Mems and Microsystems
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Lecture Number #20
Mems Inertial Sensors

Today we will discuss on MEMS inertial sensors. Inertial sensor is a major area where MEMS has captured the bigger way for making sensors and microsystems.

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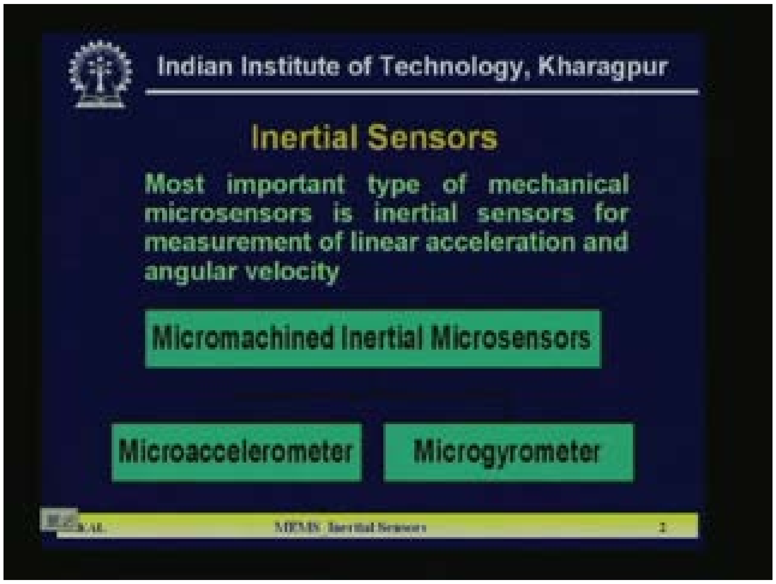

And inertial sensor is a most important type of mechanical sensors belongs to the mechanical sensor group and basically there are two sensors. Major sensor comes under this inertial sensors group. One is acceleration sensors and another is rotation sensors. So the inertial sensor basically used for measurement of linear acceleration and angular velocity linear acceleration is measured by accelerometer and angular velocity is measured by gyrosensor. Now micromachined inertial sensors accordingly are classified in two groups. One is known as microaccelerometer, other is known as microgyrometer.

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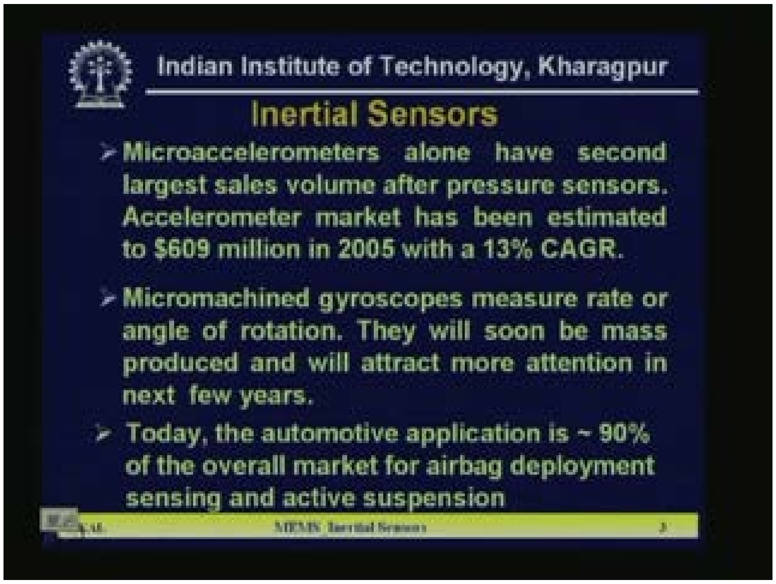

Now the inertial sensors if I give some introduction then we can say that it is the second largest sales volume after pressure sensor. The major volume of MEMS sensors as I mentioned in earlier lecture is a pressure sensor and accelerometers are the second largest sales volume. Accelerometer market has been estimated to 609 million in 2005 with a 13 percent CAGR. That is cumulative annual growth rate is 13 percent. Every year market is growing and in 2005, it is estimated to be 600 million US dollar market nearly. On the other hand micromachined gyroscopes the measure rate of angle of rotation. There should not be mass produced although at the moment the market of gyroscope is not that much like microaccelerometer. Because gyroscope is a difficult device MEMS device compared to the accelerometers and it is expected than within few years it will also draw lot of attention to the people. Today the automotive application of the inertial sensors is 90 percent of the overall market. As I told you the 609 million in 2005 estimated target, out of that 90 percent is used by automobile sector particularly airbag deployment and active suspension. These are two major application areas in automobile where the lot of MEMS sensors is being used because of its miniature form and high reliability and electronics is established for controller part as well.

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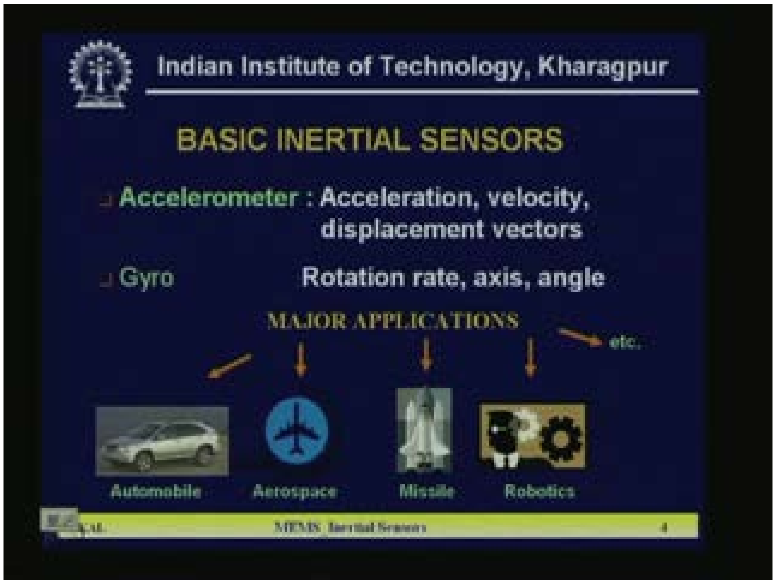

Now basic inertial sensors are as I mentioned accelerometer and gyro. Accelerometer measures acceleration, velocity, displacement. Because displacement and velocity is easily available from the acceleration by mathematical treatment. If you integrate then you can get velocity, then again for the integrate you can get the displacement. So that means from the acceleration the other parameters are also available. On the other hand in case of gyro it measures rotation rate and that is axis and angle of, here in the accelerometer displacement similarly here it can locate the angle of a particular device or system in which angle it is located it can easily measure by the gyro and as is mentioned below the application areas are; one is automobile as I mentioned, other is aerospace, third in the missile and fourth in robotics. So these are the 4 major application areas of the inertial sensors.

