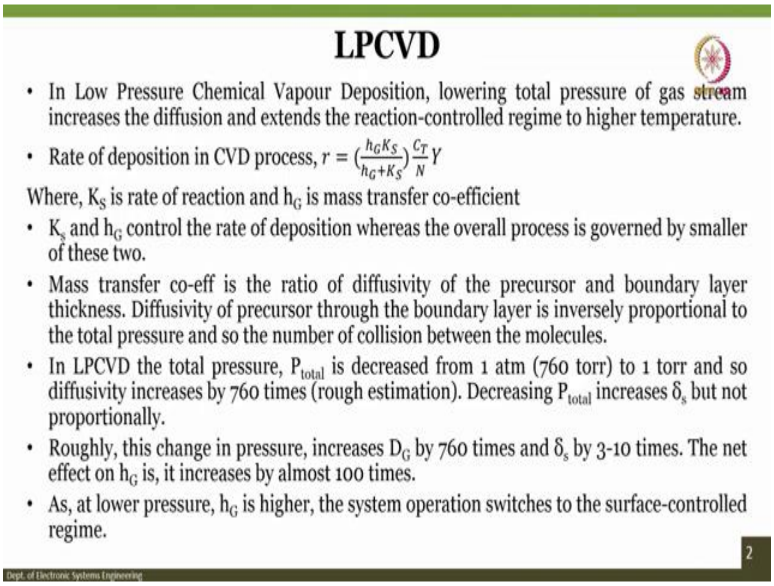
Advanced Neural Science for Engineers

Professor Hardik J. Pandya
Department of Electronic Systems Engineering, Division of EECS
Indian Institute of Science Bangalore

Lecture 25
Thin Film Deposition: Chemical Vapour Deposition – 2

Hello everyone welcomes to this lecture. Now, this is a continuation of the previous lecture on CVDs and CVD as you know stands for Chemical Vapor Deposition. So, in this lecture we will look at two different kinds of CVD one is called LPCVD - Low Pressure Chemical Vapor Deposition and LPCVD - Plasma Enhanced Chemical Vapour Deposition.

(Refer Slide Time: 0:15)



LPCVD

- In Low Pressure Chemical Vapour Deposition, lowering total pressure of gas stream increases the diffusion and extends the reaction-controlled regime to higher temperature.
- Rate of deposition in CVD process, $r = (\frac{h_G K_S}{h_G + K_S}) \frac{C_T}{N} Y$

Where, K_S is rate of reaction and h_G is mass transfer co-efficient

- K_s and h_G control the rate of deposition whereas the overall process is governed by smaller of these two.
- Mass transfer co-eff is the ratio of diffusivity of the precursor and boundary layer thickness. Diffusivity of precursor through the boundary layer is inversely proportional to the total pressure and so the number of collision between the molecules.
- In LPCVD the total pressure, P_{total} is decreased from 1 atm (760 torr) to 1 torr and so diffusivity increases by 760 times (rough estimation). Decreasing P_{total} increases δ_s but not proportionally.
- Roughly, this change in pressure, increases D_G by 760 times and δ_s by 3-10 times. The net effect on h_G is, it increases by almost 100 times.
- As, at lower pressure, h_G is higher, the system operation switches to the surface-controlled regime.

Dept. of Electronic Systems Engineering

2

So, let us start with the first one which is low pressure chemical vapor deposition. So, as the name suggests the LPCVD in LPCVD, we have to lower the total pressure of the gas stream and lowering the total pressure of gas stream what happens that diffusion would increase and if the diffusion increases, then the reaction control regime to higher temperature it, the reaction control regime would also extend.

So, if you read the first line it says that lowering total pressure of the gas stream increasing the diffusion and extends the reaction controlled regime to higher temperature. So, in this case if you want to give a rate of deposition in LPCVD or in CVD process the rate of deposition is given by

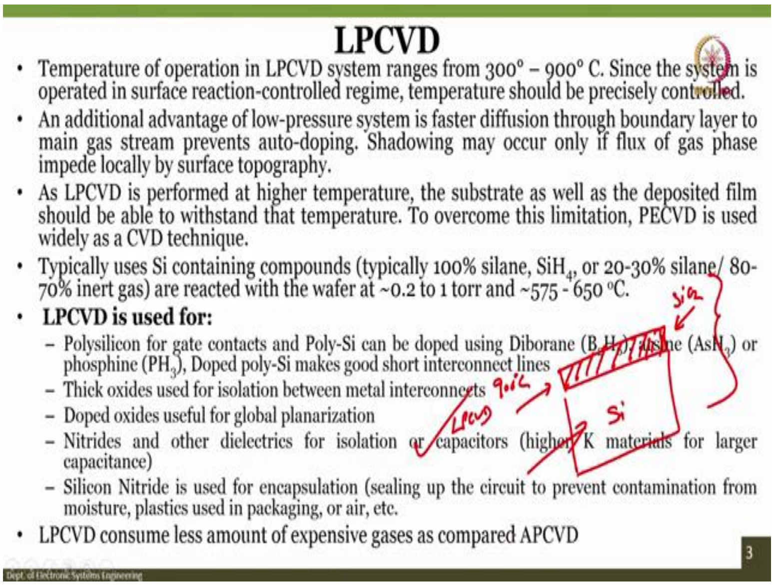
$R = (h_G K_S/h_G+K_S) \times (C_T/N) \times Y$

r equals to in the bracket hG Ks so hG is mass transfer coefficient, then the reaction rate divided by mass transfer coefficient plus reaction rate into CT by N into Y.

So, the h_G and K_S in this the K_S and h_G control the rate of deposition whereas the overall process is governed by smaller of these two correct. Mass transfer coefficient or what is h_G? Mass transfer coefficient. So, let us see the definition is the ratio of diffusivity of the precursor and boundary layer thickness, the diffusivity of the precursor through the boundary layer is inversely proportional to total pressure and so the number of collisions between the molecules.

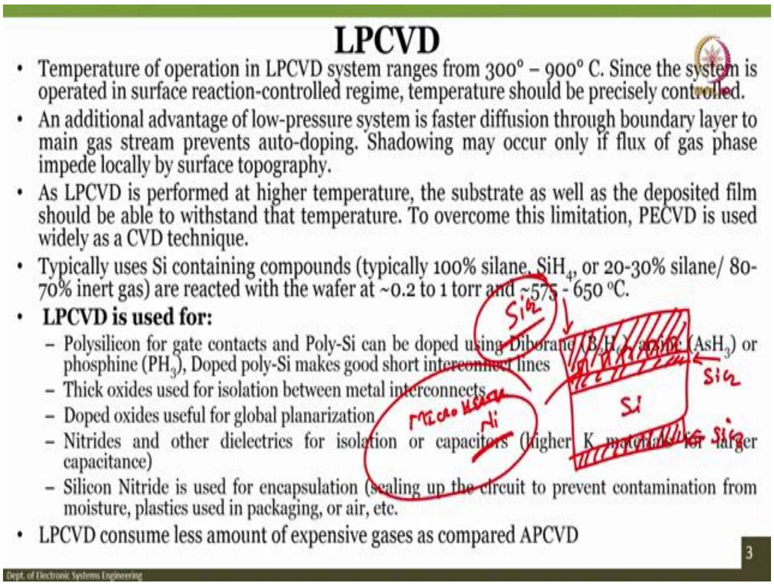
While in LPCVD, P_{total} is that is increased from one atmosphere which is 760 torr to 1 torr and so the diffusivity increases by 760 times. So, we have said that the total pressure increases the diffusion and you can see here that decreasing P total increasing delta S but not proportionally. Roughly this change in pressure increases DG by 760 times and delta S by 3 to 10 times. The net effect of h_G is it increases almost 100 times. At lower pressure h_G is higher the system operations reduce to surface control regime.

(Refer Slide Time: 2:51)



LPCVD

- Temperature of operation in LPCVD system ranges from 300° – 900° C. Since the system is operated in surface reaction-controlled regime, temperature should be precisely controlled.
- An additional advantage of low-pressure system is faster diffusion through boundary layer to main gas stream prevents auto-doping. Shadowing may occur only if flux of gas phase impede locally by surface topography.
- As LPCVD is performed at higher temperature, the substrate as well as the deposited film should be able to withstand that temperature. To overcome this limitation, PECVD is used widely as a CVD technique.
- Typically uses Si containing compounds (typically 100% silane, SiH_4, or 20-30% silane/ 80-70% inert gas) are reacted with the wafer at ~0.2 to 1 torr and ~575 - 650 °C.
- **LPCVD is used for:**
  - Polysilicon for gate contacts and Poly-Si can be doped using Diborane (B_2H_6), arsine (AsH_3) or phosphine (PH_3), Doped poly-Si makes good short interconnect lines
  - Thick oxides used for isolation between metal interconnects
  - Doped oxides useful for global planarization
  - Nitrides and other dielectrics for isolation or capacitors (higher K materials for larger capacitance)
  - Silicon Nitride is used for encapsulation (sealing up the circuit to prevent contamination from moisture, plastics used in packaging, or air, etc.
- LPCVD consume less amount of expensive gases as compared APCVD

