MEMS & Microsystems
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Lecture No. # 01
Introduction to MEMS & Microsystems

Good morning to all of you. Welcome to the course on Microsystems and MEMS. So, MEMS the full name is microelectromechanical systems and this is a very emerging area today and lot of work is going on around the globe on MEMS and Microsystems and it has got enormous applications. Today, we will highlight the basic applications and some of the introduction on MEMS and Microsystems. Now, the MEMS topic or microsystems is an offshoot of the microelectronics and so to start the course on MEMS and Microsystems, we will start from microelectronics and let us look back little bit into the back of the present MEMS which is microelectronics and we will look into the history on microelectronics.

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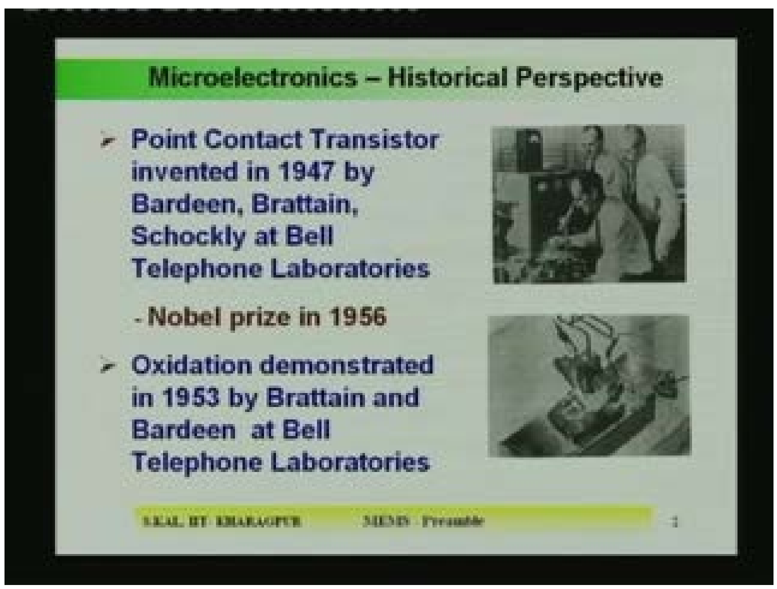

So, this particular figure you can see the three scientists who are the Bardeen, Brattain and Schokly from the Bell Laboratories and you know these three scientists first discovered the Point Contact Transistor which is in 1947. For that discovery they got Nobel Prize in 1956 and that was the first time Nobel Prize was awarded for an engineering device. You know Nobel Prize is not given for any engineering branch. It is given on basic science, physics, chemistry, mathematics, and etcetera. But here the Nobel Prize was given in physics for engineering device.

Later on these three scientists developed a technique by which silicon can be oxidized and oxidation demonstrated by them in 1953 at Bell Lab. Because of that demonstration of oxidation from silicon, basically the people started thinking why we cannot make the transistor on silicon monolithically. The first invention on transistor was a point contact that is a diskette. Basically, they combined three pieces of silicon N P N and something like that and then they took contact on each point and they got the transistor action.

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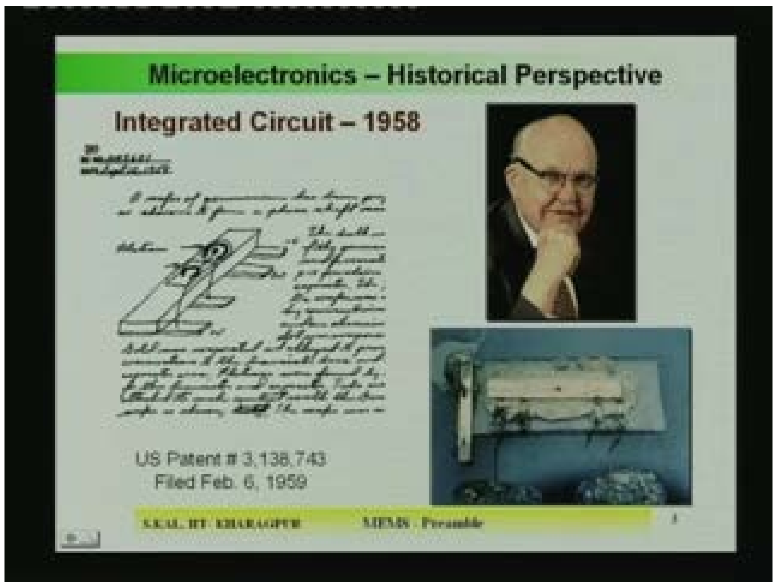

This figure you can see is Jack Kilby and he invented integrated circuit in 1958.You can see here so that is the US patent and which was submitted in February 6, 1959 and this was in September 1958 the patent was written and that was the first monolithic integrated circuit you can see the picture here and this gentleman is Jack Kilby and he got again Nobel prize for this particular device in the year 2000.

