Integrated Circuits, MOSFETs, OP-Amps and their Applications

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Lecture - 08
Introduction to fabrication technology Contd

So, in the last module what we have seen, how we can use physical vapor deposition technique to deposit metals, to deposit semiconductor, to deposit insulators right. Now, the next point or topic in this particular lecture or module is on chemical vapor deposition.

So, before we go to the chemical vapor deposition, we let us see one more technique, we have seen thermally operator, we have seen electron beam operator. Let us see one more technique called sputtering. So, my teacher, when she was teaching me, she gave an example how sputtering sounds like. Sputtering is similar to the effect of rain drop, you have heard the rain drop on a metal roof and you will hear that sound right and that sound is, similar to sputtering.

So, not exactly in terms of sound, but the point was that atom by atom, you actually deposit on the wafer that is the point and by drop you have the rain. Let us say atom by atom, you dislodge and you deposit on the wafer. So, dislodge from where? Dislodge from the source. So, that is your sputtering, let us see in terms of how sputtering will look like. So, we have seen this chemi thermal evaporation and e beam evaporation, you have seen.

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Thermal evaporation:

- Robust, simple and in widespread use.
- Use Ta, Mo, or W filaments to heat evaporation source.
- Typical filament currents are 250-300 A.
- Exposes substrates to IR and visible radiation.
- Contamination issues through heated boat/crucible.

Electron beam evaporation:

- Extremely versatile, virtually any material can be deposited. However, more complex.
- Less heating to wafer (as only small source area heated to very high T) and less contamination.
- Exposes substrates to secondary electron radiation. Additionally, high voltage electron beam may generate X-rays.
- E-beam evaporators cannot be used in MOSFET because x-rays will damage substrate and dielectrics. This may lead to trapped charges.

What is there within the chamber?

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- Plasma is needed to make the gas conductive, and generated ions can then be accelerated to strike the target.
- Target is bombarded by these ions (usually Ar^+).
- Ions knock the atoms from the target.
- Sputtered atoms are transported to the substrate where deposition occurs.
- Wide variety of materials can be deposited because material is put into the vapor phase by a mechanical rather than a chemical or thermal process (including alloys and insulators).
- Excellent step coverage of the sharp topologies because of a higher chamber pressure, causing large number of scattering events as target material travels towards wafers.
- Film stress can be controlled to some degree by the chamber pressure and RF power.

Textbook: Silicon VLSI Technology by Plummer, Deal and Griffin

Let us see this one which is your sputtering. So, if you see this particular slide, what you see is that you have the target, you have the target with you is your source and you apply the voltage between the anode and cathode right and here you put your wafer in the bottom. You load your wafer, then what will happen that, when this is happening, when you apply a very high voltage and you introduce argon and you introduce argon.

What will happen? That the plasma is ready to make the gas conductive and generated ions can then be accelerated to the strike, the target is bombarded by these ions usually argon plus the argon ions will bombard, this target will bombard. This you can see here, there is a bombardment, because of the bombardment of the target, the atoms would dislodge from your target and will start drop by drop one by one by it falling towards, the target and you can see a film getting deposited on the wafer all right.

So, what happens ions knock the atom from the target right? Which ions; argon ions sputtered atoms are, they are transported to the substrate, where deposition occurs right. This is what we have right. Now, discussed and we are not going too deep into sputtering that is why guys I am tel, telling you about basic things. Now, you see one thing here, what is difference in your thermal or e beam and sputtering. What is the difference that this two thermal and e beam, we have used a very high voltage. We have melted the metal or semiconductor and we have deposited in sputtering. We are actually dislodging the atoms from the target. So, when we are dislodging the atoms in this particular fashion. It is the mechanical way, it is the mechanical way of dislodging the atoms all right.

So, this is the mechanical way of dislodging the atoms and that is why, these are also called a mechanical way of depositing the film, mechanical way of depositing the film anyway. So, wide variety of materials can be deposited, because material is put into vapor phase by a mechanical rather than a chemical or thermal process right.