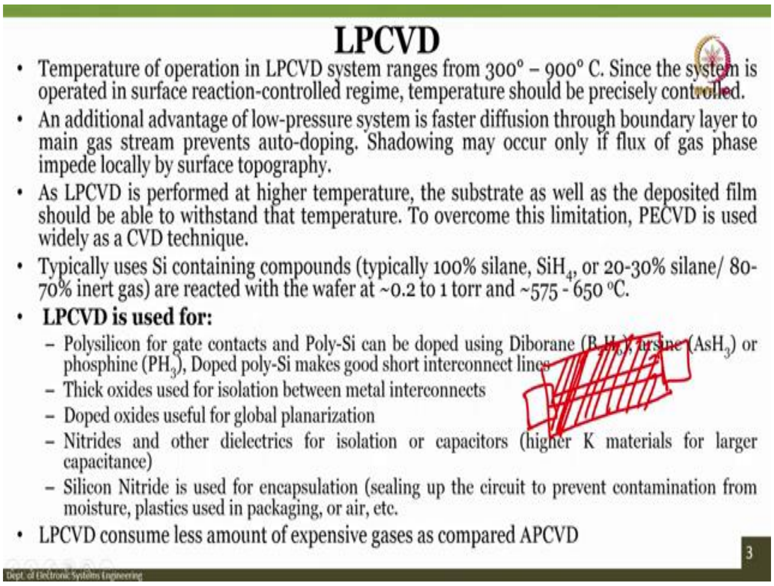


LPCVD

- Temperature of operation in LPCVD system ranges from 300° – 900° C. Since the system is operated in surface reaction-controlled regime, temperature should be precisely controlled.
- An additional advantage of low-pressure system is faster diffusion through boundary layer to main gas stream prevents auto-doping. Shadowing may occur only if flux of gas phase impede locally by surface topography.
- As LPCVD is performed at higher temperature, the substrate as well as the deposited film should be able to withstand that temperature. To overcome this limitation, PECVD is used widely as a CVD technique.
- Typically uses Si containing compounds (typically 100% silane, SiH_4, or 20-30% silane/ 80-70% inert gas) are reacted with the wafer at ~0.2 to 1 torr and ~575 - 650 °C.
- **LPCVD is used for:**
  - Polysilicon for gate contacts and Poly-Si can be doped using Diborane (B_2H_6), arsine (AsH_3) or phosphine (PH_3), Doped poly-Si makes good short interconnect lines
  - Thick oxides used for isolation between metal interconnects
  - Doped oxides useful for global planarization
  - Nitrides and other dielectrics for isolation or capacitors (higher K materials for larger capacitance)
  - Silicon Nitride is used for encapsulation (sealing up the circuit to prevent contamination from moisture, plastics used in packaging, or air, etc.
- LPCVD consume less amount of expensive gases as compared APCVD

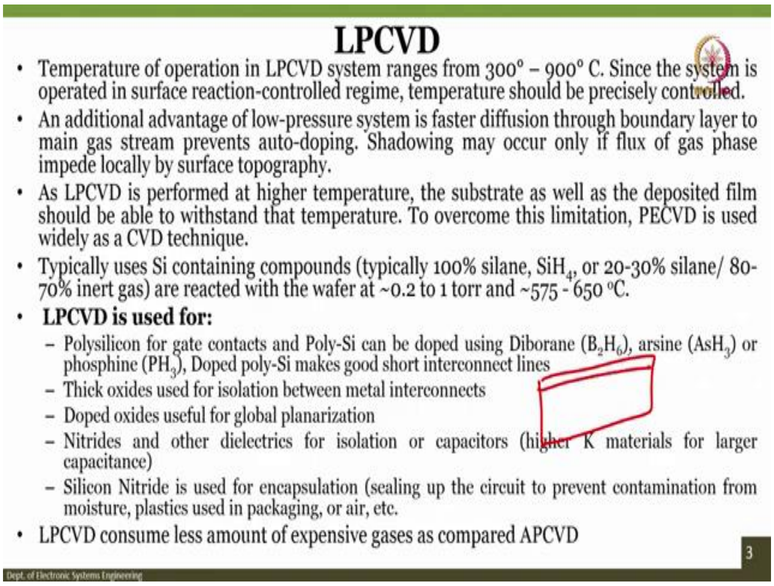
LPCVD

- Temperature of operation in LPCVD system ranges from 300° – 900° C. Since the system is operated in surface reaction-controlled regime, temperature should be precisely controlled.
- An additional advantage of low-pressure system is faster diffusion through boundary layer to main gas stream prevents auto-doping. Shadowing may occur only if flux of gas phase impede locally by surface topography.
- As LPCVD is performed at higher temperature, the substrate as well as the deposited film should be able to withstand that temperature. To overcome this limitation, PECVD is used widely as a CVD technique.
- Typically uses Si containing compounds (typically 100% silane, SiH_4, or 20-30% silane/ 80-70% inert gas) are reacted with the wafer at ~0.2 to 1 torr and ~575 - 650 °C.
- **LPCVD is used for:**
  - Polysilicon for gate contacts and Poly-Si can be doped using Diborane (B_2H_6), arsine (AsH_3) or phosphine (PH_3), Doped poly-Si makes good short interconnect lines
  - Thick oxides used for isolation between metal interconnects
  - Doped oxides useful for global planarization
  - Nitrides and other dielectrics for isolation or capacitors (higher K materials for larger capacitance)
  - Silicon Nitride is used for encapsulation (sealing up the circuit to prevent contamination from moisture, plastics used in packaging, or air, etc.
- LPCVD consume less amount of expensive gases as compared APCVD



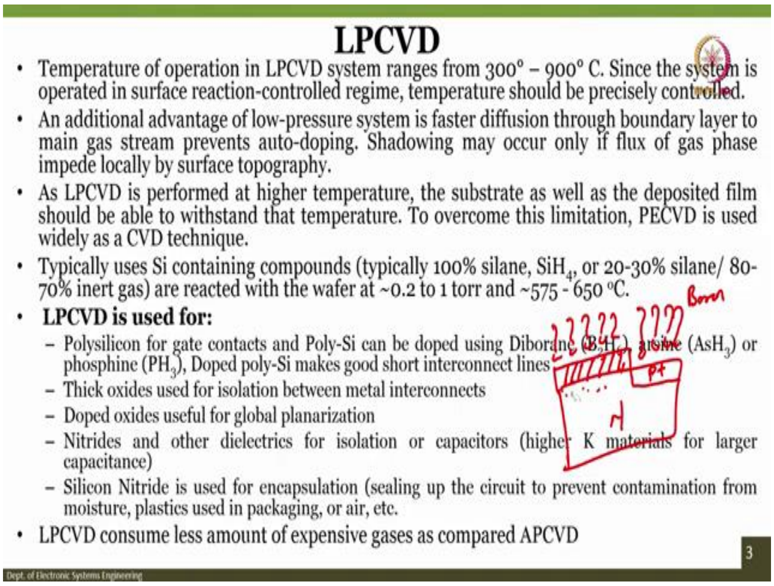
LPCVD

- Temperature of operation in LPCVD system ranges from 300° – 900° C. Since the system is operated in surface reaction-controlled regime, temperature should be precisely controlled.
- An additional advantage of low-pressure system is faster diffusion through boundary layer to main gas stream prevents auto-doping. Shadowing may occur only if flux of gas phase impede locally by surface topography.
- As LPCVD is performed at higher temperature, the substrate as well as the deposited film should be able to withstand that temperature. To overcome this limitation, PECVD is used widely as a CVD technique.
- Typically uses Si containing compounds (typically 100% silane, SiH_4, or 20-30% silane/ 80-70% inert gas) are reacted with the wafer at ~0.2 to 1 torr and ~575 - 650 °C.
- **LPCVD is used for:**
  - Polysilicon for gate contacts and Poly-Si can be doped using Diborane (B_2H_6), arsine (AsH_3) or phosphine (PH_3), Doped poly-Si makes good short interconnect lines
  - Thick oxides used for isolation between metal interconnects
  - Doped oxides useful for global planarization
  - Nitrides and other dielectrics for isolation or capacitors (higher K materials for larger capacitance)
  - Silicon Nitride is used for encapsulation (sealing up the circuit to prevent contamination from moisture, plastics used in packaging, or air, etc.
- LPCVD consume less amount of expensive gases as compared APCVD



LPCVD

- Temperature of operation in LPCVD system ranges from 300° – 900° C. Since the system is operated in surface reaction-controlled regime, temperature should be precisely controlled.
- An additional advantage of low-pressure system is faster diffusion through boundary layer to main gas stream prevents auto-doping. Shadowing may occur only if flux of gas phase impede locally by surface topography.
- As LPCVD is performed at higher temperature, the substrate as well as the deposited film should be able to withstand that temperature. To overcome this limitation, PECVD is used widely as a CVD technique.
- Typically uses Si containing compounds (typically 100% silane, SiH_4, or 20-30% silane/ 80-70% inert gas) are reacted with the wafer at ~0.2 to 1 torr and ~575 - 650 °C.
- **LPCVD is used for:**
  - Polysilicon for gate contacts and Poly-Si can be doped using Diborane (B_2H_6), arsine (AsH_3) or phosphine (PH_3), Doped poly-Si makes good short interconnect lines
  - Thick oxides used for isolation between metal interconnects
  - Doped oxides useful for global planarization
  - Nitrides and other dielectrics for isolation or capacitors (higher K materials for larger capacitance)
  - Silicon Nitride is used for encapsulation (sealing up the circuit to prevent contamination from moisture, plastics used in packaging, or air, etc.
- LPCVD consume less amount of expensive gases as compared APCVD



LPCVD

- Temperature of operation in LPCVD system ranges from 300° – 900° C. Since the system is operated in surface reaction-controlled regime, temperature should be precisely controlled.
- An additional advantage of low-pressure system is faster diffusion through boundary layer to main gas stream prevents auto-doping. Shadowing may occur only if flux of gas phase impede locally by surface topography.
- As LPCVD is performed at higher temperature, the substrate as well as the deposited film should be able to withstand that temperature. To overcome this limitation, PECVD is used widely as a CVD technique.
- Typically uses Si containing compounds (typically 100% silane, SiH_4, or 20-30% silane/ 80-70% inert gas) are reacted with the wafer at ~0.2 to 1 torr and ~575 - 650 °C.
- **LPCVD is used for:**
  - Polysilicon for gate contacts and Poly-Si can be doped using Diborane (B_2H_6), arsine (AsH_3) or phosphine (PH_3), Doped poly-Si makes good short interconnect lines
  - Thick oxides used for isolation between metal interconnects
  - Doped oxides useful for global planarization
  - Nitrides and other dielectrics for isolation or capacitors (higher K materials for larger capacitance)
  - Silicon Nitride is used for encapsulation (sealing up the circuit to prevent contamination from moisture, plastics used in packaging, or air, etc.
- LPCVD consume less amount of expensive gases as compared APCVD

And if that is the case the temperature operation of operational LPCVD is around 300 to 900 degree centigrade. Since the system is operating in surface reaction controlled regime, temperature should be precisely control. So, this is very important statement that if the temperature if you say that we have LPCVD at 900 that means it should be within very small margin of error.

