MEMS and Microsystems
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Lecture No. #0 7
MEMS Materials Properties (Cont.) and Microelectronic Technology for MEMS - I

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In my last lecture, I was discussing on the MEMS material properties. That was not completed so today or sometime I will discuss in the same topic.

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That is MEMS materials property and after that, I will switch over on to the different subjects. That is microelectronic technology which is used for MEMS. So let us now continue the last lecture which is MEMS material properties.

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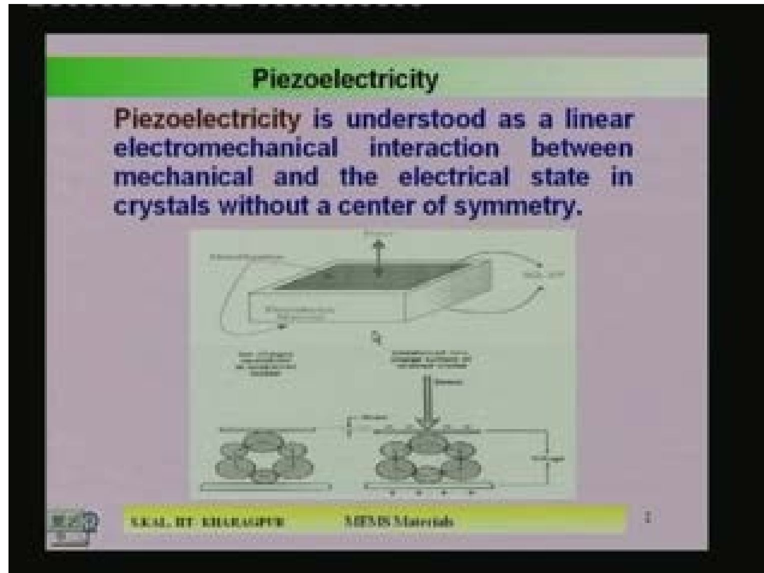

So today I will discuss on different properties which I discussed in the last class. Those are piezoelectricity of piezoelectric property of the materials. So piezoelectricity is understood as a linear electromechanical interaction between mechanical and the electrical state in crystal without a center of symmetry. Those crystals which do not have the center of symmetry will show the piezoelectric property. So basically if a piezoelectric, in this is figure, you can see a piezoelectric material is here and if we apply their force in the surface of this two surface of this particular material, then you will find that at the surface of the material some charge will be accumulated and that phenomena is a known as piezoelectric phenomena. Then if we apply force or pressure, the charge will be accumulated at the surface and there is a different, here you can see in the bottom, if you apply stress that means as a result of stress the strain will be developed inside the material and as a result of which realignment of the ions will be there and the surface will get positive and negative charges.

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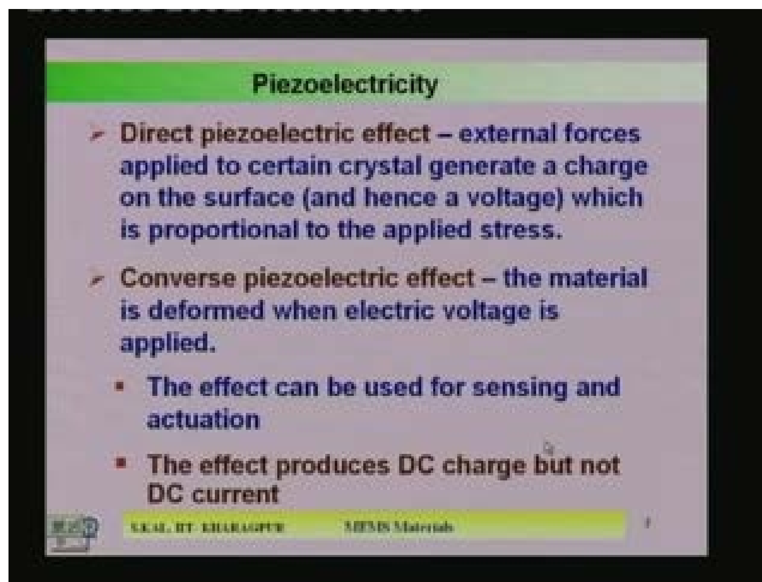

So this phenomenon is very useful in case of microsensors and microactuators. There are 2 type of piezoelectric effect. One is known as direct piezoelectric effect and another is known as converse piezoelectric effect. The direct piezoelectric effect is used for microsensor and the converse piezoelectric effect is used for actuators, microactuators. So direct piezoelectric effect basically, if we apply certain external force or pressure on the surface of the crystal, so some charge will accumulate at the surface. As a result of which you will get some voltage if you connect the 2 surface with wire, you will get some voltage.

So that means there is an electromechanical, if you apply the mechanical pressure you are getting some electric field that can be used as a microsensor. On the other hand if you apply certain electric field at the surface of the crystal then the crystal inside the crystal there is a movement or strain will be developed. That means mechanical energy or mechanical force will generate so that property can be used for designing a micro actuator. That means piezoelectric material can be used either microsensor, then it is a direct piezoelectric effect or it can be used as an actuator when you are taking help of converse piezoelectric effect.

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Piezoelectricity

- Material whose crystal structure lack a center of symmetry can show piezoresistive effect
- Effect is characterized by charge sensitivity coefficient d_{ij} (C/N)
- Relates to the amount of charge generated at the surface of the material (area A) on the i axis to the applied force F on the j axis.
- $D = \varepsilon_r E = \varepsilon_0 E + P$
- $\Delta Q_i = d_{ij} \, \Delta F_j = d_{ij} \, \Delta\sigma A$
- All ferroelctrics are piezoelectric but not vice versa

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So this particular material has got certain structure and these materials structure will always lacks a center of symmetry and they will show, this is not piezoresistive. I am sorry it will be piezoelectric effect. The effect is characterized by charge sensitivity coefficient and which is known as d_{ij} Columb per Newton C by N. It relates the amount of charge generated at the surface of the material which has got area A on the I axis to the applied force F on the j axis. If we apply force on the j axis then the i axis you will get some charge generated and that is basically d_{ij} you will get. So D equal to epsilon r into E it is a well-known relation.

