

Advanced Neural Science for Engineers
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Lecture 24
Thin Film Deposition: Chemical Vapour Deposition - 1

Hello everyone welcomes to this class. This class is on understanding the chemical vapor deposition. So, we have seen physical vapor deposition and let us see what are the chemical vapor deposition. Again, this is a thin film deposition technique.

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And if we go to the next slide the problem with the physical vapor deposition as we have discussed a few times is that the step coverage is poor, because when you deposit the film using E-beam operation or thermally operation, then there is a geometrical shadowing effect which comes into picture and that is because both evaporation and sputtering have the directional fluxes.

So, when it comes to the step coverage, the context particularly when we need to make the lower, you see here the contexts are not great. So, in that case the methods to minimize these type coverage problems are you can rotate the, rotate and tilt the substrate what does it mean is if I have the source which is in the bottom and wafer in the top, what I will do is I will rotate this wafer while the deposition is in progress. While the deposition is in progress, I will rotate the wafer, that will kind of minimize the problems of step coverage.


The second is, second way is that you can tilt this wafer a bit that means that instead of that you can put the wafer like this. So, where the steps are there, you can try to cover those steps by tilting the wafer. So, that is one thing. Then second is elevate substrate temperature because then the reorientation of the deposited grains, grains can reorient itself and it high temperature that may improve the step coverage problems or they may reduce the overage problems. And finally, use large area deposition source, the source is bigger than the you can cover most of this step.

The advantage of sputtering as we know for multi component thin film, sputtering gives better conversion control using compound targets. Evaporation depends on vapor pressure or where various vapour components and is difficult to control, while sputtering it is not. So, better lateral thickness uniformity can get with sputtering, superposition of multiple point targets is possible.

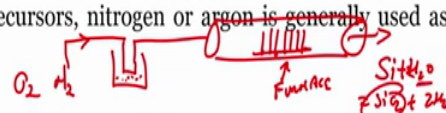
And but when you call the chemical vapor deposition when you talk about chemical vapor deposition, then the conformability is way better than the PVD, the step coverage is way better than PVD and that is because the substrate is there, the film is formed using chemical reaction.

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Chemical Vapour Deposition



- CVD can provide better uniformity than PVD. So, chemical vapour deposition (CVD) is used frequently to deposit films where uniformity is a critical condition.
- In CVD, the precursors are either appropriate gas source or liquid source with bubbler. For liquid precursors, nitrogen or argon is generally used as carrier gas.
- In this module Atmospheric Pressure Chemical Vapour Deposition (APCVD), Low Pressure Chemical Vapour Deposition (LPCVD), Plasma Enhanced Chemical Vapour Deposition (PECVD), High Density Plasma Chemical Vapour Deposition (HDPCVD) is discussed.



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So, chemical vapour deposition if you want to define what is it and can you read CVD can provide better uniformity than PVD that we know. So, chemical vapour deposition is used frequently to deposit film where uniformity is an important condition, is a critical condition. So, in CVD, the precursors are either appropriate gases source or liquid source with a bubbler either it is gases reaction or it is a liquid source where the liquid source is evaporated into gaseous with the help of the bubbler and for liquid precursors nitrogen, argon is generally used as a carrier gas.

So, there is a you remember about the bubbler that we talked about in case of the wet oxidation where you have the O_2 and then there was N_2 and N_2 was going into the bubbler and then it was taking the water vapour into the furnace when we had kept the wafers. You remember, in wet oxidation. So, that was the that is one example where the nitrogen is used to carry the water vapour into the furnace.

But, in case of CVD there are carrier gas it is not about water vapour. This is water vapour because we were talking about

$Si + H_2O$ gives $SiO_2 + 2H_2$; here $2H_2$. So, then this is the reason that we are talking about the water vapour, but in the case of CVD we are talking about different gases because we are creating layer of different insulating material; layer of insulating material. So, that depends on what kind of gases will mix, what is the reaction happening on the surface of the wafer and so on so forth.

So, in this module we will look into or understand atmospheric pressure CVD, low pressure chemical vapour deposition plasma enhanced chemical vapour deposition and high density plasma chemical vapour deposition HDPCVD.

