MEMS and Microsystems
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Lecture No. # 04
Applications of MEMS

Today I will discuss on applications of MEMS and Microsensors. In the first class already I have told you that there are various applications of MEMS in different spheres of life. For example, in military, in aerospace, in entertainment, in industrial control, in biology,like that lots of applications are there and today I will discuss some of the applications in detail. And details of the devices made using the MEMS technology and sensors will be discussed later on in individual classes on sensorsand microsystem.

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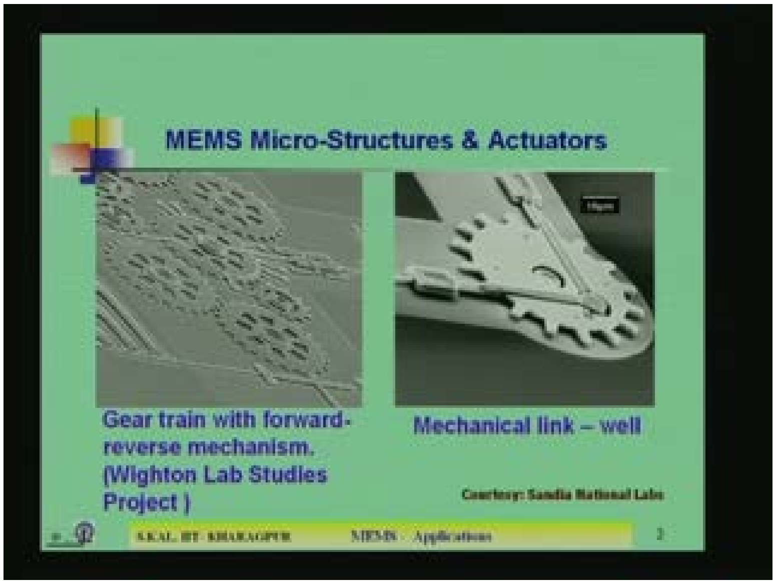

And you can see in the picturethere are some structures which are very small in size, which were earlier made using somemechanical engineering devices machines like lathe machines, grinder, polisher,and etcetera.And here you can see the structure shows here, some gear train, so lot of gears are connected and they can rotate in clockwise as well as anticlockwise.And you can see different teethare there and they are coupled from one ring to another ring through those teeth. Andusing some electromechanical energy or electrostatic driveyou can have movement of the individual wheels and as a result of which the other wheels also will rotate either in clockwise direction or anticlockwise direction.And these miniature structures have been developed using the MEMS technology particularly micromachining. In some cases they use bulk micromachining and in some cases they use surface micromachining.

In this side,if you have an idea of the size of the flexures or size of thewheel, the length this is 10micrometer as shown here.So now, the overallthe dimension or wide width of thisthe beam will be nearly say80 to 100 micrometer.And similarly here you can see one pivot and all those pivots are made using either bulk or micromachining technology.And obviously you can see, if there are different layers are there, all the layers are individually fabricated and then they are bonded together to have the complete structure. And this is a mechanical link and mechanical components are coupled with each otherso that the complete structure is obtained andyou can have some mechanical actuations or movement using either magnetic drive or electrostatic drive.

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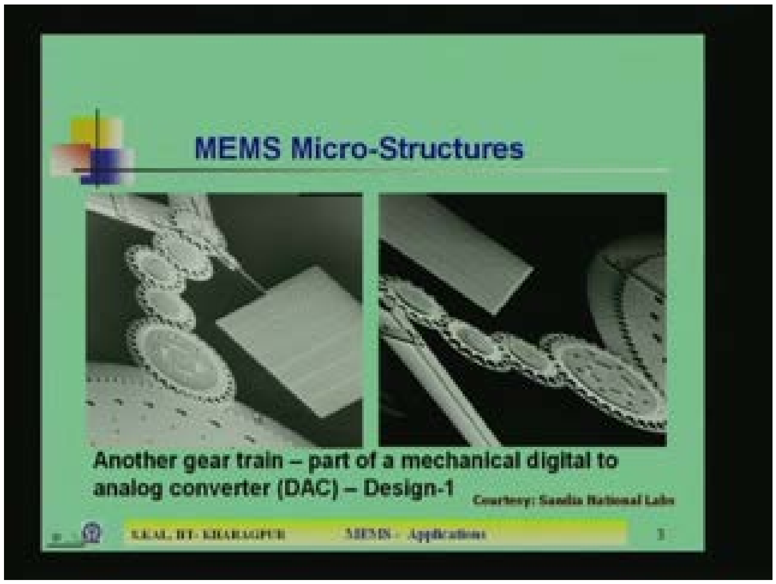

In the next figure, you will see another structure this is, these are again gear trains and is a basicallyis a part of mechanical digital to analog converter. You have come across the term DAC in case of electronics,similarly in case of mechanicalarea, mechanical arena also one can have DAC digital to analog converter. Here it means that, digital means a discrete movement and analog means continuous movement.So the mechanical structure when it needs continuous movement, then we call it as analog mechanicalmovement or mechanical signal coming from that and it is some jerk or some discrete movement is there, with small time interval,if some mechanical movements are there again it stops so we call it is a digital mechanical movement.So from a jerk to continuous movement, the jerk frequency may be very small or very high, you can adjust that,so depending on that you can have some continuous motion of the mechanical gear, mechanical train. And that can be done using somelinks or some wheels which are connectedyou can see here, one to other, then other and this is a another layer,some kind of say actuator things,so they are interlinked and these are fabricated in a lab in Sandia National Lab.Sothey have successfully done a lot of mechanical micro structures and with those micro structurethey candrive some of themicro mechanical system.

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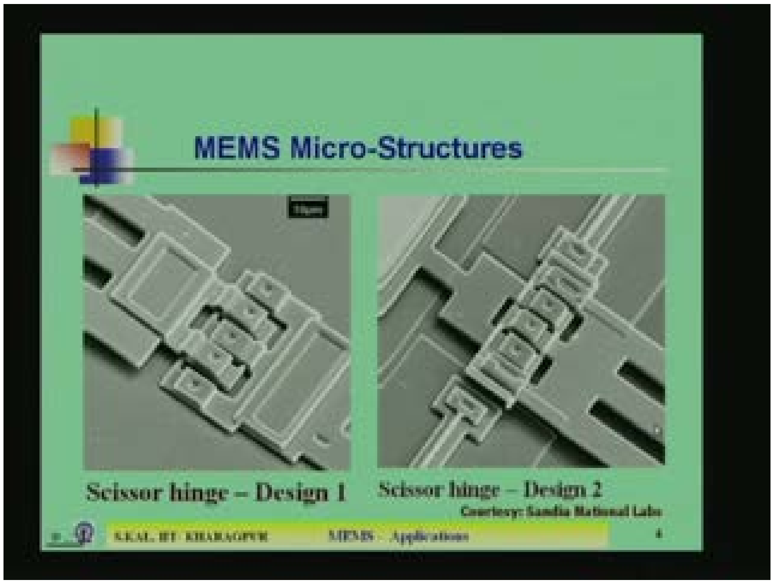

Now in another picture I can show you some of the hinges. So these are scissor hinge, again this length is ten micrometer. Obviously you can imagine this particular side is locked of inch by inch but it is at the best few millimeters by few millimeters. And there are two kinds of scissor hinges are thereand these are very useful in any of the mechanical systemsso these are only micro structures.

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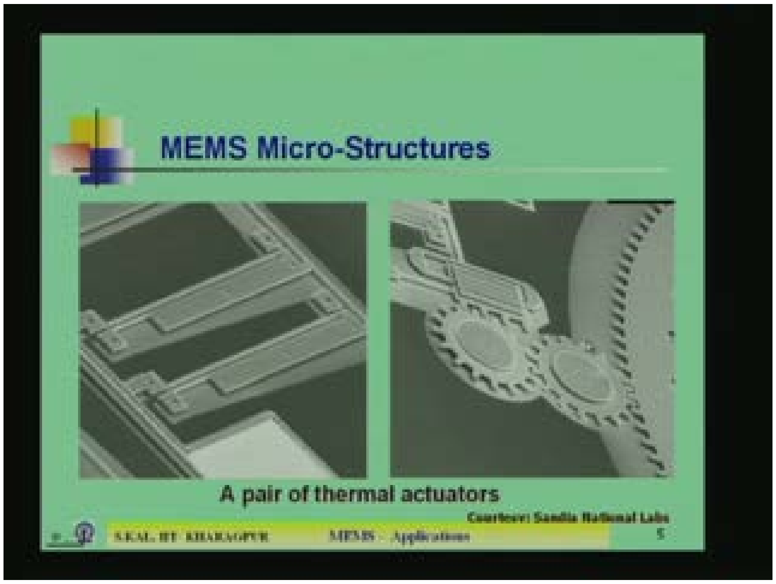

Now, here pair of thermal actuators isalso shown. That means here actuation is done with the help of not magnetic energy or not with the help of electrostatic energy but with the help of thermal energy.So thermal energy, there are lot of materials which can expand if you apply thermal energy. And if you make a very small steep and thin, thickness very thinso then, thosebeams will bend or you can applying the thermal energy, you can change the shape of these flexure. For example, you have seen the biometallic structure, different thermal expansion coefficient. So if you apply thermal energy, so they will take some shape depending on whose thermal expansion coefficient is higher and which is lower, how you are placing it like that. So in a similar fashion if you make some thin sheet of thebiometallic structure, there if you have applied thermal energy,so then if some flexure takes the shape of some bend and consequently if it is linked with some of the other mechanical structure,so they will also started moving.

So that means some actuation can take place by using the thermal energy. Earlier we have seen inthemotor that is the MEMS micro motor, there electrostatic energy is used for some sort of movement. Similarly thermal energy can be used for movement. So everything you should remember is not in a very high energy is a small energy and slow movement and slow actuation and that slow movement you can increase the movement just amplify those thing by using the different shape of the gear, wheel etcetera.So that is similar principlethat used in mechanical engineering mechanical drive also.