So, you cannot have 900 instead of that temperature is 700 because everything is depending on the temperature and it is the reaction of force is on the surface. Additionally, the advantage of low pressure system is faster diffusion through boundary layer to the main gas streams and that is why it prevents auto doping. So, if you do not want to have auto doping, mostly you see LPCVD the auto doping could not be there. Also, the shadowing may occur only if the flux of gas phase impede locally by surface topography.

So, the event of shadowing also will be less but it is possible to have the effect of shadowing depending on the surface topography. As LPCVD is performed high temperature the substrate as well as deposited film should be able to withstand that temperature. And this is very important statement because if I have let us say take an example if I have a silicon wafer and if I want to grow silicon dioxide, deposit silicon dioxide using (PCVD) LPCVD, this is your Si O2 and this is silicon wafer, Then, in this case LPCVD can work very well not a problem at all.

But, because why because if I had a temperature of 900 degree centigrade, its silicon can easily withstand and 900 degrees centigrade, but what if I have silicon dioxide oxide, oxide layer on which I have let us say a micro heater as we had an example of micro heater on which I want to deposit a silicon dioxide again using LPCVD. This is your SiO_2, this is micro heater, micro heater with nickel as a metal, then this one is your SiO_2, this one is silicon, this one is your SiO_2.

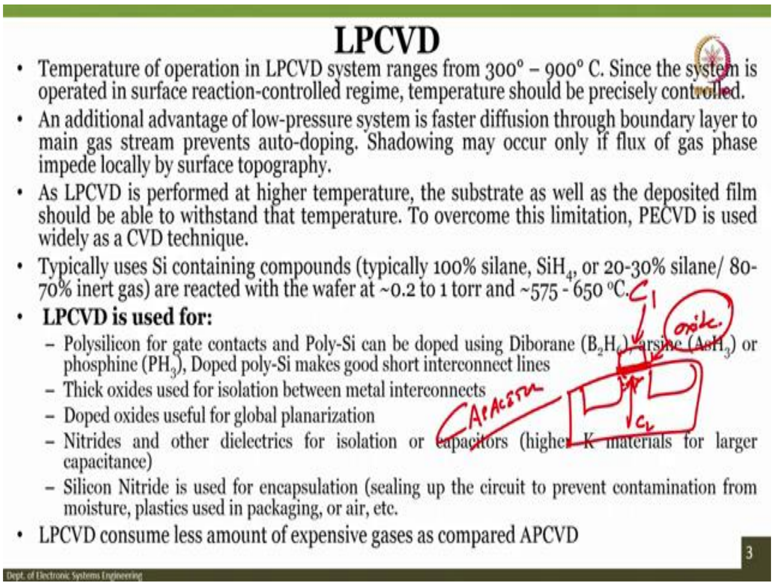
In this case what will happen? If our nickel is micro heater material and if I want to deposit Si O2 using LPCVD, what do you think what will happen? You see the temperature, temperature is extremely high. This nickel on which we need to deposit silicon dioxide, the nickel will not be able to withstand the temperature. And that this is, these are the cases where LPCVD fails or the limitation of LPCVD is that it cannot be used when the substrate or the deposited film cannot withstand higher temperature. To overcome this we have another CVD called PECVD we will see how PECVD works.

Now, typically this reaction LPCVD uses silicon containing compounds typically silane $Si\ H_4$ or 20 to 30 percent of silane is to 80 to 70 percent 70 to 80 percent inert gas which are reacted at a wafer at about 0.2 to 1 torr and about 575 to 650 degree centigrade. So, in that case you the question would be where should I use LPCVD, is not it? So, the LPCVD is used for one, polysilicon for gate contacts and polysilicon can be doped using Diborane, arsine or phosphine, doped polysilicon makes good short interconnect lines. So, in this case we can use LPCVD.

Next is, if I want to have thick oxide isolation between metal interconnects, we can do that as well. What does it mean? So, suppose I have two metal pads and a metal bar and then I want to make sure that this this one is covered with silicon dioxide, then I can make sure that only this region only this region is covered with thick silicon dioxide. If I want to do that, I can very easily do that. So, thick oxide is used for isolation between metal interconnects, doped oxide useful for global planarization, doped oxide for global planarization.

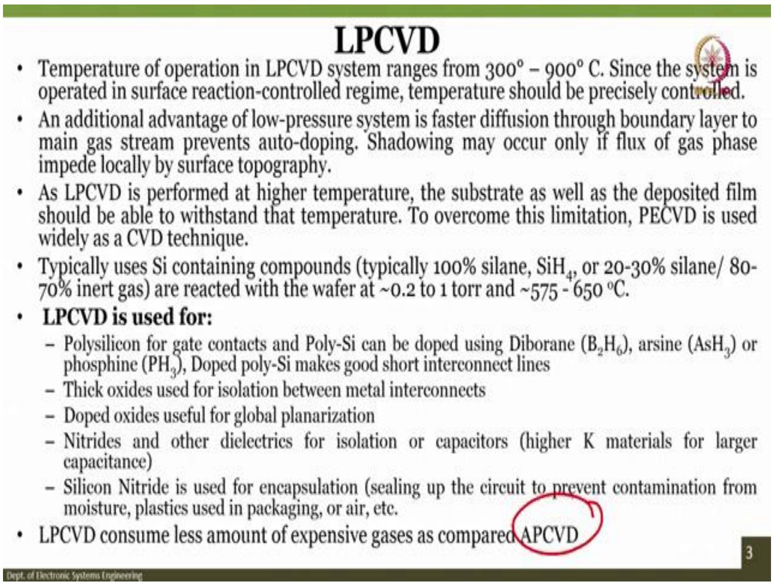
So, we can dope the oxide on to the silicon. Next one is or you can use it also as a masking layer. For example, if I have silicone dioxide and if I pattern it and then the silicon dioxide was grown and then pattern using photolithography and then I have boron which is diffused through silicon dioxide and silicon, then boron will penetrate into silicon here causing P plus assuming that there is N substrate, but boron will not be able to penetrate in this region because silicon dioxide is present. This silicon dioxide can work as a masking oxide.

(Refer Slide Time: 8:32)



LPCVD

- Temperature of operation in LPCVD system ranges from 300° – 900° C. Since the system is operated in surface reaction-controlled regime, temperature should be precisely controlled.
- An additional advantage of low-pressure system is faster diffusion through boundary layer to main gas stream prevents auto-doping. Shadowing may occur only if flux of gas phase impede locally by surface topography.
- As LPCVD is performed at higher temperature, the substrate as well as the deposited film should be able to withstand that temperature. To overcome this limitation, PECVD is used widely as a CVD technique.
- Typically uses Si containing compounds (typically 100% silane, SiH_4, or 20-30% silane/ 80-70% inert gas) are reacted with the wafer at ~0.2 to 1 torr and ~575 - 650 °C.
- **LPCVD is used for:**
  - Polysilicon for gate contacts and Poly-Si can be doped using Diborane (B_2H_6), arsine (AsH_3) or phosphine (PH_3), Doped poly-Si makes good short interconnect lines
  - Thick oxides used for isolation between metal interconnects
  - Doped oxides useful for global planarization
  - Nitrides and other dielectrics for isolation or capacitors (higher K materials for larger capacitance)
  - Silicon Nitride is used for encapsulation (sealing up the circuit to prevent contamination from moisture, plastics used in packaging, or air, etc.
- LPCVD consume less amount of expensive gases as compared APCVD



LPCVD

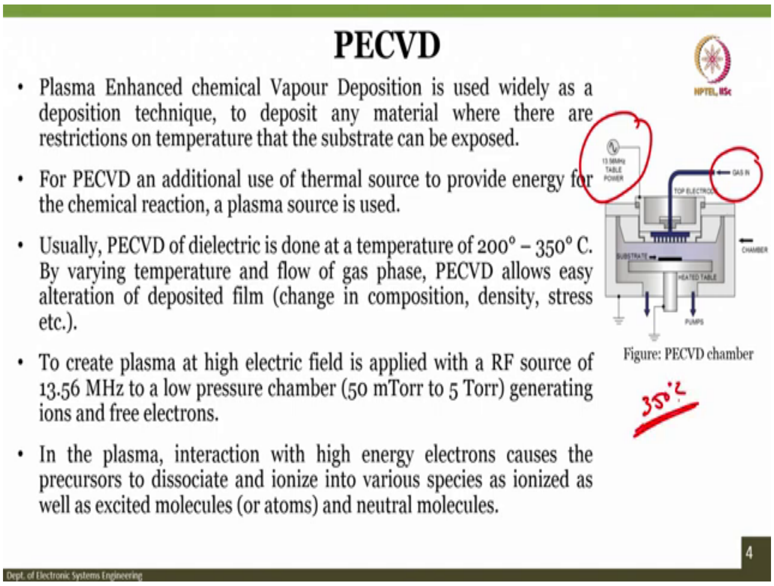
- Temperature of operation in LPCVD system ranges from 300° – 900° C. Since the system is operated in surface reaction-controlled regime, temperature should be precisely controlled.
- An additional advantage of low-pressure system is faster diffusion through boundary layer to main gas stream prevents auto-doping. Shadowing may occur only if flux of gas phase impede locally by surface topography.
- As LPCVD is performed at higher temperature, the substrate as well as the deposited film should be able to withstand that temperature. To overcome this limitation, PECVD is used widely as a CVD technique.
- Typically uses Si containing compounds (typically 100% silane, SiH_4, or 20-30% silane/ 80-70% inert gas) are reacted with the wafer at ~0.2 to 1 torr and ~575 - 650 °C.
- **LPCVD is used for:**
  - Polysilicon for gate contacts and Poly-Si can be doped using Diborane (B_2H_6), arsine (AsH_3) or phosphine (PH_3), Doped poly-Si makes good short interconnect lines
  - Thick oxides used for isolation between metal interconnects
  - Doped oxides useful for global planarization
  - Nitrides and other dielectrics for isolation or capacitors (higher K materials for larger capacitance)
  - Silicon Nitride is used for encapsulation (sealing up the circuit to prevent contamination from moisture, plastics used in packaging, or air, etc.
- LPCVD consume less amount of expensive gases as compared APCVD

