MEMS and Microsystems
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Lecture No. # 08
Microelectronic Technology for MEMS - II

So I will continue with my previous talk that is the microelectronic technology for MEMS. Here we have started discussion on the deposition of the thin film materials. So one of the techniques is spin casting technique that already I have discussed and now I will discuss some other technique by which we can get thin films, that is evaporation technique.

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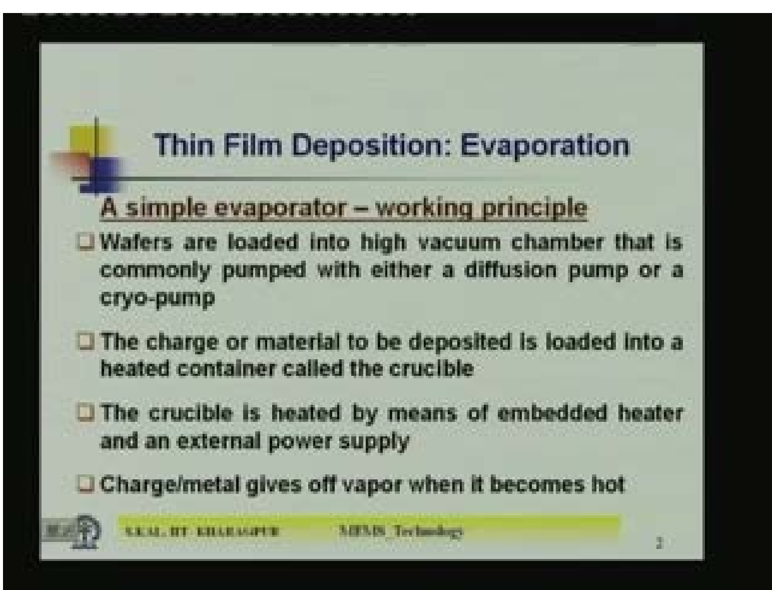

So this particular technique uses some evaporator and the basic principle is mentioned here. We load certain wafers into high vacuum chambers which are commonly pumped with either diffusion pump or a cryo-pump. So now, why we need this vacuum chamber? Because vacuum chamber is required to reduce the contamination from the environment. At the same time if you evaporate any material in vacuum its melting point and evaporation temperature will be less. So these are the two results why we need vacuum for evaporation of certain materials. So now if we use vacuum chamber, so you have to use certain vacuum pumps and those pumps are two kinds; one is oil pump other is oil free pump. So in earlier days we used to depend only an on oil pump that is rotary pump or diffusion pump or turbo molecular pump. But now days a separate class of pumps is available which you can use and there will not be any contamination from the oil. You know oil is a source of hydrocarbon contamination. So now, if you use pumps which uses oil, so there is a chance of some contamination of hydrocarbon into the vacuum chamber or into the film.

So now days most of the vacuum chambers in VLSI laboratory, they use oil free pumps, they are namely the cryo-pump or the molecular iron pump or the sublimation pump. The cryo-pump,

they use liquid cryogenic material basically liquid nitrogen, which basically condense most of the gas molecules which can condense near temperature of the liquid nitrogen. So those will be condensed and that will be observed by certain materials so automatically vacuum will be created. So you know in an atmosphere the major portion is nitrogen. So you can liquefy nitrogen and oxygen will liquefy before nitrogen. So if these 2 constituents are liquefied, then automatically in atmosphere most of the gases are gone. So pressure will go down, so that is the basic principle by cryo-pump. After then you can use the iron pump and then you can use sublimation pump for very high vacuum level. So now in this evaporator one should be the one vacuum chamber is used which is evacuated by certain pumps.

Then what is the next thing you need? The next thing you need a crucible and on which you put the material and by applying certain power, electrical power you can evaporate those materials. The materials will melt in the crucible and this crucible is heated by means of embedded heater and an external power supply and when you melt that crucible, then the material will be evaporated and it will be deposited on the wafer. So that is the basic principle. You need a vacuum chamber, you create vacuum, you put the material on and evaporator, that is crucible. Then you apply certain electric power into the crucible and crucible becomes hot and when the temperature exceeds the melting point of these particular materials, so material will evaporate. So this is the basic working principle of a simple evaporator.

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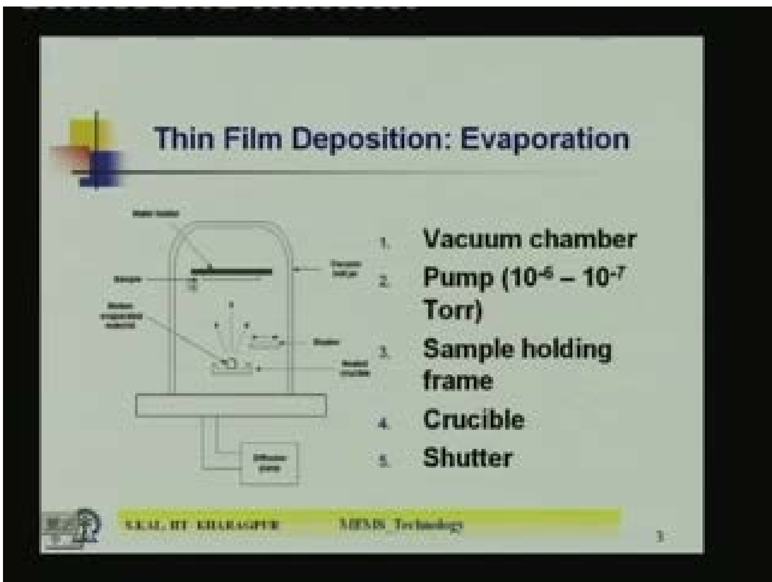

Now, you can see here the schematic diagram of that evaporated, this is a vacuum chamber and on the vacuum chamber this is a diffusion pump and using the diffusion pump you can replace the diffusion pump by the as I mentioned by cryo-pump also or other sophisticated oil free pump and the required vacuum is of the order of 10 to power minus 6 to 10 to power minus 7 Torr, means 10 to power minus 6 to 10 to power minus 7 millimeter of mercury and you have to have certain sample holding frame. These are the sample holding frame and there is a crucible. This is a crucible; here you can see the crucible here and there is a shutter. Because when you raise the

power of the crucible heated crucible, you raise the power then it started evaporation. So if you put the shutter, those evaporated material will not deposit I need when it is in full form.

So temperature raised at a high value, so the advantage there is no chances of nucleation formulation. Because if high temperature you release, the complete the evaporation temperature, then every will be melted uniformly, the uniform evaporation and there is a less chance of nucleation on the film. So that is not desirable, nucleation formation is not desirable. So that is why sometimes this shutter is used and on the same time when you got the desired thickness of the film, then you want to switch off the power supply to the crucible. So if you gradually switch off even then since it is hot, some material will be evaporated, so it will go on depositing beyond your expectation. So you put the shutter, so the evaporant will not reach on the crucible. So automatically the deposition will be stopped on the slice. So that is why this shutter is required. So these are the 5 components in a simple evaporated system.

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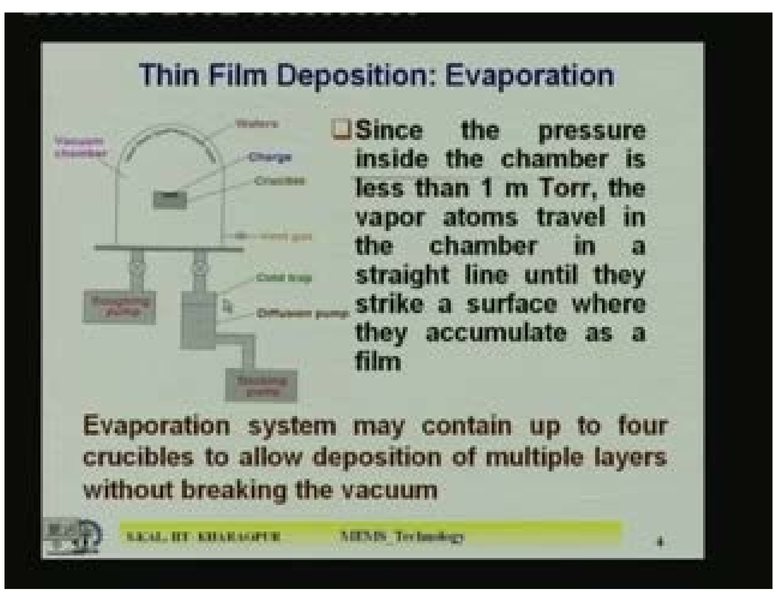

Now, the pressure inside the chamber is less than 1milli Torr it has to be. The vapour atoms travel in the chamber, in a straight line until they strike a surface where they accumulate as a film. So now here is again shown the schematic, the wafers are here and in the bell jar surface is the wafers are kept. Here these are charged means material this is a crucible and this is the pump one is roughing pump is a backing pump. There is a diffusion pump, this is a cold trap. Cold trap means liquid nitrogen trap, in the diffusion pump the diffusion oil is evaporated and it condensed back using some cold trap and when it condensed back so automatically it drags some of the air molecules from the chamber and it is vented outside. So as a result of which the chamber will be evacuated. That is the basic principle of the diffusion pump. So and here is a vent gas, so the vent is required when you want to make the chamber to atmospheric pressure. So you have to increase some amount of gas here. So that inside outside pressure is same you can open the bell jar and you can take out the substance. So that is why some venting mechanism has to be there.