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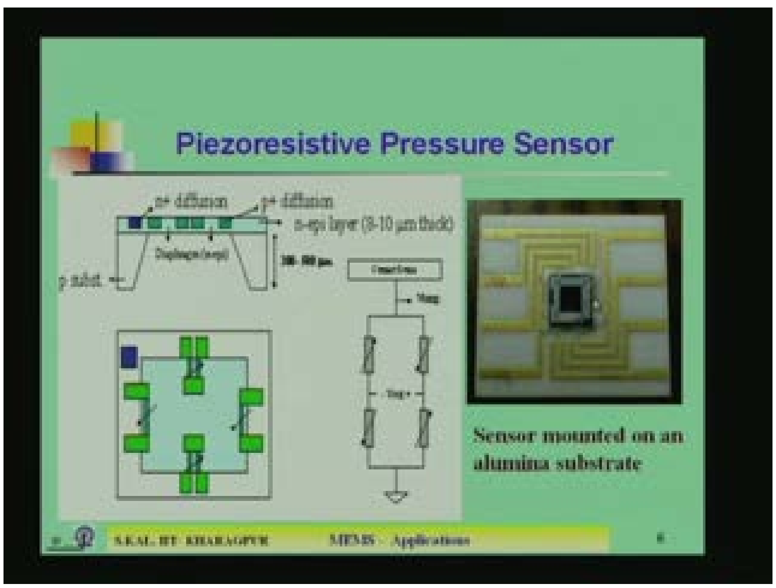

Now here, I will show you some of the sensors now. And the picture shows the pressure sensor, piezoresistive pressure sensor. That means here, the change of resistance by changing this trace ofstrain is the basic principle of making this sensor. The silicon is a very good mechanical material and not only is that silicon a piezoresistive material,that meanshere, this is the cross sectional structure of the sensor, this is the top view of the sensor. Now, this is the basically beam and this is the membrane and here n type epitaxial layer,8 to10 micron thick epitaxial layer is here.There what we have done, so we have defused the p type impurity into the n epitaxial layer to make some resistance.And those resistances are made, you can see this is the membrane and at the edges of the membrane the resistances are made.

The reason behind it is that so and if you apply some pressure on the membrane, the membrane will bend it will deform. And if you do thesimulationon the mechanical simulation or if you do the strains analysis of that particular membrane, then we will find that maximum spaceregion is at the edges of membrane. Details of that simulation results I will show you when I discuss in detail the pressure sensor its principles and fabrication. Now here, thepiezoresistance are fabricated at the edges of the membrane and all these piezoresistance are connected in a Wheatstone'sbridge like this.And if you apply signal, this pointto this point with respect to ground, if you apply certain voltage here, so we obviously as per the log of the Wheatstonebridge or principal of the Wheatstone bridge you know, if all the resistance are same,then you will not get any output voltage it will be low.

Now any of the resistance is changed, others are fixed then the bridge will imbalance and it will show some output voltage.So now depending onthe how much pressure we are applying from the top, then the beam or membrane here will deflect down or if you apply pressure from the top,so it will deflect downward. So now, as a result of which some of the piezoresistance will experience tensile stress and some will experience compressive stress.So, as a result of which in some cases resistance will increase, in some cases resistance will decrease.So in that case, the four resistance will not increase or decrease in the same fashion.Some will increase and some will decrease as a result of which the bridge will be unbalancedand you will get output voltage.So how much pressure we are applying on the membrane, depending on that,we will get the output voltage.So the output voltage is directly proportional the pressure applied on the membrane.

So this is the basic principal of the piezoresistive pressure sensor. And at the same timeall the resistance were,when you are connected in an electronic circuit like Wheatstone bridgeso you have to have the whole structure must not float you have to have some ground plain ground connection.So here in this structure, you can see here the blue color n plus diffusion,so that here the substrate contract is there. So here the n plus n epilayer and there if you want have only contact, you have to have n diffusion.So this is the n plus diffusionso that you will have the substrate contact and this substrate you can keep it at certain floating,they should not float,floatingpotential you should not keep the complete substrate.So in that case, if you plotted then the outputs,the reading may not be stable, it may flexure. To have a stable output,we have to keep this substrate and a fixed potential maybe it isthe ground potential.So this is the complete structure of the piezoresistive pressure sensor and here is the picture or microphotograph of that piezoresistive pressure sensor.So another kind of pressure sensorsis available. They are fabricated based on the capacitance change principal and those are known as the capacitive pressure sensor.

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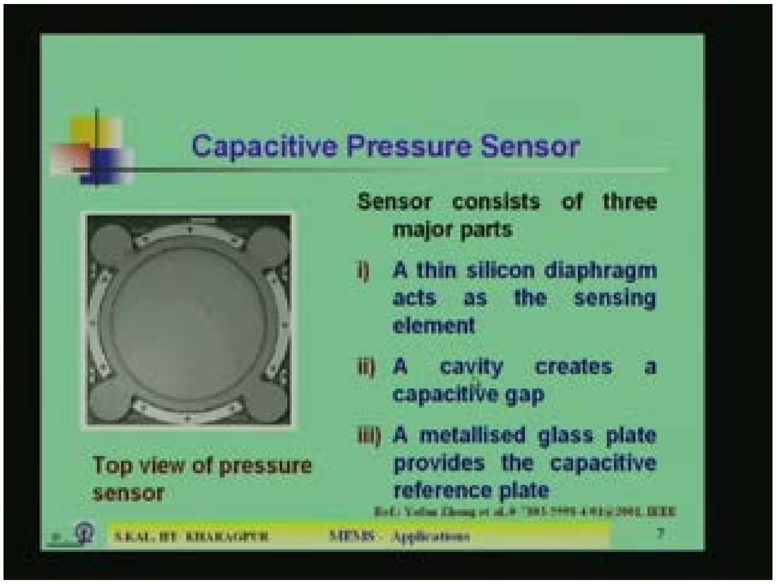

Now in this diagram you can seethe capacitive pressure sensor. This particular sensor will have three parts.Say one part is the silicon diaphragm on membrane which will act as the sensing element,the second part will be a cavity which creates a capacitive gapand third part a metalized glass plate provides the capacitive reference plate.So these are the three parts in this capacitive pressure sensor.So here what we dousing the MEMS technology, we fabricates some parallel plate capacitance.So parallel plate capacitance means, there will be two electrodes and there will be a gap or some di electric in between the two electrodes.So one electrode will be bottom the glass plate which is coated with conducting film.So that is here metalized glass plate will be the one electrode and top electrode will be a membrane. This is the thin diaphragm.So thin diaphragm, the inside of the diaphragm if you coat with metal film and top side of the bottom glass plate if youcoat with the again metallic filmso then, those two will act as a parallel plates.

So in between those two plates, there will be either here or you can put it some other directive material so better here with certain pressure.So now all you can keep it atmospheres pressure, so that the atmospheres pressure will be the reference pressure.Now if you apply pressure on the diaphragm, then the diaphragm, the top diaphragm, this will thedeflect it pressure is given from the topso it will deflect from the bottom andfrom the topto downwards. So as a result of which the gap between the bottom glass plate and the top electrode will change. And as a result of which the capacitance also will change.So depending on the deflection of the diaphragm and that deflection again depends on how much pressure you are applying at the top. So accordingly the capacitance will change. So now the change of capacitance you have to measure.So obviously you have to have the signal pickup circuit.

So that means here, the change of capacitance must be reflected change of either voltage or some other electronic parameters would change there.So either you can use a capacitance bridge or you can connect the capacitance in a circuit were the circuit frequency will change, by the change of capacitor.So you can have a calibration curve change of capacitance versus the frequency change if you apply tuning circuit at the output that also is possible.So different the signal conditioning circuits are available different signal pickup circuits are available from the sensor. So you can use any of them, so that we will discuss later on in detail how the change of capacitance is going to change in voltage current frequency,any of the electronicthe signal parameters. So this is another kind of capacitiveanother kind of MEMS pressures sensor where the basic principle is a change of capacitance by changing pressure.

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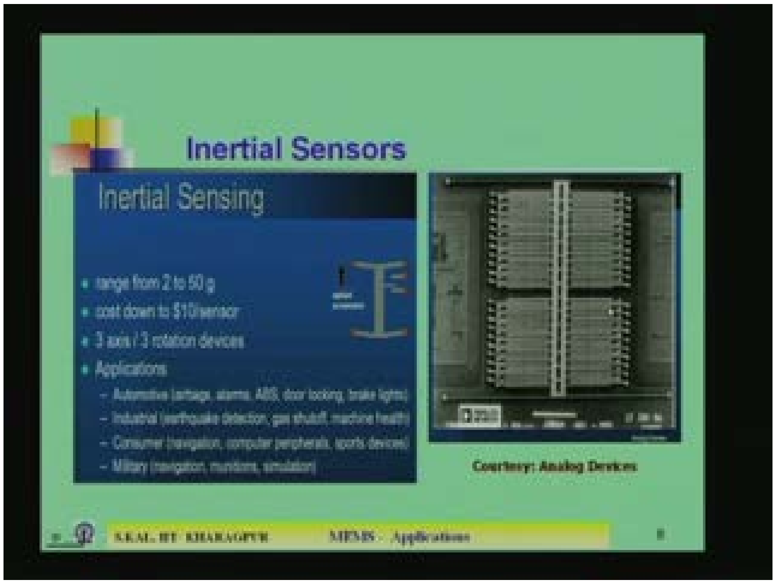

So another device here I would like tohighlight is inertial sensors. So inertial sensor are two kinds of sensors, there is only actuator sensor and another is a rotation sensor. Rotation sensor name is called the gyrosensor. Now here,the picture shows the accelerometer and that accelerometer was developedby Analog Devices, a renowned company in USA. Now in what is the basic principle the basic principle of this particular the actuator is that, you can see here the comb like structure.So in the comb like structure there are few electrodes are fixed and nowthese two sides, these electrodes are fixed.At the peripherally, these electrodes are fixed here and in between you see this, a vertical rim and there are some fingers are there. Now if you fix that, these are the fixed electrode. And if you whole structure is fixed but this can move. So with the acceleration,if you applied acceleration in this direction, so because of the mass of this structure, this will go down.

So as a result of which you can see the gap between the top electrode and the middle will increase and the bottom electrode and the middle electrode will decrease.So that meansthese are basically the two capacitances C1 and C2. One capacitance because of the increase of the gap will decrease andin the bottom capacitance, because of the decrease of the gap the capacitance will increase.So that means one is the capacitance will increase in other case capacitance will decrease the differential mode capacitance.So basically when there was no acceleration, the gap between the middle and the top and the gap between middle and the bottom will be the same.So as a result of which capacitance of both the top electrode and bottom electrode with the middle electrode will be the same. Now because of the acceleration movement of this structure,so inthis direction, so sometimes it will bottom capacitance will increase and sometime top capacitance,that meanscapacitance with top electrode will increase.