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CVD: At a glance

- Chemical gas sources are thermally, optically, or electrically (plasma) activated to react with a surface to deposit a layer and byproducts are pumped out from the chamber.
- In a simplified model, as gas flows over the substrate film growth is determined by adsorption and reaction rates.
- However, in reality, the deposition rate is affected by:
 - Distance from gas inlet
 - Specifics of the reaction
 - Radial variance
- Tricks to improve film uniformity:
 - Tilt substrate into flow
 - Increase temperature along the substrate
 - Single wafer processing

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So, let us see the first one. CVD is a glance at a glance, what you can see that you have seen this image earlier doing thermal oxidation class like the main thing that you need to understand is that the gas phase reaction occurs and there is transport to the surface of the substrate where there is forms nucleation islands and step growth some are adsorbed some are reabsorbed and some are desorbed.

So, desorption, adsorption, reabsorption and nucleation Island and step growth that is how the chemical reaction occurs during the main flow that here gas flow is there, the gas reaction

occurs on the substrate which is silicon in most of the cases but there can be other substrate as well.

So, chemical gas sources are thermally, optically or electrically activated to react with a surface to deposit different layers and the byproducts are pumped out from the chamber. In a simplified model, as gas flows over the substrate film, growth is determined by the adsorption and reaction rates. So, however in reality that desorption or the depletion rate is affected by the following parameters; the one is radial variance specifics of the reactions and distance from the gas inland. This all things these are the parameters which will affect the deposition rate.

The next is if how what are the tricks to improve the uniformity. One is you can tilt the substrate into a flow, increased temperature along the substrate and single wafer processing. If you have one wafer, you have better the deposition. If you tilt the substrate, then you have so when the gas comes you can tilt the substrate like this. And then you can increase the temperature so the more chemical reaction occurs on the substrate. So, this has all the ways to improve the uniformity.

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Four Types of CVD

- **Atmospheric Pressure CVD (APCVD)**
 - **Advantages:** High deposition rates, simple, high throughput
 - **Disadvantages:** Poor uniformity, purity is less than LPCVD

Used for thick oxide deposition
- **Low Pressure CVD (LPCVD at ~0.2 to 20 torr)**
 - **Advantages:** Excellent uniformity, purity
 - **Disadvantages:** Lower (but reasonable) deposition rates than APCVD

Used for polysilicon deposition, dielectric layer deposition, and doped dielectric deposition
- **Metal Organic CVD (MOCVD)**
 - **Advantages:** Highly flexible → can deposit semiconductors, metals, dielectrics
 - **Disadvantages:** HIGHLY TOXIC!, Very expensive source material. Environmental disposal costs are high.

Used for low cost optical (but not electronic) III-V technology, some metallization processes (W and Cu)
- **Plasma Enhance CVD (PECVD)** Plasmas are used to force reactions that would not be possible at low temperature.
 - **Advantages:** Uses low temperatures necessary for back end processing.
 - **Disadvantages:** Plasma damage typically results. Used for dielectrics coatings.

Used for dielectrics coatings.

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So, how many types of CVD? There are four types of CVD. How many types? Four types of CVD and the first one which is atmospheric pressure CVD, we also call it as APCVD. The advantage is high deposition rate it is simple and high throughput. The disadvantages are poor uniformity and purity is less than LPCVD. So, we will see advantage, disadvantage. The low pressure CVD is a has an excellent uniformity and purity however, the low deposit rates than LPCVD.

We will talk about metalorganic CVD, this is the highly flexible CVD that can deposit almost everything, semiconductor, metal and dielectrics. The disadvantage is that it is highly toxic, very expensive source material and environment disposal costs are extremely high. However, this is exclusively used for low optical, but not electronic 3 to 5 technology. Some metallization process like tungsten and copper and while the APCVD generally used for thick oxide and LPCVD generally prefer when you want to deposit polysilicon or dielectric deposition and doped dielectric deposition.

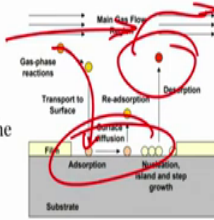
If the final one which is plasma enhanced CVD. So, in this the plasmas are used to force reaction that will not be possible at low temperature. The advantage, biggest advantage is used low temperature necessary for backend processing and plasma damage typically results are used for dielectric coating. So, this is a disadvantage. Generally used for dielectric coating whether it is silicon dioxide or silicon nitrate.