So, that is the second thing that you need to understand. Then we can also use for high K dielectric for larger capacitance. You know you do understand that there is a thin layer of oxide between gate and the channel. If you have source, if you have a drain, here you have a thin layer of oxide and then you have gate, is not it? Th.is or this gate is a conductive plate 1. This one can be a channel if channel is formed, conductive plate 2 and is oxide that is there. So, what happens two conducting plates separated by dielectric or air what is it called? That is called capacitor two conducting plates separated by dielectric or air.

So, this oxide that we have here generally we call is a thin layer of oxide grown using thermal oxidation dry oxidation, but there are groups which work on high K dielectric materials and if you have high K dielectric materials, then you know that the capacitance will be large. There is the advantage of doing that we are not go do that in because it is not part of this course, but you just keep in mind that if you want to have a better capacitance, higher capacitance you can use high K dielectric material.

Next one is silicon nitride is used for encapsulation, sealing of the circuit to prevent contamination from moisture plastics used in packaging or air etcetera. So, they finally LPCVD consumes less amount of expensive gas compared to APCVD, we have seen earlier.

(Refer Slide Time: 10:14)

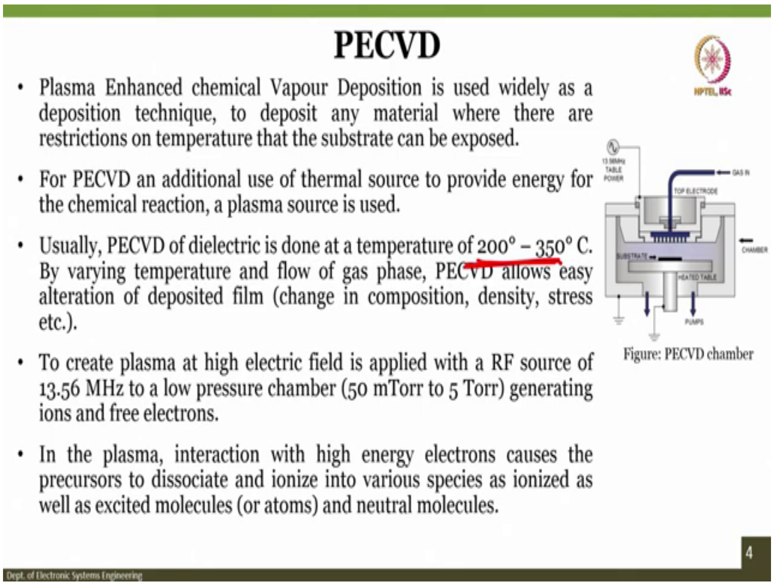


PECVD

- Plasma Enhanced chemical Vapour Deposition is used widely as a deposition technique, to deposit any material where there are restrictions on temperature that the substrate can be exposed.
- For PECVD an additional use of thermal source to provide energy for the chemical reaction, a plasma source is used.
- Usually, PECVD of dielectric is done at a temperature of 200° – 350° C. By varying temperature and flow of gas phase, PECVD allows easy alteration of deposited film (change in composition, density, stress etc.).
- To create plasma at high electric field is applied with a RF source of 13.56 MHz to a low pressure chamber (50 mTorr to 5 Torr) generating ions and free electrons.
- In the plasma, interaction with high energy electrons causes the precursors to dissociate and ionize into various species as ionized as well as excited molecules (or atoms) and neutral molecules.

Figure: PECVD chamber

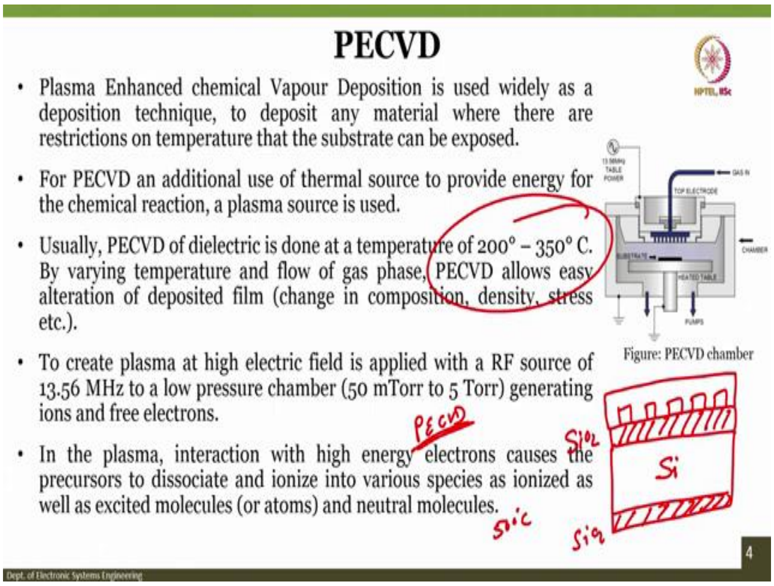
350°C



PECVD

- Plasma Enhanced chemical Vapour Deposition is used widely as a deposition technique, to deposit any material where there are restrictions on temperature that the substrate can be exposed.
- For PECVD an additional use of thermal source to provide energy for the chemical reaction, a plasma source is used.
- Usually, PECVD of dielectric is done at a temperature of 200° – 350° C. By varying temperature and flow of gas phase, PECVD allows easy alteration of deposited film (change in composition, density, stress etc.).
- To create plasma at high electric field is applied with a RF source of 13.56 MHz to a low pressure chamber (50 mTorr to 5 Torr) generating ions and free electrons.
- In the plasma, interaction with high energy electrons causes the precursors to dissociate and ionize into various species as ionized as well as excited molecules (or atoms) and neutral molecules.

Figure: PECVD chamber



PECVD

- Plasma Enhanced chemical Vapour Deposition is used widely as a deposition technique, to deposit any material where there are restrictions on temperature that the substrate can be exposed.
- For PECVD an additional use of thermal source to provide energy for the chemical reaction, a plasma source is used.
- Usually, PECVD of dielectric is done at a temperature of 200° – 350° C. By varying temperature and flow of gas phase, PECVD allows easy alteration of deposited film (change in composition, density, stress etc.).
- To create plasma at high electric field is applied with a RF source of 13.56 MHz to a low pressure chamber (50 mTorr to 5 Torr) generating ions and free electrons.
- In the plasma, interaction with high energy electrons causes the precursors to dissociate and ionize into various species as ionized as well as excited molecules (or atoms) and neutral molecules.

Figure: PECVD chamber

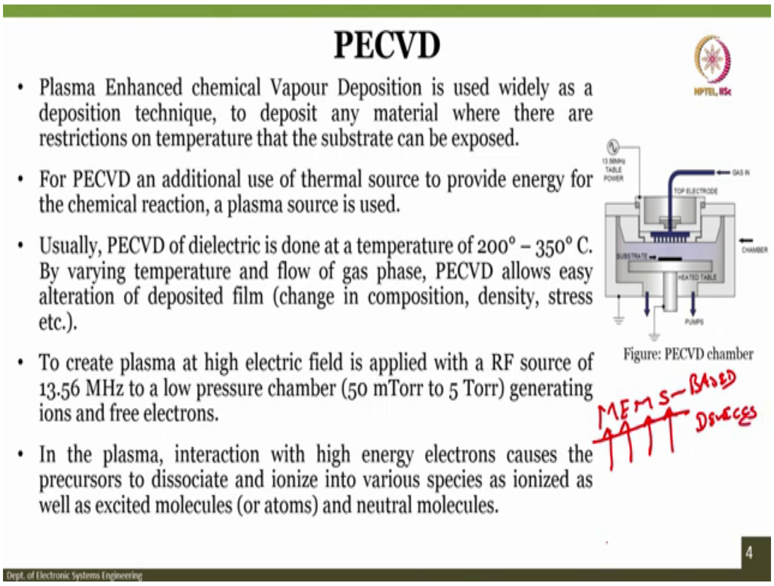
PECVD

SiO_2

Si

SiC

SiO_2



PECVD

- Plasma Enhanced chemical Vapour Deposition is used widely as a deposition technique, to deposit any material where there are restrictions on temperature that the substrate can be exposed.
- For PECVD an additional use of thermal source to provide energy for the chemical reaction, a plasma source is used.
- Usually, PECVD of dielectric is done at a temperature of 200° – 350° C. By varying temperature and flow of gas phase, PECVD allows easy alteration of deposited film (change in composition, density, stress etc.).
- To create plasma at high electric field is applied with a RF source of 13.56 MHz to a low pressure chamber (50 mTorr to 5 Torr) generating ions and free electrons.
- In the plasma, interaction with high energy electrons causes the precursors to dissociate and ionize into various species as ionized as well as excited molecules (or atoms) and neutral molecules.