So as a result of which, that if you can have some change of capacitance, some will increase and some will decrease and with convenient circuit along with the sensor you can sense how much is the acceleration.So that is, this particular comb like structures is made using surface micromachining technology. And that has beenfabricated by analog devicesat the beginning and they are marketing this kind of the combed structure accelerometer which is based on change of capacitance with acceleration.Now this kind of accelerometercan work in the range of 2 to 50g, g is basically acceleration due to gravity.Cost of each sensor here approximately 10 US dollar per sensor and you can make the design so that it can measurealong the three axis;the acceleration x axis, y axis and z axis.It has got lot of application in automobile sector, in industrial sector, consumer and military. And individually, the area wise, its applications in automotive within the airbag, alarms, ABS, door locking and brake lights;industrial application earthquakedetection, gas shutoff, machine, health; consumer application navigation, computer peripherals,sport devices;military application navigation purpose, munitions and simulation.So these are various kinds of application of inertial sensors.

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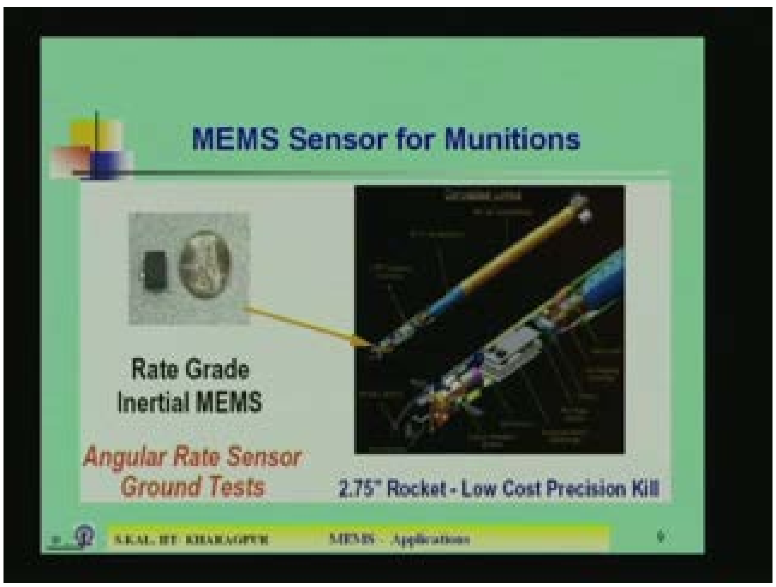

Other kind of inertial sensor is a rate grade inertial sensor which is known as gyro sensor, which sense the rotationand herethis kind of sensors are used in case of themunitions. For example,in incivil applications or in different kind of toys or this entertainment electronicsyou can see where some rotation isrequired. That means, the for examplethe joystick, you rotate joystickso there also some kind of rotation sensor is required and it will use this rate sensor. For example, in case ofmissile, there also the gyros are very much essential, in avionicsthe rotation sensors arein are important component and part of that system. So here, this picture shows some rocket 2.75 inches rocket which is very small insideand there you can have you can see here, this is the rate grade inertial MEMS sensor and this is the picture of the chip you can see how small it is and it is fixed at this head of this rocketand so that when itmakes movement, thenfrom the ground control you can rotate the rocket which direction it will move. So that can be controlled remotely by using this acceleration sensorsor rotation sensors.

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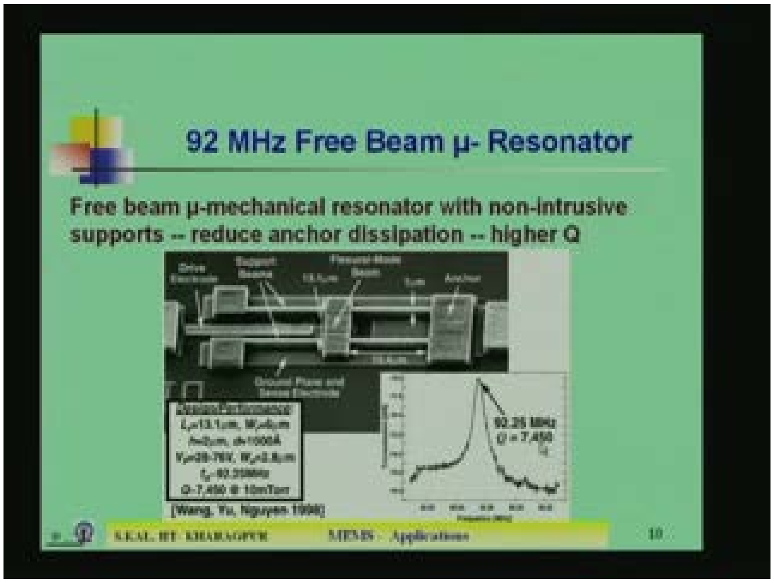

So now,another application of thosethe MEMS is a micro resonator. So here you can see a picture of micro mechanical resonator with non-intrusive supports and it reduces the anchor dissipation and as a result of which you will have higher Qand this resonator has been developed. And it works at 92.25 Megahertz is a resonance frequency and it’s Q is 7450 and you can see here, these are basically drive electrode and drive electrode are given by electrostatic energy and these two are support beam and is an extra,this is the flexuresandthese are the anchor and the anchor is supported with abeam and this beam length is 10.4 Micrometerand its width is thickness is 1micrometer and width is in the range of sayabout 2 to 4 micrometer.So this anchor is fixed here and now the whole structures is a resonate depending in how much the drive you are applying from this electrode.So the length, dimension is mentioned here the width, length and thickness andyou can see the total structure will be say1 millimeter by 2 or 3 millimeter total dimension and it will resonate at a frequency of 92 Megahertz nearlyand its Q is 7450 and 10 Millimeterthe pressure.

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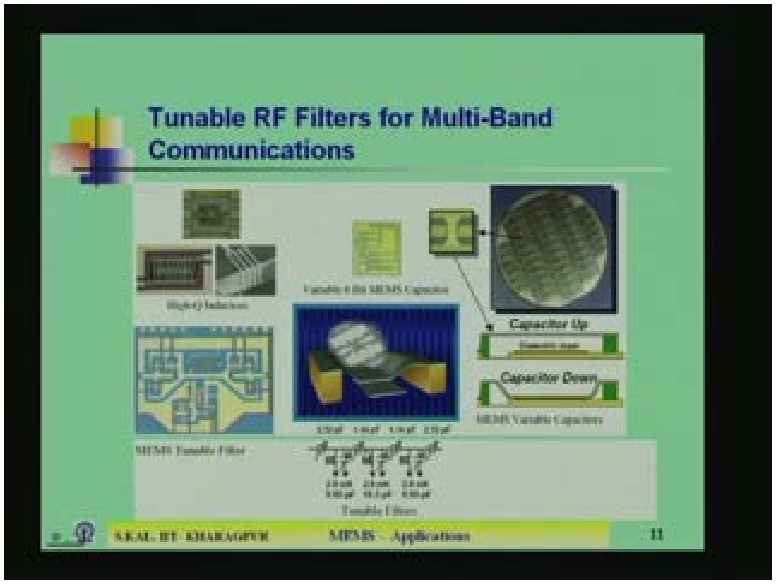

So these arereally useful in manyapplications and now this picture shows some RF filters which can be tuned. That means, filters tune means you can change itspause band or stop band frequencies. So any kind of the filter you require some the passive components like inductive and capacity particularly it is in RF filter, so we donot use resistances, all though RF filters are normal made using some capacitance and inductors. So these are the tunable filter structures where if you want to tune the frequency response of the filter, obviously you have to tune the value of the capacitance. So tunable capacitance can be made here are some of this structure you can see here.So here, how the capacitance are made, so here is you see the electrode, top electrode, the bottom electrode and these are directive layer. Now the capacitance value can be changed if we change the gap between the top and bottom electrode. Just few minutes back I mentioned that.

Now, for that you have to have certain mechanism by which these top electrodes can go down like this. So that means, that going down that means bending of this top electrode or deflection of the top electrode can be done by certain techniques.One of the techniques is applying some electrostatic energy or applying some if you keep it in someclosed chamber and if you increase the pressure,so pressure also deflects that. So now by some mechanism if you can change the gap, so capacitance can be tuned. So that capacitanceyou can connect with this filter, so as a result of which the totalfrequency response of the filter is changed. So here, you can see the total waferand in that wafer the tunable capacitance is one chip looks like this andthe cross section diagram is like thisand here you can see variable 6 bit MEMS capacitors are fabricated. There are 6 capacitance are there andits values change depending on the how much area top and bottom electrode you are allowing.

So here in the left side you can see some picture those are the high Q indictors that are also being made using the MEMS technology now a days and those indictors and those capacitors are connected here to get this tunable filters. So here is the microphotograph or the filter, the circuit is shown here.So now the values of the capacitance are mentioned also, it ranges from 1.16

PicoFarad to 2.25 Pico Farad and its inductancesare in the order of the few Nano Henry. So these are possible now a days using MEMS technology and as a result with which the RF filters, RF switches are being fabricated using the MEMS structures.

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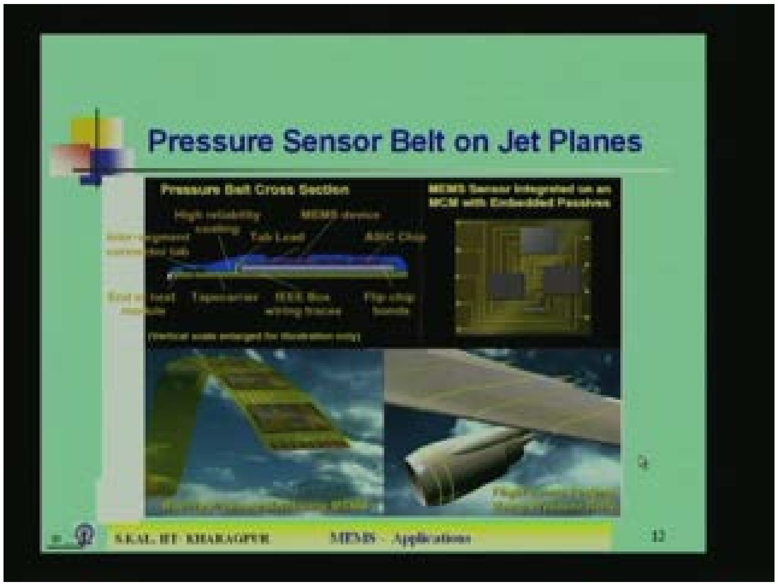

Now here are some applications and this is a pressure sensor belt on jet plane.So here, in a jet plane, in the belt lot of pressure sensors are corrected in different arrays. And those pressure sensors normally measure the pressure outside of the plane as well as inside pressure is also monitored. So for that, outside in the belt there are lot of thin film or the micro machine, the pressure sensors are indicated, the picture is shown here.And those capacitances are connected with some circuits and those circuits are some kind of ASIC and there are interconnect each otherand how the interconnections rounds to thesurface of different external surface of the jet plane is shown here and obviously when the jet plane moves, it moves with a tremendous high speed as well asthe off side pressure is not atmospheres pressure, you now if a depending on the height the pressure also goes down. So that monitoring of the pressure is very important so that inside pressure will be control andinside pressure you have to keep in atmospheric pressure for survival and outside pressure changes accordingly. So the movement of the total structure how will guide it, how willthe make this turn,all everything depends on the pressure. So in each part lots of pressure sensors arefixed in different direction and different places of the body of the planes. So accordingly you can get the monitoring of the pressure at different direction.