That is E is the electric field is a displacement here, epsilon r is the basically the permittivity so that is equal to epsilon 0 E plus P and this delta Qi which is the charged generation due to the applied mechanical force is given by small d_{ij} delta f_j which is again written as d_{ij} delta of sigma into A's area. So that equation is the charge generation equation and with that from this charge accumulation you can extract some voltage at the two surfaces. Here, there is a material called ferroelectrics. The ferroelectrics material will have piezoelectric effect. But all piezoelectric materials are not ferroelectrics material. So converse is not true, but all ferroelectrics are piezoelectric.

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Piezoelectricity

Stress sensitivity (V/με) of different systems

Resistive	Piezoresistive	Inductive	Capacitive	Piezoelectric
0.000005	0.0001	0.001	0.005	5

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Now here is a table and here some of the properties are shown. The properties are whether the crystal is single crystal or polymer or ceramic and they are d_{ij} value piezoelectric coefficient or piezoelectric constant which is the d_{ij} here is I and j stands for different axis. For example quartz which is a piezoelectric material and single crystal is a d_{33} is equal to 2.33 and its stability permittivity is 4.5. Similarly PVDF is a polymer material it also shows piezoelectric property and the piezoelectric constant and coefficients in different axis are shown here. Similarly Barium Titanate with the ceramic material and this is a ceramic and it will have also piezoelectric property and is very high permittivity 1700 or 4100 in different axis direction. One is 33 and 31, another is 33. So 33 direction permittivity is higher than the 31 direction.

Another ceramic material which is PZT lead zirconate titanate. It is a very useful material for microsensor that also source piezoelectric property with these values the coefficients are 110 to 370 into 3 axis. Zinc Oxide is another material which is a metal oxide and with a permittivity of 1400 and it will show the piezoelectric coefficient or constant is 246 and now if you see here, this bottom table, that means stress sensitivity of different materials. So what is the effect on resistance if we apply certain mechanical pressure on particular body? If what is the effect on piezoresistive effect inductance change and capacity and piezoelectric.

Now if you compare the values there we have seen that those materials where stress sensitivity in case of piezoelectric material is highest. Its value is 5 when comparison to other materials which is 0.005 the piezo capacitance effect piezo inductive effect is 0.001 piezo resistance is 0.0001 and only resistant is 0.00005. So that means compared to other property change we found that piezoelectric material, source the piezo sensitivity is almost 5, which is which is a very large value and this property may be fruitfully utilized you can utilized it for making some piezo sensors or some other actuators also.

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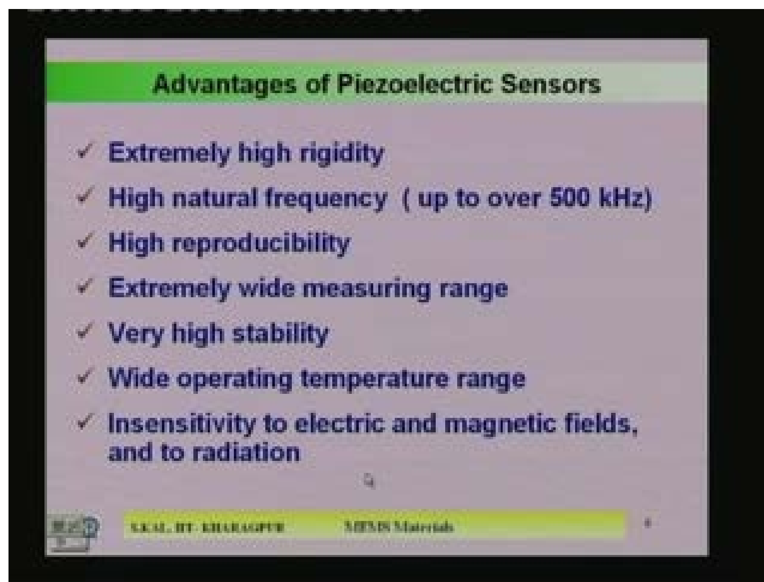

Now what are the advantages of the piezoelectric sensors? There are meaningful advantages and those advantages are namely: it is extremely high rigidity materials and or rigid material high natural frequency up to 500 Kilohertz you can get with the piezoelectric materials if you make sensor is the high reproducibility, extremely wide measuring range, very high stability, that means full scale is very wide you can get it extremely wide measuring range, very high stability, wide operating temperature range is a very important property which you cannot get in case of piezoresistance sensor. Because piezoelectric effect does not depend on the temperature. That is why this kind of sensors you can use in wide temperature ranges. Insensitivity to electric magnetic fields and to radiation that is also very important property and whenever you use any sensors, lots of other electromagnetic fields are there.

For example lot of cosmic radiation, ironic radiation, if you used that particular sensor in space will be there, you can get rid of that. Not only that electromagnetic field should be there electric and magnetic field. Even if you in a laboratory, there are certain amount of the magnetic or electric field may be available due to some line voltage or due to some high voltage equipment or due to presence of very heavy magnet in the laboratory, you cannot get rid of that. So you want your sensor should not be disturbed with those, the extra radiation or extra field. So in that respect, the piezoelectric material is one good choice because this property or this effect does not depend on the radiation. It does not change with respect to the magnetic and extra electric fields.

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Now, another property we will discuss that is thermoresistivity. Thermoresistivity is known, you know the different material will have temperature coefficient of resistance that is thermoresistivity. That means if you change the temperature the resistance will change that property is known as thermoresistivity. The resistance changes with change in temperature and the well-known relation is here R equal to row into L by A row is the resistivity, L is the length of a bar and A is the area. Area is equal to w into t and t is the thickness of that bar and w is the width. So row equal to L divided by w into t where e equal w into t and sigma which is nothing but reciprocal of the resistivity, sigma is the conductivity is given by q mu and n plus mu pp is an well-known relation preliminary relations and these thermoresistivity basically it change of resistance with temperature that relation is given by RT is equal to R_0 into 1 plus alpha into T minus T_0 where the alpha R is the temperature coefficient of resistance.

This alpha R value is different for different material and because of that alpha R change, you will get different thermoresistive property of different material and here is the table which shows the resistivity as well as temperature coefficient of resistant which is the alpha R. Alpha R and resistivity is compared for different material. For example carbon, magnesium, nichrome, chromium, aluminum, silver, copper, platinum, tungsten, iron, nickel and gold. These materials are frequently used in many microsensors MEMS or in case of VLSI also. So there are if you look into the table, then we will find that the gold will have the highest TC which is 8300 ppm per degree centigrade. But this particular material you cannot use because of certain reason and one of the reason I mentioned earlier gold alone you cannot make the film with good addition and although it is a noble metal, but the problem is the thin film does not adhere properly with gold.