Figure: PECVD chamber

MEMS-BASED DEVICES

Great. So, let us go to the next one which is the beautiful PECVD, why I said that? Let us understand. So, plasma enhanced chemical vapor deposition is used widely as a deposition technique to deposit any material where there are reactions on the temperature that substrate can be exposed. For PECVD and additional use of thermal source to provide energy for the chemical reaction a plasma source is used.

You have the similar things you have 1.56 megahertz double cable power, there is a gas in, there is a top electrode, there is a bottom electrode with substrate, there is a heated table, there is a chamber and then when you have a gas in and presence of these two electrodes what will happen there is a creation of plasma and then on the substrate in the presence of plasma the reaction of the chemical happens to grow different films.

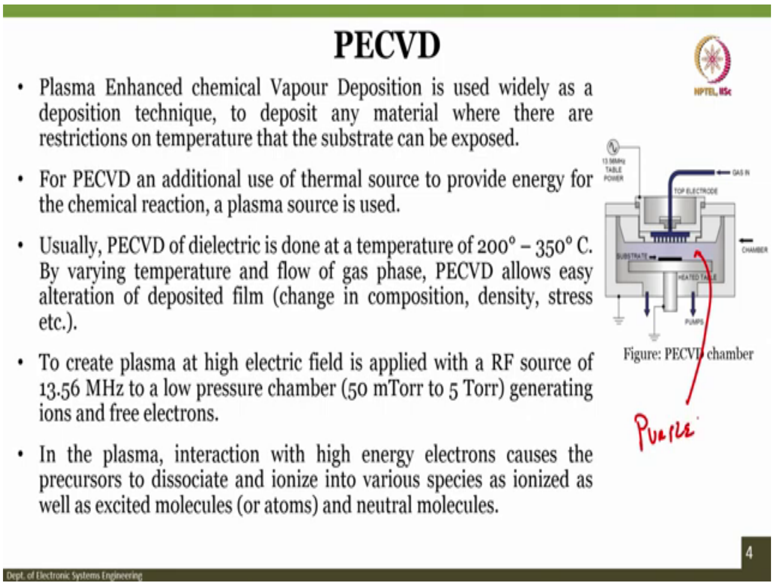
The advantage of this is that the temperature is no greater than 350 degrees centigrade the maximum is 350 degree centigrade, you can also grow at deposit 100 degree centigrade, as low as 100, the maximum is 350. So, usually PECVD of dielectric is done at a temperature of 200 to 350 degree centigrade, by varying the temperature and flow of gas phase, PECVD allows us easy alteration of the deposited film. I mean, changing combustion density and stress. The advantage and why I said I like this system is that you have a material which has a lower melting point that is about 500 degrees centigrade.

This is silicon dioxide extremely high melting, we do not worry about it. This is also silicon dioxide at extremely high melting point, we never worried about it. Si O2, Si O2 and then we have silicon in between that also has a very high temperature withstanding capacity we do not worry about it. But, what if I have here nicrome or a nickel or aluminum can I grow silicon dioxide on this? The answer is yes, we can when we go for PECVD. Why? Because the temperature is less than 100 or from 100 to 350 degree centigrade, even here it is 200, we, I have used PECVD 100 degree centigrade as well only point is that the rate of deposition will decrease as you decrease the temperature.

But you can very well control the film thickness, you can change the flow of the gas, you can change the temperature and with this changing of the parameters we will change the overall composition of the film, the stress in the film and the density of the film. So, the advantage of PECVD is that you can deposit dielectric materials at lower temperature. This is used exclusively when we are going to fabricate a MEMS based devices I had a term or I heard a term called MEMS it stands for micro electro mechanical systems, micro electro mechanical systems based devices.

So, MEMS when we use MEMS based chip, MEMS based sensors, MEMS based devices, everything uses or most of them we you will use PECVD, will see. Now, to create high electric field is applied. So, what to create what? To create plasma you can see here just to have a very representation you have here purple color plasma but because when you see it looks like bluish purple color.

(Refer Slide Time: 14:14)



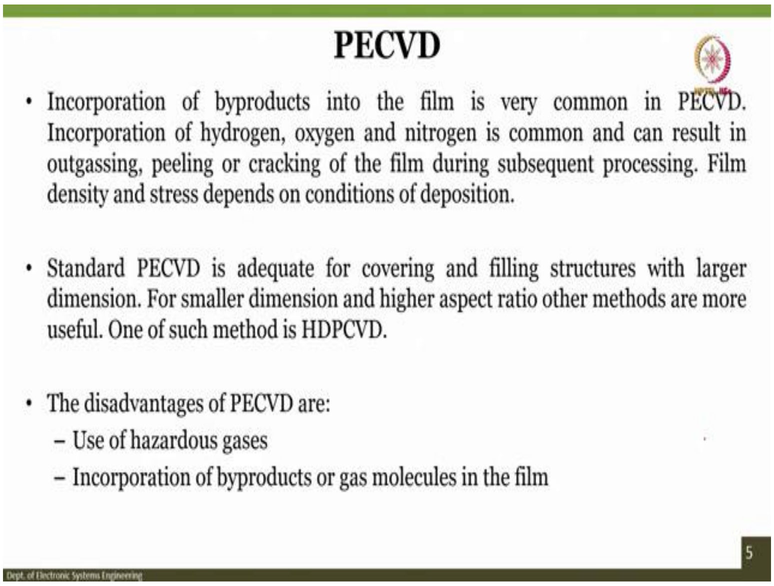
PECVD

- Plasma Enhanced chemical Vapour Deposition is used widely as a deposition technique, to deposit any material where there are restrictions on temperature that the substrate can be exposed.
- For PECVD an additional use of thermal source to provide energy for the chemical reaction, a plasma source is used.
- Usually, PECVD of dielectric is done at a temperature of 200° – 350° C. By varying temperature and flow of gas phase, PECVD allows easy alteration of deposited film (change in composition, density, stress etc.).
- To create plasma at high electric field is applied with a RF source of 13.56 MHz to a low pressure chamber (50 mTorr to 5 Torr) generating ions and free electrons.
- In the plasma, interaction with high energy electrons causes the precursors to dissociate and ionize into various species as ionized as well as excited molecules (or atoms) and neutral molecules.

Figure: PECVD chamber

Dept. of Electronic Systems Engineering

4



PECVD

- Incorporation of byproducts into the film is very common in PECVD. Incorporation of hydrogen, oxygen and nitrogen is common and can result in outgassing, peeling or cracking of the film during subsequent processing. Film density and stress depends on conditions of deposition.
- Standard PECVD is adequate for covering and filling structures with larger dimension. For smaller dimension and higher aspect ratio other methods are more useful. One of such method is HDPCVD.
- The disadvantages of PECVD are:
  - Use of hazardous gases
  - Incorporation of byproducts or gas molecules in the film

Dept. of Electronic Systems Engineering

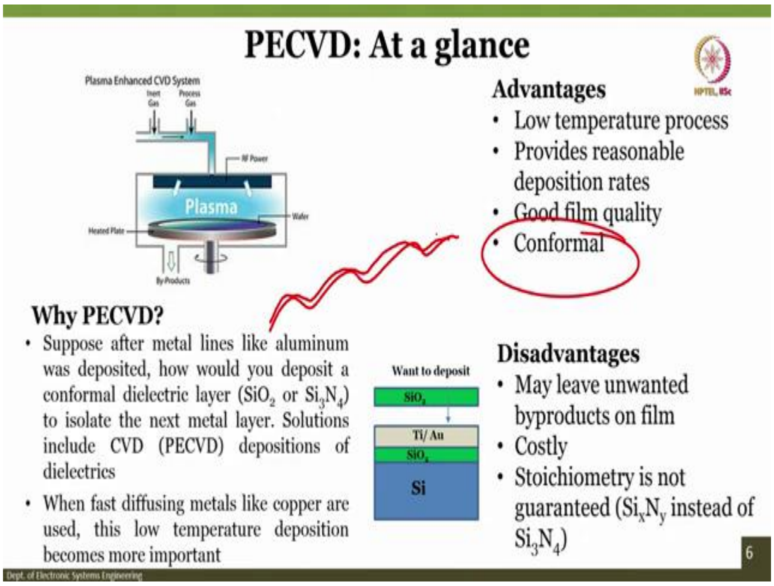
5

So, the to create plasma high electric field is applied with RF source of 13.56 megahertz to a low pressure chamber about 50 mill torr to 5 torr generating ions and free electrons. In the plasma interaction with the high energy electron causes the precursors to dissociate and ionize into various pieces and as ionized as well as excited molecules and neutral molecules.

So, if that is the case the thing will be that we can grow the different dielectric materials and any material that can be reacted to the substrate, surface of the substrate at different temperature. But generally, exclusively we will see the use of PECVD in growing the or depositing silicon dioxide. So, incorporation of the byproducts into film is very common in PECVD. Incorporation of hydrogen, oxygen and nitrogen is common and can result in outgassing peeling or cracking of the film during subsequent processing, film density and stress depends on the condition of the deposition.

So, this is a little bit of limitation of PECVD, however standard PECVD is adequate for covering and filling structures with large dimensions and this is beautiful. For smaller dimension high aspect ratio other methods are more useful ones such as HDPECVD. But for the larger dimensions and you have to cover the field the structures with larger dimensions, the PECVD is an advantageous technique. The limitations of PECVD are the use of hazardous gases and incorporation of byproducts or gas molecules in the film that is the disadvantage of PECVD.