So now here one thing is told the pressure inside the chamber should be very low 1 milli torr or less. So reason is that, for getting uniform deposition of the material on the material or any material on the surface, so you need high vacuum. If vacuum is low then means free path will be low. Because there, if vacuum is low there is a chances is high collision between the evaporated molecules. Because of the a collision so the evaporated molecules will not travel in a straight line path. If it does not travel in a straight line path so then the problem is the deposition on the wafer will not be uniform. Say due to the scattering among the molecules so the deposition will be highly non uniform. So that is why we need the vacuum inside the chamber to a high value so may be 10 to the power minus 6 torr is very good vacuum for evaporation. So other point is evaporation system may contain up to 4 crucibles to allow deposition on multiple layer without breaking vacuum.

So this is one crucible shown so similar 3, 4 crucibles you can attach. So that without breaking the vacuum, so one material you can deposit, then you feed power to second crucible. So second material will be evaporated then you feed power to the third crucible. Third material will be evaporated. When you want to evaporate certain material, so the other crucibles are covered by the shutter. So that from there, no contamination can come. So in this way there is a possibility of layer by layer different film you can evaporate. For example, as I mentioned earlier, the chromium gold so is required. Always gold alone will not serve any purpose. You need chromium and gold, so you can have 2 crucibles; in 1 crucible chromium and another crucible gold. So chromium is evaporated, then put the shutter over the chromium source then feed power to the gold crucible. The gold will be evaporated so without breaking the vacuum so 2 materials you can deposit.

Another is possible that is a co-evaporation if you want have the alloy film. So alloy film is sometimes required to make some thin film resistance. Nichrome, nickel and chromium alloy so there is also that is also possible if you feed power both the crucible, so both chromium and nickel will evaporate simultaneously they will mix together and deposition will be the alloy deposition. So both alloy deposition and layer by layer individual deposition is possible by using the multiple crucible inside the vacuum chamber. So evaporation system thus it can accommodate, if there is a big bell jar you can use it chamber it can accommodate more that one crucible to get various kinds of films.

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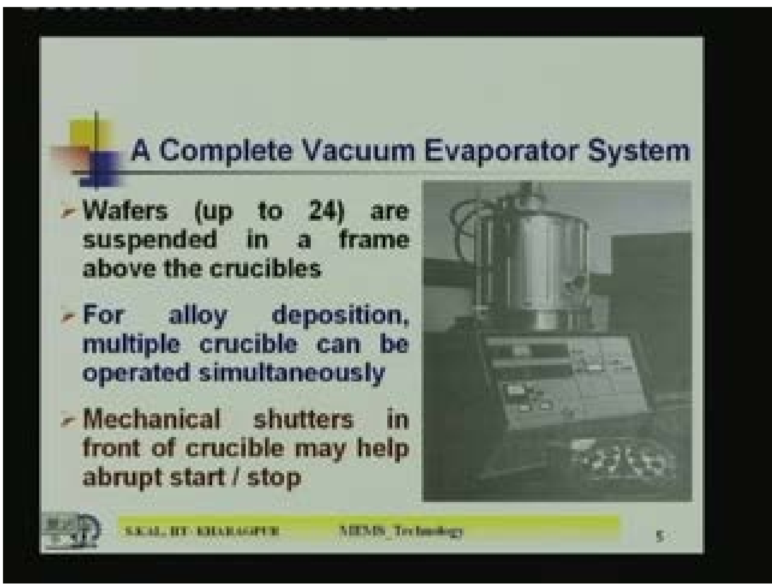

Now a complete evaporator system is shown here. The wafers up to 24 can be suspended in a frame above crucible and the bottom you can see the diagram here, the picture it is as you see these circular wafers are fixed on the wafer holder and this wafer holders are placed on the top of the chamber and it can rotate. So this individual wafers will rotate in its own axis of the holder and the 2, 3 holders together it can rotate around the central axis of the evaporation chamber. That means you can get 2 axis rotation which is known as planetary rotation and the planetary rotation helps you to get uniform film thickness on the surface of the wafer and this kind of arrangement is attached now days in most of the vacuum evaporator system. So planetary rotation that is 2 axis rotation. The individual wafer will rotate in its own axis and the holders also will rotate around the central axis of the evaporation chamber.

There is 2 axis rotation like planets moving in the solar system. So now this is the picture and mechanical shutters in front of crucible may help abrupt start and stop. I just mentioned the use of the mechanical shutter, at the same time alloy deposition is possible with this particular machine. Now the I am just now switch over to the filament. What kind of filaments or crucible you can use it? There are 3 kinds of evaporation you can use. One is known as the electron beam evaporation, another is known as the RF induction heating evaporation and the third is the resistive heating evaporation.

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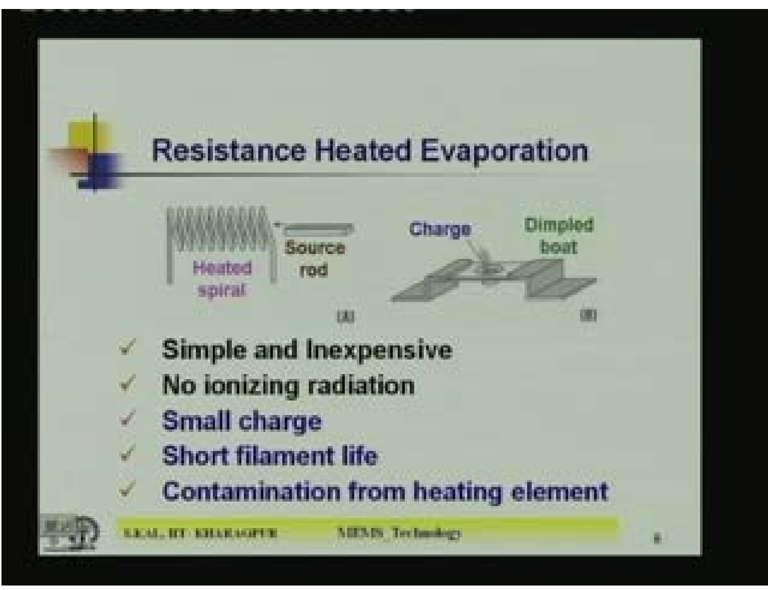

So resistive heating evaporation is shown in the diagram. Some of the crucible here you can see the heated spiral or you can dimple boat spiral, both can be used. So this is the heating element. So this is normally made of either tungsten or molybdenum. Because molybdenum or tungsten will have very high melting point. So that you can use materials which melted below the melting part of tungsten or molybdenum and that is nearly 2000 degree centigrade. Now the source material is inserted into the crystal here into the spiral here and then if you apply the current, if you allow the current flowing through the coil, so automatically it will be red hot. Its resistive heating principal basically I square r is the heat generation. So it will be red hot and this material will be melted and will be evaporated and this kind of arrangement is useful if the source is in the form of rod or form of stick. But if the source is in the form of the powder, then this kind of arrangement will not help you. Then you have to go for a dimpled boat arrangement where in the central there is a small boat and there you can put the charge, powder form charge and then if you apply the power or current to this boat, so it will be heated and evaporation will take place. So this is the basic resistance heated evaporation filaments.

So if you, there are salient points on this particular evaporation technique which are very simple and inexpensive technique. There is no ionizing radiation takes place from this resistivity evaporation. Charge requirement is very small, short filament life is the advantage and contamination from the heating element, short filament life is disadvantage not advantage. Because if you use frequently this kind of filament when the current flow is not uniform through that then sometimes the some location of the filament will be excessively heated and because of that point will be the weak point and then it filament may break. That happens because when the source will melt so it will agglomerate certain position, some of the filament you can rings will be short circuited short circuited means resistance will be less, current will be more; current will be more means I square into r, so heat generation will be more. So that means heat generation allow the filament will not be uniform. In that case in some location heat generation is more obviously the there is chance of breaking of that particular filament two reasons.

One is that filament that particular portion will soft and the second reason is again you know thermal expansion coefficient mismatch if the temperature or heat throughout the filament wire is different at different location. Because of that there will be the breaking of the filament, that is why life of the filament is short and another disadvantage of this technique is contamination from the filament. Because they melt the material which is which is evaporated that molted material will be in touch with the filament either both or the spiral wire. So some of the constituents from the filament will evaporate also along with the material. As a result of which the film will be contaminated with the filament material that is disadvantage and small charge it because here in this boat you cannot accommodate large amount of material or in the filament you cannot accommodate a large amount of source. So if you need very thicker film then you may go for 2, 3 filament small filament can accommodate small chart and the total film thickness on the wafer may be very small that is one kind of the disadvantage.