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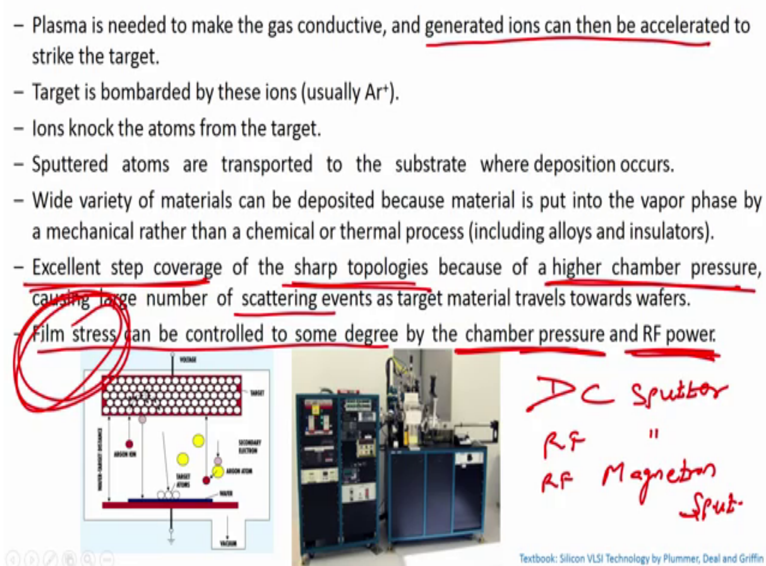

So, here because you are dislodging mechanically, you can deposit variety of metals and we can also deposit alloys and insulators, we can also deposit alloys and we can also deposit insulators. So, what is the advantage here? Excellent step coverage of the sharp topologies, because of high chamber pressure causing a large amount of scattering events as target materials travels towards the wafers.

So, what does that mean? That in the particular process, first is ve, very high chamber pressure is required, second is very sharp topologies are LED like this and you want to coat this right, coat this tap like this then sputtering is better compared to thermal evaporation or E beam evaporation, sputtering is better, compared to thermal evaporation or E beam evaporation. When you want to have a excellent step coverage of the sharp topologies. Next is the film stress can be controlled to some degree by chamber pressure and R F power, but you see there are several types sputtering d c sputtering, which you can see here then there are R S sputtering, then there is R F magnetron sputtering, magnetron, R F magnetron sputtering ok.

So, point is you can change the chamber pressure, you can change the R F power and your stress can also be controlled your film stress, can also be controlled.

So, what we have understood that there are three ways of physical vapor deposition mainly, and that three ways are thermally operation, E beam operation and sputtering.

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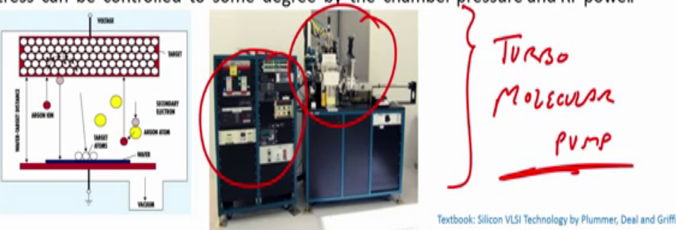

Here, you can see the equipment, here you can see the equipment, which is your sputter deposition, which is a sputter deposition, here you load the wafer and you can change your voltage and power using this particular section and this is connected again to the vacuum pump, which is your turbo molecular pump nothing, but your turbomolecular pump, there are vacuum gauge to measure the pressure, there are vacuum gauge to measure the pressure and then there is a R F source or b c source based on, either it is R F sputtering or say b c sputtering. You can load, you have load the, your source, which is a plate on to this.

