Fabrication Techniques for MEMs-based Sensors: Clinical Perspective

Prof. Hardik J Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture – 07
Physical Vapour Deposition contd

Hi, welcome to this module. In this module, we will be looking at different technology for evaporating the material. So, what we have understood till now is a physical vapour deposition. And what exactly physical vapour deposition means, physical vapour deposition means to evaporate or to vaporize a material from its physical form that is a solid form to melt to its liquid form and to vaporise it to form a thin film of that particular material.

Now, in physical vapour deposition, what we have seen; we have seen two techniques one is called thermal evaporation; and second is called electron beam evaporation. Thermal evaporation is easy; e-beam evaporation is little bit difficult, it is complex, the physics is complex the mechanism is complex. The limitation for thermal evaporation was that it cannot cover the step coverage is poor and there is shadowing effect.

The another problem with thermally operation is that you cannot evaporate a material which has a higher melting point than the boat or the coil. The problem with e-beam evaporation is that there are generation of x-rays. And this will be particularly important because it will cause a problem when we fabricate MOSFETs.

So, another point is that we are thermally heating the material to evaporate it right. So, what are the alternative or what is the alternative technique alternative technique is mechanically depositing a material. So, what do you what do I mean by mechanical way of depositing a material onto a substrate. Let us see that and that is called a sputter deposition or sputtering.

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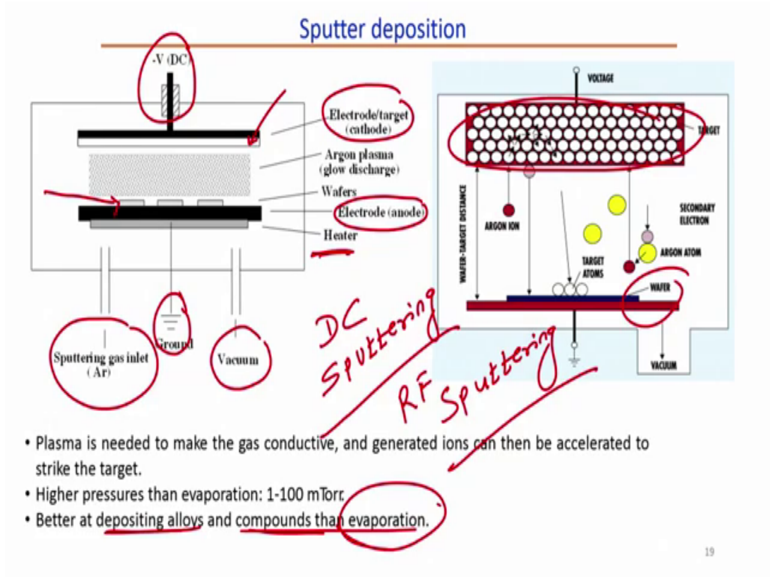

So, if you see the screen what do you see here is that of course, this is a part of physical vapour deposition. So, we have to create vacuum. There is a ground here; there is a voltage here. So, this is a DC sputtering this is called DC sputtering. There is another one which is called RF sputtering all right; DC sputtering and RF sputtering. Cathode, then we have electrode which is anode is grounded. We have heater. And here the target is there. This is the material that we want to sputter. And here are our substrates; these are our wafers or substrates all right.

So, plasma is required to make the gas conductive what gas we are using argon; argon gas is used, and generated ions can then be accelerated to strike the targets. So, the argons ions are generated from argon. And they are accelerated to bombard on the target to bombard on the target to dislodge the atoms from the target or targeted atoms. And this dislodge target atoms will stick onto the wafer which is at the anode. Higher pressures than evaporation about 1 to 100 milli Torr. Better at depositing alloys depositing alloys is better in case of sputtering and compounds then evaporation, there is a advantage of sputtering.

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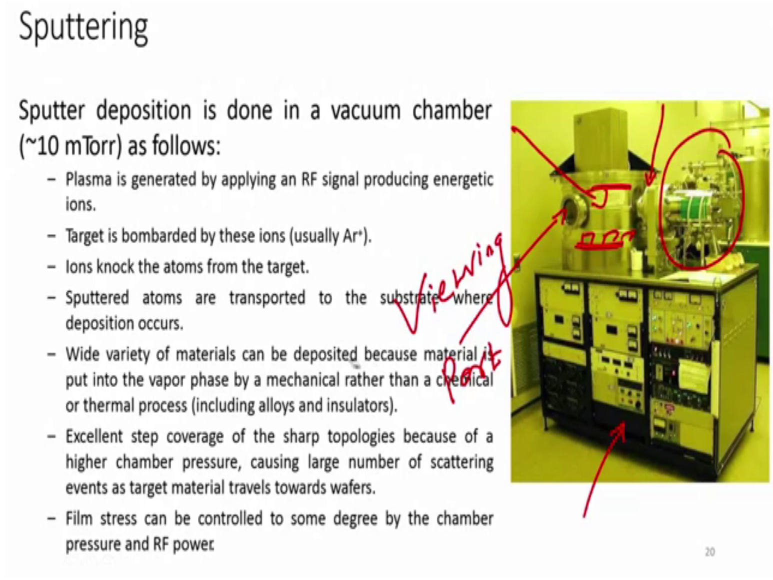