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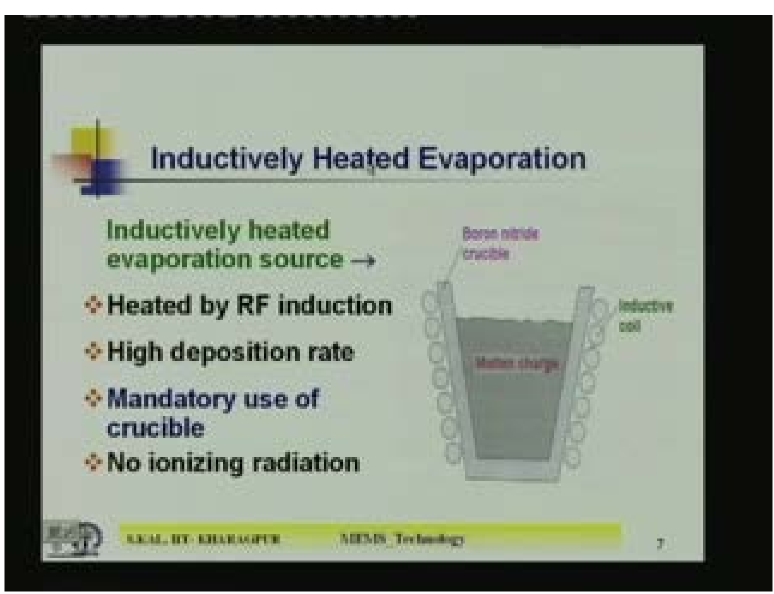

Now the second technique we are going to use is heated an inductively heated evaporation. Here you can see is it crucible is made of boron nitride material. Because boron nitride melting temperature is very high and is not only that, it is basically, if you use the inductive coil it should not be metal. It is an insulated boron nitride is insulated also. So here is the molten charge and the RF induction heating is used to melt this charge. So that means here again the molten material is in contact with the crucible. So the conduction or contamination from the crucible will still be there. But one advantage compared to the earlier process is that here you can accommodate more charge.

So if the volume of the material here in the crucible is large compared to the filament which is used in resistivity operation technique. So in that respect you can have evaporation for longtime. So you can have a larger thickness of the deposited film on the wafer by using the inductive heated evaporation and disadvantage of this is again mandatory use of crucible and another advantage is known no ionizing radiation. Ionizing radiation is not desired and the ionizing radiation is visible in some kind of evaporation which is known as electron beam evaporation.

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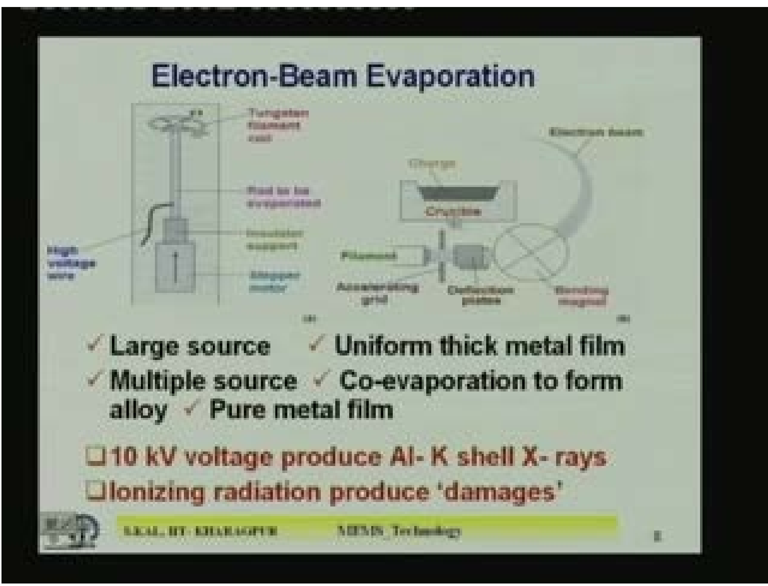

So electron beam evaporation technique is shown here. Here what is being done? A crucible is used here this is a chart and here is a filament from which the electrons are ejected, basically the cathode rays and now some accelerated accelerating grid is there and through that accelerating grid those electrons are ejected accelerated and they are deflected using electrostatic or electromagnetic field. If you apply certain electric field, then deflection will be there because electrons are charged particle. Then here is a magnetic field, high magnetic field, so that the electron beam will be deflected and it may be focused to a certain point and after focusing it that point is incident on the crucible. So that means electron beam generation, then acceleration, then guiding. Guiding the beam, so through the electrostatic deflecting plates or magnet, then it will be focused to a point and this high energy electron beam is incident on the charge and as a result of which locally heat will be transferred to the charge and locally it will be melted so and it will be evaporated.

Now this particular focused beam if you can scan over the surface so only surface will melt and from there evaporation will take place. So since the complete material is not going to melt, so there is no chance of contamination from the crucible. Because from the surface, only the kinetic energy of the electron beam is transferred and because of that transfer of energy locally it is melting. Because local melting is taking place and so less contamination from the crucible. Almost no contamination from the crucible. So that is the advantage and here also you can use large source because depending on the capacity of the crucible, you can use more materials for evaporation and uniform thick metal films because you are using large amount of charge. You can have uniform thick metal film and the purity of the film will be good compared to earlier two techniques, co-evaporation to form alloy and multiple source. These are the points because similar crucible if you use side by side. So one by one first electron will be focused in this charge. So then is the next charge you can focus it. So that will be evaporated then in the next that will be evaporated.

So same electron beam can be used for heating the material from one hearth; another name of the crucible is hearth from one hearth to second hearth to third hearth. So in that way one by one you can just deposit the material and if you want to make alloy material, that is also possible then you have to have two electron source here. There are two hearth, two electron beam source so different beam will be incident on the different material. So automatically the evaporation to will take place. So this is the basic principle of the electron beam evaporation. Here the disadvantage I have shown here. For accelerating the electron beam you need very high voltage nearly 10 Kilo Volt voltage is required. So this 10 Kilo volt acceleration voltage if it is incident on the aluminum. For example or any metal they can produce x-rays.

Because x-ray principle is also you know that is a high energy electron beam is incident on a target and from the target x-ray is emitted. So that means there is a chance of ionizing radiation in this particular technique. So the metal may be contaminated with those ions which are basically x-ray or other rays may be emitted after heating this accelerated electron on to the material. So the ionization radiation and another is to another important point is that that beam is to be focused. So if that beam is not properly focused, there may be secondary ion emission from other materials. So that secondary ion emission from other periphery material, it may contaminate the film also. But it with proper care if you take, then you can get very high purity film using the electron beam evaporation technique.

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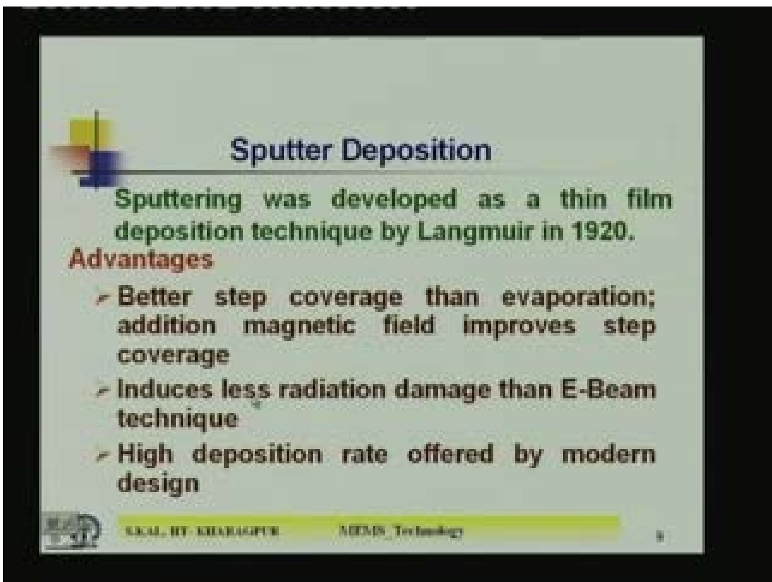

So now, there is another technique by which you can deposit thin films. So that is a sputtered deposition. Sputtering was developed by Langmuir in 1920. So it has got certain advantage. What are those advantages? Sputtering technique will have better step coverage than evaporation. Addition of magnetic field improves step coverage. This is important because you see in case of interconnected materialization, so the surface of the MEMS if you go machining at the beginning, so then it is not uniform or it is not plainer. So there will be lot of the ups and downs. So this ups and downs means there will be a certain steps over the surface that is also true in case of VLSI also.

So there is a one demand or need that all the steps should be covered by the aluminum or whatever material you are using the material film. So that on the surface you need the plainer metal. So the planarity is another important aspect when you go for deposition of any of the film. So for ensuring the planarity you have to use certain techniques which cover all the steps. So this is one technique is sputter deposition by which the step coverage will be better than the evaporation. It induces less radiation damage than E-beam technique; sputtering technique that 10 kilo volt or higher electron beam is not used. So radiation damage is less that is advantage high deposition rate offered by modern design. If you design the sputtering chamber properly, the evaporation rate will be higher. So that these are the advantage, other advantages are also mentioned here.