Then you have to take help from some other the adherence other thin film material for proper addition with the substance. So gold is very rarely used for TC sensitive sensor or where thermo resistivity effect is used. Rather one material is used frequently which is nickel and which is having 6900 ppm per degree centigrade is alpha and this is also very high for many cases for example, the flow sensor, where the thermoelectric where these alpha R or temperature coefficient of resistance effective property is utilized. So there we use nickel as a

sensing material. Because of very high temperature coefficient of resistance value and with that nickel as a sensing material, the only contact you can use for chromium gold it does not matter but nickel is a good choice for sensor where you want to utilize the property of thermoresistivity.

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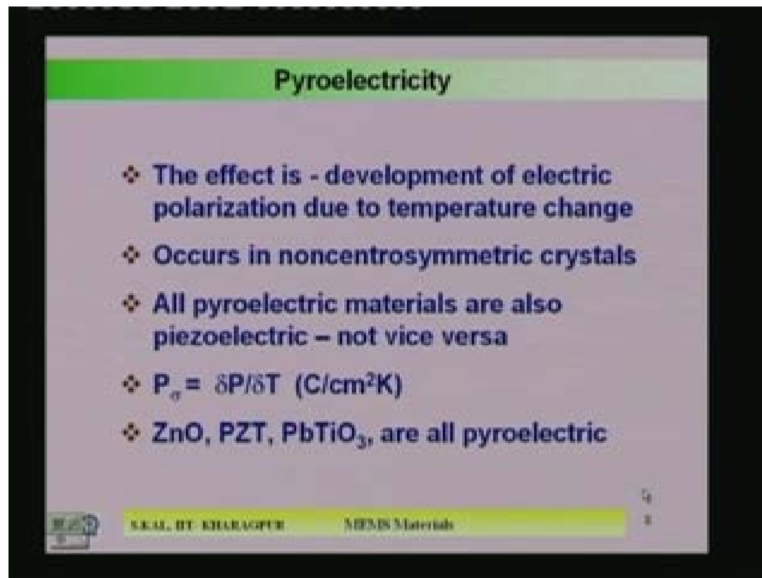

Now another property I would like to discuss is pyroelectricity. Pyroelectricity effect is basically development of electric polarization due to temperature change. Temperature change that means if you change the temperature of that particular body or crystal or material the electric polarization dipole realignment will be done inside the crystal. As a result of which you will have certain charge at the surface which is a pyroelectricity effect. Thermoelectric is a temperature change your resistance is changing that is the thermo electricity which is earlier I mentioned. Another is the pyroelectricity, is again there we are changing the resistance but here we are getting some electric field charge you get at the surface. So both are dependent on the temperature. So the pyroelectricity effect is utilized in many cases of the temperature or radiation sensor. Iron radiation sensor or many other high temperature measurement sometimes pyroelectric materials are used and it occurs in noncentrosymmetric crystals.

This pyroelectric effect is observed in case of noncentrosymmetric crystals. Again all pyroelectric materials are also piezoelectric not vice versa. Because pyroelectric is a subset of the piezoelectric material. So pyroelectricity you can, all pyroelectric materials basically shows the pyro the piezoelectric effect. So that means all piezoelectric may not show the pyroelectric, but all the pyroelectric will show the piezoelectric effect. Now the P sigma is equal to the relation is sigma P by sigma T where P stands for polarization and T is the temperature change. So materials in the pyroelectricity with materials which show the pyroelectric effect are zinc oxide and PZT and lead titanate. PZT is the lead zirconium titanate and the lead titanate PbTio3. So here you see among 3 materials, these 2 materials PZT and lead titanate is having some lead composition but zinc oxide does not have. So lead material normally is not used in case of the VLSI process line because you know lead and a single material is not an user friendly material. It is some kind of hazard chemical.

So that is why now it is zinc oxide material is used frequently for either piezoelectric material or pyroelectric material rather than PZT and lead titanate. Earlier PZT and lead titanate where used for making sensor where the MEMS technology is not used and where the peripheral integrated circuit is not connected. So then individually you can process it, you may not bring those material into clean room environment, so there is no problem. But if you go for MEMS technique or MEMS method for making those sensor then obviously you have to choose certain material which is user friendly to the VLSI process and because you should not contaminate the whole the process equipment or the process gadgets means accessories by lead contamination. So that is why out of the three material zinc oxide is much popular and lot of work is going on zinc oxide. So next is a another property is a black body radiation.

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So black body radiation, you know blackbody is an always any short of property on radiation is compared. It is compared with respect to the blackbody. So blackbody is a radiation, the equation is given by Planks equation and what is the Planks equation. Planks equation is a relation between the radiant flux and the emissivity at a particular temperature. So radiant flux is basically the spectrum flux density denoted by w lambda and emitted by blackbody of emissivity epsilon at temperature T is given by a Planks equation, which is given here, w lambda is equal to epsilon lambda twice pi h c square where h is a planks constant and c is the velocity of light. So the epsilon which is the emissivity is a degree to which it is basically to find as a degree to which a body emits less efficiently than a blackbody.

Degree to which a body emits less efficiently than a blackbody is the emissivity definition and for a blackbody e equal to 1 and another important equation which is used in case of radiation physics that is Wien's displacement Wien's or Wien's displacement law which is lambda peak equal 2898 divided by T. T is the temperature in absolute in micrometer that means all body which is which is heated it emits certain radiation and wave length of that radiation is given by this relation. And another equation is very important which is Stefans-Boltzmanns equation and that also if you heat a body of the temperature T it emits certain radiation and that radiation flux emitted from that body is the WT is given by epsilon sigma T to the power 4. T is the temperature, and epsilon and sigma and the sigma is the Stefan-Boltzmann constant, epsilon is the permittivity.

So these are the relations used in case of blackbody radiation and here is a plot, radiation flux versus wave length or epsilon equal to 1 and T equal to room temperature in Kelvin. So here this particular nearly 10 micron, the radiation peak is maximum and in this particular plot or particular body if you get it, so total power is calculated from the area of the corner. So that is a normal the power available from a particular body is calculated in this technique and the radiation flux at different wave length because different body or different temperature emits different wave length which is given by this equation which is the displacement Wien’s displacement law. Now this is a radiation pyrometer one sensor or device which is used for measuring very high temperature because at low temperature. We use thermocouple kind of sensor but if you want to measure the temperature in the range of 1500 or 2000 degree centigrade.