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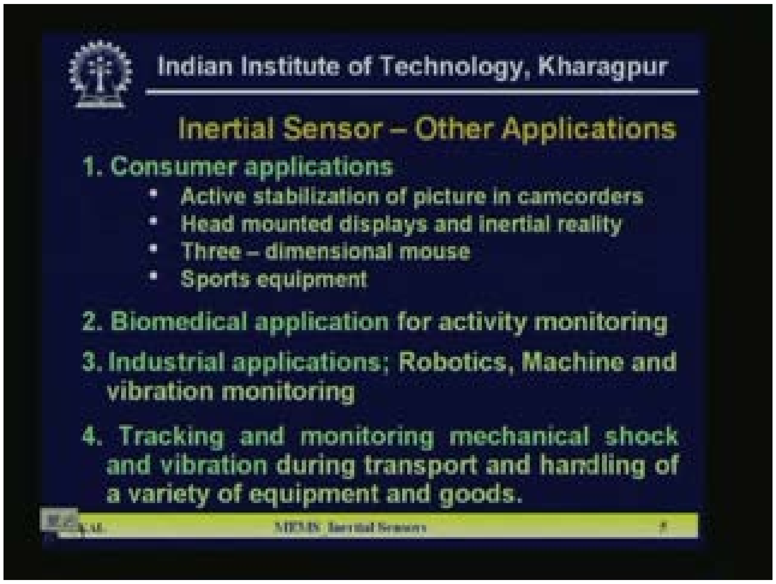

Now other applications as well are also very big in consumer market. These are basically active stabilization of picture in camcorder. There you need acceleration sensors hand mounted displays and inertial reality. Three dimensional mouse which is used in many of the computer application and sports equipment. There are some household consumers items are also there. Those are as I mentioned earlier. Also the electronic toys, washing machines etc. Biomedical applications are also there for inertial sensors, particularly for activity monitoring. Industrial applications are in robotics machine and vibration monitoring.

Tracking and monitoring mechanical shock and vibration during transport and handling of a variety of equipment and goods. So this is one of the very important. Tracking and monitoring of mechanical shock. There is certain high sensitive equipment when you are transporting from one place to other place. So you have to avoid the shock or large vibrations that may damage the equipment as well as the balancing part may be damaged. So for that you have to use certain some kind of acceleration sensor. So that you can properly monitor and track the vibration of the table on which you are transporting the machine from one place to other place. So these are some other kind of applications of the inertial sensors.

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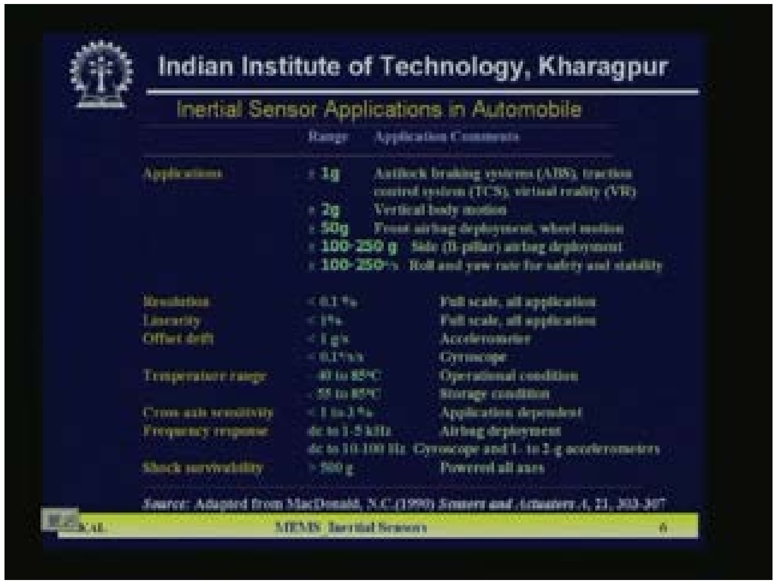

Now here if we concentrate on automobile application, as I told you the 90 percent market is from automobile sector for inertial sensors. What are the ranges and what are the typical aspects of that particular property of that accelerometer in case of automobile? So there are different range of the acceleration sensor used in automobile plus minus 1g is used for antilock breaking system ABS, Tracks and control system TCS, virtual reality VR. Plus minus 2g is used for vertical body motion, plus minus 50g required for front airbag deployment wheel motion. Airbag deployment wheel motion is a major area as I told you. Another is active suspension, 100 to 250g required side airbag deployment side means side of the automobile and 50g is a front automobile 50g jerk if you get it, it will open the airbag immediately and it will basically the protective measure. So that there will not be any accident of the driver. But side way if hit about 150g is not much in. If you side push is there in automobile sideway it is 100 to 250g will be harmful for the persons inside.

But in the front if it is a 50g it should be the airbag deployment should start there. Similarly roll and yaw rate of safety and stability you required 100 to 250 degree per second. That is basically in case of the gyro rotation sensor, 100 to 250 degree per second the yaw rate required for gyro sensor. A resolution requirement less than 0.1 percent full scale for all applications, linearity require less than 1 percent full scale for all application, offset drift allowed is less than 1g per second for accelerometer less than 0.1 degree per second per second is for gyroscope. Temperature range of application for operation condition is minus 40 to 85 degree centigrade, for storage condition minus 55 to 85 degree centigrade. Cross axis sensitivity should be less than 1 to 3 percent. Its application dependent frequency response for airbag deployment, its dc 21 to 5 kilo hertz for gyroscope and, 1 and 2g accelerometer it is dc 210 to 100 hertz is the frequency requirement, shocks survivability should be greater than 500g power all axis. So these are the different properties of the accelerometers required for automobile application.

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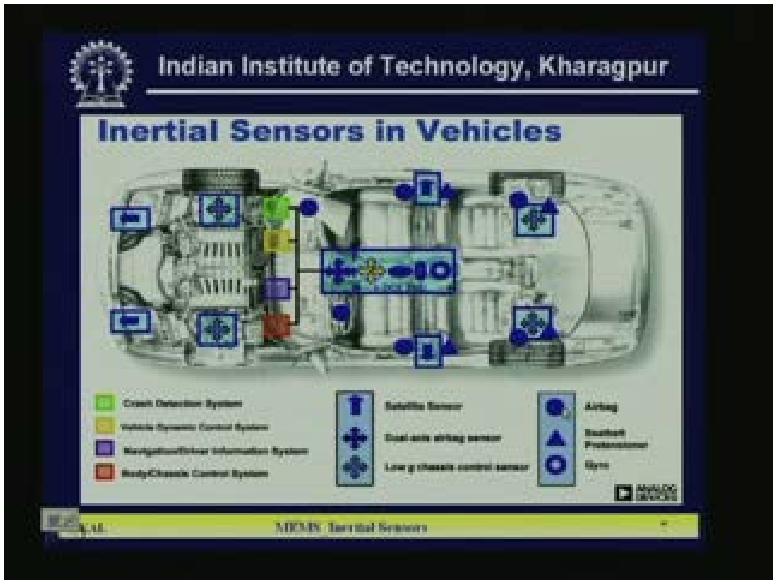

Now we can show you a picture of the full automobile where the sensors are located at different position. You can see here in the front and in the back lot of sensors are there. So there the cross one here this is the airbag is the round circle. You can see how many airbags are there. So this is one because in front this is one, this is one, this is one side, this is one and here is one, here is one. These are the airbag sensors for side in front and seatbelt pretensioner is this one, here one and here one satellite sensors is here in the front here and here these are satellite sensor is when a remote working front something is coming out. It can detect that what speed something is coming at the front. That is a satellite sensor. Dual axis airbag sensors is 41234 both in the front and both in the side dual axis airbag 1234 these are dual axis airbag, low g chassis control sensors are also there. Now body or chassis control system is this one navigation driver information system here, vehicle dynamic control is here, crash detection sensor is here. So in a modern automobile you can see the whole vehicle is equipped with lot of this inertial sensors either it is a acceleration or it is a rotation sensor.