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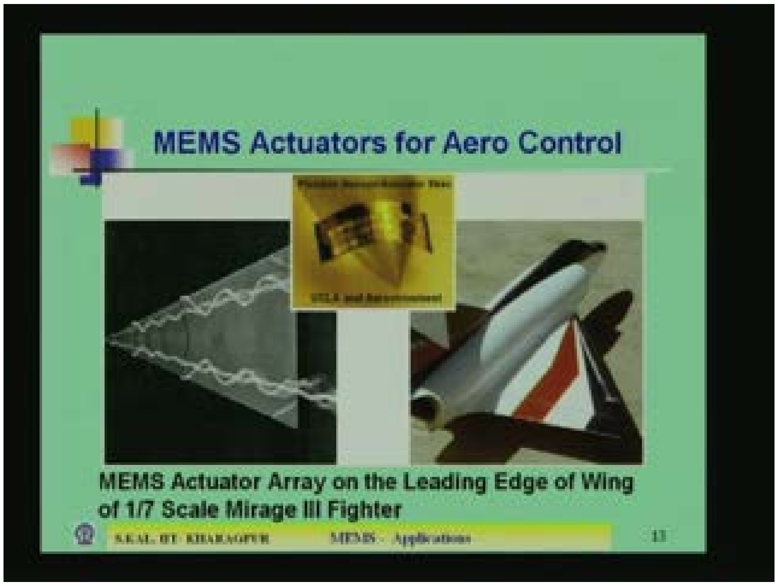

So another application is the actuators for aero dynamic control. These are some of the actuator array on the leading edge of the wing and of the mirage fighter. So in the modern, all kind of the all kind of theavionics or airplanes, they are taking advantage of miniatures and level operation of the miniature size and level operation of the MEMS devices and here are some sort of actuators is shown.These are flexible sensor stroke actuator scheme something like that.So it can deflect, it can change its shape depending on how muchsome kindsof materials are safe memory alloy. So its shape can change by changing some magnetic energy, so that can be used as actuators also.

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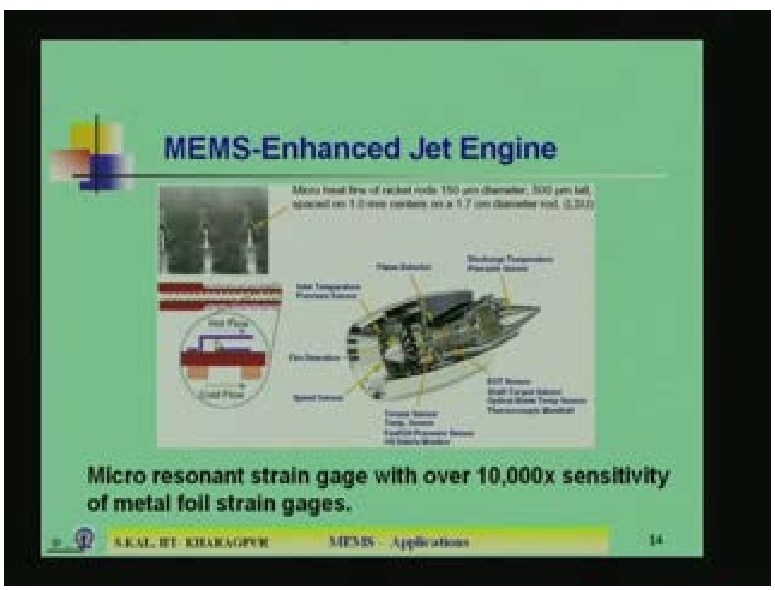

So these are someexamples I am showing here had another exampleso some jet engine there also they use some strain gage and which will have 10000 timessensitivity of metal foil strain gage. So strain gage is a very important part of any of the civil structures and they earlier are the metal foil strain gages were usedand they have been replaced by the MEMS strain gage. And some of thestructures is shownin this diagram shows the cold flow and hot flow. Depending on that, this shape will change and as a result, if the shape changes, how much this strain is developing the structure, that you have to measure.So that can be used with the help of some thin films material on some membrane or flexures and accurately so its sensitivity also increases nearly 10000 times more than the metal foil strain gage.

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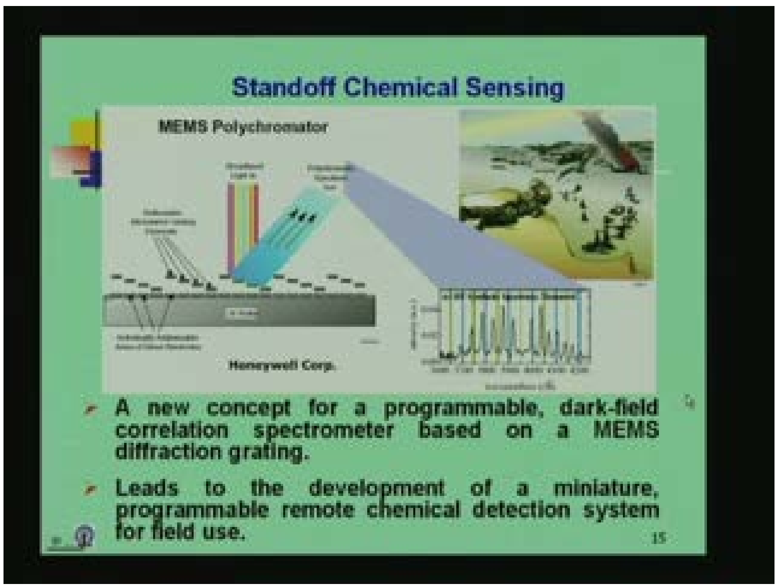

So another application here is the chemical sensing,that is remote chemical sensing. So that is also possible and here you can see the structure here, this is silicon wafer and the individually adjustable array of driver electrodes are fabricated on the silicon waferand on silicon there is a silicon dioxide,on silicon dioxide top thisthe array of driver electrodes are formed. And then in this direction, you can see lot of deflectable, the micrometer grating elements. Basically the gratings are made using the MEMS technology. And this grating when a broadband light is incident over the grating, the grating will defectand the deflected lights is analyzed using polychromatic spectrum analyzer. So you can have the spectrum of this and intensity versus if you look into thatthisthe spectrum, then from this pick you can you can identify what are the different kinds of chemicals are available in that particular area.

So by using remote energy, for example, some of the chemicals available on the surface or in environment can be detected using this miniaturized MEMS polychromator. So one of the advantages is, programmable and you can use in a remote way so that in the distance place where you cannot go, those particular location you can have some idea regarding the chemical composition or regarding the hazardous gas composition available in that particular area. That is using the MEMS polychromator is the device and that is used basic principal, is the diffraction of light and that diffracted light is analyzed using this spectrum analyzer. And the frequency response, that means the peaks you can identify from there you can guess the composition of that those chemicals and another things.

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So now here, another application is Pico Satellite. Pico Satellite, there all the components mostly are the RF switch, RF components are there and the first demonstration of the Pico satellite was made by the USA Air Force and Machine System Center in January 2000in 26 January 2000, twoPico satellites are linked by 30 meter long. This isthe tether and it wasmonitored by mother ship OPAL Stanford and it wasjust 7 February 2000,it was first demonstration was being made and it operates MEMS RF switches in spaceand these are basicallyfor tracking and communication this is the tether 30 meter long.

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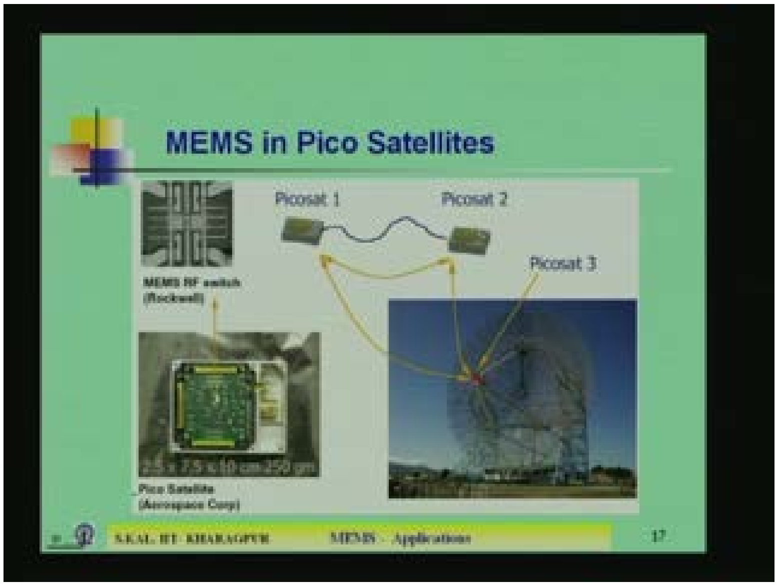

And these are the small kind of switch which is shown also here the MEMS RF switch. The complete the diagram here is a basically Pico satellite and its size you can see 2.5 by seven point by 10 centimeter and its total weight is 250 gram,that is the weight of the complete satelliteand inside at the same time you can see a switch and that isMEMS RF switch and there are three satellites; one, two, three, everything is controlled from the ground station here. So one advantage is the less weight you can see 250 grams satellite, that it is known as a Pico satellite. Now a daythe satellites widths are in the range of plutons.