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APCVD



- Atmospheric Pressure Chemical Vapour Deposition is performed in a chamber at atmospheric pressure.
- Sticking co-efficient of the product on the substrate is very important to predict coverage of surface and filling of trench. In low pressure systems, it becomes more important.
- Low sticking co-efficient leads to better coverage.
- Few basic steps are involved in APCVD:
 - Transport of reactants by forced convection to deposition region.
 - Transport of reactants by diffusion from main gas stream through the boundary layer to the wafer surface.
 - Adsorption of reactants on wafer surface.
 - Surface processes including chemical decomposition or reaction
 - Desorption of byproducts from the surface
 - Transport of byproducts by diffusion through the boundary layer and back to main gas stream.
 - Transport of byproducts by forced convection away from the chamber.



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So, you start with the APCVD - Atmospheric Pressure Chemical Vapor Deposition is performed in a chamber at atmospheric pressure. As the name suggests, the reaction occurs at atmospheric pressure. Sticking coefficient of the product on subset is very important to predict the coverage of the surface and filling of the trench. In low pressure system it becomes more important, low sticking coefficient to better coverage we know that. Few basic steps are involved in APCVD.

The first one is transport of reaction by force convection to deposition region. One is you have the gas, then there is a forced convection to the deposition region, transport reactants by diffusion from main gas stream through the boundary layer of the surface as you can see here.

And then, adsorption of the reactants on the wafer surface, surface processing including chemical deposition or decomposition or reaction.

Desorption of byproducts, byproducts are desorbed and it will again be carried by the carrier case. Finally, transfer of byproducts by diffusion to the boundary layer and back to the main gas stream and transfer of byproducts by forced convection away from the chamber because the byproducts should not again come back and react with the main gas flow and react again with the substrate. So, they are forced with the forced convection way we throw them out of the chamber. And we had to process these gases if they are harmful before letting it go into the atmosphere.

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APCVD

- CVD can be analyzed as combination of two processes:
 - Mass transfer of reactants through the boundary layer.
 - Reaction at the interface of deposited film surface
- If r is the rate of deposition and N is the number of atoms incorporated per unit volume in the film.

Here, $r = \frac{F}{N} = K_S C_S \frac{1}{N} = \left(\frac{h_G K_S}{h_G + K_S} \right) \frac{C_G}{N}$; where, rate of reaction (K_S) and mass transfer (h_G) and the number of atoms incorporated per unit volume in the film (N) controls the rate of deposition

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APCVD

Practically, h_G is not constant over the region, a completely stagnant boundary layer δ_s exist next to surface of the wafer. Beyond that boundary, the gas is well-mixed and flow at a constant velocity. Transfer of gas across the boundary layer occurs via diffusion.

According to Fick's Law, at steady state condition,

$$F_1 = -D_G \frac{\partial C}{\partial x} = \frac{D_G}{\delta_s} (C_G - C_S)$$

Where, D_G is diffusion co-efficient

δ_s is not constant throughout the chamber.
 Right next to the wafer sample, the gas velocity is zero and the velocity gradually increases to U within boundary region.
 Since, δ_s increases along the length of the susceptor, effective mass transfer co-efficient decreases along the length of susceptor.

As reacting gases are consumed to deposit the thin layer, their concentration decreases with distance along the susceptor. Since, growth rate is proportional to the partial pressure of reactants, the growth rate will decrease downstream.

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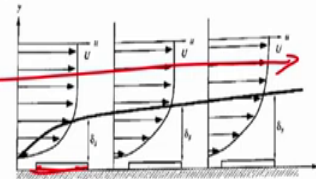
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So, if you understand in this particular manner, then you have the mass transfer which is given by h_G , you have the concentration of gas concentration of silicone and then you have flux 1, flux 2, this boundary layer we did not get some silicone. So, CVD can be analyzed as combination of two process, mass transfer of reactants through the boundary layer and reaction at the interface of the deposited film surface.

So, if r if you consider r is the rate of depletion and N is the number of atoms incorporated per unit volume in the film, then we can define

$$r = F/N = (K_S C_S) \times (1/N) = (h_G K_S / (h_G + K_S)) \times (C_G / N)$$

where rate of reaction of K_S and mass transfer h_G and the number of atoms incorporated per unit volume in the film controls the rate of deposition.