(Refer Slide Time: 15:59)



PECVD: At a glance

Advantages

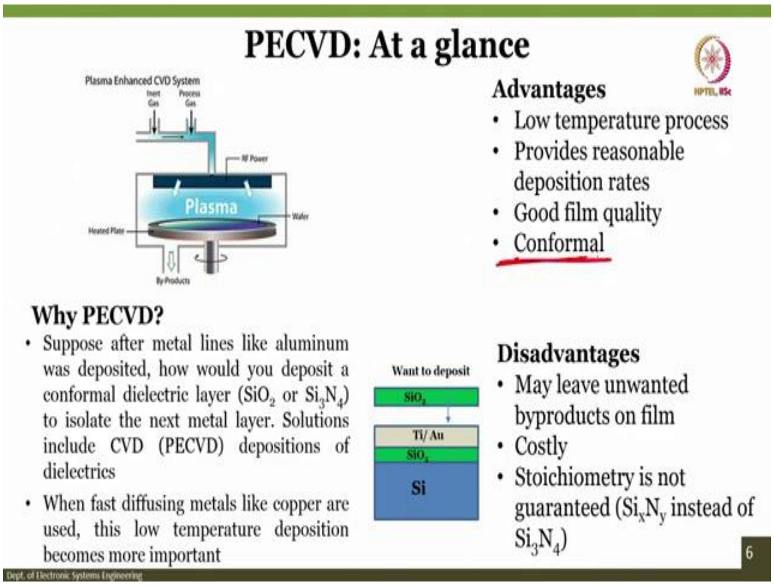
- Low temperature process
- Provides reasonable deposition rates
- Good film quality
- Conformal

Why PECVD?

- Suppose after metal lines like aluminum was deposited, how would you deposit a conformal dielectric layer (SiO_2 or Si_3N_4) to isolate the next metal layer. Solutions include CVD (PECVD) depositions of dielectrics
- When fast diffusing metals like copper are used, this low temperature deposition becomes more important

Disadvantages

- May leave unwanted byproducts on film
- Costly
- Stoichiometry is not guaranteed (Si_xN_y instead of Si_3N_4)


Plasma Enhanced CVD System
Inert Gas
Process Gas
RF Power
Plasma
Wafer
Heated Plate
By Products
NPTEL, IISc
Want to deposit
SiO$_2$
Ti/ Au
SiO$_2$
Si
6
Dept. of Electronic Systems Engineering

PECVD: At a glance

Advantages

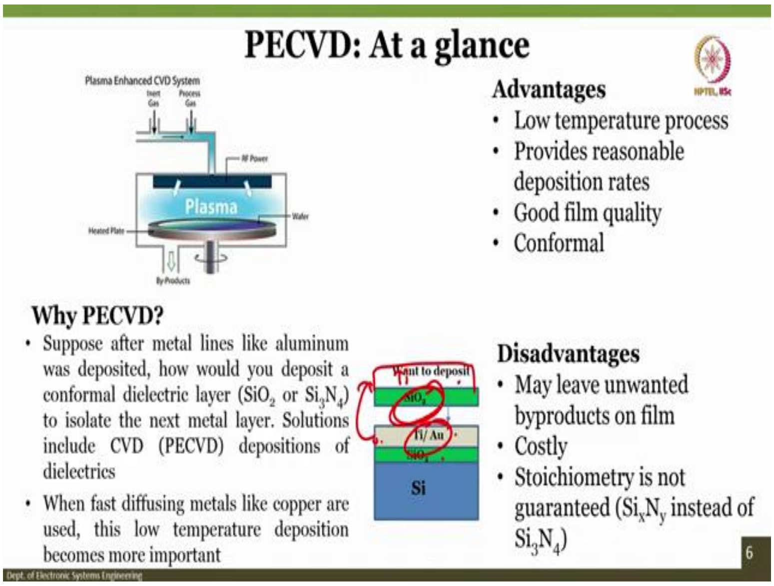
- Low temperature process
- Provides reasonable deposition rates
- Good film quality
- Conformal

Why PECVD?

- Suppose after metal lines like aluminum was deposited, how would you deposit a conformal dielectric layer (SiO_2 or Si_3N_4) to isolate the next metal layer. Solutions include CVD (PECVD) depositions of dielectrics
- When fast diffusing metals like copper are used, this low temperature deposition becomes more important

Disadvantages

- May leave unwanted byproducts on film
- Costly
- Stoichiometry is not guaranteed (Si_xN_y instead of Si_3N_4)



PECVD: At a glance

Advantages

- Low temperature process
- Provides reasonable deposition rates
- Good film quality
- Conformal

Why PECVD?

- Suppose after metal lines like aluminum was deposited, how would you deposit a conformal dielectric layer (SiO_2 or Si_3N_4) to isolate the next metal layer. Solutions include CVD (PECVD) depositions of dielectrics
- When fast diffusing metals like copper are used, this low temperature deposition becomes more important

Disadvantages

- May leave unwanted byproducts on film
- Costly
- Stoichiometry is not guaranteed (Si_xN_y instead of Si_3N_4)

Dept. of Electronic Systems Engineering

6

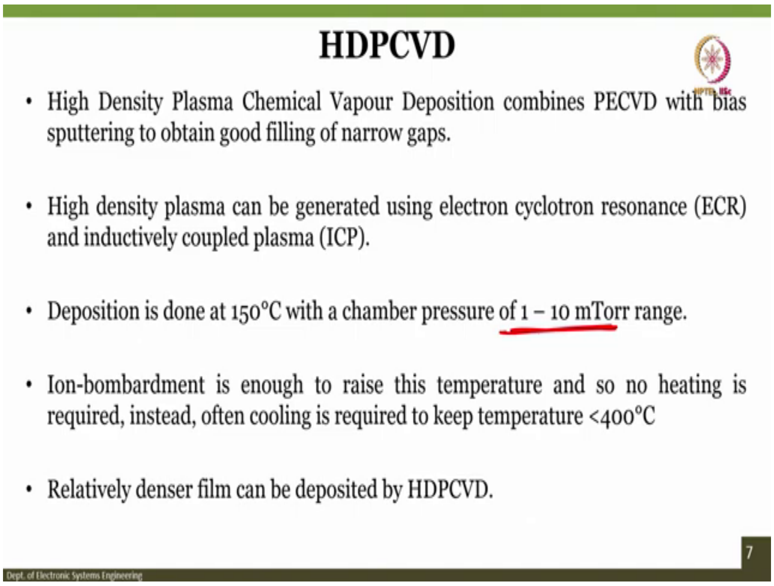
So, now if you want to see PECVD at a glance we have we can create high electric field applied between two electrodes in the presence of RF frequency 13.56 megahertz, there is a inert gas it goes in, there is a process gas which also goes in within inert gas and then there is a heated plate, the byproducts comes out, the wafer is placed, one wafer at a time there is something that we are using with PECVD.

The disadvantage of this particular process is that it may leave unwanted byproducts, it is a bit costly and documentary is not really guaranteed particularly when it will talk about silicon nitride it can be Si X and Y instead of Si 3 and 4. X and Y can be some numbers. Suppose you have metal like this titanium or gold or aluminum you can deposit silicon dioxide on that because the temperature of this PECVD is lower.

So, the advantage of lower temperature process provides reasonable deposition rates, good film quality and conformal. Conformity is very important particularly when we talk about structure which are flexible in nature. The silicon dioxide should be conformal with the structure of the substrate. This will see particularly when we are talking about the implantable devices for brain. So, will talk about conformity in that particular case.

So, the now the point is suppose after metal lines like aluminum was deposited, how would you deposit a conformal dielectric layer to isolate the next layer? You see here Si O2 Ti and then Si O2 again you have to have a Ti. So, in that case you should if I have Ti here and there is a Ti here, then this will be short-circuit Si O2 is not there. So, how to grow Si O2 over this kind of material when the temperature or melting point of this material is lower. So, we can use PECVD, when fast division metals like copper are used this low temperature deposition becomes extremely important. So, this is the advantage of PECVD.

(Refer Slide Time: 17:59)



HDPCVD

- High Density Plasma Chemical Vapour Deposition combines PECVD with bias sputtering to obtain good filling of narrow gaps.
- High density plasma can be generated using electron cyclotron resonance (ECR) and inductively coupled plasma (ICP).
- Deposition is done at 150°C with a chamber pressure of 1 – 10 mTorr range.
- Ion-bombardment is enough to raise this temperature and so no heating is required, instead, often cooling is required to keep temperature <400°C
- Relatively denser film can be deposited by HDPCVD.

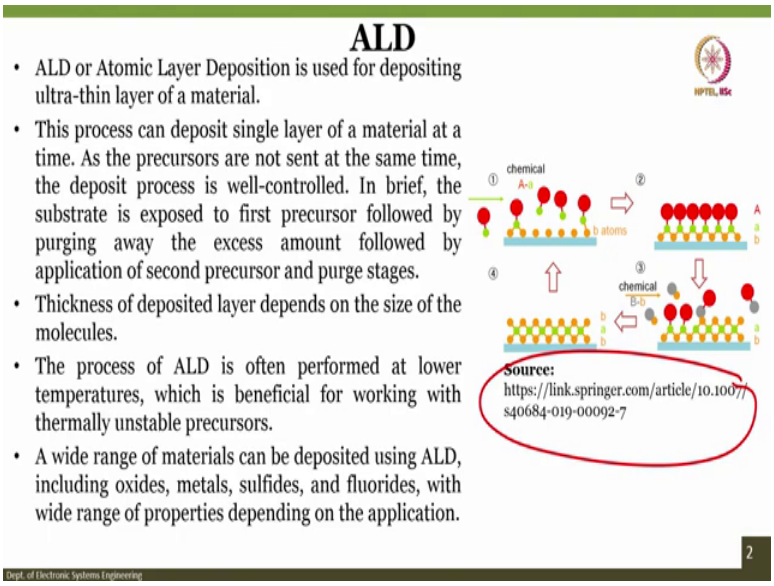
Now, if you just let us glance HDPCVD high density plasma chemical vapor deposition combines PECVD with bias sputtering to obtain good film of narrowing gaps. Very small gaps if you want to fill it with the oxide layer, you can use HDPCVD. High density plasma can generate can be generated using electron cyclotron resonance ECR and inductively coupled plasma.