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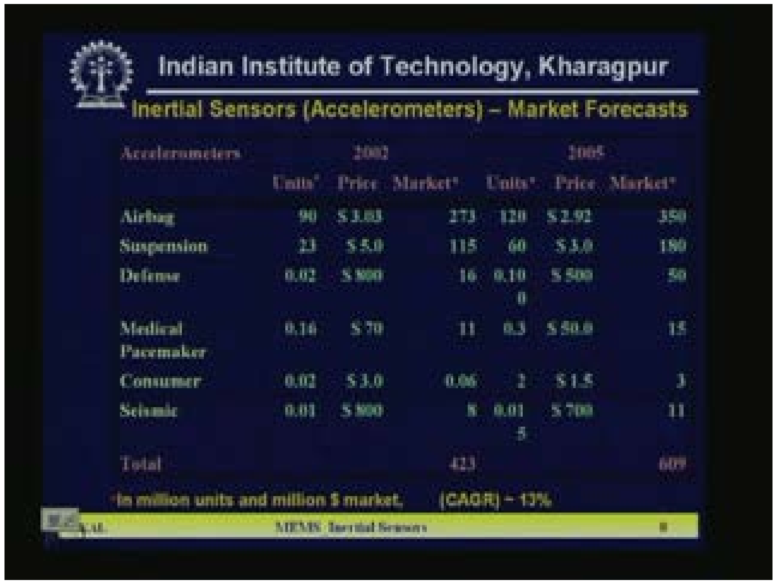

Now this table gives you the market and price. That means commercial aspects of the inertial sensors in particular acceleration. Now values are compared 2002 and 2005. Recent development you can guess from this table 2002 to 2005. For air bag suspension the applications of accelerometer identified in airbag vehicle suspension, defense, medical pacemaker, particularly medical pacemaker, consumer, seismic. These are the areas application areas are identified. Here is the unit and units are in million units price are unit price and the market is shown is here that is basically million dollar market. This is in million, this also million and this is the unit price. Now if you compare you can see that 90 million to 120 million 120 million in 2005 where one important feature is that the unit price has gone down from 3 Dollar to 2.92 Dollar. In case of suspension from 5 Dollar in 2005 it is gone down to 3 Dollar each piece and for defense these are expensive. One of the reasons is that these are navigational grade. Navigational grade means its performance is much more crucial. The properties used or the parameters used for those navigation grade sensors used in particular defence and avionics are very crucial requirement and for them the sensors are expensive also.

So there you see 800 Dollar it has come down to 500 Dollar although it is expensive. But medical pacemaker it has gone down, unit price from 70 Dollar to 50 Dollar market also has from 11 million to 50 million consumer is this and seismic application is expensive because it is not much application and people have started using and not one of the aspect of not much reduction of price is that in some cases the business is confined into some monopoly. Hardly worldwide one or two companies or three companies are making not many. But in case of, for example airbag and suspension etc where applications are more and here the players are more around the world, so their reduction of the cost of unit price has gone down drastically. That is one of the reasons and in many cases for example seismic application or the navigational grade application sensors the foundry capability is not there with major players. Hardly 2 or 3 companies have got that competence to make those sensors that is one of the main reasons for high price.

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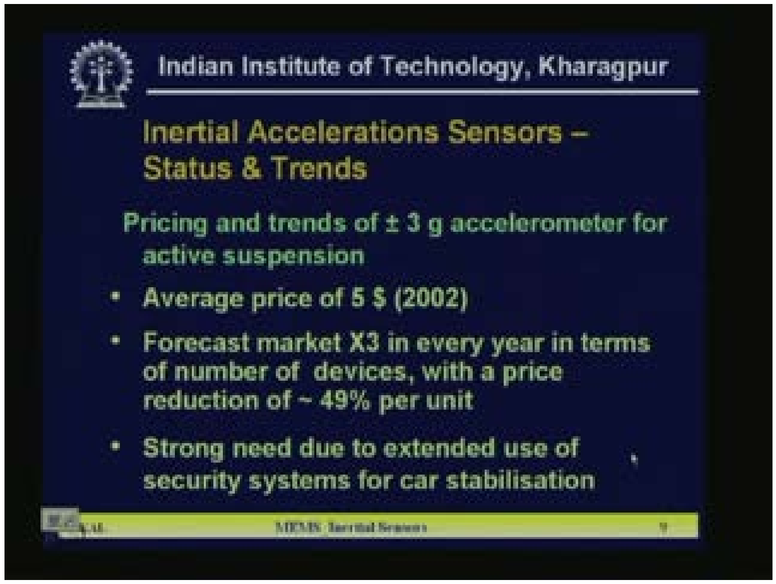

Now inertial acceleration sensors if you look into its status and what trend it is going on, you can see the pricing and trends of plus minus 3g accelerometer for active suspension which is one of the major area of application in automobile active suspension. Its average price at in 2002 is a 5 Dollar forecasting is there. The market will multiply is going to multiply 3 times every year in terms of number of devices with a price reduction of nearly 50 percent per unit. Strong need due to extended use of security systems for car stabilization. That is why here players are more, users are more and say R&D is going to mature day by day so that price has gone down because the suppliers are more.

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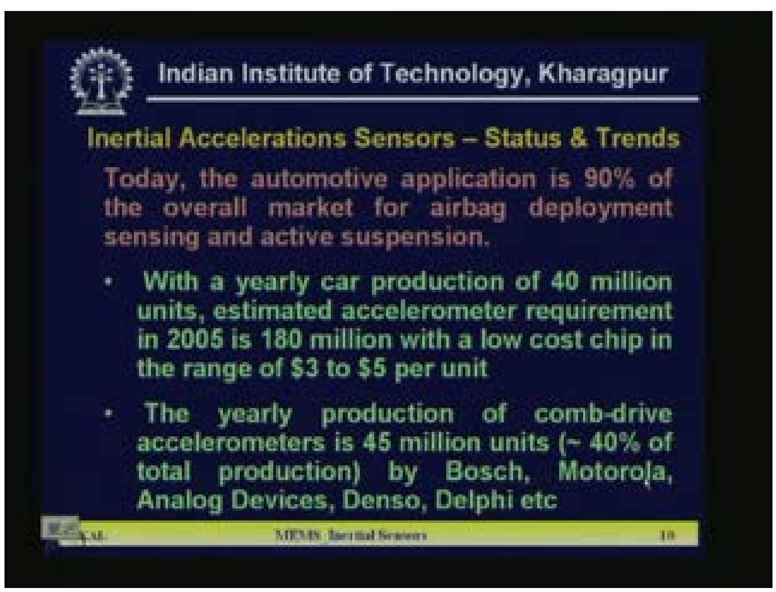

Inertial accelerations sensors today although 90 percent application is automobile, overall market for airbag deployment sensing and active suspension is there with yearly car production of 40 million units estimated accelerometer requirement in 2005 is 180 million with a low cost chip in the range of 3 to 5 Dollar per unit. So requirement today is 180 million of the airbag deployment sensor. The yearly production of the comb-drive accelerometers is 45 million units. Comb drive is another kind of accelerometers and which are highly sensitive and which can withstand temperature range also. Variation with temperature is not that much, that is a comb-drive. 40 percent of the total production is a comb-drive and the production agencies are Bosch, Motorola, Analog devices, Denso, Delphi, and etcetera.

