. So, first you can heat first particular source to deposit. So, the very it can be used when we want deposit chrome gold.

(Refer Slide Time: 16:55)



We cannot as you know we only few deposit gold, gold as a poor adhesion. So, to improve the adhesion of the gold we have to deposit a thin layer of chrome, now how to deposit chrome and gold both. So, if we have multiple source within the same chamber we can deposit first chrome followed by gold. So, here we can do multiple layer deposition using this the source shown here right. There is a advantage of this particular technology.

(Refer Slide Time: 17:47)



The another point is the shutter, what is a role of shutter? So, how you know the question is when I deposit let us say a metal how you know let us say I want to deposit one micron of material, when one micron will reach like when if I have a wafer and if I am depositing metal right.

This is my silicon dioxide this is my silicon and I want to deposit this metal which is 1 micron. How I know this is one micron for that we have something called quartz crystal monitor Q C M quartz crystal monitor is used to measure the thickness of the material that is deposited on the wafer ok, that is first answer what how you know what is the thickness.

Second thing is when we heat this material we only want to start deposition when everything is melted right. First is a solid we need to heat it should be melted once it is melted it will start evaporating when it start evaporating then it start depositing. So, we want to let everything melt it properly and then when we start evaporating at a time we want to start the deposition. So, how can we control this deposition by using a shutter.

So, you assume that there is a substrate that is a source which is in my hand here. Let us say this is a source this is a material with I am depositing right this is my hand is a sub boat and I applying very high voltage. So, this will start melting and when it start melting I do not want it to get deposited. So, somewhere in the top there is a there is a substrate and here there is a shutter.

When I open the shutter then only this material will get deposited on the substrate. If I have shuttered in between it cannot get deposited right this is the role of shutter, you see this is a role of shutter. So, shutter is very important in case, of evaporating a material because we want to start evaporating the material when it is completely melted in my source.

So, this is the idea that is why if you see the screen you will see very clearly the role of a shutter in thermal evaporation right. So, that is the role of shutter if you see here this is your shutter right. That is how your thermal evaporation will work, but like I mentioned if your material that you want to deposit has very high melting point thermal evaporation cannot be used, cannot be used.

(Refer Slide Time: 20:51)

So, now let us see the video of how the thermal evaporation can be used to deposit a material.

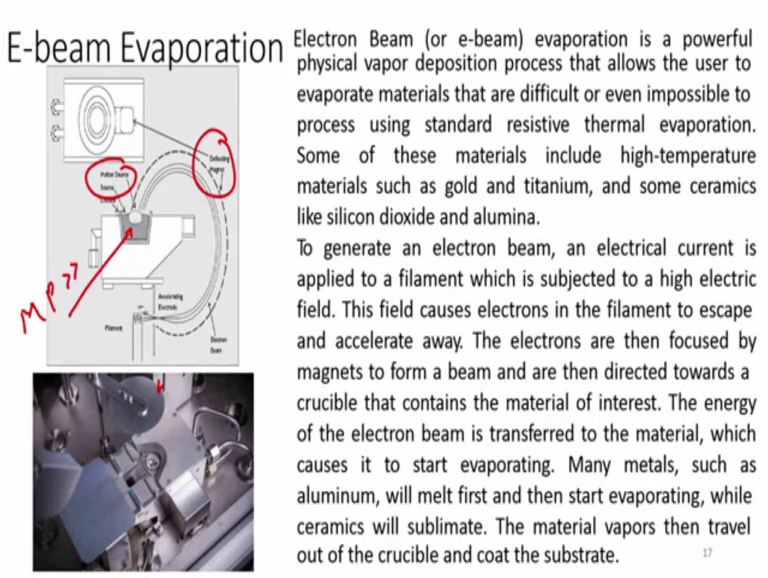
(Refer Slide Time: 21:14)

(Refer Slide Time: 21:53)

(Refer Slide Time: 23:14)

(Refer Slide Time: 25:16)

(Refer Slide Time: 25:26)



We will now see the e-beam evaporation. So, we have been looking at thermal evaporation and we have seen the there are few limitations of thermal evaporation. That if the material melting point is very high we cannot use it. So, what is an alternative technique, so that even the material has high melting point. We can still use the thermal way of depositing the material; thermal way of depositing the material.

So, the answer is electron beam evaporation electron beam evaporation. Here we have a crucible in which there is a source then there is a filament, accelerating electrode the electron beams are generated in the filament and they are accelerated through the accelerating electrodes. They are bent through a magnets which is a deflecting magnet and they are incident on the source. And because of the high energy the source will start melting that is why we have written here molten source, molten source.

In this case even the material that is the material of high intrest which is right over here. Is having a higher melting point material has higher melting point melting point is very high still we can melt it using e beam evaporation.