So, deposition is done at 150 degree centigrade with a chamber pressure of 1 to 10 milli torr range. So, that is another thing that you need to keep in mind that the deposition is done around 150 centigrade. Second is that iron bombardment is enough to raise the temperature. So, no heating is required, instead often cooling is required to keep temperature less than 400 degree centigrade and relatively denser film can be obtained with the help of the HDPCVD.

So, like I said, we are just glancing about it we are not really going into detail about the physics, the chemistry of that, but to understand that there are some techniques, there are some tools that can be used utilized to deposit films depending on the application you can use deposition at a lower temperature or you can use deposition at a higher temperature. So, that is the point that I wanted to make in this particular class.

But this is not where we have to finish, there is one more CVD that we need to look after. And that one is called the ALD, it is a part of CVD, ALD. At ALD will be the one that will be the last topic in the CVD section. And ALD stands for atomic layer deposition, it is very important technique particularly when you want to grow ultra-thin film of material. So, what is ALD? Let us see that and then let us see the CVD at a glance and then will end the lecture.

(Refer Slide Time: 20:05)



ALD

- ALD or Atomic Layer Deposition is used for depositing ultra-thin layer of a material.
- This process can deposit single layer of a material at a time. As the precursors are not sent at the same time, the deposit process is well-controlled. In brief, the substrate is exposed to first precursor followed by purging away the excess amount followed by application of second precursor and purge stages.
- Thickness of deposited layer depends on the size of the molecules.
- The process of ALD is often performed at lower temperatures, which is beneficial for working with thermally unstable precursors.
- A wide range of materials can be deposited using ALD, including oxides, metals, sulfides, and fluorides, with wide range of properties depending on the application.

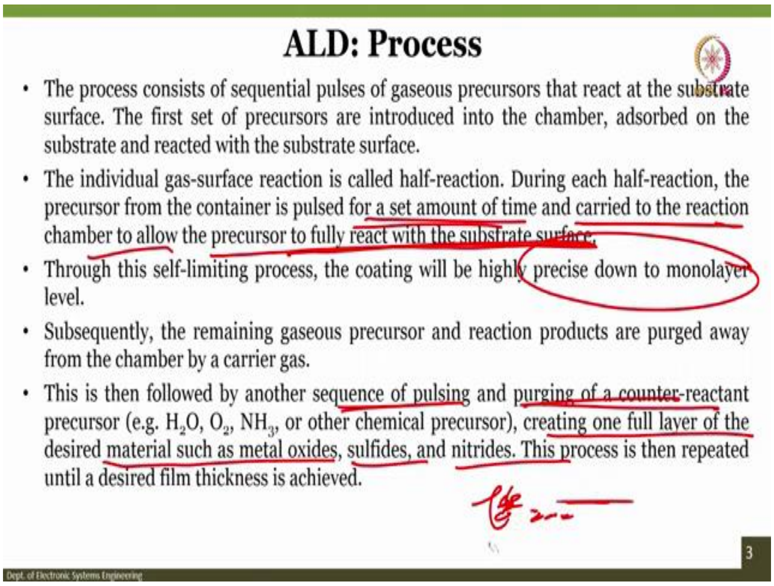
Source:
https://link.springer.com/article/10.1007/s40684-019-00092-7

So, if you see the screen, ALD or atomic layer deposition is used for depositing ultra-thin layer of material this process can deposit a single layer of metal at a time as the precursors are not sent at the same time, the deposit processes well control. In brief, the substrate is exposed to first precursors followed by purging away the excess amount followed by application of second precursors and purge stages.

So, it is keep on exposing, flushing out, exposing flushing out, exposing, flushing out that way you can have atom by atom layer of deposition forming a layer using deposition, were we what is we called ALD. So, atomic layer deposition is often performed at lower temperature which is beneficial for working with thermally unstable precursors. And the advantage is that a wide range of materials can be deposited using ALD including oxides, metal, sulfides, fluorides, with wide range of properties depending on the application.

You can see here is a source from springer where you have a chemical, it reacts with a substrate and then there are atoms, it forms a layer and then again there is purging and again there is a chemical, so you can form this beautiful thin layer of film; ultra-thin film using the atomic layer deposition technique.

(Refer Slide Time: 21:27)



ALD: Process

- The process consists of sequential pulses of gaseous precursors that react at the substrate surface. The first set of precursors are introduced into the chamber, adsorbed on the substrate and reacted with the substrate surface.
- The individual gas-surface reaction is called half-reaction. During each half-reaction, the precursor from the container is pulsed for a set amount of time and carried to the reaction chamber to allow the precursor to fully react with the substrate surface.
- Through this self-limiting process, the coating will be highly precise down to monolayer level.
- Subsequently, the remaining gaseous precursor and reaction products are purged away from the chamber by a carrier gas.
- This is then followed by another sequence of pulsing and purging of a counter-reactant precursor (e.g. H_2O, O_2, NH_3, or other chemical precursor), creating one full layer of the desired material such as metal oxides, sulfides, and nitrides. This process is then repeated until a desired film thickness is achieved.

So, the process consists of sequential pulses of gases precursors that react at the substrate surface, that is one thing. The first set of precursors are introduced into the chamber, adsorbed on the substrate and reacted with the substrate surface. So, we need to understand that how this process works. So, like I said it is a sequential pulses of the gaseous precursors and the first time the first set of precursors I introduced and then adsorbed substrate and then it is first, then second set of precursor introduced.

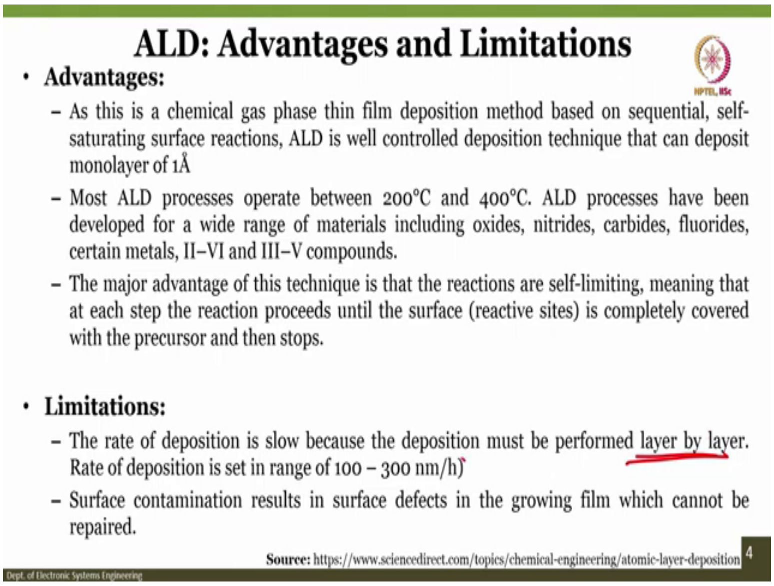
So, the individual gas-surface is called half reaction. During each half reaction, the precursors from container is pulsed for a set amount of time and carry it to the reaction chamber to allow the precursors to fully react with the substrate surface. So, though this is self-limiting process, the coating will be highly precise down to mono layer that is the advantage of this particular process that we can have a monolayer of coating atom by atom depletion of the material subsequently the remaining gases precursors and reaction products are purged away from the chamber by their carrier gas.

So, every half reaction cycle, there is a formation of some layer and then next layer these, then followed by another sequence of passing as I told you had a purging of counter reactant precursors creating one full layer of the design materials such as metal oxide sulfides and nitrites. So, this one, then purge, then another one, then purge, another one and you have a thin layer of the material.

So, that is what is shown in the previous slide as well. So, this is the ALD process for you. So, as I told you that this process is then repeated until a desired frame thickness is achieved.

This we have seen in the previous slide as you can see here. To more about ALD please visit the springer article, it is given here you type in google you will find the article.

(Refer Slide Time: 23:32)



ALD: Advantages and Limitations

- **Advantages:**
  - As this is a chemical gas phase thin film deposition method based on sequential, self-saturating surface reactions, ALD is well controlled deposition technique that can deposit monolayer of 1Å
  - Most ALD processes operate between 200°C and 400°C. ALD processes have been developed for a wide range of materials including oxides, nitrides, carbides, fluorides, certain metals, II–VI and III–V compounds.
  - The major advantage of this technique is that the reactions are self-limiting, meaning that at each step the reaction proceeds until the surface (reactive sites) is completely covered with the precursor and then stops.
- **Limitations:**
  - The rate of deposition is slow because the deposition must be performed layer by layer. Rate of deposition is set in range of 100 – 300 nm/h)
  - Surface contamination results in surface defects in the growing film which cannot be repaired.

Source: https://www.sciencedirect.com/topics/chemical-engineering/atomic-layer-deposition

4

Dept. of Electronic Systems Engineering

So, in summary if I want to say what are the advantages and limitations of atomic layer deposition; the advantages are as this is a chemical gas phase thin film deposition method based on sequential self-saturating surface reactions, ALD is well controlled deposition technique that can deposit monolayer of 1 angstrom, as thin monolayer is 1 angstrom. So, that is one advantage.