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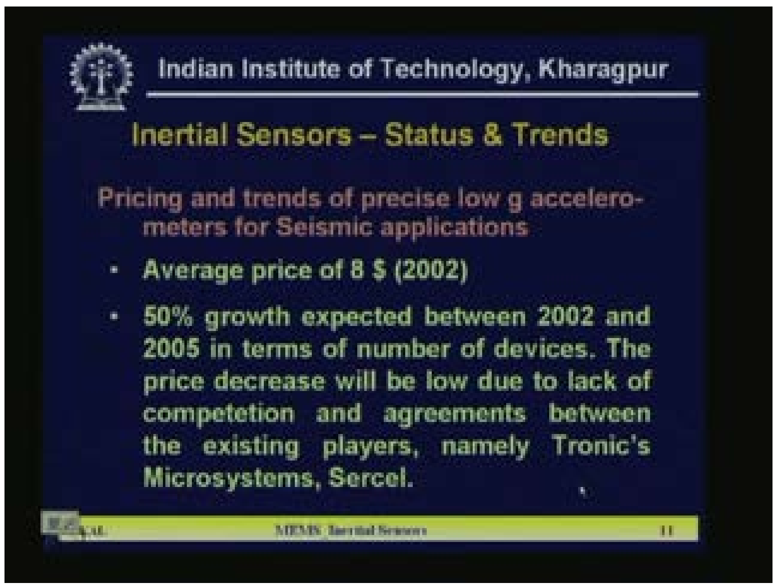

Now, pricing trends of the precise low g accelerometer for seismic applications. Here the deduction is not that much. Average price is 8 Dollar in 2002. 50 percent growth expected between 2002 and 2005 in terms of number of devices. The price decrease will be low due to lack of competition and agreements between the existing players namely Tronics and Microsystems and Sercel. Agreement means they have packed so that this is a business strategy. They will not produce much and automatically if the requirement goes up. So there will be scarcity and price will be high. So this is some kind of tactics they follow at the same time it is also true. So this kind of seismic application the very low g accelerometer. The basic principles are also different fabrication principle or mechanisms of those accelerometers are not like physio resistive of kind of thick thing. May be some other techniques are used there. So those techniques are not very easy and easily translated into the foundry by most of the companies is not possible. That may be the reason why it is, the price deduction is not that much low.

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Now major players worldwide for accelerometers are VTI technologies leader with 35 percent market share. Denso, Delphi-Delco, Analog Devices Bosch are the other challengers. Possible new comers in the accelerometers are Infineon, Sensonor, STM, Tronics Microsystems, Colibrys, X- Fab are there. So these possible new companies but out of the famous are the Analog Devices Bosch and VTI technologies. They are the leaders in accelerometer. In case of gyroscope, there are not many companies BAE, Bosch, Delphi-Delco, Murata and Samsung. These are the contenders in case of the gyroscope or the rotation sensors manufacturer.

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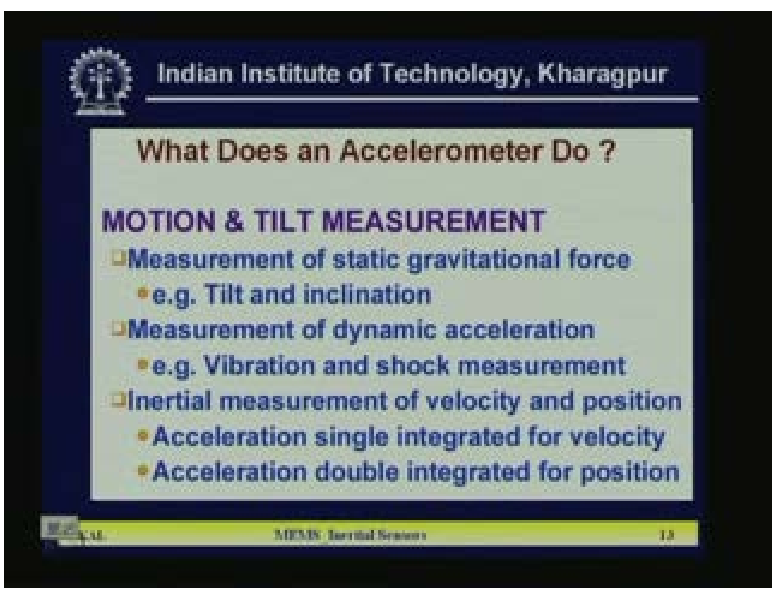

Now what does an accelerometer do and here some of the points is highlighted. Other than acceleration there are measurements of static gravitational force. For example tilt and inclination, that is possible with the help of the accelerometer. Measurement of dynamic acceleration. That is basically vibration and shock. That means you can see here the accelerometer is not only used for velocity or acceleration measurement. It can be used from other application also like how much it is tilted, how much is inclination, how much is the vibration, how much is a shock, for that also it is going to use. Other is inertial measurement of velocity and position. That is the normal application of accelerometer. Position and velocity, acceleration single integrated for velocity and acceleration double integrated for position. Just very simple that those two applications. So these are the application area the accelerometer the applications and the players and status I mentioned.

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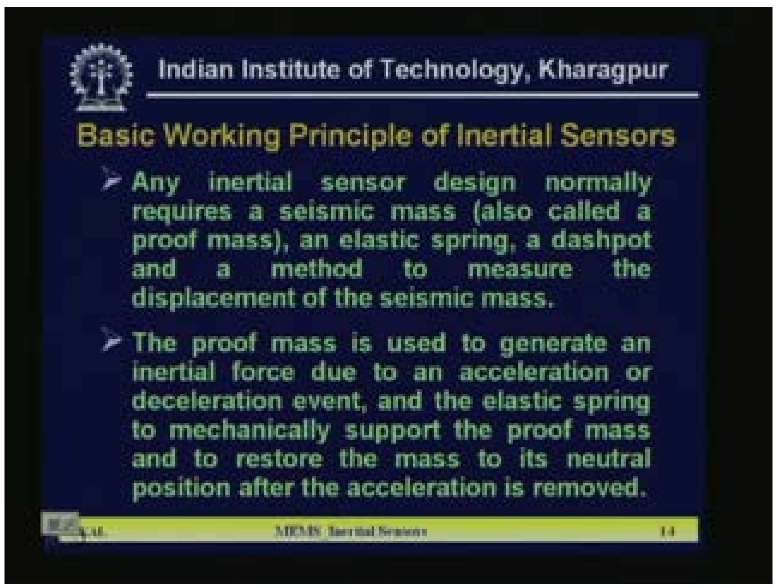

Now I will discuss on basic working principle of the inertial sensors. Most of the inertial sensors either it is an accelerometer or gyro or whatever it is. They normally need a seismic mass which is also called a proof mass. They need an elastic spring a dashpot and a method to measure the displacement of the seismic mass. Basically a seismic mass or the proof mass will be there and that proof mass must be connected with an elastic spring and a dashpot is required to protect the system. Because if the proof mass moves faster and moves beyond its limit, so dashpot will resist it and it will protect the proof mass before it breaks from the elastic spring. So that is the job of the dashpot. A method to measure the displacement of the seismic mass. So that means a measurement method technique that should be there for different inertial systems.

Proof mass is used to generate an inertial force due to an acceleration or deceleration event and the elastic spring to mechanically support the proof mass and to restore the mass to its neutral position after the acceleration is removed. That is why it is known as the elastic spring. The acceleration is measured, at the same time negative acceleration means deceleration. Means when very high velocity moving it will come to a rest so that deceleration so both are possible. So that the spring which is used to connect the proof mass has to be elastic in nature; should not be plastic in nature. That means if the acceleration becomes deceleration it will come to its normal position. The deformation which is being taken place due to the acceleration should not be permanent. When is in opposite direction its moves, it will come back to its original shape and position. That is the elastic spring is essential to hold this proof mass with the body.