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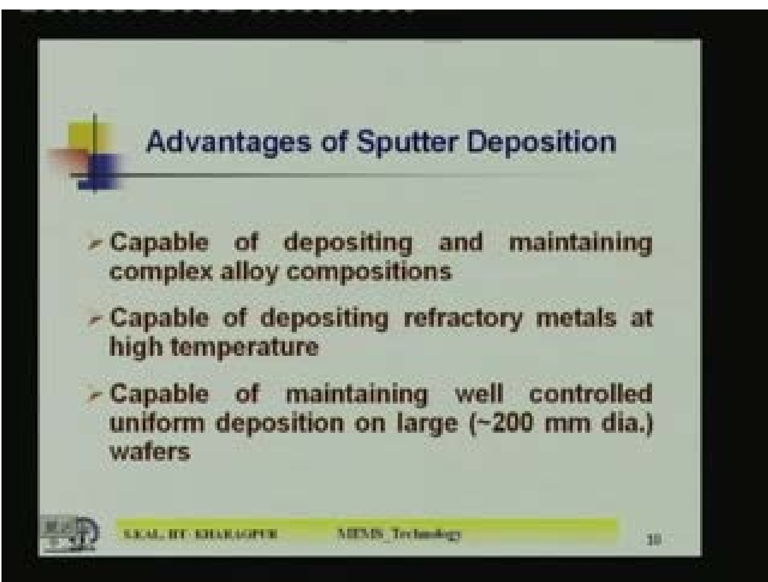

It is capable of depositing and maintaining complex alloy composition, capable of depositing refractory metals at high temperature, capable of maintaining well controlled uniform deposition on large wafers. Now this the complex alloy composition or refractory metal because refractory metal capability is one unique thing. Because you see the basic principle of the sputtering is the basically you have to create certain ions, the ions will be accelerated there is positive ions not electron beam. So positive ions why because it will have higher mass if you energize its impact will be more you when it hits on the surface. So as a result of which it will dislodge some of the materials from the target. So that is the basic material, basic mechanism of the sputtering. So now here one point is mentioned the alloy composition will be, you see deposition of maintaining complex alloy composition.

So now if you make the target before hand with proper stoichiometric ratio, then if in sputter deposition in the same ratio, the material will come out and it will deposit. But if you go for the electron beam or the resistive heating technique, by using simultaneous evaporation of the material, then controlling of the composition with certain stoichiometric ratio will be difficult. But here in case of sputtering, the target composition for fixed composition, fixed stoichiometric ratio composition you can have and then if you use that particular target then in the film more or

less you can ensure that composition. May not be the exact composition of a target, it depends on the yield of the individual components in the alloy. But you will have better the alloy composition compared to the earlier technique.

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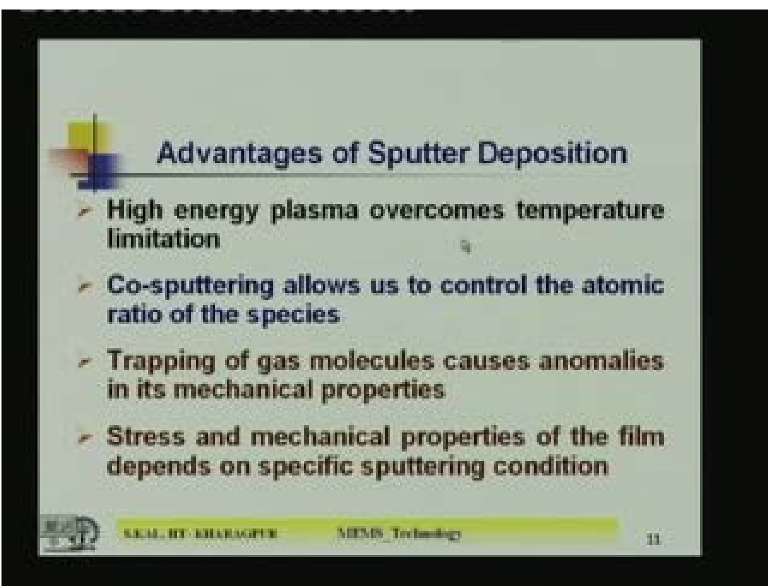

Other than that, there are other advantages in case of sputter deposition. They are high energy plasma overcomes temperature limitation. That is why you can have the refractory metal evaporation because refractory metal, if you want to evaporate using the earlier techniques of resistive heat heated or inductive heat evaporation, you have to increase the temperature to a high value. Because refractory metals evaporation temperature is very high, melting point is very high. For example, tungsten molybdenum, if you want to evaporate those materials you have to raise the temperature nearly say 1800 or 1600 degree centigrade. It is very difficult, but if you use a sputter, technique so it is different technique so there without raising the temperature to a high value, you can deposit those refractory metals very easily.

Now co-sputtering allows us to control the atomic ratio of the species that I already told you mentioned you. Trapping of gas molecules causes anomalies and its mechanical properties these are these two points are disadvantage of sputtering technique. One is a trapping of gas molecules because in sputtering you are using some ions. Those ions are normally argon ions are used. So in that, in the film may be some argon ions will be trapped. So because of the trapping of the argon ions, the property of the film may little bit change, mechanical property also may change. And other important point is a stress. Stress is another very important point of thin film deposition and this stress0 depends on the specific sputtering condition that too is very critical to manage in case of sputtering or sputtered technique.

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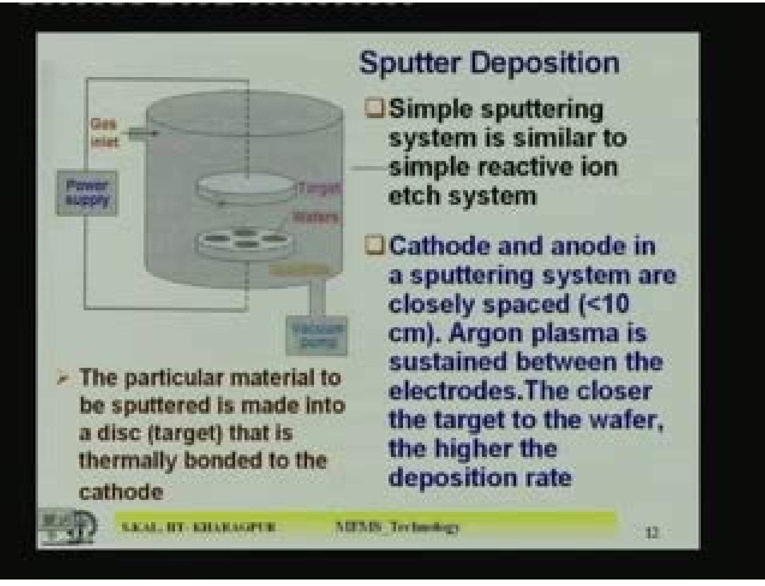

So now this is a chamber, sputtering chamber. Here basically this is the target you see in the top and bottom is the substrate holder. These are the wafers kept and now these are vacuum chamber. All these sputtering or evaporation is done in some vacuum I told you the reason of vacuum using vacuum chamber. Now if you apply power, so first the one will be the cathode, another will be the anode. Now since the positive ions were creating so you have to keep the wafers on the cathode. So if you apply certain electric field in between the two plates, so the argon gas will be ionized. Ionization of the argon gas if the gas inlet is basically that we normally use argon gas. So if it is ionized, so the ionized means the depositive ion. So obviously if the target is negative it will basically proceed towards the target. If the target is kept negative, so then it will bombard on the target.

So after bombardment the target material will come out and since you are keeping the wafers at the bottom, those materials will fall down and it will deposit on the wafer. So that is a basic mechanizing of the simple sputtered system and one of the limitation here, the particular material to be sputtered is made into a disk or target that is thermally bonded to the cathode. So this a black plate, is a cathode and you have to thermally bond the disk. That means source material, if you want to deposit has to be in the form of the target. No powder, no rod, or no plates is used in case of sputter. You have to have certain target, so you have to prepare the target material first then you can go for the sputtered deposition. So another important aspect is the gap between the cathode and anode. So this is less than 10cm, we have seen argon plasma is sustained between the electrodes.

The closer the target to the wafer the higher the deposition rate. Obviously, so if the to is the target is close to the wafer, so higher will be the deposition rate. So these are parameters of the deposition. One is the gap between the cathode and anode; another is the pressure inside the chamber, vacuum inside the chamber, another is the ions density. That means you have to in some sputter chamber, the plasma that is the ions means ion collection of ions in a system is basically plasma. So confinement of the plasma, argon plasma is another important aspect. If you

confine those, so plasma density will be higher. So where the deposition will be more so that means it depends on many parameters like the pressure inside the chamber, like the voltage applied, like the physical distance between the cathode and anode. So the deposition rate also will change and quality of the film also will change.