So if you reduce into the few grams, so automatically the launching of satellite will be very easy. And there the cost is less, well requirement is less and only thing is the reliability how long it will work,that is need to be tested but lot of work is going on in this direction to make the Pico satellite and to see a its reliability and how muchinformation it can provide at the ground to monitor the environment and other things. So these are the Pico satellite program, there also MEMS is plying a major role in terms of this switches,in terms of the filter, in terms of the RF, what about the RF circuit you require and that are being made using to MEMS technology.

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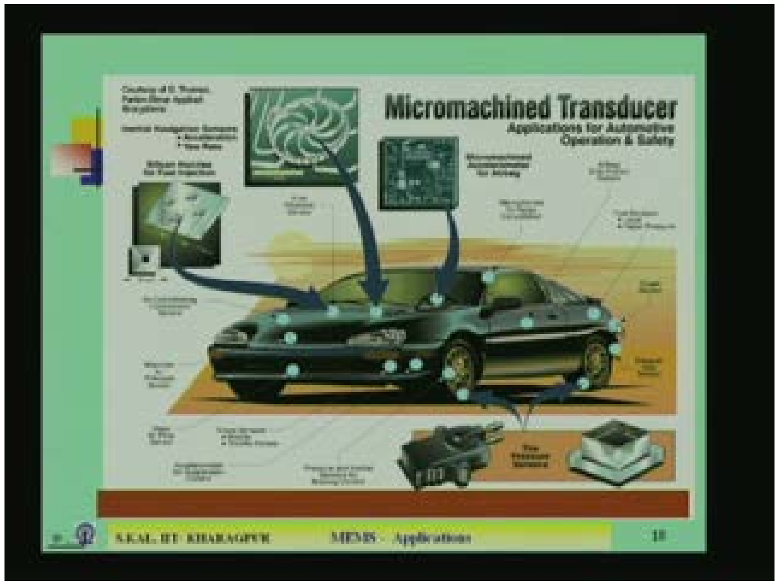

Now here is the automobile application is the picture you can see the smart car and here lot of sensors MEMS sensors are used and some of the picture are shown in different places. Here you can see the silicon nozzle for fuel injection and how the nozzle, this is the picture of a nozzle 50 micron by 50 micron and this is the area of nozzles which is used for fuel injection. Here you can see another sensor which is the structure, which is basically the wheel andit candepend on the nozzle fluid and it can rotate here also by fuel. This is the fuel pressure sensor.Here you can see the airbag; micromachine accelerometer airbag is here. So for example, these are thin pressure sensors which are connected, which are fixed at the tyre.

So that tyre pressure can be continually monitor and these are the exhaust gas sensor.At the back you can see some crash sensor; so that it can it can give you some signal before crash so these are the fuel level sensors the airbag side impact sensors are here, side impact. So air condition compressor sensor is connected here, so thepressure sensors are inside in not only wheel but also the outside pressure, inside pressure you can monitor. Mass flow air sensors is connected here. So you can see full of sensors are indicated in whole body of this automobile so that it can safely runwithout any problem as well as without any danger. Before any danger comes,so it can give some signal to the driver also so that he can take care of.

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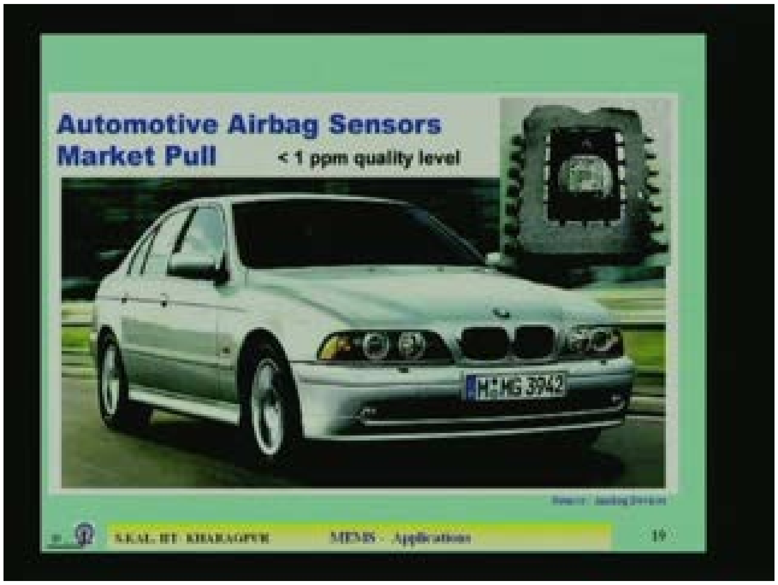

So lot of sensors MEMS sensors are used in automobile. Here particularly one sensor I am highlighting, that is the airbag sensor. That airbag sensor is basicallythe one safe guard it protectsfrom during accident the airbag blows and it prevents accident of the driver whose is sitting near the wheel.So that that particular sensoris day by day a great demand and different countries governments are making compulsory ruleso that all the automobiles must have the airbag sensor inside the car.So that sensor is in great demand and that can be fabricated using the MEMS technology this is basically the acceleration sensor and either by capacity or piezoresistive we can make it.

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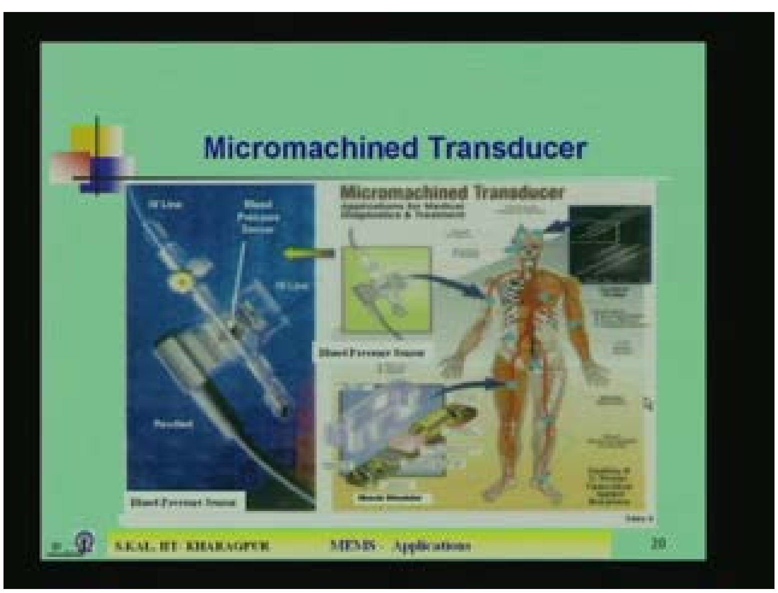

So now, this is a health monitoring application, you can see the picture here micromachined transducer. And hereagain some kind of pressure sensor which can sense the blood pressure, is you can connect here that is the blood pressure sensor is inside we will show here.Andnot only that blood pressure, here is one sensors is connected here, which can simulate the muscle, simulator. Another sensor is used which is here which is pacemaker.So pacemaker is another kind of pressure sensor, so that is alsoembedded inside the different parts of the body for a health monitoring purpose. Biological applications are enormous.

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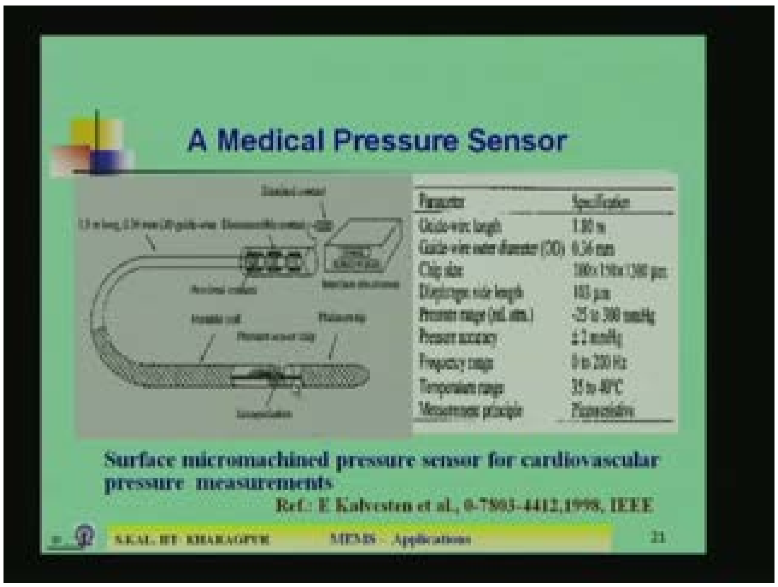

Here is another pressure sensor which is connected at the tip of a catheter. And this total guide, well length is nearly 1.8 meter and a total thick side which is connected here,so that is nearly 100 micrometer by 150 micrometer by 1300 micrometer and total diaphragm length of the sensor is 130 micrometer. By 130 micrometer it can measure the pressure in, is 25 to 300 millimeter of mercury and accuracies plus minus 2 millimeter and it can work in the temperature 935 to 40 degree centigrade and it basic principle is piezoresistive.So this kind of the catheter tip pressure sensor is used for medical diagnostic or during the surgery.Doctors are also using the catheter,some kind of pressure sensoris a surface micromachine pressure sensor that is used for cardiovascular pressure measurements.

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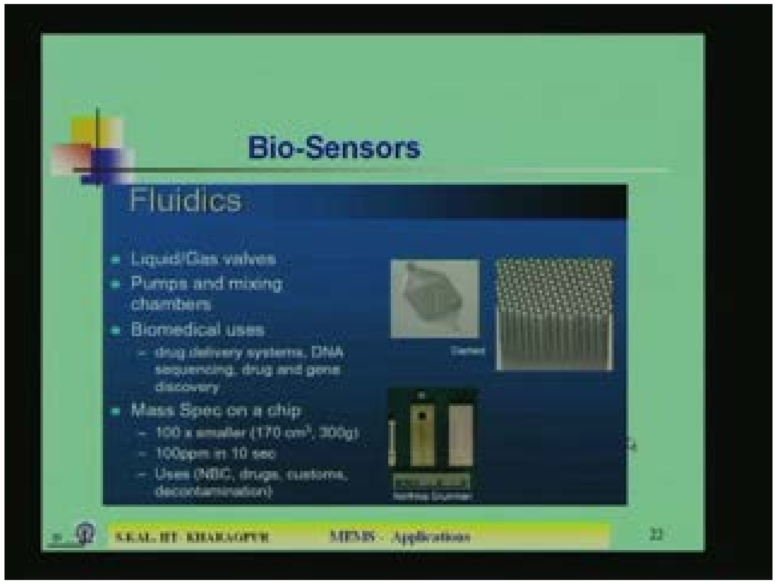

So anotherfluidics application and fluidics are liquids or gasses, so those flow measurements can be done using some flow sensors. And it has got enormous applicationnot only in biology but also in fluid dynamics.So some of the applications are drug delivery systems in DNA sequencing, drug and gene discovery, and its size isvery small about say 170 centimeter cube and its weight is300 gram that is specification of the mass spectrometry.The chip that is also for analyzing any of the biological fluidics you need those kinds ofdevices.