For example you want to measure the temperature of blast furnace in meteorological industry; there temperature is in the range of 800 or 1200. 800 to say 2000 degree centigrade and that temperature is very difficult to measure using the conventional thermoelectric effect. That sensor if you use it thermocouple sensor, you cannot get it. Because at that temperature the material will soft melt if you use thermocouple. But there one technique you can use radiation pyrometer. So radiation pyrometer basically uses these laws these laws basically Stefan’s law or the Wein’s displacement law. So the radiation in that body if you absorb its wavelength it emits and that from that wavelength you can calculate the temperature. So that is one of the applications of the radiation sensors. So now comes to optical properties.

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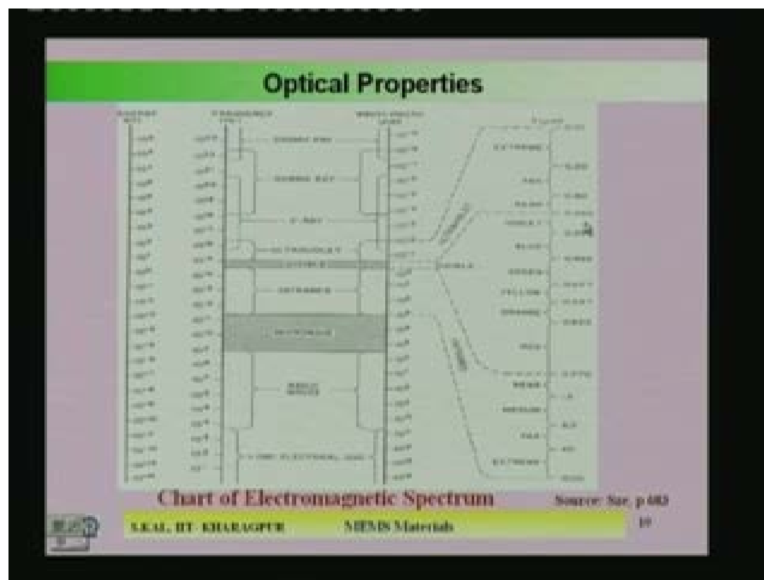

I told you that the there is a class of MEMS which is known as MOEMs micro optoelectrical or optomechanical system that is MOEMs. So these MOEMs use the optical properties of the materials. So we have to know little bit about the optical properties also. So this particular table shows the electromagnetic spectrum basically the visible spectrum. We can see the radiation from red to violet, the temperature, the wavelength ranges are say 319 micrometer to here say red is a 0.770 micrometer. So in between you will get blue, green, yellow, orange. These are visible range and other than the visible range, the ultraviolet and infrared charge frequently used in many sensors and ultraviolet range is 0.390 to 0.01 micrometer.

On the other hand infrared, near infrared, medium infrared, far infrared and extreme infrared. They are separated, different spectrum region and it extends from 0.77 micrometer to 1000 micrometer which is extreme infrared region. Now, so in between these infrared and ultraviolet, they are certain wavelength ranges or frequency spectrum frequency ranges in the left side wavelength is in the right side. So for example radio waves, long electrical oscillation, infrared or ultraviolet, x-ray, gamma ray, cosmic rays in this range. So this is the complete spectrum is given in this particular diagram in this chart. So different sensor operates in different spectrum spectral location and accordingly the property of the sensor will also change.

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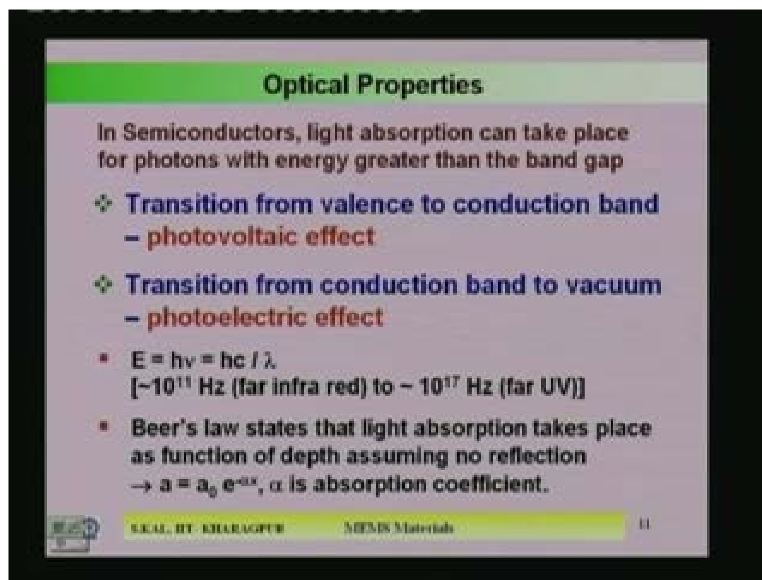

Now, there are 2 kinds of optical effect in case of materials which is used in case of sensor. One is the photovoltaic effect other is the photoelectric effect. Both effects basically based on the photon. Photon is incident on that particular body. You will get photovoltaic or photoelectric. What is the difference between these two is mentioned here? On absorption of the photons, that means optical energy, when there is a transition from valence to conduction band, that effect is known as photovoltaic effect. On the other hand, on the absorption of the photo energy, if the transition of the carrier is from conduction band to vacuum, so it is known as photoelectric effect. So both effects are used in making sensor. So obviously if we use semiconductor materials, then the energy of the photon will be such that the electron can have a transition from valence band to the conduction band.

That means the photon energy is given by h nu. So h nu must be greater than Eg. Eg is the band gap. So if that energy is less than Eg, so that will not, so any of this optical effect or it will not change the properties. Then it emits to the crystals and those things are known as optical windows basically. So there is no transition. But if h nu is greater than Eg, so there will be a transition there is a possibility, some of the carriers will jump from valance band to conduction band of the carriers it may go from conduction band to the vacuum level as a result of which we will if the movements of carriers are there, we will get some current and that is known as the photo current.