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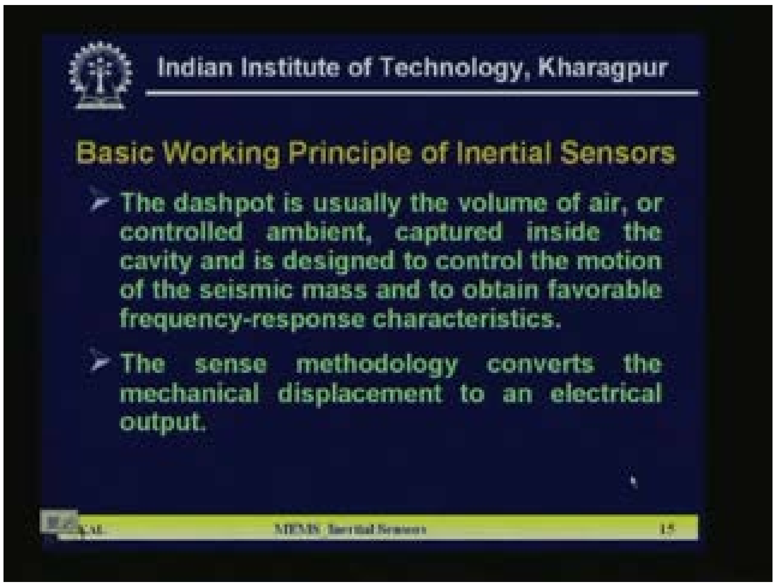

Now the dashpot. As I told you is usually the volume of air or the controlled ambient. Captured inside the cavity and is designed to control the motion of the seismic mass and to obtain favorable frequency response characteristics. So that you see the dashpot means in case of accelerometer, basically the sensing element, the proof mass and the flexure. It is covered by the top and bottom encapsulation layer and in the encapsulation layer there will be some gap and in the gap that is filled with the air or some other gases with certain density and pressure. So that will work as a dashpot and basically that is the damping. If damping is not there what will happen? The spring is holding the proof mass. When it starts vibrating so it will stop after infinite time.

It oscillates so it has to be some damping arrangement, so that the oscillation dies out and it comes to rest within a very short time. So for that requirement you have to have a damping arrangement and this is being done with the help of the dashpot configuration. Dashpot configuration basically the gap between the proof mass in the top and bottom layer and the density of the gas and the pressure of the gas used in this small cavities top and bottom of the proof mass along with the flexure. And at the same time this kind of the dashpot also determines the frequency response characteristics. Because what is the natural frequency of that particular structure and if it resonates then the problem. Resonance means there is a chance of damaging the complete thing. So complete thing means is a breaking of the flexure.

So that is why the frequency response is also an important criteria when you are going to design the complete structure. And the last one for basic principle is the sense methodology. The sense methodology converts the mechanical displacement to an electrical output. Whatever it is, whether it is a gyro or the acceleration sensor, you have seen that some mechanical displacement will be there and that has to be converted into electrical output. These are the 4 aspects of the accelerometer and which is to be precisely designed. Number one is a proof mass, number two are the flexures which will have the elastic spring property, number three is the dashpot configuration and number four is methodology to convert the mechanical displacement into the electrical output. These are the 4 aspects you have to take care precisely to design an inertial sensor.

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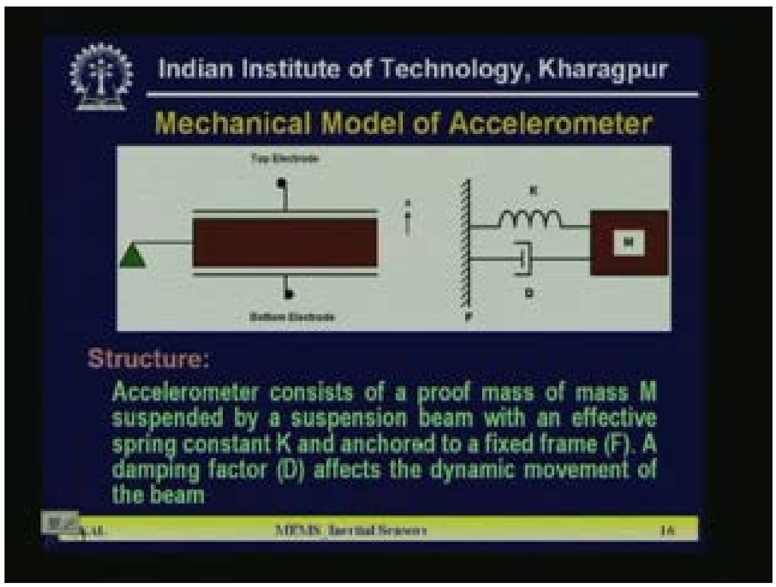

Now here you can see the structure which I just mentioned for designing. That diagram is shown here and here in the left side you can see the two diagrams are shown here. The left side, the big field thing is basically the proof mass. Proof mass is held on pivot with a flexure and the bottom and top there are two electrodes; top electrode and bottom electrode. Now this pivot, now this structure moves, then obviously because is the spring operation of this flexure, it will also move. So according to the capacitance of the top and bottom electrode will change. On the right side a structure, this is a mechanical model of accelerometer. Here is the proof mass m which is fixed with a spring constant K. This is a spring constant is K which is the elastic spring which I mentioned and also in the bottom you can find a structure which is the model of the dashpot.

That means if the proof mass moves downward, so after some time this thing will block further down. So that it will heat this top portion, so it will stop going further down. Similarly if it goes up, so this bottom plate will obstruct here. So it will not allow the proof mass to go drastically upward direction. So that is why this model is the ideal dashpot model to protect the proof mass before it breaks away from the spring. Now so this structure consists of a proof mass of mass M suspended by a suspension beam. This is a suspension beam with an effective spring constant K and anchored to a fixed frame F. Here is an anchored, here fixed frame F or here also, it is anchored here fixed frame F. A damping factor D affects the dynamic movement of the beam. Here is a damping factor D which affects the dynamic movement of the mass or the beam.

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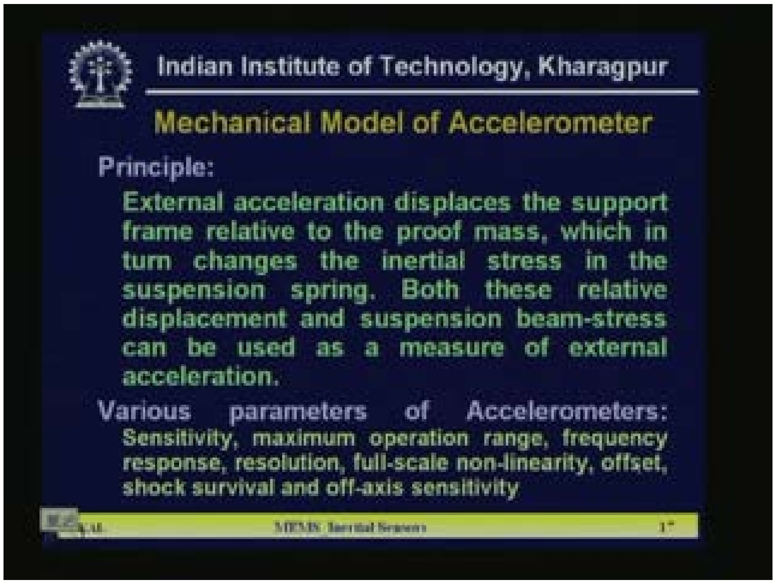

Now mechanical model which I am discussing, its basic principle is that external acceleration displaces the support frame relative to the proof mass which in turn changes the inertial stress in the suspension spring. Both these relative displacement and suspension beam stress can be used as a measure of external acceleration. So relative displacement and suspension beam stress you see the acceleration can be measured from two things. One is the relative displacement that will be proportional to the acceleration and other is the stress developed on the suspension spring. If you see in the earlier diagram, so relative displacement. Because what is the gap here, what is the gap here. If you can measure the gap minutely, so that this displacement can be measure of the acceleration. On the other hand the left side model, this stress developed in the spring. This is general model I am telling not the MEMS structure.

General model or mechanical model of the accelerometer. So now the stress developed at a spring will depend on how much the mass is moving which in turn depends on the how much acceleration you are applying. So that means in the two model here you can just sense the stress developed due to the spring action and here the displacement of the mass with respect to the fixed electrodes. So these two ways, in both the ways you can just measure acceleration precisely either the displacement measurement or the stress measurement. Now what are the other parameters of the accelerometers? Those parameters are sensitivity, maximum operation range, frequency response, resolution, full scale, non-linearity offset, shock survival and off-axis sensitivity. These are the various parameters which are to take care when you are going design an accelerometer.