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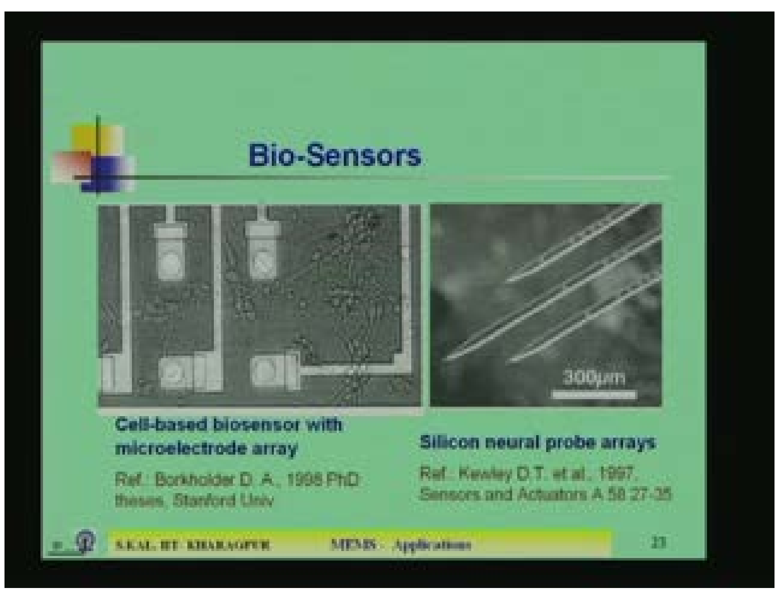

So some other biosensors are here. These are cell based biosensor with microelectrode array. These are the typical cells and the cells may contain some of thechemicals or agents. And these are the some channels and some electrodes are there, which you can apply certain field here.So as a result of which they can decompose and you can analyze those composition using some technique. And theirmain advantage is the reasonsrequirement is very small and you can have reliable measurementon a small miniature from small body.So in this picture you can see some of the neural probes, silicon neural probes. These are usedfor theneurology application as well as some neural researches is lot of neural researches taking place in different labs. So for then they need someneural probes and these are successfully made using the silicon technology. The tip of thisneural probe are of the order of shape 1 or 2 or 3 micro micrometerand these are successfully made using the MEMS technology.

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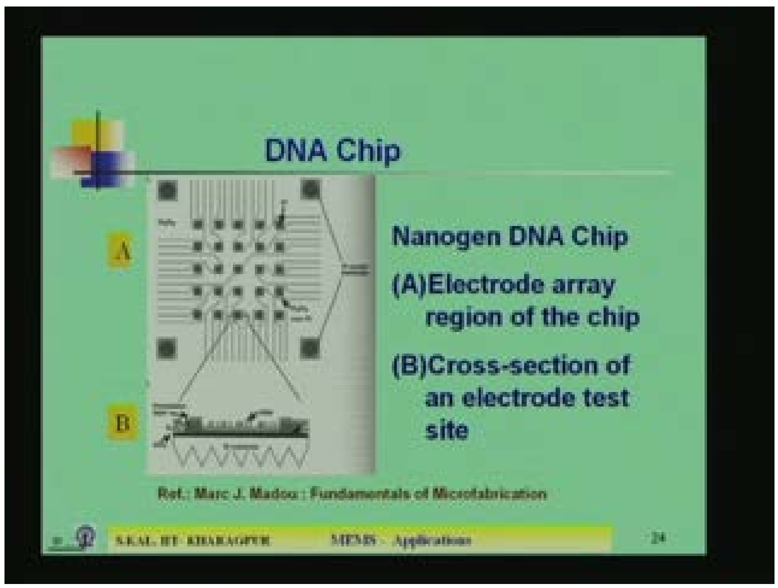

These are that DNA chip you can see total DNA chip and each cell is shown is here, lot ofthe silicon nitrides are used as a passivation layerand DNA synthesis DNA analysis are being made using the DNA chipand these are the electrode arrays and this is the cross section of the individual the cell andin bio MEMS, I will discuss a little bit in detail in the bio MEMS. In different class there I will again explain the detail function of those DNA chip.

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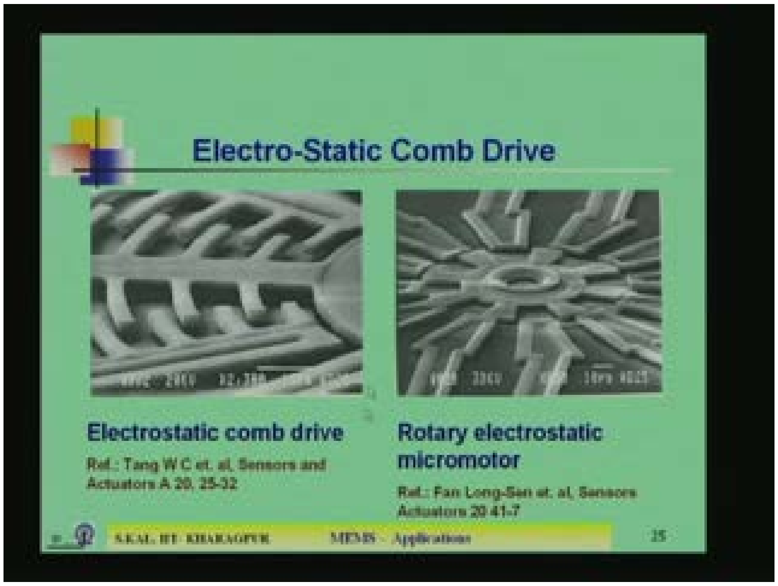

Now, these aresome of the micro electrostatic comb drive motors which also I have shown in earlier.So these are the comb drive, electrostatic comb drives and these are the motors anditrequires some of the electrostatic energy and it is an electrostatic drive micromotorsand I have explained earlier the functioning of this particular comb drive motors.

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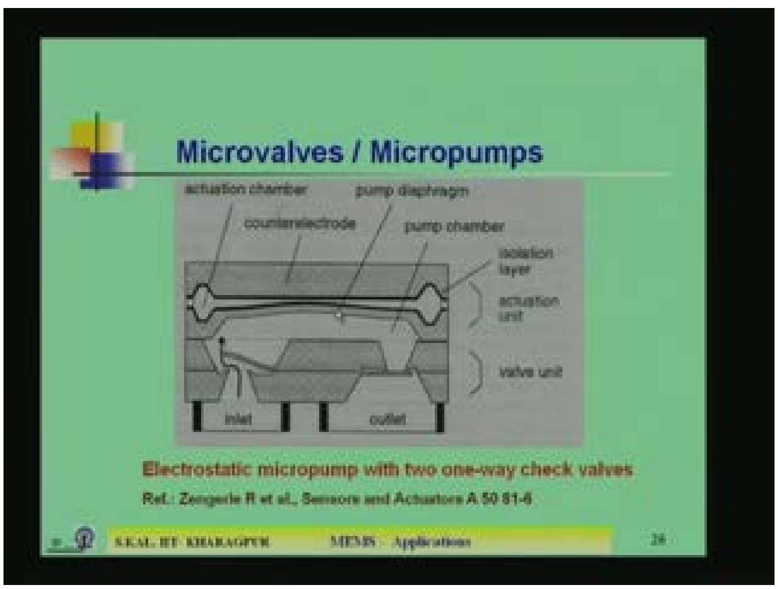

So here is another application, this is the microvalves and micropumps. So you can see here, in this particularpicture you can see 3 or 4 pieces 1, 2, 3 and 4. Now that is, 2 way check valve.We see individual pieces are made separately using the MEMS technology. Now all the 4 layers now bonded using some special kind of bonding machine. After aligning,you can make bond by silicon to silicon or you can make bonding by silicon to glassandif you bond, then you can have the complete structure.Now here you can see, so this is the actuation chamber here and these are the electrodes; this one and this one.Now here you can see the basic the valve,the basicpump diaphragm is here. So now these are 2 inputs inlet and outlet.Now this top portion is the actuation unit and the bottom portion is the valve unit.Now, how actuation is being made? Now, you see here that top and bottom these are, if you apply certain this is fixed.

Now this is some kind of membrane. Now if you apply certain electrostatic feel, so that the membrane can be attractive with the bottom electrodetop electrode.So that means there is a deflection here so this membrane is attracted towards the topso as a result of which the volumein the chamber will increase. See the volume in the chamber increases, so this valve will open it because of the pressure. Because here initial it was closed,now you suck it.So here from outside pressure the valve will open so if the valve will open so the fluid it can go here.Now,after the fluid enters into the chamber, then you do one thing, this, the flexure you release it. That means whateverthe electrostatic energy you applied you just stop it. So, automatically what will happen? This, the middle diaphragmwill take its own shape. So it will go downwards.

So a result of which it will apply some pressure on the fluid here.So then what will happen because, this valve opens in this direction it will be closed if you apply pressure in downward. So the valve will be closed. So but this valve will open. So when this diaphragm goes downward, so the valve open, so liquid goes in this direction. So by applying, that is why this unitis known as the actuation unit, so in the actuation unit by changing the potential, electrostatic potential or by applying or not applying the electrical field,so the diaphragm flexure you can attract toward stop or you can release it so as a result with it the liquid can suck and in the other valve it can eject. So this some kind of the microvalve and micropumps using MEMS technology you can easily make it.