Now, this is actual sputtering system, photograph of a sputtering system. This is chamber viewing port you can view it viewing part viewing port right. And vacuum system where you create a vacuum right; here is a wafer loading system and load the wafer. And of course, there are the sputtering source and substrate.

So, sputter deposition is done in vacuum chamber approximately 10 milli Torr like I said 1 to 100 milli Torr we can change the pressure. Plasma is generated by applying RF signal producing energetic ions target is bombarded by usually argon. Ions knocks the atom from the target. Sputtered atoms are transported to the substrate where deposition occurs.

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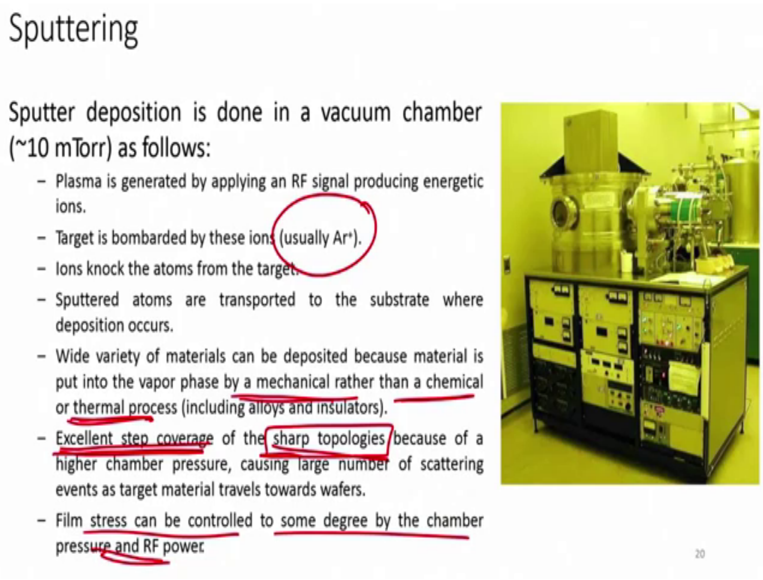

Wide variety of materials can be deposited using material put in the vapour phase by mechanical rather than let rather than chemical or thermal process. So, because in some mechanical way of dislodging the atoms and depositing it on to the substrate; variety of materials can be deposited. Another advantage of sputtering is its excellent step coverage you see excellent step coverage of the sharp topologies, because of a higher chamber pressure, causing large number of scattering events as target material travels towards the wafers.

Finally film stress can be controlled to some degree by the chamber pressure and RF power. So, there are certain advantages of sputtering over e beam evaporation or thermal process or chemical process.

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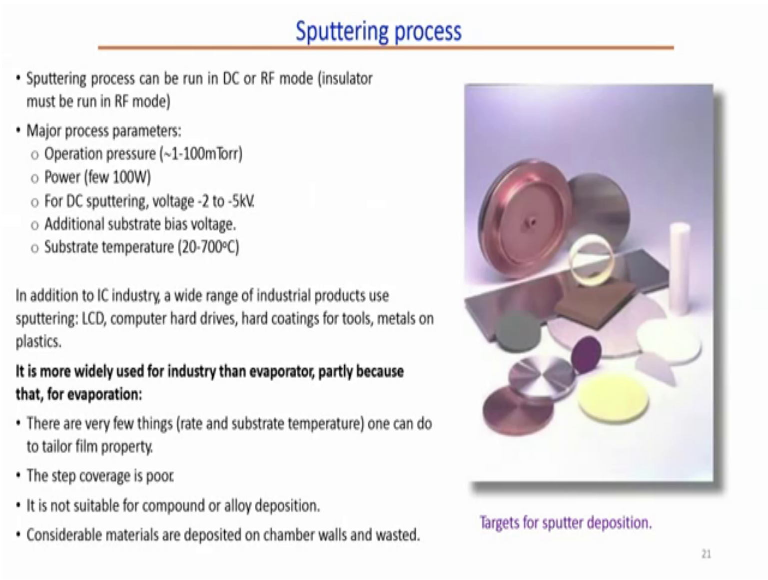

So, sputtering process like I discussed early can be run in DC or RF mode. Particularly when we are using insulator we have to use RF mode. The process parameters are listed here; operating pressure around 1 to 100 milli Torr power few of 100 watts; it is can be 200 watts, 300 watts. This is sputtering voltage minus 2 to minus 5 kilo volts.