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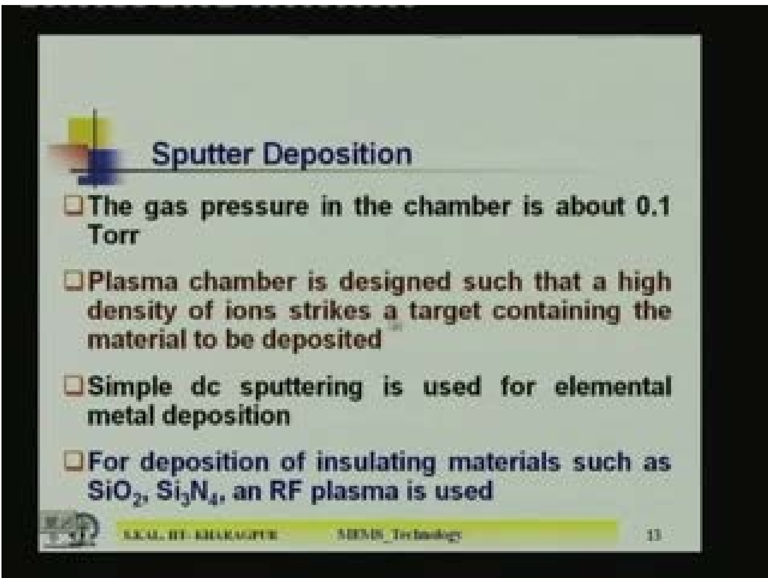

Now these are some of the points which I just talked is mentioned here. The gas pressure in the chamber is about 0.1 Torr. Plasma chamber is designed such that a high density of ions strikes a target containing the material to be deposited. Simple dc sputtering is used for elemental metal deposition. For deposition of insulating material such as silicon dioxide, silicon nitride and R and RF plasma is used because, for metal can be used as a cathode. You can attach with the cathode but if it is a insulator, then very difficult for dc sputtering. Because you cannot get the negative field at the insulator. Then you have to go for RF energy. So for deposition of the insulated material the dc sputtering is not used rather you have to go for the RF sputtering technique.

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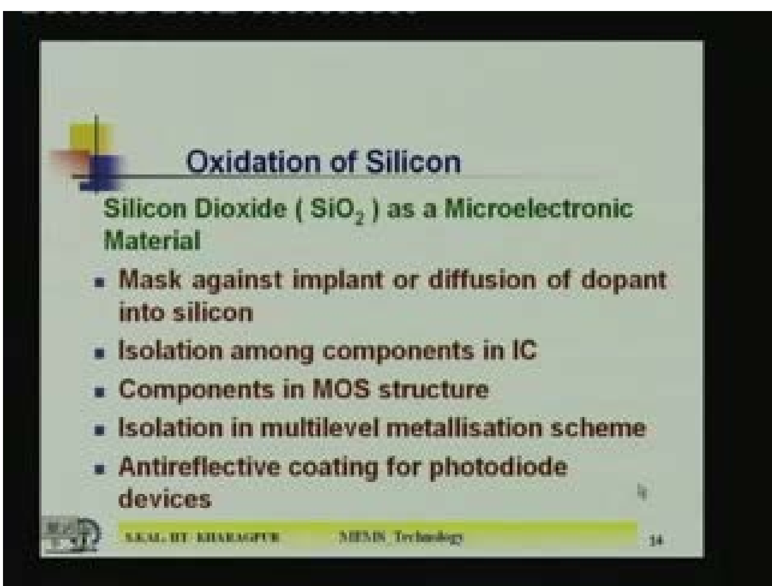

Now next topic is the oxidation of silicon. So this is an important material which is used in case of microelectronic devices as well as MEMS devices. Silicon dioxide is basically a dielectric material which is from silicon reaction with oxygen or reaction with H_2O molecules and that particular material formation is also very easy by thermal technique and is a very good microelectronic material and this particular material is used as a mask against implantation or diffusion of dopant into the silicon. That means, mask means it will prohibit diffusion or implantation in that particular region. When you open the windows which the implantation or diffusion will take place. So that means silicon dioxide is used as a mask. Second is the isolation among components in IC. That in integrated circuit the silicon dioxide is used for isolation because this is a dielectric.

So in between 2 devices if you want to isolate, so when you are making the transistors or FETs or whatever it is, so in between the two device if you fill with the silicon dioxide, so automatically they are isolated each other. So it is used for isolation also. Third application is components in MOS structure. That is a gate electron silicon dioxide is used as a gate material that is a component in MOS structure. Then it is isolation in multilevel materialization scheme. In case of VLSI you know there are 3, 4, 5, 6 and 7 to 8 layers materialization is used now days. So obviously from small layer to other layer you have to isolate. So for that isolation you can use silicon dioxide as a dielectric material in between 2 metal layers for isolation. So that is one application of the silicon dioxide for multilevel materialization scheme isolation. Then another application is anti-reflective coating for photodiode devices. It has got very good antireflective coating, but it can absorb the radiation. So in case of photodiode or in case of other optical devices it can be used for as an antireflective coating.

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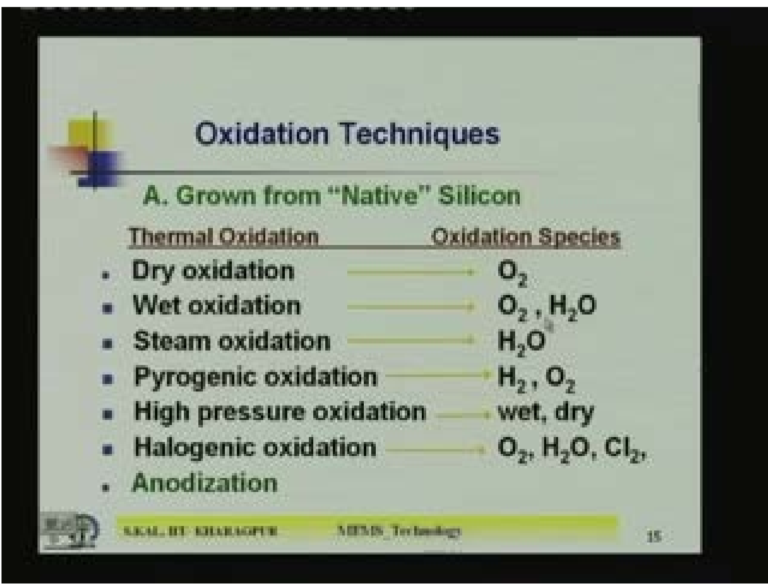

So these are the various applications of silicon dioxide and there are certain growth techniques of silicon dioxide. One technique is known as the native silicon. Native silicon dioxide growth that means if the silicon itself is converted into silicon dioxide, which is known as native growth of silicon dioxide. Locally silicon is converted into silicon dioxide and that particular technique is very much used. Because in that technique you can get very high quality dense silicon dioxide and there are different techniques of native silicon dioxide growth. One technique is known as the thermal oxidation and there is a one is a dry oxidation and where you can use only dry oxygen and the dry oxygen is reacted with silicon, it will form silicon dioxide is known as the dry oxidation. Second is wet oxidation, there oxygen species are the oxygen molecule or H_2 molecule. Basically H_2 will decompose into hydrogen and oxygen and the same oxygen will be used for forming silicon dioxide layer. So dry oxidation, wet oxidation, third is steam oxidation, if we use only H_2 molecule as an oxidation oxidation species then it is known as steam oxidation. Here no separate oxygen gas is used. But if you use combination of oxidation and H_2O molecule, then it is called wet oxidation.

Next is pyrogenic oxidation. Here basically pyrogenic steam is used. What is that? That is hydrogen and oxygen gas separately used and then it will form the H_2O molecule and that H_2O molecule will act as an oxidation species. Then what is the difference between steam and pyrogenic? The difference is in the steam, the water vapor is used. But here the gases are used. The reason is that in water vapor there may be some contamination. But here the high purity gas hydrogen, oxygen, if you use, there is no chance of contamination. If you use H_2O molecule, there is a formation of the pits. Because H_2O when it will decompose it will get oxygen on hydrogen, but if it is not as a molecule H_2O, it can create some nucleation on the surface. So as a result of which there may be some defects and pits if you use high pressure steam. On the other hand if you use 3 high purity gas of hydrogen and oxygen and if you form the steam high, pure steam inside on the surface of the silicon wafer, then they will form both oxygen and H_2O molecule and they will form native silicon dioxide and then growth rate will be fast and purity will be high compared to the H_2O or H_2O steam oxidation and wet oxidation.

Now days in most of the cases in VLSI they use pyrogenic oxidation. But only problem is that if you use hydrogen as a separate gas entity, then handing of hydrogen gas is not easy. Because hydrogen burns itself and if you use oxygen and hydrogen together to form H_2O molecule. So there is a chance of explosion. Isn't it? So that is why in the total system there should not any leak and you have to take a great precaution if you use the pyrogenic oxidation. That is why until and unless the safety arrangement is assured the pyrogenic oxidation. One should not do it one should not go for pyrogenic oxidation. The another technique is high pressure oxidation that can be wet and dry because in other the oxidation techniques which I mentioned that may be done at atmospheric pressure but sometimes we need at a high pressure oxidation because we need faster growth of oxide. So for faster growth of oxide if you increase the pressure inside the chamber the growth rate will be faster. Because over a small time you will get thicker oxide layer sometime it is also required but the quality of that oxide will not be as good as the dry oxidation which is very slow.

So in some cases we may not require very good quality oxide, moderate quality oxide if you need then you go for either steam oxidation or high pressure oxidation. For example filling up groups for isolation technique, we may require say 7 micron or 5 micron of silicon dioxide. If you go for thermal oxidation in normal pressure, atmospheric pressure it may take 2, 3 days; may be 50 hours, 60 hours like that even then you may not get it. But if you go for the high pressure oxidation growth rate will be very fast over a small time, you can get thicker oxide at high pressure. So these are the thermal oxidation, dry, wet, steam, pyrogenic and high pressure. There is another technique which is known as halogenic oxidation. Here is some halogenic materials are used that is chlorine and that hologenic material will help to purify the oxide. Because in your system if there is any alkaline element like sodium and potassium are there, the chlorine atom will react with that they will form silicon or potassium chloride which is easily dissolved in water, so that the sodium and potassium ions contamination can be protected by using some chlorine incorporation into the chamber.