Basic definition of sensitivity already I have discussed, it depends on which factor in this case of the MEMS accelerometer. That will depend sensitivity mainly the flexure dimension is one important parameter. If the flexures are very thin so you can have much more sensitivity. Another is flexure thin; means the stress developed on the spring also will be more if the flexures are very thin. Maximum operation range accordingly you have to design the proof mass and other dimension of the accelerometers. Frequency response is mainly determined by the dashpot configuration and the proof mass dimension. Resolution is also the minimum amount of the measurements which can be detected. That is the resolution that depends on how your device is sensitive to small variation. Full scale non linearity is also because everybody wants in any kind of sensor the linearity so that output change will be exactly near with respect to the input. So that in case the calibration carbon and measurement principles also will be easy.

So that is why linearity is another important criteria. Offset should not be there although you cannot avoid it so. But you have to have certain arrangement so that offset should be as minimum as possible inside your design and if outside there is some kind of offset is coming in the between. So you have to have certain external arrangement. So that offset should be made to negligible. Shock survival is another parameter so that although you design an accelerometer, for example say plus minus 2g or plus minus 5g, so there may be a certain situation where it will experience a shock. So in that case it should not be destroyed or damaged. The typical example is in case of automobile, for example. Active suspension you make plus minus 2g, the active suspension plus minus 2 to plus minus 5g is the design values of these microaccelerometers. But there if suddenly a car collide with some rigid body that means in case of accident they experience lot of shock sudden jerk and shock.

So under that condition the accelerometer which is designed for plus minus 5g should not be damaged completely. So for that you have optimum shock survivability. That means it is again some tradeoffs is to be done between the sensitivity and the resolution and at the same of the high shock survivability. So in most of the accelerometers they mention the company, they mention how much maximum acceleration it can go before destroying and that region, that high region of acceleration which is shock survival region, shock region. So there sensitivity and resolution are not the prime factor. They are not going to consider that one. So may be not be that is not linear in that region but what we want in that particular region is that sensor will survive. Means it will not break easily from the flexures or it destroy the complete structure that should not be there. So that is the shock survivability and off axis sensitivity also is I hope you know.

Because there are different kinds of the inertial sensors where we need sensing in different axis particularly three axis in three direction x, y and z. There are certain sensors we need single axis accelerometer, we need acceleration measurement, is possible only in one direction. In other direction it should not measure. So out of these categories of accelerometer if we need single axis accelerometer then the off axis sensitivity is very important. Means it measures its sense. Highly sensitive and resolution is very high in a certain axis. But in other two axis, resolution is not there in sensitivity, is almost nil.

There is no sensitivity along other two axis so that you can say it is your design is made only for single acceleration not in all axis. There are certain accelerometers which are meant for measuring all the 3 direction acceleration in the same device. You can measure all the 3 directions, so that there off axis sensitivity is not that much crucial or stringent requirement. These are the parameters of accelerometer.

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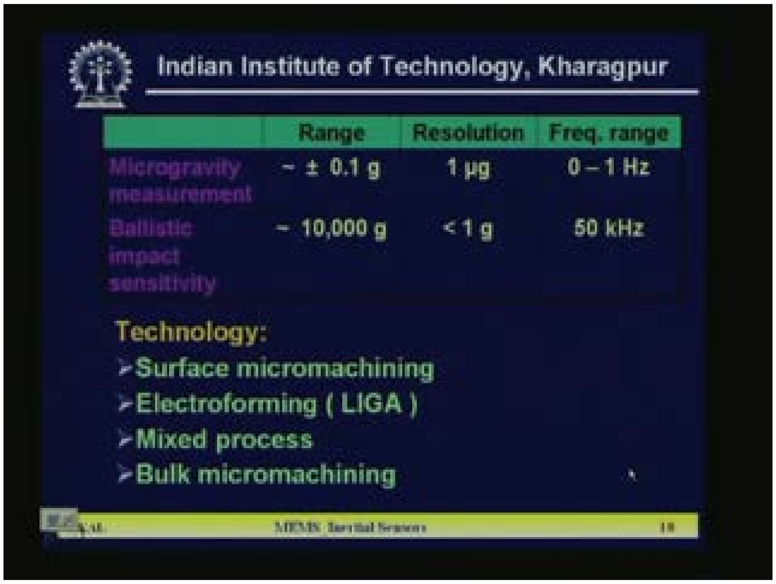

Now here just mentioned typical range resolution and frequency range of two class of accelerometers used for microgravity measurement and ballistic impact sensitivity. So microgravity measurement the range is plus minus 0.1g and resolution required obviously 1 micro g. If the total range is 0.1g and its frequency range is 0 to 1 hertz, another class of this is to extreme required extreme class of accelerometer. One is for microgravity measurement; other is the ballistic impact sensitivity. That is basically the shock survival requirement, there what I mentioned that is a ballistic impact. So there 10000g is the range and here resolution is not expected, that is in milli g or micro g, it should be nearly g level 1g level and frequency respond their range is required 50 kilo hertz where the microgravity requirement is 1 hertz, for ballistic impact it is nearly 50kilo hertz and now the technology.

What are the various kinds of technology used for making inertial sensors? Those are namely surface micromachining technology, electroforming which is a LIGA technology mixed process means combining surface and LIGA is a mixed process and bulk micromachining. All these process either bulk or surface or electroforming. All these are discussed in my in earlier lectures in detail we have talked about it. Mixed process is nowadays and many of the sensor they require some kind of LIGA and the surface machining micromachining also. That is why those called is a mixed process although in that case the technology will be little bit complicated. But for getting some innovative structure of innovative features, innovative devices, using the accelerometer you may go for a complicated mixing process of bulk surface along with the LIGA.

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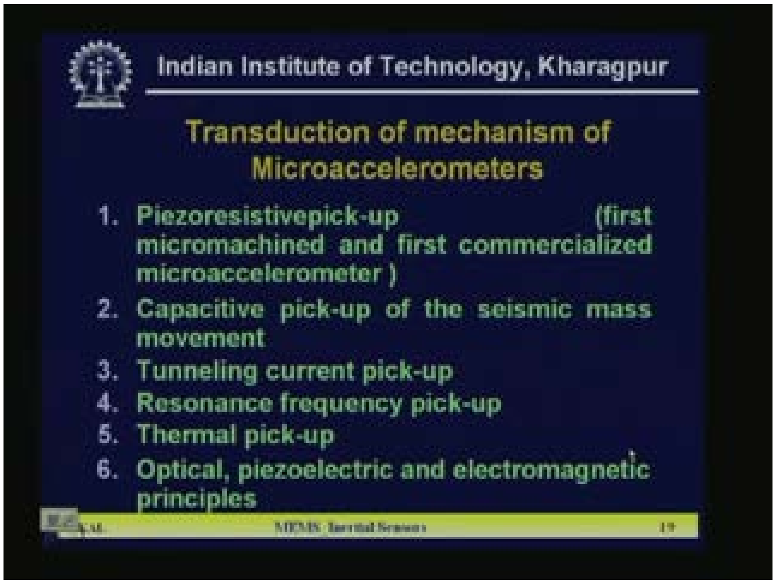

Now what are the transduction mechanisms of microaccelerometer? Transduction of mechanism for microaccelerometer, what are those? Some are discussed in earlier first two is known to you. First one is piezoresistive pickup; second one is capacity pick up. Piezoresistive pickup you know first is a micromachined. At first micromachined accelerometer and which has commercialized at the beginning. That is a pickup is piezoresistive pickup. That is piezoresistive accelerometers and second one is a capacitive pickup of the seismic mass movement and mechanical model in one model I saw where the displacement is sense. So that kind of accelerometers ideal for capacitive pickup. These are two known. Third one is a tunneling current pickup. Tunneling current pickup is important because this tunneling current pickup is used for micro g acceleration measurement.