Additional substrate bias voltage is required. Substrate temperature you can change it from 20 to 700 degree centigrade. And depending on the substrate temperature you can get different kind of film it can be amorphous to polycrystalline. In addition to IC industry, a wide range of industrial products use sputtering you see that is a advantage of sputtering it can be it is used in fact by lot of industries apart from IC industry and that is for LCD, computer hard drives, hard coating for tools metal and plastics and so on.

So, it is more widely used for industry than evaporator partly because there are few things one can do to tailor film that is rate and substrate temperature can be changed. The step coverage is poor in case of evaporation. It is suitable not suitable for compound or alloy deposition right. And considerable materials are deposited on chamber walls and wasted in case of in case of evaporation that is why sputtering is used over evaporation right. Targets look like this. There are several targets here that are that can be used for depositing.

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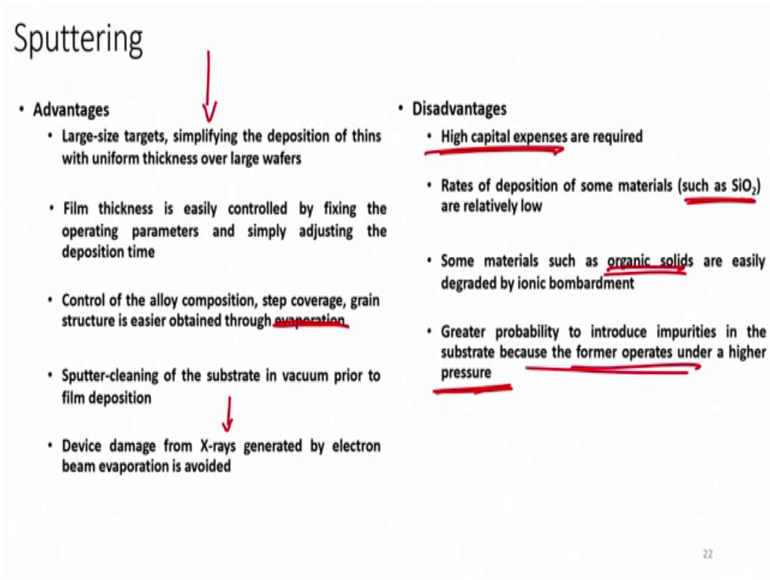

Now, let us see advantages and some disadvantages of sputtering. The advantages are large size targets simplifying the deposition of the of thins with uniform thickness over wafers. Now, thins is thin films with uniform thickness, we can deposit over large size targets that is a one advantage. Second advantage is film thickness can be easily controlled by fixing the operating parameters and deposition time. Control of the alloy composition, step coverage, grain structure is easily or is easier obtained through evaporation. However, this is this is not correct not through evaporation, but through sputtering.

Sputtering or cleaning sputter-cleaning of subset in vacuum prior to film deposition is possible in case of course, sputtering. And finally, the device damage that happens from generation of X-ray in e beam can be avoided in case of sputtering. So, if you see the device damage from X-rays generated by electron beam evaporation is avoided. These are few advantages of sputtering.

What are disadvantages? Disadvantages, first is high capital expenses. Second is rate of deposition of some materials such as silicon dioxide are relatively low. Next is some material such as organic solids are easily degraded by ionic bombardment. Final point is greater portability to introduce impurities in substrate because former operates under higher pressure. So, the probability of introducing impurities into the substrate is higher in case of sputtering right. However sputtering, because of its advantages over e beam evaporation and thermally evaporation is widely used in IC industry and several other industries.

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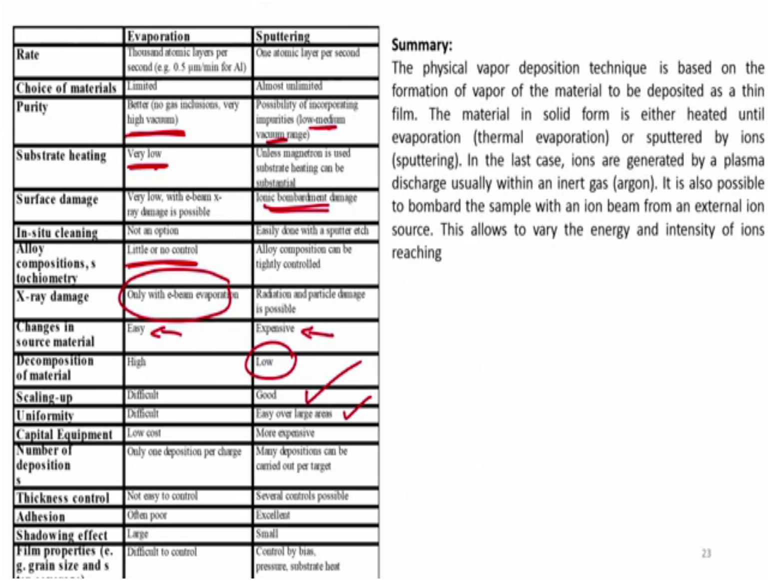