So that is why in some cases, the halogenic oxidation is also popular in case of mass grade high purity oxide growth and these are basically thermal oxidation techniques you are growing. Another technique is deposition which is known as the anodization. Anodization is basically the process of extension of the electrolysis process because there, 1 cathode and anode inside the electrolytic cell and if you take water and decompose the water the water will be H plus and OH minus. So OH minus will go towards the positive electrode anode and there the OH minus, there with silicon it will from SiOH whole twice and SiOH whole twice electron decompose with silicon dioxide and hydrogen. So that is the electrolysis process basically you need an electrolytic cell and there you can deposit the silicon dioxide not grown from the native that is difference. Here in other techniques you are grown from the native silicon, but here anodization your deposition depositing the silicon dioxide as a molecule on the surface of the silicon.

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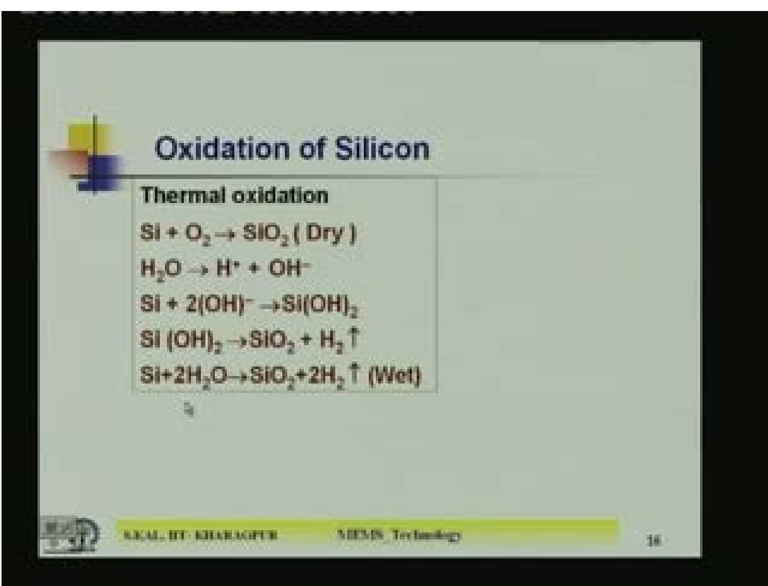

So these are growth techniques. Now these are the reactions are shown. Several reactions silicon oxygen, silicon dioxide, there is a dry oxidation H_2O H plus OH minus. This OH minus is reacted with silicon, it forms SiOH whole twice this SiOH whole twice again decompose it will form silicon dioxide and hydrogen gas will evolve. So total reaction is silicon plus $2H_2O$ will give you silicon dioxide plus $2H_2$, this will evolve and this will leave certain pores. So because you see if some H_2O molecules is there, obviously the hydrogen gas is to be evolved from the surface. So during reaction if the hydrogen gas evolves so then the problem is during the ejection process of the hydrogen gas, it will leave certain pores into the crystal. So density of the silicon dioxide material will not be high if you go for steam oxidation, go for wet oxidation. But if you use only dry oxidation using oxygen there is no residual gas, there is no formation of hydrogen. In that case you can get very good quality silicon dioxide and density will be very high less pores and those dry oxide dry oxidation technique is used in formation of the gate oxide incase of most because, there you need very good quality oxide.

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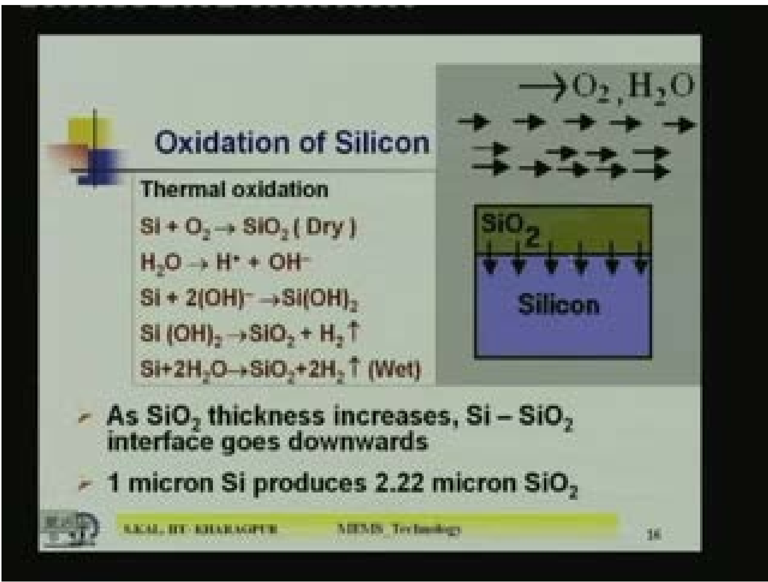

Now here is certain things are shown. Now this is silicon, how the oxide is formed? So here either oxygen or H_2 molecules are flowing over the silicon. So obviously some of the gas molecules will come in contact with silicon, a silicon dioxide will form. So when silicon dioxide is formed, then top layer will be the silicon. Then these oxidation species will not come in contact with the silicon. So those species through diffuse to the silicon dioxide and then it will come in. At the interface the reaction will take place then the silicon dioxide will grow. So as the thickness grows, the interface goes down, thickness goes upward the Si SiO_2 interface goes down. That is one important parameter and an important factor. At the same time you can see since after the growth of certain thickness, the growth rate is controlled by the diffusion also. So it will be slowed down. Initially it will be fast, initially when they are no silicon dioxide the reaction is controlled by surface reaction rate constant.

But later on when certain thickness of oxide is grown, then the growth rate is controlled by the diffusion phenomena. Because first this oxidation species means either oxygen or H_2 molecule will diffuse through the silicon dioxide, then it will come in contact with the silicon interface, then oxide will grow. This is the growth mechanism and now since Si oxygen is combined to form $SiO_{2,}$ so thickness increases. If you see the volume and molecular weight of the oxygen and silicon, then it has been observed that 1 micron of silicon if it converts into silicon dioxide it will produce 2.22 micron of silicon dioxide. The volume increases 1 micron of silicon. This one micron silicon will give you 2.22 micron of silicon dioxide.

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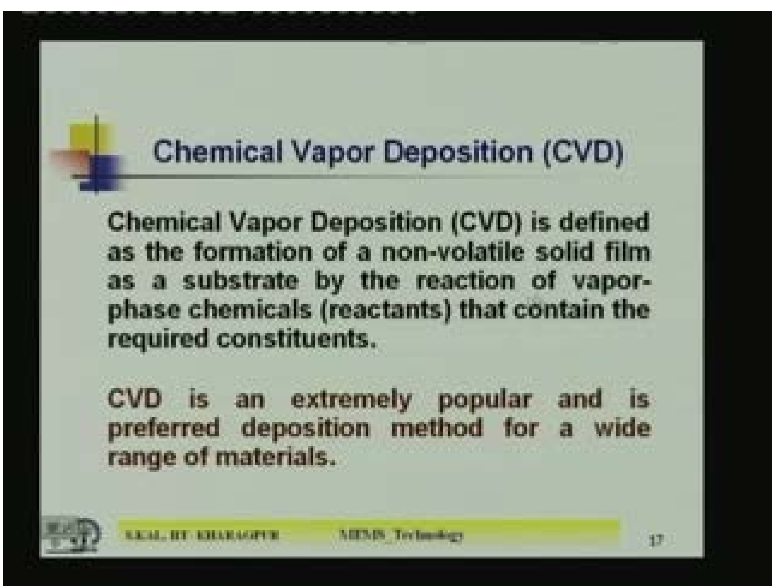

So now there are other deposition techniques; one is a chemical vapor deposition CVD that obviously here the constituents will be some form of the chemical, so chemical vapor. Chemical vapor will decompose to form certain layer and that layer may be dielectric layer, that may be may be metallic layer. If you use metal organic compound then you can get metal film deposition by using the CVD technique. CVD technique is very useful and very much used nowadays in integrated circuits and MEMS and basically is a defined as a formation of a nonvolatile solid film as a substrate by the reaction of vapor phase chemical that contains the required constituents. You have to have a chemical in vapor phase which will have that constituent and that will deposit as a solid after decomposition. CVD is an extremely popular and is preferred deposition method for a wide range of materials.