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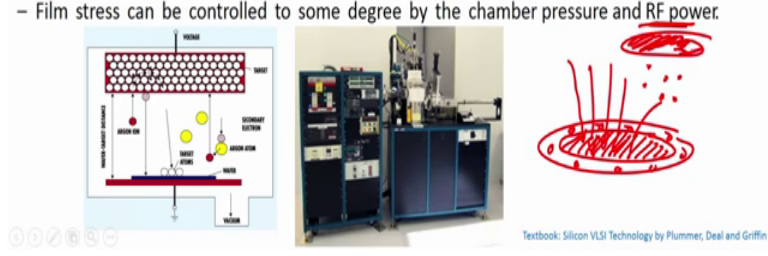

On to the source holder like this, this is your material all right. This is your material and this plate; you can load on the source holder. Now, when the argon ion is inserted at very high, an R F voltage or R F power, they will strike, the ions will strike. This source and dislodge the atoms from the source, which will ultimately, till you have deposited on the wafer, that is kept on the substrate holder, that is loaded on the substrate holder all right. Point is that, we have three way of depositing the materials, first is your thermally evaporation, second is your e beam evaporation and third is your sputtering all right.

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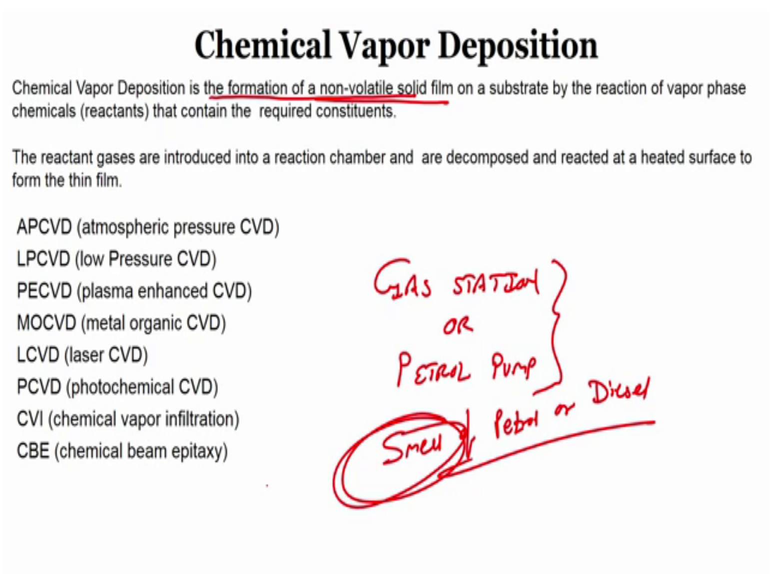

So, let us move to the next one, which is your chemical vapor deposition? Now, chemical vapor deposition is used in several format. What does it mean; that let us see one by one chemical vapor deposition also called as CVD, is a formation of non volatile solid film. What is volatile and what is non volatile all right. So, you see if I all of us have visited at least a gas station right, gas station or we also call here, petrol pump right. Now, when we go to gas station petrol pump, we feel there a smell, we feel a smell of petrol or diesel right. We feel a smell of petrol or diesel, why there is a smell? Because when you drop a drop of a petrol; that means, once a petrol is on, the on the surface.

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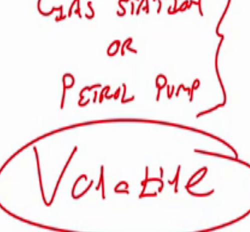
Chemical Vapor Deposition

Chemical Vapor Deposition is the formation of a non-volatile solid film on a substrate by the reaction of vapor phase chemicals (reactants) that contain the required constituents.

The reactant gases are introduced into a reaction chamber and are decomposed and reacted at a heated surface to form the thin film.

APCVD (atmospheric pressure CVD)
LPCVD (low Pressure CVD)
PECVD (plasma enhanced CVD)
MOCVD (metal organic CVD)
LCVD (laser CVD)
PCVD (photochemical CVD)
CVI (chemical vapor infiltration)
CBE (chemical beam epitaxy)



What will happen? It will start evaporating all right; that means that the petrol is volatile all right that is why we can smell it. It starts evaporating immediately at room temperature right, at a normal temperature, it starts evaporating what are other kind of volatile organic compound, if I ask you then, you can immediately say what are other kind of volatile compounds, ethanol, acetone, methanol, butanol, isopropyl, alcohol right, kerosene, diesel, petrol.