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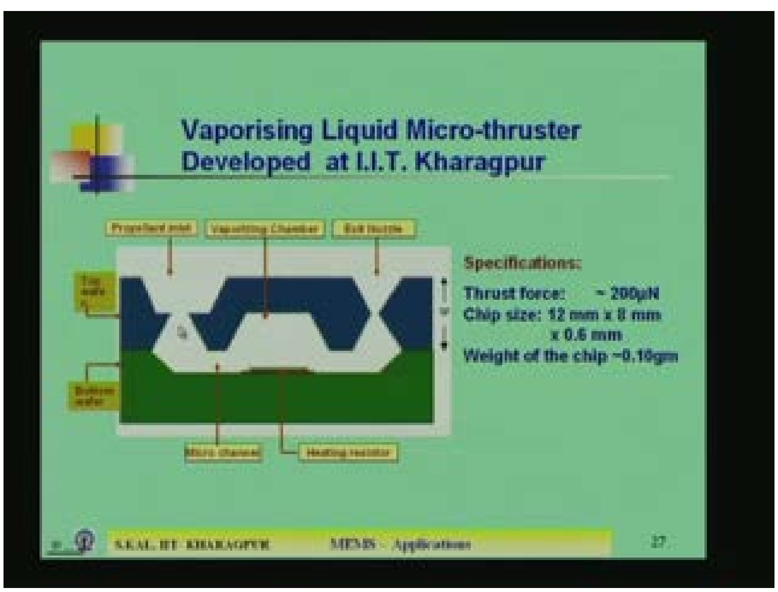

So here had another application, which is the micro thruster application it has been developed at out laboratory. So here you can see, there are again2 pieces; the bottom is thesilicon wafer which is safe like saythe U shaped the some silicon is etched and this is structure some immediate heater has been fabricated. This is the heater,micro heater. So now there is another wafer, top wafer. You safe like that now you bond these 2 wafers by bonding machine. Now this is a vaporizing chamber. Now propellant, if you insert the propellant here through a narrow tube, now if you heat these resistances by applying current to the resistance,so the heat will be generated.As a result of which here, the propellant which is inserted here, that will vaporize. Those propellants will again, when it will vaporize, so it will exist to at nozzle.

So when it exists to the nozzle, it will apply some back thrust. It will apply some back thrust becausethrough that nozzle the wafer is ejected, as a result of which it will apply Newton's third law of motion. In the high speed the liquid is rejected, so as a result, thrust is develop in the opposite direction. So that is that is why it is known as the micro thruster and thrust force is 200 micro neutrons you can apply and totalsize is 12 millimeter, by 8 millimeter, by 0.6 millimeter. So this micro thruster is used proper positioning of the satellite in space. Now here are some applications I am highlighting in different areas I am naming.

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So in defense application or inertial navigation on chip for munitions distributed unattended sensor for asset tracking border control environmental monitoring and other cases. Integrated fluidic system for miniature analytical instruments, hydraulic and pneumatic systems, propellant and combustion control. Weapons safing, arming and fuzing to replace current warhead and weapons systems to improve safety, reliability and long term stability.

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So, other applications are embedded sensors and actuators, mass data storage devices, integrated micro optomechanical components, to identify the friend or foe systems, displays and fiber optic switches.

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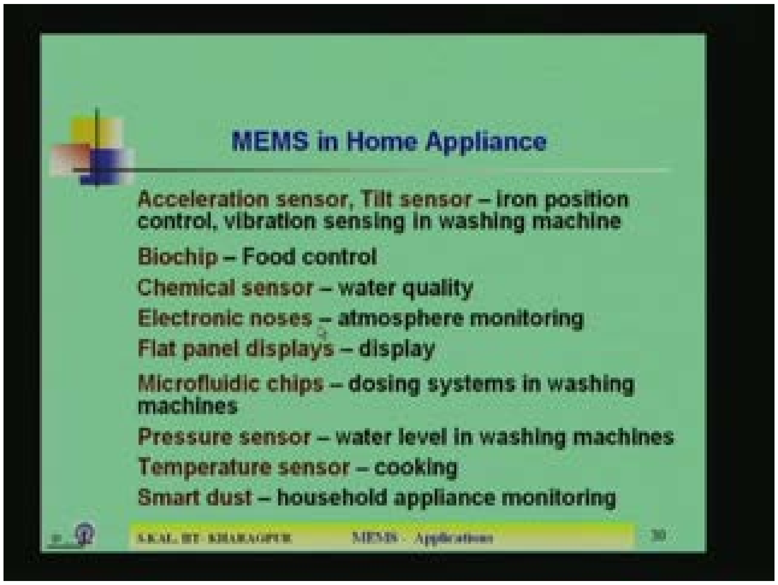

Here are MEMS for home appliance.Accelerations sensor or tilt sensor, it used in iron position control vibration sensing in washing machine.Biochip is used in food control, chemical sensor in water quality, electronic nose I will discuss in detail later on. Atmosphere monitoring, flat panel for display, microfluidic chips dosing systems in washing machines, pressure sensor so water level in washing machines, temperature sensor used in cooking, smart dust is used household appliance monitoring.

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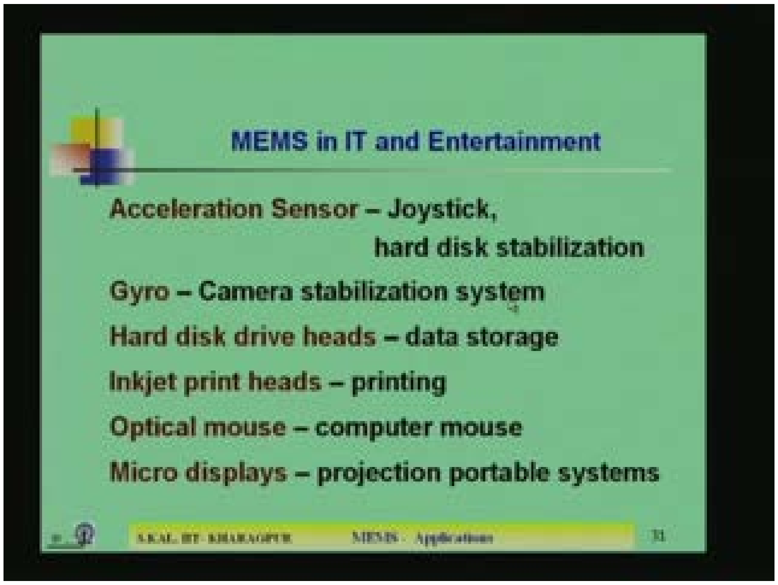

So MEMS in IT and entertainment. Here again joystick and hard disk stabilization, there the accelerations sensors are used. Gyro is used for camera stabilization system, hard disk drive heads in data storage, inkjet print heads printing, optical mouse for computer mouse and micro displays projection portable systems.

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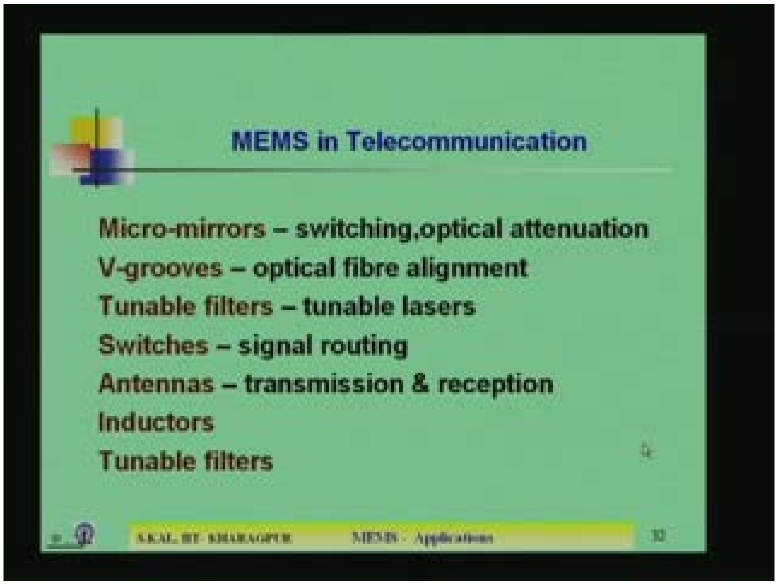

Other area is telecommunication. There micro mirrors used in switching and optical attenuation, V grooves used for optical fiber alignment, tunable filters are used for tunable lasers, switches for signal routing, antennas for transmission and reception, inductors and tunable filters also have shown earlier.

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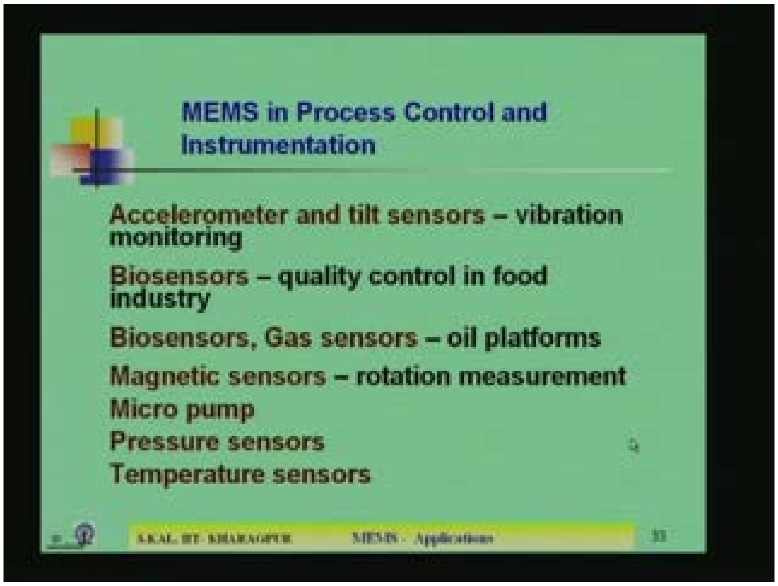

So this is in process control and instrument in application. Accelerometer and tilt sensor again for vibrationmonitoring. Biosensors quality control in food industry,biosensor, gas sensors in oil platforms, magnetic sensor is used in rotation measurement, micro pumps, pressure sensors and temperature sensors has got enormous application in process control and instrumentation.