Now its energy e equal to h nu and it is given by hc by lambda and for far infra-red, this is a 10 to the 11 hertz is the nu frequency and for ultraviolet is 10 to the 17 Hertz. There is a law which is known as the Beer's law it relates to the observation of the radiation of different material. So the absorption is a function of depth. So if photon is incident on a body, so this photon is absorbed, first it has to absorb then other effect will show one by one. So this absorption is again is a function of depth. So some of the radiation it depends on the energy, so it goes higher depth and it is observed there and some of the radiation cannot penetrate its higher depth and that Beer's law states that absorption a is equal to a_0 e to the power minus alpha into x where this alpha is known as the absorption coefficient and x is the depth and a_0 is obviously x is equal to 0 so a is equal to a_0 so at the surface the absorption is a_0 and then if you go higher and higher depth. Obviously the a value will reduce that is the Beer's law.

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Optical Properties - Semiconductors

- Direct band gap semi-conductor can be used for optical setectors (GaAs). No phonon is necessary for electron transfer.
- Indirect band gap semi-conductor (Si, Ge), phonon is necessary for electron transfer. Probability of using optical device decreases as it is two particle process

Direct band gap semiconductor

Indirect band gap semiconductor

Now, the optical properties in the semiconductor if you discuss so you have to discuss on direct band semiconductor and indirect band semiconductor. So which has got much more optical effect? So if you concentrate on the direct band semiconductor which is gallium arsenide or 3 5 semiconductor or 2 4 semiconductors are there. That means, here minimum of the conduction band and the maximum of the valence band on the same wave number. It is aligned on the same wave number. So in a movement of axis, so there the transition from the valence band, conduction band which is direct there is no loss of energy in between. So that is basically the direct band semiconductor with no phonon is necessary for electron transfer. Phonon is basically the lattice vibration that energy is a phonon, and photon is the optical radiation energy the photon. Now no phonon necessary directly from valance to the conduction band it transfer and as a result of which you can have some radiation from there whose color depends on the Eg value which is calculated from Eg equal to h nu from that relation.

Now on other hand, indirect band of semiconductor examples are silicon and germanium. There you see direct transition is not possible. So now, here the minimum of the conduction band and the maximum of the valence band do not lie on the same wave number, so in the different wave number. So as a result of which there will not be a direct transition. So first, from the valance band top, it will go here and from there again there might be, there is a

collision here in between and from there it transfers in the conduction band. So here probability of going the carrier from valence band to conduction band is less because the semiconductors are indirect band gap so it will goes through high some lattice collision. So here the phonon chart required. So probability of using optical device decreases as it is 2 particle processes. Because from here you require another particle here. So from there after the collision or say scattering from here it goes to the conduction band. So that is why this class of semiconductors are not normally used in optical devices whether this, the direct band semiconductor are much popular in case of optical devices.

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Now some of the optical properties are also mentioned in this table. Band gap at room temperature is 300 Kelvin and band gap at 0 Kelvin are shown here in electron volt and the lambda max, at that means radiation from that particular material of wave length at room temperature is shown in this particular column. So materials starting from boron nitride, carbon, zinc sulphide, gallium nitride, zinc oxide, silicon carbide, cadmium sulfide, gallium phosphide and so on. Lot of 3 5 materials and 2 6 materials have shown its band gap along with the radiation, you will get from that particular material. You will find some of the materials you will get if the wave length is beyond 0.8 Micron or 0.9 Micron. Then only you get some radiation which is in the visible region. Otherwise if we use too low, so that will be in the infrared region which you cannot see. So for visibility, sometimes we use the material whose band gap lies in the range of 0.8 or 0.9 micrometer.

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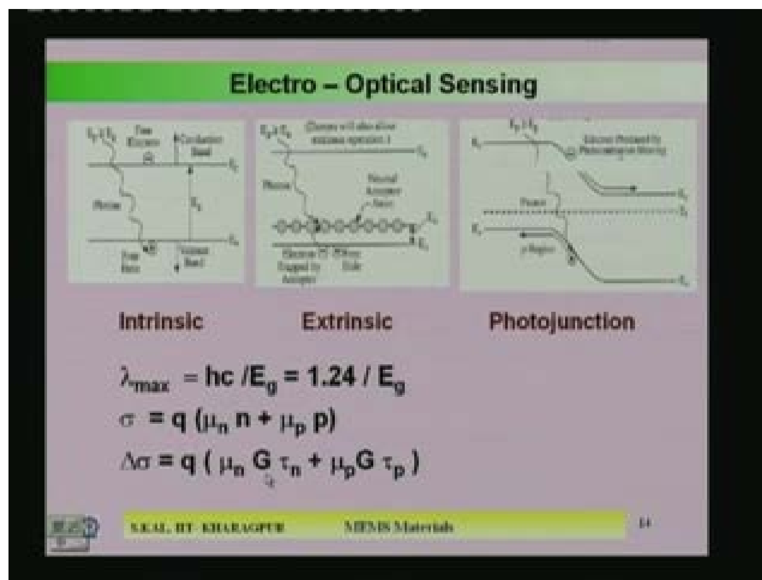

So now, the other method is the electro optic sensing. That by applying its electric field so optical by radiation or optical energy some electric energy is evolved. For example say photo detector is one example. So there if you apply certain optical energies incident on that particular device which is a basically PN junction device diode, then because of the absorption of the photo energy, some carriers will be generated and those carrier if you bias that particular junction, they will transfer from one region to other region. They will cross the junction as a result of which you will get some photo current and that is one kind of sensor which is highly sensitive to radiation. So this kind of sensor depends basically or how much carriers will be generated, how many carriers of the generated after absorption of the photon? So then obviously it depends on how much photon energy is absorbed. So after absorption, then only photo generation. So generation will be there.

So now here one parameter is the is known as the G. G is the optical carrier generation rate so that G parameter is important at the same time after generation so lifetime of the carrier is a tow n. So this optically generated carrier is g and tow n is the electron lifetime and tow p is the whole lifetime, so then the conductivity because of the absorption of the radiation is given by increase of the conductivity that is a delta sigma is equal to q into mu n G tau n plus mu p G tau p. This relation is directly related with optical absorption generate generation of the carrier and lifetime of the period but without in absence in absence of this photon absorption the equation is sigma equal to q into mu n n plus mu p p is well known and this relation is also well known here how the carrier generation takes place is shown one parameter is E_p the energy of the photon must be greater than E_g.