This everything is volatile, it will evaporate, it will vaporized right, vaporized at room temperature all right. So, when we talk about chemical vapor deposition, what is written chemical vapor deposition is the formation of non volatile solid film; that means, it is not volatile, once it is deposited, it will stay, it will stay that is non volatile all right. So, I was just showing you the difference between volatile and non volatile. Now, we know that CVD is formation of non volatile film on a substrate by the reaction of vapor phase chemical reactants, that contains the required constituents; that means, the chemical reaction that we are working in the, we are using on to the substrate right.

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The reaction that happen on to the substrate, because of the chemicals, that chemical would contain the required constituents, required constituent is the material, which we want to deposit on the substrate as a solid film ok.

Now, the reactant gases are introduced into reaction chamber and are decomposed and reacted at a heated surface to form the film. So, what will happen? We have to introduce a reactant gas into a reaction chamber and then there is a chemical reaction, because of which decomposition happens, when decomposition happens, this chemical reaction has to be done at some heated surface right and then the film formation. You will be observing a film formation again; this is a thif, thin film technology that is why we always say, thin film, all right, thin film. I have told you in the first class, I have shown you the example, screen painting all right.

So, what are the kind of chemical vapor deposition? See it is mind boggling, there are. So, many kind of chemical vapor deposition, you can start with atmospheric pressure, CVD low pressure, CVD plasma enhanced, CVD metal organic, CVD photochemical, CVD laser, CVD chemical beam, epitaxy chemical vapor infiltration. So, many things or. So, many kind of CVD right. What we have to see? Here is two CVD's; one is low pressure chemical CVD another one is plasma enhanced chemical vapor deposition or CVD all right.

So, low pressure CVD is nothing, but low pressure chemical vapor deposition pla, plasma enhanced is plasma enhanced chemical vapor deposition all right. So, these two we will see and we will see that which one we can use when. So, if you go to the next, slide, same slide.

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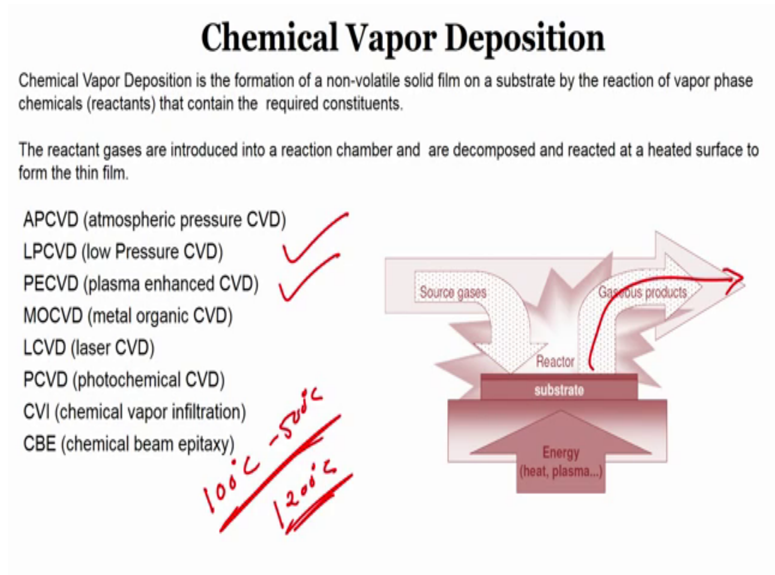

These are the CVD system is right, you have an high energy heated plasma right. This is a substrate, this is a chamber, everything is in inside the chamber. I will show it to you, example here and then there is a source gases, that we have introduced and there is a reaction occurs on the substrate right and then the ou the product, the not useful gases right, the gases that are bi product of this particular reactions that are thrown out of the chamber all right.