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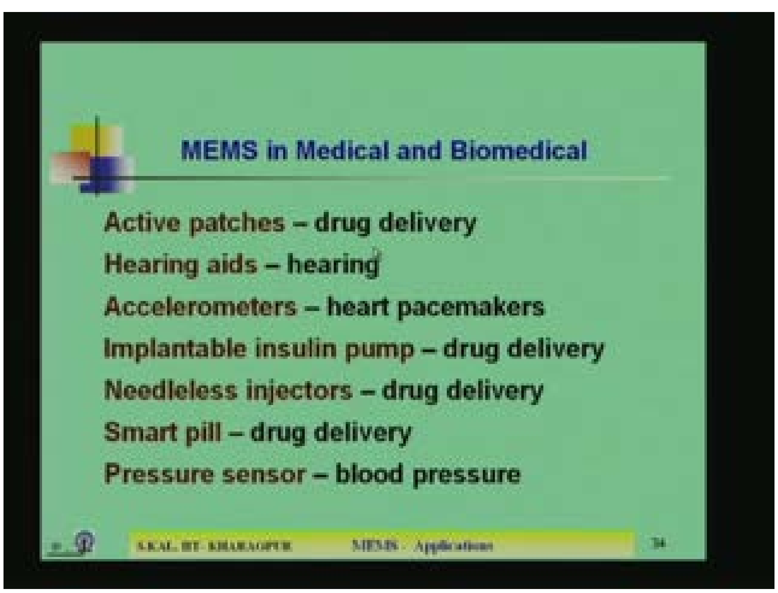

And medical and biomedical.They are active patches for drug delivery, hearing aids for hearing, accelerometers for heart pacemakers,implantable insulin pump for drug delivery,needleless injectors again for drug delivery, smart pill for drug delivery, pressure sensor for blood pressure. These are all biomedical applications. So these are the few applications I mentioned, so other applications I will discusswhenother topics I will discuss in detail. Some typical applications also I will highlight during those time.Thank You.

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Preview of Next Lecture

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So today, we will discuss on materials which are used for MEMS and microsensor devices. So you know, materials are the fundamental things or basic things based on which we develop various kinds sensors. While exploiting the properties of materials, the materials are of different class and all those classes little bit I will discuss in today's lectures.So,the materials which are used for MEMS are basically from different group. Some group belongs to the metals or metal alloys.
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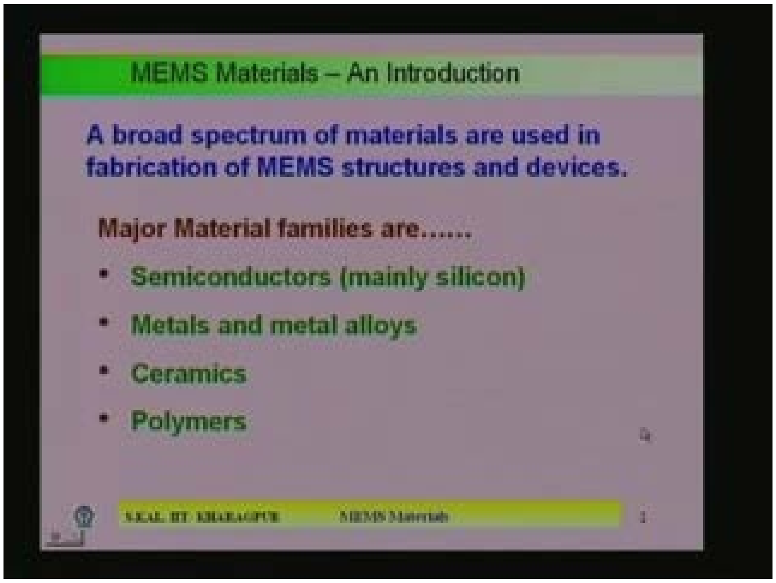

Some group are metals belongs to semiconductor particularly silicon, and metals and metal alloys other than those, sometimes we use some ceramic materials also and polymers material.So theseare the 4 classes of materials which are used for making various kinds of microsensors.

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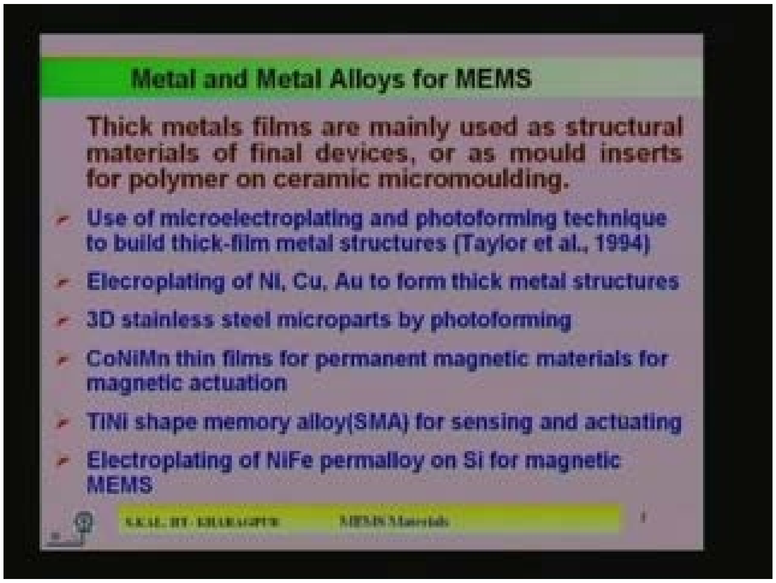

Now let us concentrate first on metal and metal alloys for MEMS. So we use thick metal films for those devices which are used for structural materials for final sensors and sometimes it is also used as the mould which is inserted into the polymer on ceramic micromoulding. What do you mean by micromoulding and what are the moulds? That I will discuss during the micromachining class? These are the techniques by which you can make the mould or micromoulds that is in chapter micromachining. Now,other than this micromoulding there are other techniques which are mainly micro electroplating or photoforming. These are used to build thick metal film structure for different components of the Microsystems or MEMS devices. Electroplating is another technique which is used for making thick metal films. Thick means I want tosay several microns may be 20 micron,30 micron, 40micron in that range.

If you want to deposit the more than 10sof microns then, conventional the thin film evaporation technique or sputtering technique cannot help. With that technique you can get films of the order of maximum 2 to 3 micron and if you want more than that 10 microns,15 microns,20 microns like that, then you have to add of certain techniques, those are mainly the CVD techniques and the electroplating technique. Electroplating technique is getting lot of importance now a day because, this particular technique is a low temperature process and that stage is known as thermal stage and because of that trace, some of the sensorbehavior or sensor output may also change. So that also you have to keep in mind. So,other than the mechanical stress, another stress is also involved which is known as the thermal stresshardness is another mechanical property.

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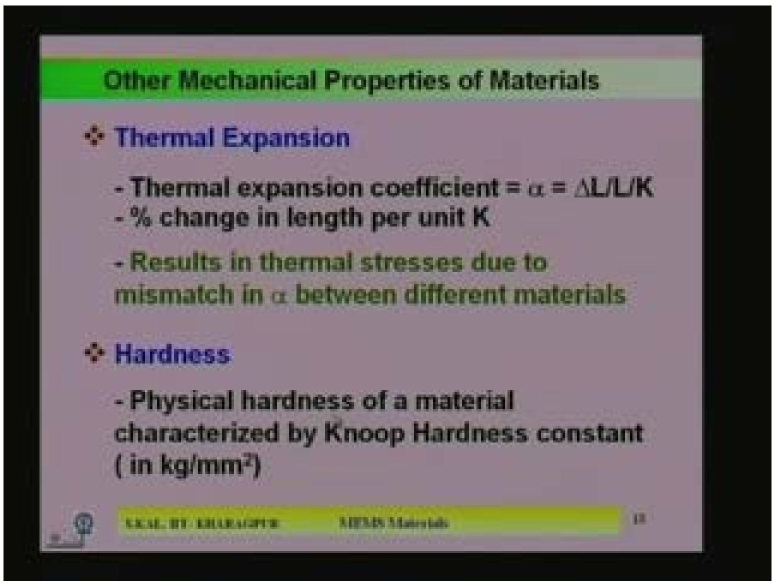

Physical hardness of the material is characterized by Knoop hardness constant and is in kg per millimeter square.Knoop is basically name of a scientist;he investigated that particular property of the material. That is why it is characterized by Knoop hardness and it isdefined by kg per millimeter square.

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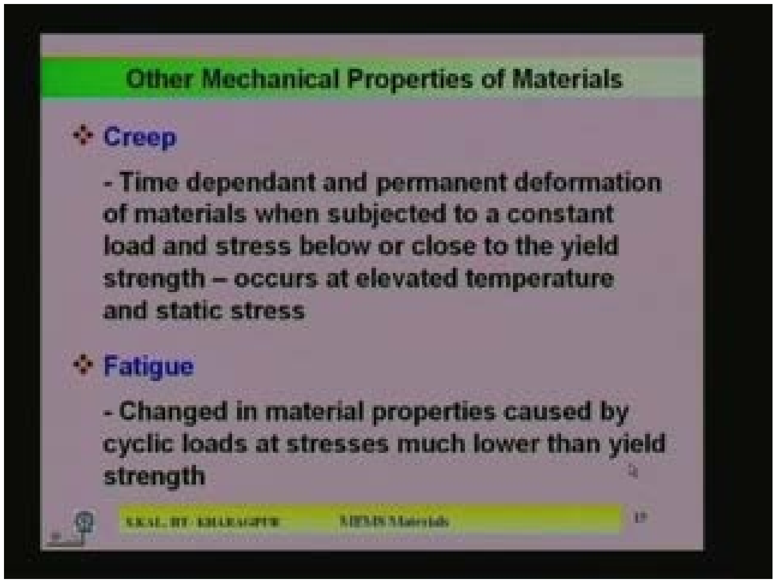

Now, others are creep and fatigue. These are all mechanical properties. What is a creep? Creep is basically time dependent and permanent deformation of materials when subjected to a constant load and stress below or close to the yield strength. It occurs at elevated temperature and static stress.If temperature is elevated and a static stress is applied, then this is known as the creepand other property is known as the fatigue. What is fatigue?Change in material properties caused by cyclic loads at stresses much lower than yield strength. That means you are applying stress lower than the yield strength,but if you are applying cyclic stress that means once you are applying stress then release it, again you are applying stress then release it, again you are applying stress then release it, in a cyclic way if you apply stress and then release,then the material property that particular mechanical property of the material will little bit change and that is known as the fatigue.

As if the material reached its condition, it may not follow the linear stress ten relation, so that is the fatigue. So these are various kinds of the mechanical properties, the axial stress, shear stress, the yield strength, brittle, ductile, creep,and fatigue. These are the various kinds of mechanical properties once you take care of when you are going for design of any microstructure using silicon or any other single crystal or even using the metalor metal alloys.So let me stop here today. So in next class I will discuss on the different properties of the materials which are used for making Microsensors and MEMS devices. Thank you very much.