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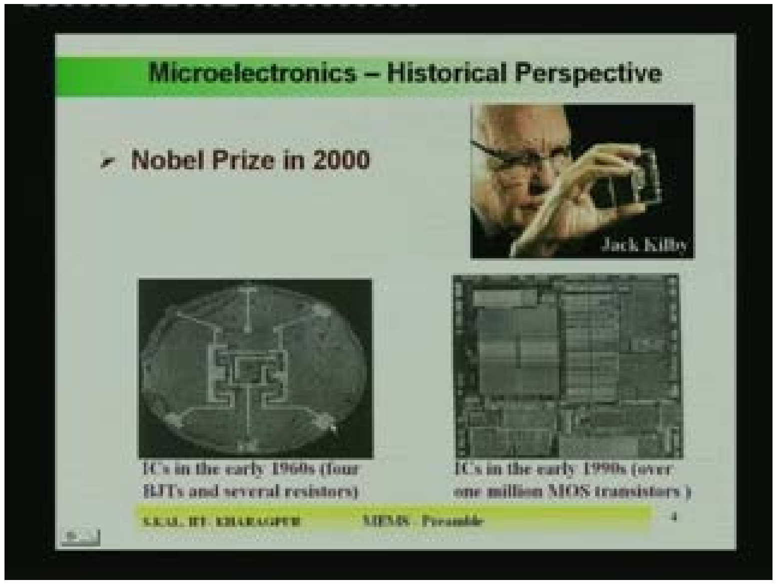

So, from that time onwards people are not seeing back and they are proceeding forward, particularly in the context of miniaturization of different components and making the integrated circuits. Now this picture you see is the MOS transistor which contains over one million MOS transistors and that is in early 1990s. Now if you look back to compare the revolution in the integration of the components, we have to go back to the first transistor which is also monolithic and that was made in 1960s, where four BJTs and several resistors are connected together with some metal line. You can see this is a metal contact, this is a metal born pad, here is another metal born pad and the four transistors and several resistances were integrated to get some functions off to get some circuit.

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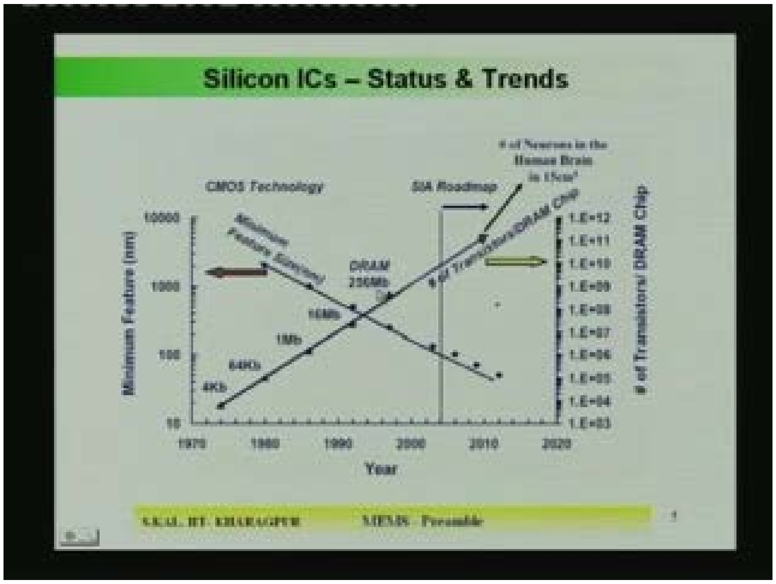

Now, after that if we see the what is the status and the what are the trends of silicon ICs, we have to see this particular figure where this has been obtained from CR route map and here in one side you can see the minimum feature size of the transistor starting from 1970 to 2020 and on the other side you can see the number of transistors for DRAM chip. So now look at this figure, here in 1980 where these minimum feature sizes was nearly say 2000 nanometer and then if you go, at present this is the present line 2004 and there you can see the feature size is nearly 100 nanometer. So, on the other side, the DRAM chip which is basically always cited the integration level and that integration level starts from the 4 Kilobyte this is the nineteen four kilobit DRAM which has come in 1970 and later on you can see from 4 Kilobyte to 64 Kilobyte then 1 Megabyte to16 Megabyte and so on.