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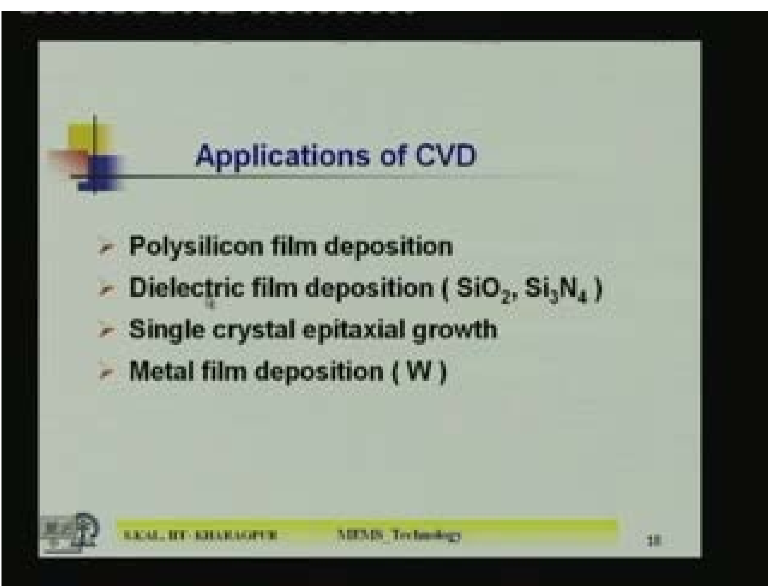

Now what kind of materials we use in case of CVD technique? In using CVD technique the one is a polysilicon film deposition in poly crystal silicon you can get using CVD technique. Dielectric film like silicon dioxide silicon nitride you can have. Single crystal epitaxial growth that is also a CVD process. Single crystal silicon is known as epitaxial formation that means, epitaxial means ordered growth you can get using CVD technique metal film deposition. If you use organometallic compound just now I mentioned tungsten, molybdenum, etcetera, you can deposit using the CVD technique, and these are the various applications.

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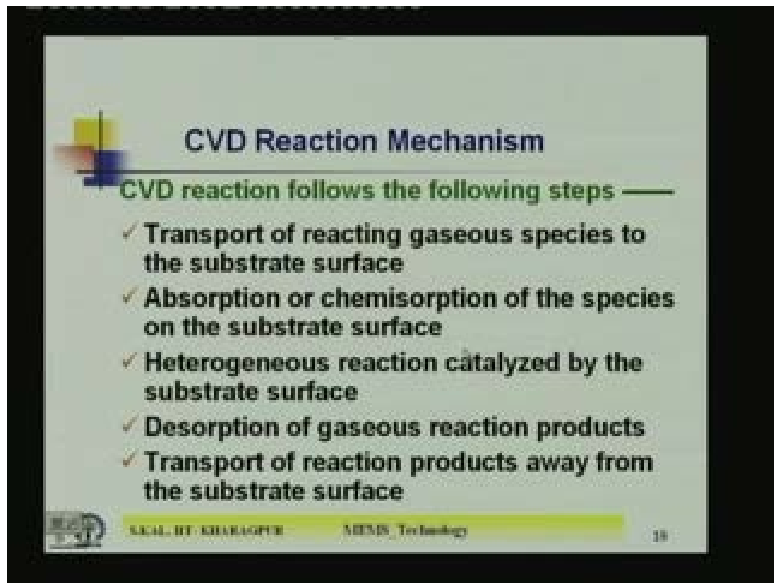

Now CVD reaction mechanisms I am just discussing. So here what are the reactions? First transport of the reacting gaseous species to the substrate surface. Then what is the next step? Absorption or chemisorption of the species on the substrate surface. Because those species after transportation you have, that has to absorb. Third step is heterogeneous reaction catalyzed by the substrate surface. Next step is desorption of the gaseous reaction and products. What are the byproduct desorption should be there rest of the gases transport of the reaction products away from the substrate surface. So these are the 5 steps followed one by one in a CVD reaction chamber.

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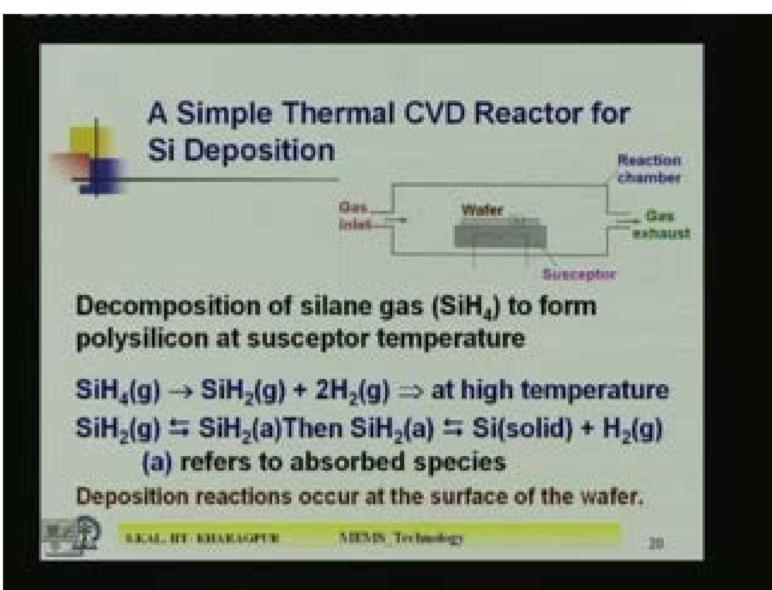

So now this is a simple thermal CVD reactor system. So this is a gas inlet, this is the susceptor on which the wafers are kept and susceptors are heated. Susceptor means container of the silicon wafer. So if you heat it then gas is flown on to the surface of the wafer. So in this reaction chamber at high temperature the gas will decompose and the solid material will deposit on the substrate. Here the what are the gases used? One is silane SiH_4 gas form, so it will decompose first at high temperature SiH_2 gas plus $2H_2$ is also gas. Then SiH_2 it again changes to SiH_2 a means amorphous and then SiH_2 amorphous will give silicon solid and H_2 gas. So this is a reaction step. First SiH_4 at high temperature decomposes into SiH_2, then SiH_2 gas to amorphous then from amorphous SiH_2 to silicon solid and hydrogen gas. So after absorption, then the solid material is coming out and it is deposited. Deposition reaction occurs at the surface of the wafer.

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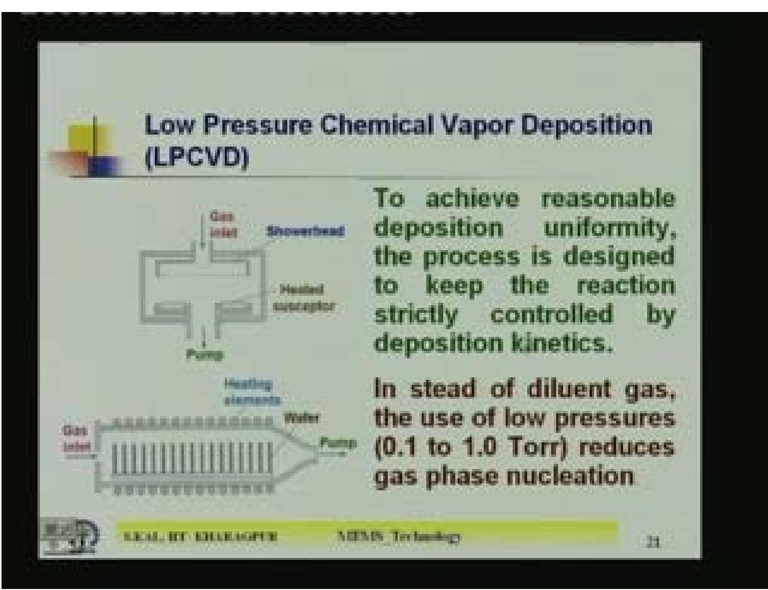

So now the there is another the CVD technique which is known as LPCVD, low pressure chemical vapor deposition. So to achieve reasonable deposition uniformity the process is designed to keep the reaction strictly controlled by deposition kinetics. So in this ONA chamber you can stack the wafer is the heating element. This is the furnace tube, the gas inlet you are ejecting gas means some reactant gases are coming up. This is one reaction chamber and one of the advantage of this LPCVD is to prohibit the formation of nucleation. So if you do the complete reaction inside a chamber which is at a low pressure, the nucleation of the particle will not be there. If the chamber pressure is high the nucleation will be there. What is the nucleation silicon? Silicon, silicon 2, 3 molecule together form a nuclear and that particular particle will deposit on to the wafer. That means that is a defect.

We need if you go for single crystal silicon we need a ordered growth molecule by molecule just like building a house by using brick. But instead of that if the silicon particles are conglomerated and 2, 3 particles together form a particulate and that particulate means, that is a nucleation and that nucleation stops. So if one defect is formed that defect will continue throughout the crystal and that crystal you cannot use. If you use it at a low pressure CVD, so formation of the nucleation of the particles can be prohibited can be prevented. So this is the low pressure CVD the technique and it is much better than the atmospheric pressure CVD. Let me stop here today. So in next class we will continue with the same topic that is microelectronic technology for MEMS. Thank you very much.