So then, this is an intrinsic semiconductor. This is an extrinsic semiconductor and these are photo junction. 3 cases it is shown how the carriers are generated. Here after absorption if the E_p is greater than E_g, then it will absorb the energy then obviously after absorption the some of the electrons will jump from the valance band to conduction band. As a result of which some holes will be created which is known as Ehp electron hole pair. Similarly in the extrinsic semiconductor, donors atoms will be there, you know in case of the hole, in case of p type semiconductor the acceptor atom level will be very close to the valance band E_v that is E_a that is acceptable atom level. Similarly in the case of the entire semiconductor there is an

energy level which is donor energy level very close to the E_c just below q electron volt below that and now in case of this extrinsic semiconductor the carriers will generate not only intrinsic means bulk, there is below valance level but also in the E_a level or Ed level acceptor level or donor level that means impurity level. Both from the impurity level and from the bulk semiconductor which is available in case of intrinsic semiconductor. Both will be generated and as a result which here, you will get much more the carrier available due to absorption of the radiation or optical energy or photon absorption.

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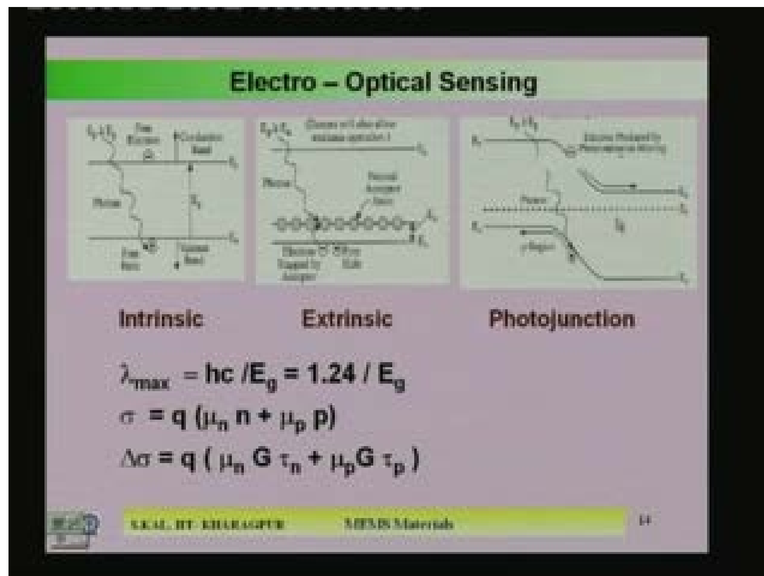

Now in this continual picture it shows how the current is obtained. So you see in if this is a junction and if you properly bias the junction, the photo generated carrier so which you say the hole here and electron here. The hole can go up the hill you know and the electron can push down the hill so as a result of which when this will be generated it will, there will be tendency, thus particular electron always flow down the hill and it will cross the junction and on the other hand, hole which is generated here, that will go up the hill. So it will go in across the valance band in other side of the junction. So as a result of which electron and hole will cross the junction and you will get the photo current that is the photo junction. So these are the properties which are utilized in making various kinds of sensors and actuators.

So with this just I finished this particular chapter which is basically based on the material properties and those material properties used for making microsensors and MEMS. Now I will switch over to the next chapter so that is the microelectronic technology for MEMS. So that is a very important chapter. Till now we discussed regarding the different materials their properties, various applications. Now, how the sensors are fabricated in the lab. So here in case of MEMS, we utilize some of the process which is being used for long time for making the integrated circuits. Those properties or those particular process steps first I will discuss and then I will concentrate on the steps which are only required for MEMS fabrication.

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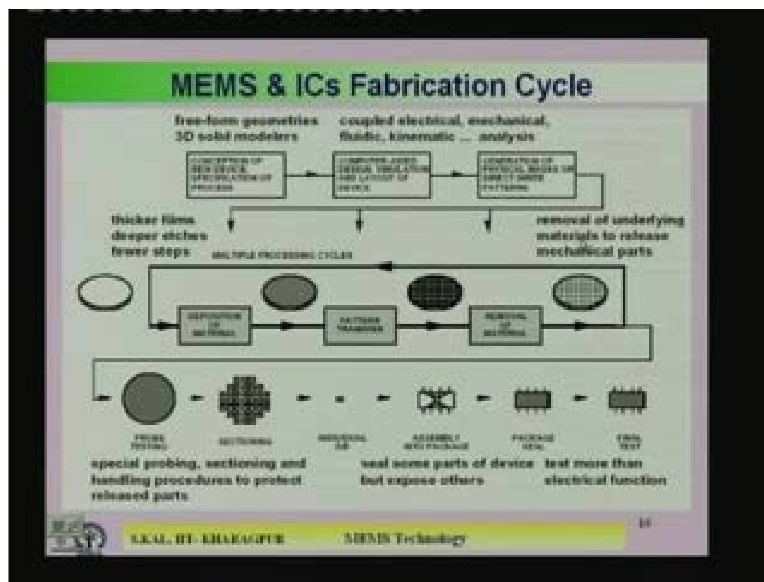

So now this particular chart will show you the IC or MEMS fabrication cycle. So it starts from here is the design thing and bottom of the cycle is the fabrication cycle. So first you have to design a particular MEMS device and what are the steps? First you make the solid models of the device and that solid model means, you were going to use a certain material may be that is crystalline material or that may be amorphous or some other materials ceramic materials also may be. So that material you first model it and free from the geometry. That means that particular material may not be a regular geometry or regular shape it may be irregular shape. So in irregular shape body or material, simulation is little bit difficult and only the numerical only you have to use the numeric tool is the only technique by which we can simulate any kind of the irregular shape or free shape body. So that modeling is to be done first. Then I have to coupled many other property, because in MEMS involves the electrical, mechanical, fluidic properties also.

So then you have to use certain simulators and using that simulator you couple the electrical, mechanical, fluidic, kinematic properties also you include that. Then, with that, this 3D solid model basically the finite element model you have to mesh it and you have to define the size of the mesh. Then you couple these properties with that particular solid body then you simulate it and when you are satisfied with the simulation result. The next is the making of the layout. After making the layout of the devices, MEMS devices, then you have to go for mask making and that is generation of physical mask or direct right pattern. So direct right pattern sometimes we use it for making the master mask and then we get step and repeat camera and using that we get the regular mask which is used for fabrication.