At present 256 Megabyte DRAM, where this is nearly in 1998 or 99 it came and there transistor count you can see here is one 10 to the power 9 so that means is nearly people are thinking at the moment so transistor level has come of the order of 10 to the power 10 transistors for DRAM chip. Now, if you here is one limit by 2010 and 2012, we can see the number of neurons in the human brain in 15 centimeters cube is nearly 10 to the power 11. 11 is the total number of the neuron cells and people are speculating that, by that time the number of transistors for IC or DRAM chip will achieve in that level.

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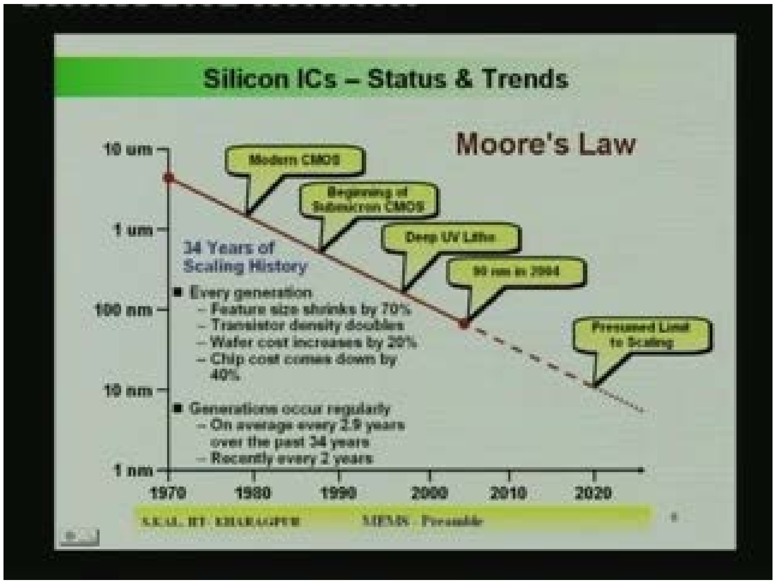

So now, this is another picture you can see which is basically Moore's Law and that gives you the scaling of the CMOS. That means year to year how the integration is taking place, you can see from here the model CMOS in 1980 which is nearly one micron technology and then at present in 2004, the transistor size has come down to 19 nanometer only. Here basically a route map is given by an international organization and that is the semiconductor route map they call it, and in the last 34 years the scaling history is such that every generation feature size sinks by 70 percent. What do you mean by the generation? The generation basically, on an average of every 2.9 years they speculate something, they foresee something and after that on that particular year again depending on the progress of the design and progress of the technology they again just to control something so the next two years what will happen, so that is basically the route map.

Earlier this generation is nearly 2.9 years but later on the progress is so fast that has been changed to 2 years recently every two year they are speculating something. Before that time target achieved, they got something else, much more progress has been done. Now, basically the scaling of the CMOS if you can see that the beginning of the some micron era is started nearly say mid of 85, a mid of 80s that is 1985 nearly in that after that deep UV lithography then 19 nanometer in 2004. So if you continue in this fashion so reasonably by 2020, they will come to a limit and that limit of scaling, that means there the problem is the lithography alignment or which will be the source of lithography. So, optical lithography is a commercial technique, you know after they highlight, they proceed to UV, deep UV and then after deep UV there are certain other lithography techniques which are basically x-ray or (Refer Slide Time: 09:45) lithography but those are not commercially viable.

The people want to stick on optical lithography itself so that's why optical lithography create some problem after the 90s nanometer and below. Lot of intervention and techniques people are using in the optical lithography so that they can get the feature size below these 90 or now at present 60 or 65 nanometer people are working on.