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Preview of the Next Lecture

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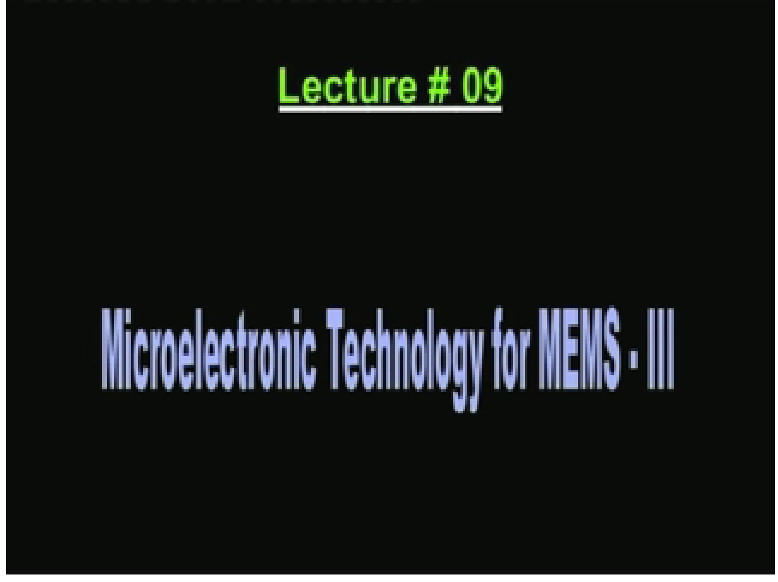

We will continue our discussion on microelectronic technology for MEMS. In the last lecture already we have discussed on the deposition techniques namely the evaporation chemical vapor deposition and various kinds of evaporation techniques also. Today's lecture we will continue on discussion on different topics like metallization, lithography, diffusion and iron implantation. All these steps are very much required for fabrication of microsensors and MEMS. Let us first discuss on lithography.

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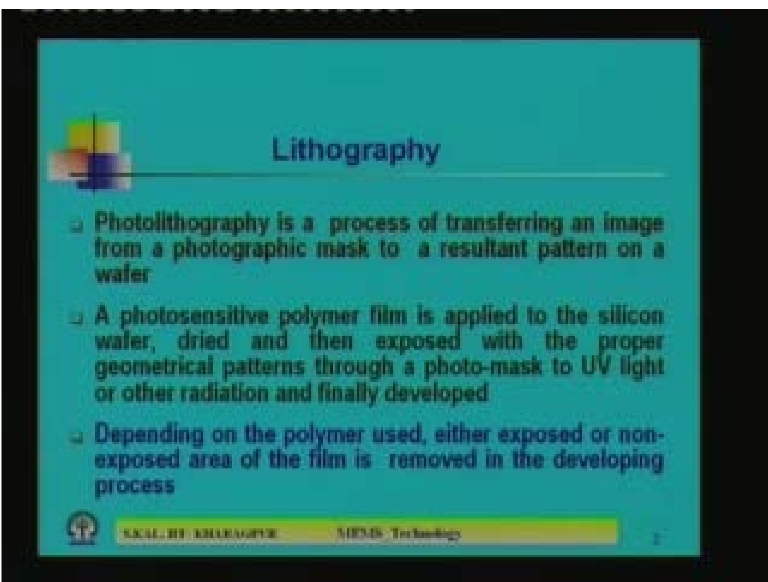

Lithography and sometime it is call also photolithography is a process by which we can transfer some pattern from photographic mask to a resultant pattern on a wafer. Then we transfer of any kind of structure from mask level on to the wafer level is known as photolithography. What is the technique? In photolithography process a photosensitive polymer film is applied on silicon wafer. This photosensitive polymer film is known as photo resist, this film is dried and then it is exposed with a proper geometrical patterns through a photo mask to UV light or other radiation and finally developed. Instead of UV light, in some cases we use x-ray electron beam or iron beam. Accordingly those techniques are known as electron beam lithography or ion beam lithography or x-ray lithography.

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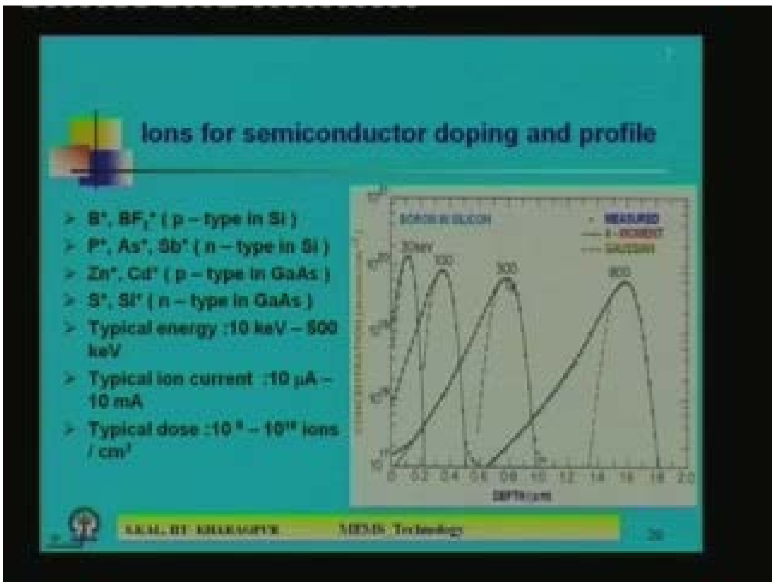

If you want a profile at a particular depth of the silicon, then go for 100 KB. There you will get the profile like this. So that means subsequent implantation if you go. So then you can get a profile like this you can combine. If you combine all these things something like that, so that means by controlling energy and dope you can have any arbitrary profile in case of ion implantation which is not at all possible in normal diffusion technique.

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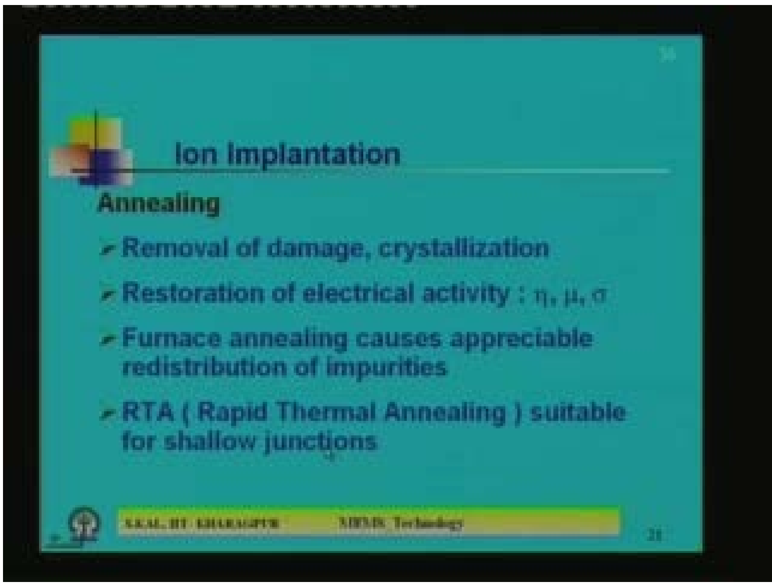

So annealing is a must in case of ion implantation for removal of damage and for recrystallization as I mentioned. Restoration of electrical activity because mu, sigma, eta all with be restored after annealing. Then furnace annealing causes appreciable redistribution of impurities. So if you prefer for RTA which is rapid thermal annealing and it is suitable for shallow junctions. Two kinds of annealings are there; one is furnace annealing and rapid thermal annealing. So furnace annealing causes again redistribution of impurities. But if you use RTA that means high temperature in small time, may be 1 minute may be 45 seconds, you can use for annealing at high temperature, say 800 or 900 or 1000 degree. So that will heal up all damages and again if you recrystallize, that is the preferred ion implantation followed by rapid thermal annealing.

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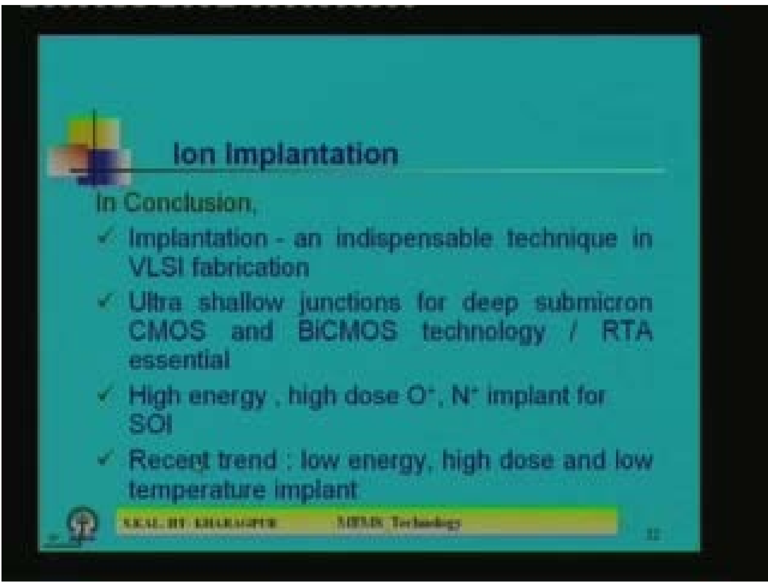

Now in conclusion of an ion implantation you can say, implantation is an indispensable technique in VLSI fabrication. Ultra shallow junctions for deep submicron CMOS and BiCMOS technology RTA is essential. High energy, high dose oxygen, nitrogen implants are required for SOI fabrication. Recent trend is low energy, high dose and low temperature implant for the submicron VLSI IC. Let us stop here today. So next class we start micromachining of silicon and first step is a etching of silicon, we will discuss in the next class. Thank you.