Here what is being done? Since it is micro g, that means there the movement of the proof mass will not be much, what is being done here, a small gap is maintained and an electric field is applied over the small gap and the gap may be in air or any dielectric medium air is also a dielectric. So you know from your electrical engineering experience, so two electrodes are separated in a small gap and if you apply electric field in the gap, so a current will flow which will tunnel to the dielectric medium provided the gap between the two electrodes are extremely small. That is known as the tunneling current. Now the thing is that if you make certain devices a microtip and tip is separated from a base plate or say proof mass by say few angstrom, may be 5 2 or say 10 angstrom level may be 2 angstrom in some cases. Then what will happen? The base plate is fixed or the tip is fixed.

Now if you proof mass is moved so that means gap between the tip and the proof mass will change, so accordingly the tunneling current also will change. We know the change of proof mass is going to reflect in the stress of a flexure which in turn changes the piezoresistance. That is in piezoresistive pickup. Proof mass movement can change the gap between the electrodes. In turn it is going to change the capacitance of tunnel parallel bit capacitance. Now the proof mass movement if it is a small in magnitude that can be sensed by the tunneling current also. Because tunneling current is highly sensitive with the small gap between the two electrodes. Now if the gap between the two electrode is changed by movement of one of the electrode which may work as a proof mass, then the small variation of the gap is going to change the tunneling current in a big way. So that measurement may be or that pickup techniques may be useful for measurement of micro g.

Fourth one is a resonance frequency pick-up. A resonance frequency pickup, so there you can just construct an oscillator and in the oscillator the one component is the capacitor and you know in the RC or LC or RLC capacitor, in one of the parameter a reactive parameter either the L or C change. Then what will happen? The resonance frequency will also will change. Now with the variation of capacitance which may be connected in some way with the accelerometer structure, then that can be design to make an oscillator whose frequency oscillation or resonance frequency change with the movement of the proof mass which in other way, which is the variation of the accelerometer. So that is one possibility resonance frequency pickup. Fifth is a thermal pickup. Thermal pickup is an innovative idea. So basically it is not much report has been done. But here thermal pickup means if you move a accelerometer, so then a high sensitive, and the thermal sensor if you fix up, then if something moves accelerometer then there should be heat source and sink.

So if the gap between source and sink changes, then conduction through that media also changes. Heat is flowing from source to sink clear. Now source and sink are kept at a certain distance. Now let the sink is fixed or source moves. So then the conduction path is going to change and from source to sink transfer of the heat also is going to change. So that in some way can be detected using very high sensitive thermal sensor. So that may be a measure of the acceleration. That is the thermal pickup. That is not highly matured and not commercialized in a drastic way because it has some inherent draw backs. But it is possible in thermal pickup. Optical piezoelectric and electromagnetic principles. These are also used for making accelerometer sensors. Optical piezoelectric and electromagnetic principle, but it is not highly matured and is not used extensively for accelerometers. So rather first, second and third, these three pickup techniques are highly promising. First two are commercialized; third one is being commercialized or will be commercialized in future which is tunneling current pickup for micro g measurement.

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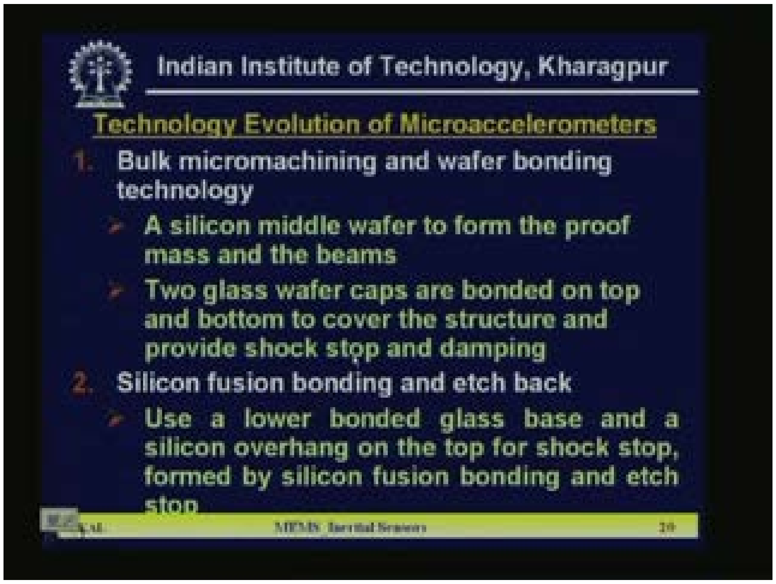

Now technology evolution of the microaccelerometer. So first is the bulk micromachining and wafer bonding technology is used at the preliminary phase of making the microaccelerometers. There silicon middle wafers to form the proof mass and the beams. Two glass wafer caps are bounded on top and bottom to cover the structure and provide shock stop and damping. So this is the technology of bulk micromachining and wafer bonding technology is necessary for making such kind of devices. Silicon fusion bonding and etch back. There use a lower bonded glass base and a silicon overhand. On the top of the shock stop formed by silicon fusion bonding and etch stop. That is another technique. That is silicon fusion bonding and etches back. So these two are the basic technology which are used for making accelerometers, microaccelerometer I should say and others are it evolves the technology.

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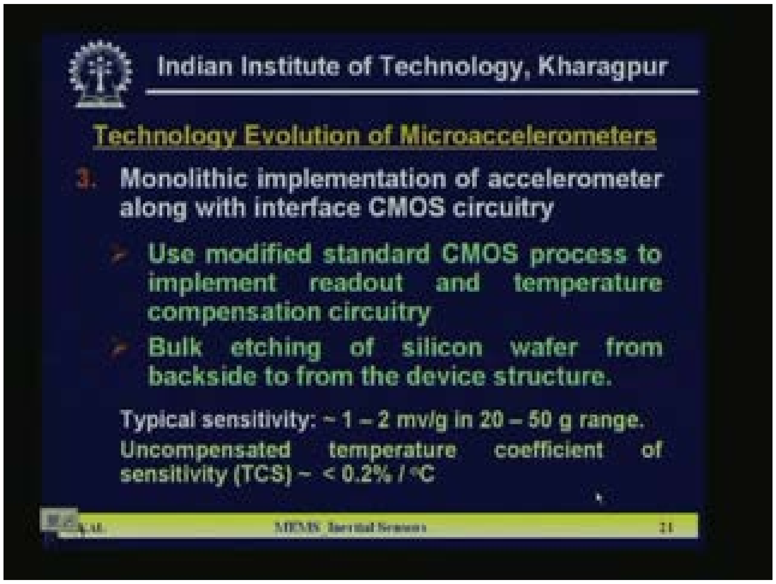

Monolithic implementation of accelerometer along with interface CMOS circuitry. This is the third evolution. That is in this particular case they use modified standard CMOS process to implement readout and temperature compensation circuitry. Bulk etching of silicon wafer from backside to form the device structure. So that means here in the third generation what people are doing? That is smart sensors. The CMOS processes are integrated with the micromachining process to implement the temperature compensation circuitry or read out circuitry along with the sensing element. Typical sensitivity in these cases is 1 to 2 millivolt per g in 20 to 50g range. Uncompensated temperature coefficient of sensitivity is less than 0.2 percent per degree centigrade which is very difficult to compensate. The other portions are already compensated. Now there we just discuss today the basic principle of the inertial sensors, its market prospects, its status and what are the basic principles involved there, technology evolutions and mechanical model of the inertial sensors. In the next class we start from one full design of one inertial sensor. Basically microaccelerometers we will start from that and we will discuss in depth the full design and fabrication principles of the microaccelerometers. Thank you very much.