So, that is what we need to understand, rate of the reaction that is obvious that K_S is responsible. Mass transfer, how much mass is transferred but in volume in the film. So, this case, h_G is not constant. What is h_G ? If you remember, h_G is the mass transfer. So, that will not be constant over a region and you can see that are completely stagnant boundary layer δ_s exist next to the surface of the wafer. Beyond the boundary the gas is well mixed and flow at constant velocity. Initially, there is a flow and then this is actually the these are many what we call substrate in one chamber 1, 2 and 3, the transfer of this gas across this boundary layer occurs because of the diffusion or via diffusion.

Now, if you remember the Fick's law at a steady condition

$$F_1 = -D_G (\delta C / \delta x) = (D_G / \delta_s) \times (C_G - C_S)$$

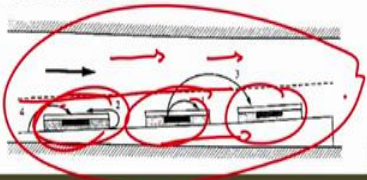
where D_G is your diffusion coefficient, δ_s is not constant throughout the chamber and right next to the wafer sample, the gas velocity is 0 you can see here just next to the wafer sample, the gas velocity is 0 and the velocity gradually increases to u , within a boundary region.

So, then, if your δ_s increases along the length of susceptor, the effective mass transfer coefficient decreases along the length of susceptor. So, as a reaction gases are consumed to deposit that thin film or thin layer, the concentration would decrease with distance along the susceptor. So, as you go on inside the chamber, the kind of concentration they keep on decreasing. Hence, the rate, growth rate is proportional partial pressure of the reactants, the growth will also decrease downstream. So, that is the reason why we keep it on tilted angle and we will keep the wafers little bit tilted and we also have a higher temperature.

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APCVD

- As reacting gases are consumed to deposit the thin layer, their concentration decreases with distance along the susceptor. Since, growth rate is proportional to the partial pressure of reactants, the growth rate will decrease downstream.
- To compensate boundary layer variation and depletion effect, reactor geometry is modified.
- The decrease in the cross-section of chamber causes gas velocity to increase. And to compensate the depletion effect, a temperature gradient is imposed increasing from front to back.
- The deposited layer can be doped during deposition. But if large concentration gradient of dopant exist in chamber at high temperature, due to solid state diffusion, unwanted doping may happen to the wafers.
- Auto-doping processes include:
 - The wafer front side
 - Wafer backside or edges
 - Other wafers
 - From susceptor



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As you can see in this particular case you see the tilt and because the reactant flow like this and then in here it is a maximum one, but if you tilt it, then you have enough area for reaction. As reacting gases are consumed to deposit thin layer, the concentration decreases with distance as you go further in the chamber, the concentration decreases. Since growth rate is proportional to the partial pressure of reactants, the growth rate will also decrease downstream. And to compensate boundary layer variation and depletion effect, reactor geometry is modified.

So, what is a modification to decrease in the cross section of chamber causes gas velocity to increase. So, as you go further the kind of cross section of the chamber decreases and to compensate the depletion effect, a temperature gradient is imposed increasing from front to back. So, from front to back the change in the temperature. The deposit layer can be doped

during the deposition, but if a large concentration gradient of dopant exists in chamber at high temperature due to solid state diffusion, unwanted doping may happen.

So, you can dope it but again depends on the optimization parameters. Auto doping process includes a wafer front side, wafer back side, other wafers from susceptor. If there is initial chemical gases if you do not let the all the gases come out from the chamber, the, there can be previous gases present that may again react, the, there can be auto doping which is unwanted doping that is possible in this particular case.

So, we have seen APCVD. In the next class, let us see the other types of CVD. In general, like I said all CVDs has its own advantages and disadvantages. Particularly, APCVD which we have seen now the advantages high dispersion. So, if you want to grow the materials faster thick oxide, you can go for APCVD it is very simple technique to grow silicon dioxide or a insulating material. The difficulty here is only the poor uniformity and purity.

So, let us see the other CVDs in the next class. Till then you take care. I will continue the next class. Just let us get understanding about what are the CVDs and how they can be utilized. I will see in the next class bye for now.