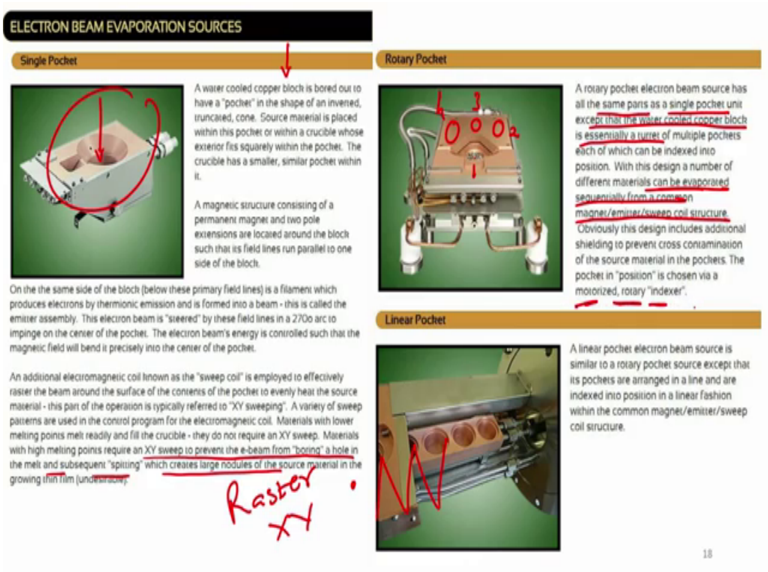
This is a actual photograph you can clearly see there is a shutter here right this is your shutter let me just clear the screen yeah. This is shutter, this is the source right e beam will come from here and will be incident on source alright. And the deflecting magnets as well as the source everything lies way below here.

Now let us see here, electron beam evaporation is a powerful physical vapour deposition process that allows the user to evaporate materials that are difficult or even impossible to process using standard, resistive, thermal, evaporation. Some of these materials which includes high temperature material such as gold, titanium and some ceramics like silicon dioxide and alumina. We can deposit very easily using e beam evaporation.

To generate an electron beam an electron electrical current is applied to a filament which is subjected to high electric field. This field causes electrons in the filament to escape and accelerate, accelerate. The electrons are then focused by magnets to form a beam and are then directed towards the crucible that contains a material of interest. We have just discussed this thing right. The energy of electron beam is transferred to the material which causes it to start evaporating.

A many metals such as aluminium will melt first and then evaporate while ceramics will sublimate we know it right, ceramics will sublimate. The materials the material vapours then travel out of the crucible and coat the substrate once it is melted it will travel out of the crucible and it will coat the substrate.

(Refer Slide Time: 29:38)



Now, we have a different type of evaporation sources for e beam, we have either single pocket or we have a rotary pocket or we have a linear pocket. So, single pocket for every single pocket we can have only one source loaded in this area only one.

Rotary you can see the one that we have seen was rotary you see here this one is a rotary pocket system. So, you can see one source here there are other source is here. So, whenever you want we can bring the source in front and remaining source we can shield it using this particular mechanism.

So, a single pocket is a water cooled copper block is bored out to have a pocket. In the shape of an inverted truncated cone source material is placed within this pocket or within a crucible whose exterior fits squarely within the pocket, the crucible has a smaller similar pocket within it.

A magnet structure consisting of permanent magnet and two pole extensions are located around the block such that its fields run parallel to one of the side blocks alright. So, here we have everything comprising in same system, on the same slide of the block is a filament which produces electrons by thermionic emission and is formed into a beam that is called emitter assembly.

The electron beam is steered by this fields in 270 degree arc to impinge on the center of the pocket. The e beam energy is controlled such that magnetic field will bend it precisely into the center of the pocket. An additional electromagnetic coil called sweep coil is employed to effectively raster the beamer on the surface of the content of the pocket to eventually heat the source material.

This part of operation is typically referred to as XY sweeping alright. So, there is a XY sweeping there is a raster scan raster scan, there is a XY sweeping and there is a direct incident of the e beam.

A variety of sweep patterns can be controlled there is also something called triangular. A verity of sweep patterns are used in control program for electromagnetic coil, materials with lower melting points melt readily and fill the crucible they do not require expensive materials with a higher melting point require an expensive to prevent e beam from boring a hole in the melt. And subsequent spitting which creates large nodules of source in the material growing thin film, what do you mean by that?

That if a material has a very high melting point then we require XY sweep if the material does not have a melting point it can readily melt when the e beam is incident on the material.

Let us see rotary pocket, a rotary pocket e beam source has all same parts as a single pocket unit except that the wafer cool coppers is essentially a turret of multiple pockets. Each of which can be indexed into position with the design a number of different materials can be evaporated sequentially from a common magnet the emitter or sweep coil structure right.

So, this is a advantage obviously this design includes additional shielding to prevent cross contamination of the pockets, the pocket in position is chosen via a motorized or rotary index. So, we can we can change this pocket let us say there are four pockets 1, 2, 3, and 4. We can change the number of pocket by using a rotary or a motorized indexer.

Linear pocket linear pocket e beam is a similar to a rotary pocket except that its pockets are arranged in a linear fashion you see there is a linear fashion. First pocket goes then if you do not want second pocket will go this pocket will move further right. So, this one is now here the first one is here again shielded, this is shielded. So, into position in a linear fashion within common magnet emitter sweep coil structure. So, this where about the e beam evaporation sources.

So, when we talk about e beam evaporation sources we can see that this if we compare this one. Now you can easily understand this is a rotary pocket source, this is a rotary pocket source, but what if I do not want to use e beam evaporation, is there any other method that can be used for depositing metal or a material which has a very high melting point.

Now, this is our electrical way of heating electrical way of heating the material melting the material or evaporating the material and depositing on the substrate, is there an alternative way. So, we will see in the next class in, the next module an alternative way of depositing the material onto the substrate and that is called sputtering.

Sputtering is a mechanical way of depositing a material onto the substrate. So, let us see what is sputtering in the next module followed by photolithography very interesting application and a heart of micro engineering till then you take care I will see you in the next class, bye.