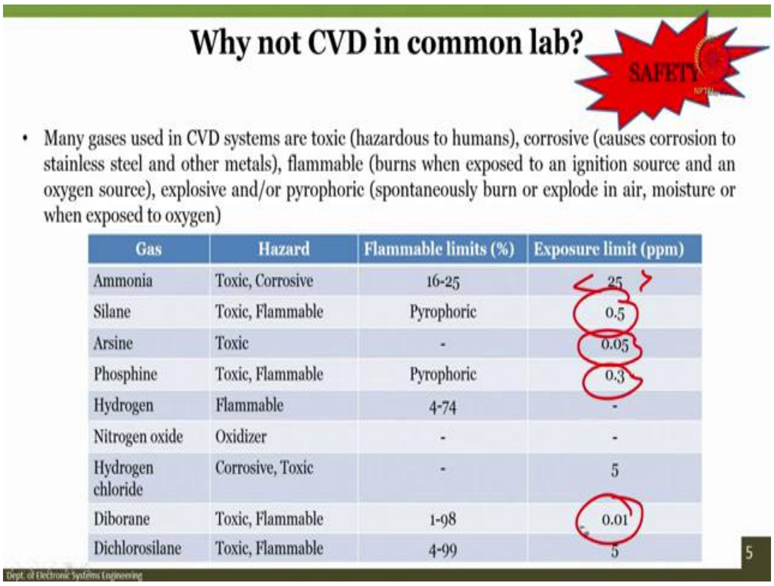
The second is most ALD process operate between 200 and 400 degrees centigrade. So, the rate the temperature is also extremely low. ALD process have been developed for a wide range of materials including oxides, nitrides, carbides, fluorides, certain materials like 2 to 6 and 3 to 5 compounds. That is another thing that several kinds of materials we can deposit.

But the major advantage of this technique is that the reactions are self-limiting meaning that, at each step reaction proceeds until the surface at reactive side is completed, completely recovered with the precursors and then stops and then we flush and then we introduce another precursor. Like I said, is there half reaction steps or you can say or half reaction gas surface reaction which is called half reaction cycle.

And then the limitations of this techniques are the rate of deposition is low because the deposition must be performed layer by layer; that is one thing. Rate of deposition range of 100 to 300 nanometer per hour; this is the little bit of limitation because 100 to 300 nanometer per hour is extremely low rate of deposition.

Also, there is one more thing that we need to take care which is the surface contamination. This surface contamination results in surface defects in growing film which cannot be repaired. This is another thing we need to really understand that the surface contamination will affect the film quality, properties of the film. So, these are the limitations, advantage and limitation of the ALD technique.

(Refer Slide Time: 25:40)

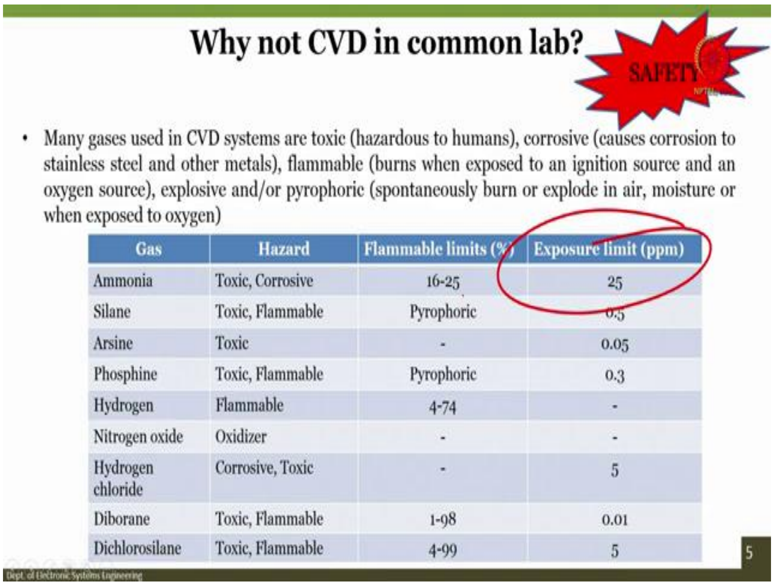


Why not CVD in common lab?

SAFETY

- Many gases used in CVD systems are toxic (hazardous to humans), corrosive (causes corrosion to stainless steel and other metals), flammable (burns when exposed to an ignition source and an oxygen source), explosive and/or pyrophoric (spontaneously burn or explode in air, moisture or when exposed to oxygen)

Gas	Hazard	Flammable limits (%)	Exposure limit (ppm)
Ammonia	Toxic, Corrosive	16-25	25
Silane	Toxic, Flammable	Pyrophoric	0.5
Arsine	Toxic	-	0.05
Phosphine	Toxic, Flammable	Pyrophoric	0.3
Hydrogen	Flammable	4-74	-
Nitrogen oxide	Oxidizer	-	-
Hydrogen chloride	Corrosive, Toxic	-	5
Diborane	Toxic, Flammable	1-98	0.01
Dichlorosilane	Toxic, Flammable	4-99	5



Why not CVD in common lab?

SAFETY

- Many gases used in CVD systems are toxic (hazardous to humans), corrosive (causes corrosion to stainless steel and other metals), flammable (burns when exposed to an ignition source and an oxygen source), explosive and/or pyrophoric (spontaneously burn or explode in air, moisture or when exposed to oxygen)

Gas	Hazard	Flammable limits (%)	Exposure limit (ppm)
Ammonia	Toxic, Corrosive	16-25	25
Silane	Toxic, Flammable	Pyrophoric	0.5
Arsine	Toxic	-	0.05
Phosphine	Toxic, Flammable	Pyrophoric	0.3
Hydrogen	Flammable	4-74	-
Nitrogen oxide	Oxidizer	-	-
Hydrogen chloride	Corrosive, Toxic	-	5
Diborane	Toxic, Flammable	1-98	0.01
Dichlorosilane	Toxic, Flammable	4-99	5

So, if you want to now summarize why we cannot use CVD in common laboratories why you cannot just have CVD installed everywhere? Because many gases that is that are used in CVD are toxic and particularly, they are hazardous to humans, corrosive in nature which will cause the corrosion to stainless and other metals. They are flammable, burns when exposed to an ignition source and oxygen source. They are explosive and or pyrophoric that means spontaneously burn or explode in air, moisture when exposed to oxygen.

So, what is the what we should do? The important point is safety. The safety and the proper control of the gas, proper control of the byproducts making sure that the byproducts comes out and it we do not just expose it directly to air if it is a harmful that we need to process the byproducts. So, all these things require you to have a proper clean room setting and then for each system you should have a proper engineer working with the system.

So, you cannot just use CVD everywhere. That is why even for the laboratory that we have which is a clean room, we do not have CVD, but we have CVD as a process or as a technology available with our mother facility which we call sense in the institute. So, the different gases if you see at the hazardous limits, the flammable limits, and exposure limit, you can see that we use several gases like ammonia, silane, arsine, phosphine, hydrogen, nitrogen oxide, nitrogen chloride, diborane, dichlorosilane and all these materials are either toxic or flammable or oxidizer or corrosive. So, this is very important.

Also you see the limits is so low 16 to 25 pyrophoric, saline is pyrophoric, phosphine is pyrophoric, hydrogen is 4 to 74. The exposure limit you see just 25 ppm of ammonia is extremely harmful here. 0.5 ppm of silane, 0.05 ppm of phosphine, 0.3 ppm of hydrogen, 0.3 ppm phosphine, 0.05 ppm of arsine, 0.01 ppm of diborane, so this is extremely low parts per million.

This is the exposure limit and that is why it is very important that there is no leakage. And every few weeks, one can see the health of the system. So, in general this is the last slide what I wanted to show it to you through this slides or to this lecture is that we have the deposition techniques, we had thermal evaporation technique, we have e beam operation technique, we have some sputtering technique, these are all three in physical vapor deposition. But, when you can talk about chemical vapor deposition these are ALD, CVD These PECVD, LPCVD, APCVD.

And then the advantages of CVD is that it can have a better conformability, one. Second is that the shadowing effect will be less. Third is that the step coverage will be better. So, these are the advantages. The limitation is that here the harmful gases are used, sometimes the rate of deposition extremely low and then the flammable limit the hazardous limit are there, the optimization is extremely important, some CVD is at a really high temperature but some CVD is at low temperature.

So, the when we fabricate a device you should keep all this in mind and you can mix and match the different technologies, different techniques to realize your device. So, we will see that in the coming lectures. One thing that I wanted to show it to you before we really move into the fabrication part or into the brain research part is micro machining, something very important technique called micro machining.

You know machining, you take material and your machine it you can either do subtractive manufacturing or you can do additive. If you printing, your adding you are adding layers onto the substrate; additive manufacturing. But if you have a metal and we want to create let us say the diaframe, in the metal you are doing subtractive manufacturing. So, how additive manufacturing will be used how subtractive manufacturing will be used. So, that that will we will learn in the next class what we call as a micro machining.

So, till then you take care I will see you in the next class and will learn quickly the surface and bulk micromachining followed by what are the EEG, signals how the signals are originated or ECoG signals and then how we can start fabricating device that can be implanted for applications like epilepsy parkinson. Also, will see a technique to understand the EEG arising from 1020 system and how the signature would vary depending on whether a person can hear or not. So, this all things are part of this entire course.

I will see in the next class with micro machining and the details of micro machining. Sometimes you may feel that the topics are a little bit difficult to grasp, so do understand that CVD is a process of chemicals. So, require a good chemical engineering background chemistry background to understand how the reaction occurs. also, the lot of physics or how the gas is introduced were between two electrodes, how much the voltage we are applying? What frequency we are using? How this plasma will generate?

So, you do not worry about all these things, my request to you would be that understand the technology that is there and try to utilize the technology to fabricate device. And that is what the focus is if you want to go in deep physics will take another course for that. We are going to understand reactions, there is another course for that.

But to understand how the devices are fabricated, to understand how we can implant these devices into the brain, you to understand how the brain signals originate, to understand what are the applications of these devices for acquiring different signals in the brain. That is what our idea should be, so that is where we are focusing on. So, let us meet in the next class and discuss more about micro machining. Till then you have a great time, cheers.