Now once the mask is fabricated, then design part is over. Then you come to the fabrication fab lab and there it starts from the crystal. So it is basically first step we have to have the material that material in case of silicon, the single crystal silicon is used. So I will show you may be one two slides in a after that how this single crystal silicon is grown and polished and then here in case of MEMS technology, the mainly we require the deposition of material, patterning of the material and removal of the material. So this process, the cycle continued. So here on the wafer you deposit certain material. So these are blank wafer, we deposited certain material on the wafer.

Then you have to transfer certain pattern. That is known as a pattern transfer and that is known lithography. All of you know, so using the lithography technique the pattern is transferred and you can see here, this is the film here on the wafer and here some pattern has been transferred and after transferring the pattern on the wafer, then selectively you have to remove some of the materials. Removal of selective of the material and that is basically the etching or machining. So etching and machining if you do it, then the wafers looks like this. So this cycle may continue. So maybe once, twice, thrice, so repeatedly depending on how complex is your process. So how complex is your device structure, depending on that, this cycle will continue and after that we will come up with the wafer having different kinds of structure and different kind of sensing or pick up electronic circuit on the structure. So then next job is the probe testing. After using the probe art machine, you have to test.

Before bounding, testing is done by using with the help of certain probes so probe testing is being done and whenever you are satisfied with the probe testing, then you have to do the sectioning. Sectioning means small pieces you are getting from the whole wafer and then is the individual dye. Individual dye is put on the package base, so how many package bases you take the connection? That is the wiring from the bond pads to the external leads. So that connection is that is known as assembling to the package and after the bonding is over, then you have to seal the package. Package sealing is being done. After sealing then you have to go for a final test. So here you are doing one test which is known as the probe test and here is the final test. So number of devices which you are getting here which shows the correct results, that number may reduce here because of the intermediate certain process step. But here, some special points are to be mentioned here because, from here to here in case of IC packaging and testing, the loss is less.

But in case of MEMS devices, damage is more because here you are going to use very thin membrane or thin cantilever or thin structure. So special probing sectioning and handling procedures is to be adopted to protect a release part. So some of the structure, roof mass is hanged to the help of a cantilever. So if you go for conventional probing and conventional packaging which is used for VLSI packaging, so that will not solve your purpose. So you have to go for special technique, you have to adopt for special techniques otherwise the lot of the structures will be released. That means which are hanging in case of MEMS devices, they may break and you can spoil the devices. So other, there is still some part another distinction from the normal ways I think is that you have to seal some selective parts.

So in case of VLSI, the complete part is sealed and packaged and the external leads you can connect by wire using some external wire or in PCB board you can put it. But in VLSI, in MEMS packaging, so some portion you are covering and some portion you should not cover. Because that will be in touch with the external volt, physical volt. For example, in case of gas sensor, the sensing element must expose to the environment that you cannot keep it inside the packet. Similarly things are not there in case of VLSI. The whole complete thing you can seal and seal it. So in MEMS, some portion which requires the interaction with the environment has to be taken outside the sealed portion. So that is the difference in the normal VLSI package and the MEMS package. So then you have to final test and something in a test if it qualifies, then only you can go for the marketing.

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Now, this particular slide show the conventional methods, conventional process or steps taken from the VLSI technology steps. Those are crystal growth, thin film deposition process, pattern transfer lithography, etching of materials, doping semiconductors, metallization, bonding and packaging. So all these VLSI steps are also used in MEMS. So this has been taken from normal IC technology step. So first let one by one we will discuss first let me discuss on crystal growth.

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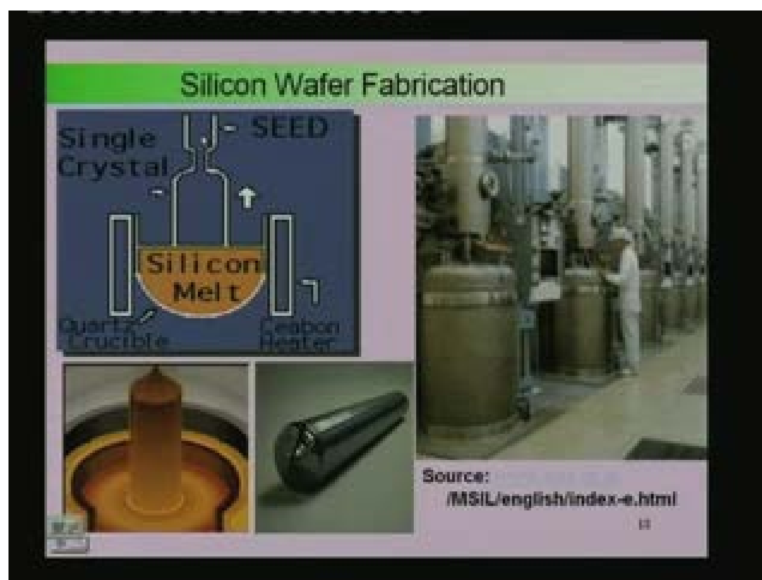

So crystal growth basically silicon wafer fabrication. You can see here, you now this technique is known as Czochralski's technique. So here silicon is melt and here is the quartz crucible and these are the heaters. So it has melted nearly 1400 degree centigrade. There is a seed crystal, then this is a seed crystal when you pull the crystal, just you rotate it and pull upward so automatically from the seed the crystal will fall and the orientation of the crystal where it is 100 or 111 and 110, all things depends on the seed crystal. If you take 100 seed

crystal, the crystal will form according to that orientation. So after pulling, that means very slow pulling and rotating and rotations is being given so that you can get uniform diameter, the ingot. That thing is known as ingot. So this bottom figure just after pulling you got the ingot and if you cool it, so this side cooling is also very important. So when you are cooling the melt, so automatically the impurity, which are lot of impurities, may be there in the melt which is not dissolved. Those impurities atoms and these by segregation it will come into the hottest zone from the cold zone. As a result of which if you slowly cool down, so from the cool zone it comes to the hotter zone and at the end of the process, those particular end, few slices you can reject it, so that the other portion will be pure. You will get the pure crystal. So after getting that, your next, this is the industrial house where lot of these crystal coolers are there.

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So after getting the ingot, next your steps will be to make slices. So these are the instruments which are used for slicing. The ingot is placed here, so the diamond cutter is there, so you see by slicing the ingot is made into thin slices. After making thin slices, it is basically transported here. So which is basically the polishing machine, so there using certain fine green powders and may be some fine green carbon particles also is used for polishing along with some fluid and just using 3 4 wafers and certain rotation was giving using certain carbonate on its powder, small particle carbon, the diamond particles is another helping in the cleaning or polishing material. You can use those to get the polished single crystal silicon.