	Evaporation	Sputtering
Rate	Thousand atomic layers per second (e.g. 0.5 μm/min for Al)	One atomic layer per second
Choice of materials	Limited	Almost unlimited
Purity	Better (no gas inclusions, very high vacuum)	Possibility of incorporating impurities (low-medium vacuum range)
Substrate heating	Very 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

Summary:
The physical vapor deposition technique is based on the formation of vapor of the material to be deposited as a thin film. The material in solid form is either heated until evaporation (thermal evaporation) or sputtered by ions (sputtering). In the last case, ions are generated by a plasma discharge usually within an inert gas (argon). It is also possible to bombard the sample with an ion beam from an external ion source. This allows to vary the energy and intensity of ions reaching

23

So, if you want to compare evaporation versus sputtering, this is the table that you need to look at. First let us see rate of deposition. In case of evaporation thousands atomic layers per second or 0.5 micron per minute for aluminium; it is very fast 1 atomic layer per second. The choice of material in case of evaporation is limited. While in case of sputtering is almost unlimited.

Purity, the purity is better here, because no gas inclusions very high vacuum. While possibility of incorporating impurities because of low medium or vacuum range, that is a disadvantage here of sputtering. Substrate heating very low unless magnetron is used substrate heating is substantial. So, there is something called RF magnetron sputtering. Surface damage in which if you use magnetron the substrate heating can be substantial. If you use magnetron substrate heating would be less; if you do not use a magnetron then substrate heating would be substantial.

The damage on the surface is very low with e-beam; however, x-ray damage is possible in case of evaporation. Here the ionic bombardment damage is possible on the surface. In situ cleaning is not possible in evaporation, while can be easily done with sputter etch. Alloy compositions, stochiometry later on no control right because you have very little time for the rearrangement. While in the sputtering alloy composition can be tightly controlled. X-ray damage only with e-beam evaporation radiation particle damage is possible; however, x-ray is not generated.

Changes in source material are easy; here it is expensive. Decomposition is high; here is low. Scaling up is very good in case of sputtering; it is not possible in evaporation. Uniformity easy over large edges is difficult in case of evaporation, but easy for over large areas for sputtering.

Capital equipment, when you talk about capital equipment, it is low cost for evaporation; while it is very expensive for sputtering. Number of depositions only one deposition per charge many deposition can be carried out per target. Thickness control in sputtering we have several control possible, we cannot exactly say not easy to control there are new sophisticated tools that can control the thickness of the film in e-beam and thermally evaporation as well.

Finally it comes to adhesion of the film sticking the film on the substrate at thermally evaporation or e beam evaporation the adhesion of the film is poor; while in case of sputtering it is excellent. Another problem with e beam evaporation or thermal evaporation is shadowing effect; while in sputtering it is small. Finally, grain size say film property such as grain size difficult to control; here you can control by bias pressure or substrate heat. So, there are several advantages as you can see of sputtering over evaporation right.

So, in summary what we understand, in summary we understand that the physical vapour deposition technique is based on formation of vapour of the material to be deposited as thin film. The material is in solid form is either heated until evaporation or sputtered by ions.

In the last case, ions are generated by plasma discharge usually within an with an inert gas; and inert gas we use is argon. It is also possible to bombard the sample with an ion beam right from an external ion source. This allows to vary the energy and intensity of iron reaching the substrate. So, this is something we can say about the summary of the things that we have understood in this particular module.

So, just to have a recap what we learned, we learn physical vapour deposition and in the physical vapour deposition we learned evaporation and sputtering. Then in evaporation we have seen thermal evaporation and e-beam evaporation. Followed by understanding what exactly is sputtering. So, sputtering is mechanical way of depositing a thin film on the on the on the substrate; while evaporation is a electrical way or a thermal way of depositing a material on the substrate.

There are several advantages for sputtering over thermally operation or e-beam evaporation. However, having said that in the in the laboratory in most of the research labs right now we use thermal evaporation and e beam operation heavily. When you want to scale it up when you want to cover large area, then sputtering is better over thermal evaporation or sputtering or e-beam evaporation right.

So, in the next class, let us understand what is photolithography; a very important aspect to understand when you want to learn microengineering.

Till then you take care, I will see you in the next class, bye.