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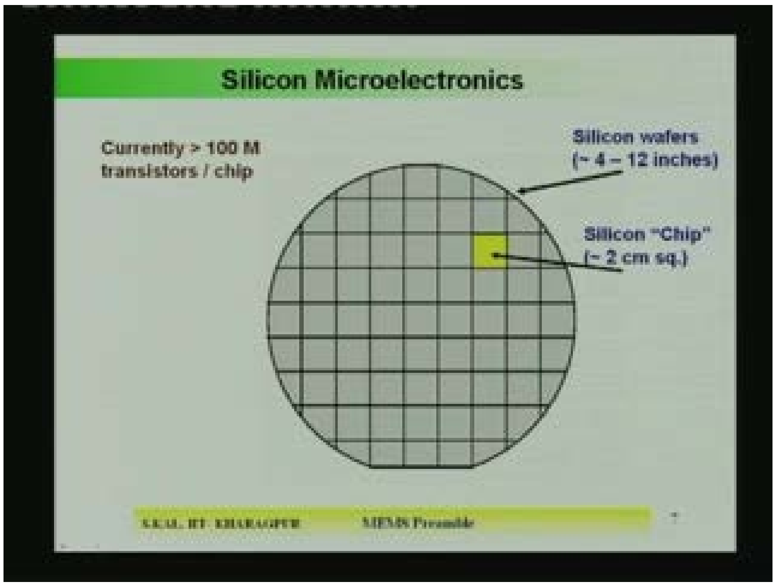

But now the silicon microelectronics basically if you see, that is the silicon wafer is 1 0 0 crystal orientation wafer. Now, at present the standard size of the silicon wafer in industry is nearly 12 inches. Normally in some cases the 4 inch or 6 inch and 8 inch wafers are also used in some of the small fabs but in big fabs they are working on 8 to 12 inches. Now, you know the lots of circuits are made on silicon wafer and individual single chip and that is of the order of 2 centimeter square.

I am talking about a larger chip size which you can make now days, is of the order of 2 centimeter square that does not mean that feature size is also very large. Feature size is very small and if you can get the larger die side that is another achievement. Feature size goes down and this is known as the die and the die size goes up so that is the challenge of the technology. Now currently what I just mentioned few minutes back, that the number of transistors per chip has exceeded the 1000 million. So this is heading towards the billion and projection in 2014 is 20 billion transistors per chip and that is the projection at the moment.

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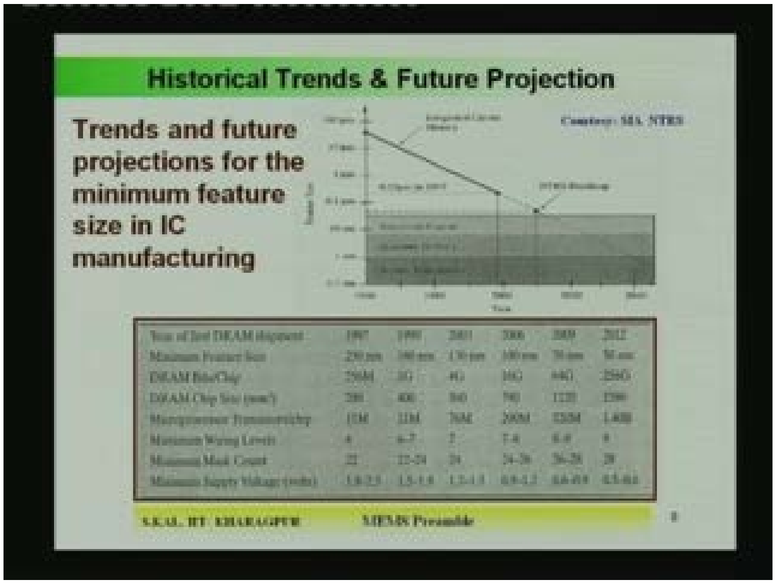

Now, here is another (Refer Slide Time: 11:45) diagram, where you can see the feature size goes down, so if you look into the integrated circuit history, below this is a 0.1 micrometer and this is 10 nanometer range, this is the one transition 0.1 to 10 nanometer and then another transition level is 10 nanometer to 1 nanometer. So 1 nanometer means this transition is very important to people and is basically the quantum devices. Now you know the lattice, the constant of silicon is nearly 3 or 4 or 5 nanometer. Now if you go into 10 nanometer that means few 2 or 3 the atomic diameter is like that. So, that means the few monolayers of silicon within that if you go into this region then you have to make the devices. So there, the normal physics of the transistor may not be valid and you have to go into the quantum mechanical analysis and those are basically the quantum devices. Below that are atomic dimension and the automatic atomic dimension level, when you make the transistor lot of other problems will come into the picture.