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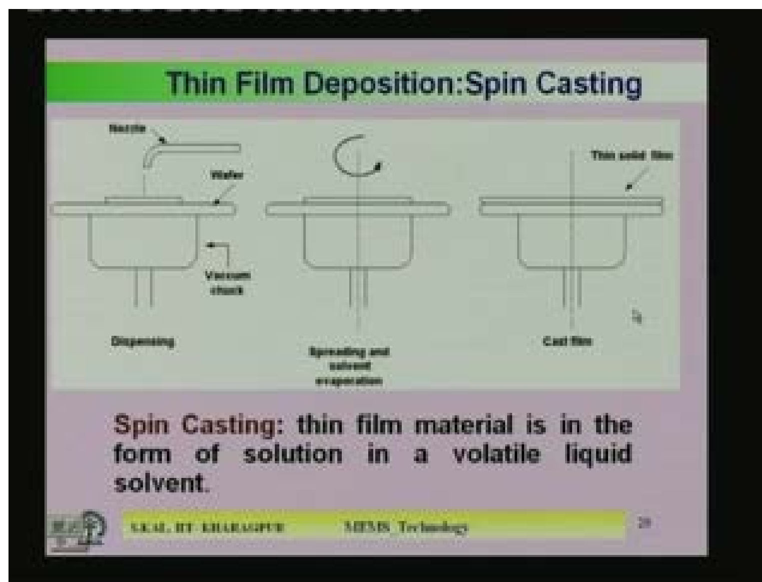

After getting wafer, so then you can process the wafer. So next step is thin film deposition. So thin film deposition, one technique is known as the spin casting technique. So spin casting technique which is used earlier, although this particular technique will not give you very good quality of the crystal, even then so this is used in some cases where normal deposition facility is not available. So here, you see through the nozzle you just eject some of the liquids here and then this particular chuck is rotated at a high speed. So that using the centrifugal force, it will spread over, the solvent will spread and at the same time, what are the in that particular paste, what the solvent that will evaporate. A total mixture will spread and solvent will evaporate and as a result of which at the end you will get the film casted film only. There is some sort of spinner arrangement which is used for thick film. A photo resist coating similar kind of thing is used here. So here, one thing is the material must be in a liquid form otherwise you cannot spread over the entire slice.

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So now, this particular thing has certain problem and this type of film have a high stress value. It will have less dense and more susceptible to chemical attack. Why? The reason is that, when are you spreading the film over the chuck, by rotating chuck you are putting the putting the liquid, then at the same time evaporation takes place. During the evaporation of the solvents so it leaves some pores. Because of those pores the film will not be highly dense and at the same time when you subsequently used those films through the pores some other gases may enter and that is why it is susceptible to chemical attack. Because of it is less dense. So that is why this particular technique is not that much popular technique although is used in some typical cases and here is the actual system the spin coding system is shown in the diagram. Now, this is one technique and other technique is the evaporation technique that technique I will discuss in the next lecture. Thank You .

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Preview of Next Lecture

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

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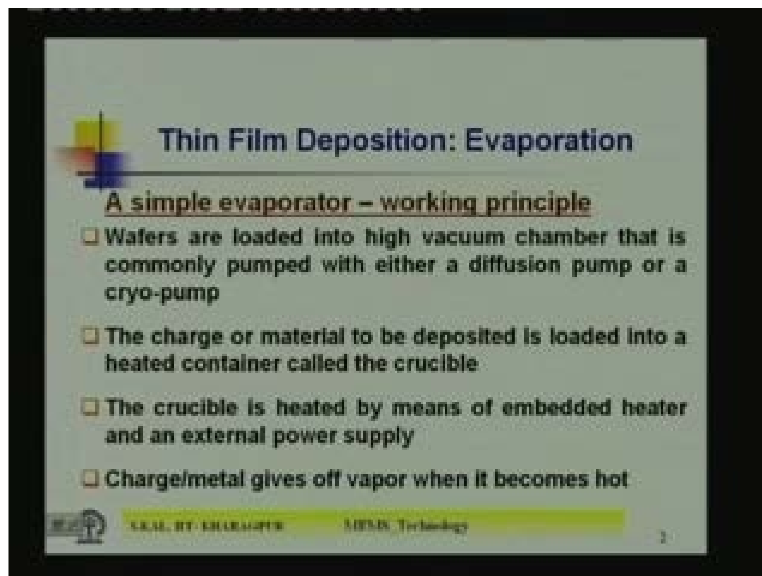

So this particular technique use some evaporation and the basic principle is mention here. We load certain wafers in to high vacuum chamber which is commonly pumped with either diffusion pump or a cryo-pump. So now, why we need this vacuum chamber? Because, vacuum chamber is required to reduce the contamination 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 reasons 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 2 kinds; one is oil pump, other is oil free pump. So in earlier days, we use to depend only on oil pumps that is the rotary pump or the diffusion pump or the turbo molecular pump. But nowadays a separate class of pumps are 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 know if we use pumps with use oils, there is a chance of some contamination of hydrocarbon into the vacuum chamber or into the film. So now a day, most of the vacuum chamber 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 used liquid cryogenic material basically liquid nitrogen which basically condensed most of the gas molecules, which can condense temperature near temperature of the liquid nitrogen. So those will be condensed and that will be absorbed by certain materials. So automatically vacuum will be created. So you know in an atmosphere, the major portion is nitrogen. So if I liquefy hydrogen and oxygen will liquefy before nitrogen, so if these two constituents are liquefied, then automatically in the atmosphere most of the gases are gone. So pressure will go down, so that is the basic principle by cryo-pump. So this is a reaction steps.

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First SiH_4 at high temperature decomposes into SiH_2, then SiH_2 to 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 deposition. Deposition reactions occurs at the surface of the wafer.

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So know, there is another DPCD 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 way, the chamber you can stack the wafer. This is the heating elements, 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 advantages 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 2 3 molecules together form a nucleus and that particular particle will deposit on to the wafer. That means that is the defect. We need if you go for single crystal silicon. We need an 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 stop 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 particular 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 next class we will continue with the same topic, that is microelectronic technology for MEMS. Thank you very much.