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Preview of next lecture

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Lecture #21
Micromachined Microaccelerometers for MEMS

In my last lecture I remember that I discussed on the inertial sensors. As an extension for inertial sensors, today I will concentrate on a particular inertial sensor which has got lot of importance in application also that is accelerometer. So micromachined accelerometer for MEMS. So I will briefly discuss on that. After that I will go for a case study detailed discussion on design aspects, development, packaging and fabrication of MEMS accelerometer for avionics application. Detailed case study I would like to make only one device in this lecture series that is accelerometer. So it will take may be 2, 3 lectures. But today just for a background of that case study I want to discuss on the accelerometers. MEMS accelerometers in particular its classification, its basic principle and what are the various aspects of the accelerometer.

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Now if I go for micromachined accelerometers, obviously a thing is coming in your mind. What is the different micromachine and conventional accelerometer is not that true that the accelerometers we are making first times in micromachined accelerometers before that it was not there. For long time last 25, 30, 40 years accelerometers are there. But those are bulky accelerometers conventional and these are made of heavy metals. Different small parts are integrated and to make those kind of accelerometers and these are basically made from electromechanical principles, mechanical parts are there as well as electronics is there and each weighs several kilos like that and it requires a higher operating voltage and also current. Obviously you need larger power for those kinds of accelerometers. It also needs careful maintenance and calibration time to time. Heavy mechanical structures are there. Obviously maintenance part will be there and with frequent use you need calibration of those devices after certain period of time.

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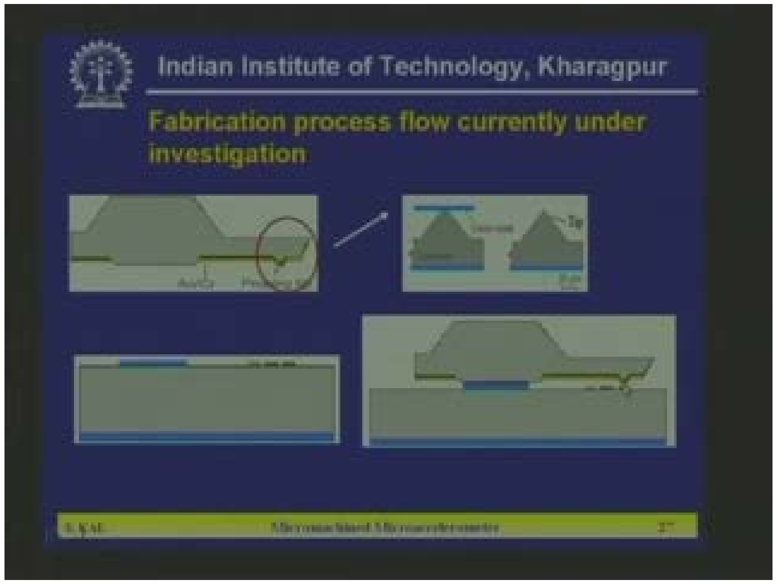

And then how it is imparted and fixed top and bottom that is also shown here.

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Now there is another two kinds of accelerometers are there just I will take 2, 3 minutes. So that is micromachined resonant accelerometer. They use a resonant silicon cantilever beam. Silicon resonant accelerometers transfer the proof mass inertial force to axial force on a resonant beam and shifting their frequency. So here basically the frequency change is the observation for variation of g. A differential matched resonator configuration helps to cancel device thermal mismatches and non-linearities. So this kind of sensors obviously free from any thermal problems or the parasitic capacitance problems etcetera.

Because you are not directly dealing with the capacitance. But directly frequency structural vibrations etcetera that frequency is going to change and one example is quartz micromachined resonators.

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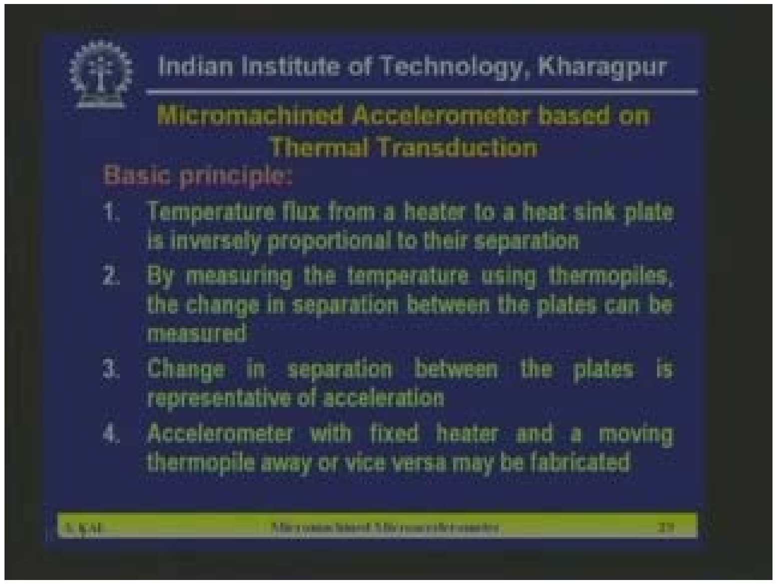

So these are the thermal transduction mechanism that also I told you a temperature flux from heater to heat sink plate is inversely proportional to their separation by measuring the temperature using thermopiles. The change in separation between the plates can be measured change in separation between the plates is representative of the acceleration. Accelerometer with fixed heater and a moving thermopile array or vice versa may be fabricated. That is not very much popular.

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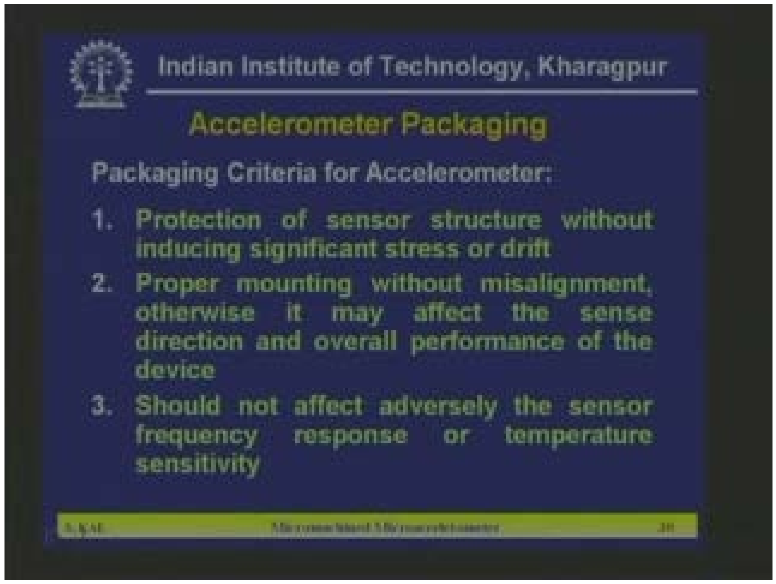

The thermal transduction mechanism and last is the packaging packaged type of accelerometer is also very important issue. Protection of sensor structure without inducing significant stress or drift. Because package should not produce additional space or drift, proper mounting without misalignment. Otherwise it may affect the sense direction and overall performance of the device should not affect adversely. The sensor frequency response or temperature sensitivity. These are the 3 points which you have to look into in details before going for packaging. So with this let me stop here today. So in next class I will just concentrate on a case study; first design, then analysis, then fabrication. Thank you very much.