So, the point is you have to apply a high energy, heat plasma the substrate is heated or it is kept at low heat that is the temperature is around 100 degree centigrade to 500 degree centigrade. In some cases, it is at very high temperature 1200 degree centigrade. We will see depending on the type of CVD, the temperature also changes all right the point is

that you have the substrate, you have the reactor and then introduce source gases and the bi product or a gaseous products, will we have to, we have to throw out of the chamber. It is not in the air, it is just out of the chamber to the proper processing lights ok.

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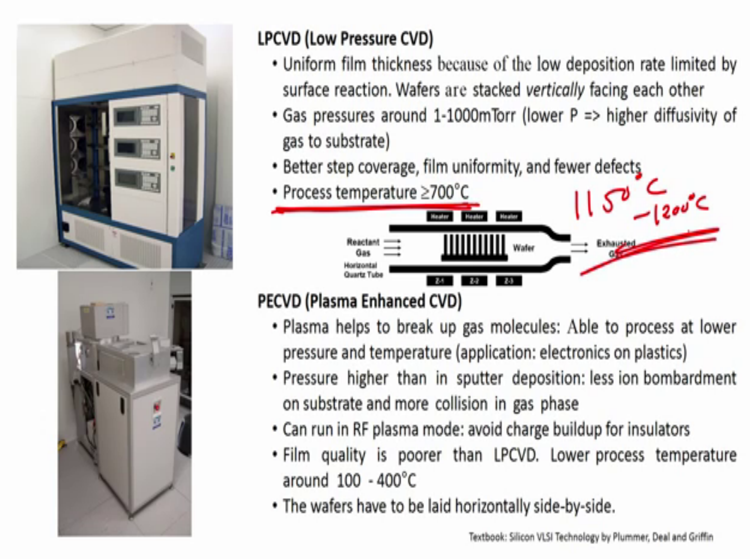

So, when we talk about LPCVD, it is similar to what you have guessed, already we have seen this LPCVD for wet and dry oxidation. We have seen this LPCVD in wet oxidation, we have seen this LPCVD in dry oxidation correct, that is why LPCVD or low pressure chemical vapor deposition can be used in unifor uniform film thickness, because of the low deposition rate, you have seen that right in dry oxidation.

We can only have few nanometers and or 0.1 micron, that is I think the maximum in wet oxidation, we can use 1 to 2 microns right. So, the deposition is extremely slow and that is why the thickness would be the film, thickness would be more uniform compared to PVD wafers are stacked vertically facing each other. You know this particular tube right, what is it? It is a horizontal tube, because tube is in horizontal reaction and then it is kept in the furnace.

So, horizontal tube furnace, you can see horizontal tube furnace right and we also know that this material is nothing, but your quartz. This material is your quartz the reactant gases, you insert in here the exhausted gases are out right. You have put the wafer stacked in the stacked, in the vertical facing to each other right, vertically facing. You can see here right. Now, gas pressures around 1 to 1,000 milli torr and lower pressure means higher diffusivity of gas to substrate, then another advantage of CVD, LPCVD better step coverage film uniformity and fewer defects all right, but in case of LPCVD

the temperature the temperature o at which we perform this experiment, we use this tool is greater than 700 degree centigrade.

In case of silicon dioxide, we have seen it is 1,150 to 1,200 degree centigrade right. So, the temperature is extremely high guys temperature is high. Now, what is another type PECVD. So, the system will look like this LPCVD, PECVD system is like this right. This is the chamber in which the reactants will occur; you can see here, you can see the plasma generated. Here, you can load the substrate, which comes over here, you can lift it, you can put the wafer and the wafer will go in this particular direction, you can load onto the substrate and then there is generation of plasma, the chemical reactions will deposit the materials on the substrate all right.

So, how this, how things happen within this particular system? This system how the process happens, you can also see there is a vacuum pump. Here, also we require a vacuum, but of a low order all right not like in case of PVD that will require very high pressure. Here is a low order vacuum. So, plasma enhanced CVD, plasma helps to break up gas molecules, one able to process at low temperature and pressure and that is why the application is electronics on plastic electronics, on plastic why? Because, if I use plastic at 700 degree centigrade or more, what will happen? Correct, it will burn.

But if I want to use or if I want to have flexible electronics and if I want the insulator film or insulating film, then I can use plasma enhanced chemical vapor deposition right, one is the example that I gave it to you. When I was teaching you about gas sensor is if I aluminum right. In other words you have oxidized silicon substrate on which you have a aluminum pattern, I said this is aluminum right.

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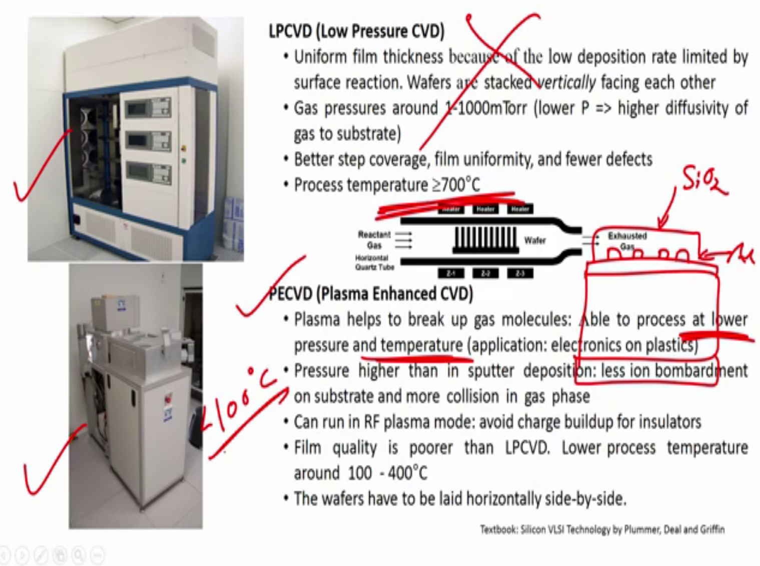

On this you want to grow silicon dioxide, then you cannot use LPCVD, because temperature is greater than 700 degree centigrade. Now, we can use PCVD, because the temperature is low temperature is low. Low is how much? We can deposit the film or we can grow the film at 100 degree centigrade also. We can deposit the film even less than 100 degree centigrade less than 200 degree centigrade anyway.

So, the point is the, point is that PECVD comes at a rescue, when you want to have electronics on plastics right, pressure higher than in sputter deposition less ion bombardment on substrate and more collision in gas phase all right, can run in RF plasma mode, avoid charge buildup for insulators that is the advantage film quality is poorer than LPCVD film quality is poorer, but temperature is low temperature, is low. The wafers have to be laid down horizontally side by side, in this case vertically, in this case horizontally right. So, LPCVD, vertically you have to load the wafer PECVD. You have to load the wafer horizontally all right.

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CVD advantages and disadvantages
(compared to physical vapor deposition)

Advantages:

•Good reproducibility and high growth rates possible,
•Can deposit materials which are hard to evaporate.
•Can grow epitaxial films. In this case also termed as "vapor phase epitaxy (VPE)". For instance, MOCVD (metal-organic CVD) is also called OMVPE (organo-metallic VPE).
•Generally better film quality, more conformal step coverage.

Disadvantages:

•High process temperatures.
•Complex processes, corrosive and toxic gasses.
•Film may not be pure (hydrogen incorporation...).

Now, if I want to see the advantages and disadvantages of chemical vapor deposition over physical vapor deposition, if there is question that when I compare a CVD with respect to PVD. What the advantages of CVD or PVD? What are the disadvantages of CVD or PVD?

So, first the first advantage is good reproducibility and high growth rates, possible we can reproducible, we can reproduce the film much more accurately and with high higher growth rate compared to PVD, second is can deposit material which are hard to evaporate. Do you see, you can deposit material, which are hard to evaporate that is why what we are depositing silicon dioxide. What we are depositing silicon nitride S i O 2 S i 3 n 4. These are the materials, very hard to deposit all right, means very hard to deposit via evaporation, but if I use CVD, it becomes, my life becomes easy that is why you can use or deposit material which are hard to evaporate.

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Next, is can grow epitaxial film in this case also called vapor epitaxy. For instance, metal organic, CVD is also called organo metallic vpe vapor phase epitaxy we have not seen that. So, do not worry about it, generally better quality film, quality more conformal step, coverage step. Coverage is better in case of CVD, when we compare with respect to PVD right.

In case of CVD, the step coverage is better compared to PVD. What are disadvantages? First disadvantage, it is high process temperatures, second disadvantage is complex processes corrosive and toxic gasses right. High process temperature is greater than 700 degree centigrade right, toxic and corrosive gasses you see. So, you have to be careful film may not pure hydrogen incorporation, this you always remember right. We have talked about hydrogen incorporation, when we use wet oxidation; we have seen right advantages of dry and wet oxidation.

What we found is in wet oxidation the growth is higher; however, there will be pores there in, because of the hydrogen incorporation and that will cause a problem in your MOSFET, that is we do not use gate oxide using we do not grow gate oxide, using wet oxidation. We do not grow gate oxide using wet oxidation all right. So, these are some advantages and disadvantages of CVD over PVD and.

Now, let us see what we meant by the step coverage. What do you mean by step coverage?

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CVD Sputtering Evaporation

You see here carefully right. When I use evaporation, you see I can cover this area, but my this area is not covered all right. These are step right. What I am talking about is a step, what I want is, I want that I have, should have film, which can cover the entire step like this right. So, what I see first in evaporation? I can cover this, I can cover this, I can cover this, I cannot cover this area.

Now, if I talk about sputtering somewhat this area, you see until here, see from here till here, till here till here, but it is not covering completely right, but if you talk about CVD about chemical vapor deposition, you can see a perfect or better step coverage compared to the PVD, better step coverage compared to PVD. There is lot of physics behind it. What is the angle? Why we have to keep the wafer at 90 degree with respect to source, but that is not our that is not our objective to understand the details about that, our objective is to understand that, if you are given equipment, which equipment you can use for depositing or growing metal semi conductor or insulator all right that is the interest.

Now, what we have seen? We have seen PVD, we have seen CVD. In CVD, we have seen LPCVD and PECVD,right. So, I hope that you understood what is PVD. I hope what you understood, what is CVD? I hope that you understand how we can or you understood how we can deposit the metal using thermal evaporator by heating it by using e beam, by incidenting the e baem using the magnets right and e beam generator. Then we have seen the comparison between e beam and thermal evaporator, then we move on

to the sputtering and we see that we have to insert the argon gas then argon ions, will this bombard on the target or the source? The source on bombarding the source the atom from the source will be dislodged will get deposit on the substrate.

Then we have seen advantages of sputtering, that it can practically deposit any material then we have seen chemical vapor deposition, in chemical vapor deposition what we have seen? There is a lot of CVD's, but what we are interested in understanding two CVD's, one is LPCVD, one is PECVD, all right. Then we have compared, if you have to cover a step which one would be better? LPCVD will be better or P or in general CVD would be better or sputtering would be better or thermal evaporator would be better, that is what we have done until now right.

Now, you are able to understand, if you have a silicon, you can grow oxide on the oxide, you can deposit any material right. The next class, let us understand photolithography, once you understand photolithography that will be end of understanding the process, then using this process, using this knowledge that we will acquire right. We will see how we can fabricate our mosfet. I will fabricate our mosfet. So, read this particular slides, what I have taught you today, understand it and let us see, let u see how photolithography can be used and we will take an example.

We have already taken an example in the earlier class. We have taken an example of an IDE with within SU 8. We have taken example of an gas sensor all right, but we will quickly take an example. So, you finally, at the end of photolithography, you will understand how you can use the steps that we have learn to fabricate a device all right. So, I will see you in the next class.

Let us learn the next class, what is photolithography all right. So, till then you take care. Bye.