Then here is another table which shows that the trend of the feature size as well as the wiring levels the mask count and supply voltage that all this figure tells that is in 1997 where the supply voltage is nearly 2 volts and in 2003 it is 1.2 volts and people are looking for the circuits and devices which will work in the 1 volt and at 2012 it's a 0.5 to 0.6 volt. So, you see how the feature size goes down and at the same time the chip size is going up as just now I mentioned to 80 millimeter square so they are speculating in 2012 it will be 1580 millimeter square. The number of transistors in that regime is 1.4 billion and that is wiring level. That means in the present all the microprocessor chips, the seven or eight level of metallization is being done there. You know if the number of levels is more the technology is getting much more complicated and obviously the yield is another important point which is another yardstick. So, how your technology is good, how it is commercially viable etcetera, so yield should be very good.

So, for that if number of levels of metallization increases, so then automatically you have to compromise with some yield but you have to make a compromise on a good yield. At the same time, number of wiring level increases that is the motto and target. And mask count is going to increase if the levels are more. So that the interlevel metal you have to have a dielectric layer then some metal pattern then again another dielectric layer so automatically the mask level will also increase. So that was the present scenario.

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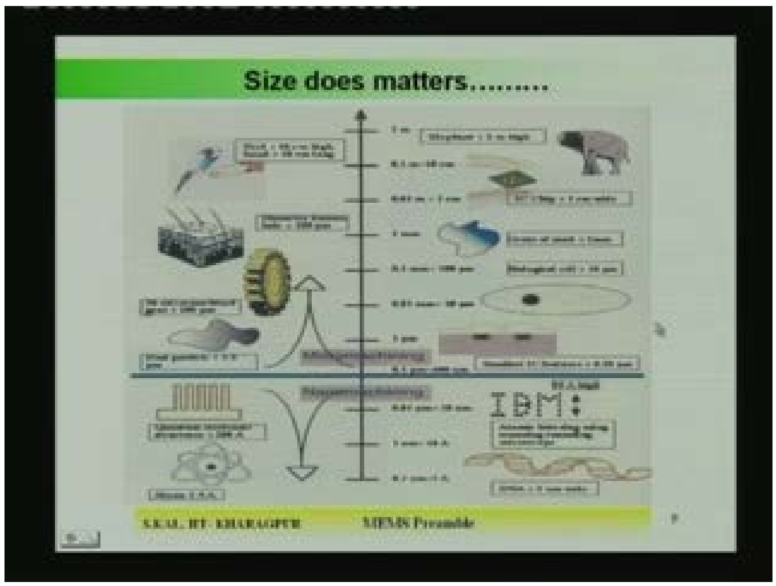

Now the size what I am discussing does matters how you can see this figure here. So, this is the the area of the micromachining and this Nano machining. So another word you are coming across now is machining. So machining, the terminology initially it was in mechanical engineering, people they used to point machining, that means from a huge bulk steel or any of the metal beam they used to machine it to get small miniature structures. Well later on the machining is used in microelectronics laboratory also to fabricate the MEMS devices. Now here you can see the 1meter, that is that elephant and then is gone down to 0.1 so that is the chip size is you say this is the area where 0.01 meter to 1 centimeter in that area you can get the IC chip.

Then this is the size of 1 millimeter the grain of sand and then biological cell comes nearly 0.01 millimeter to 10 micrometer and then comes 1 micrometer which is the smallest feature size 0.35 micrometer is sometimes back may be in 1996,97 where that level is micro. Now, if you go beyond that 0.1 micrometer below, that is entering to the nano area and there some of the examples are shown that the atomic littering using the scanning telling microscope. This is 1 nanometer, they are obtained from the feature size then DNA is of the 2 nanometer wide that is the size.

On the other hand if you see the machining, this is the micro machine gear which is nearly 100 micrometer, then this is dust particle side you can compare with that which is a 1 to 5 micrometer and these are some quantum electronic structures, the width of these structures in nearly 200 Angstrom and the atomic level 1 to 4 Angstrom. So that means, the size does matters because the with the reduction of the size and minimum feature size all the technology is going to change and at the same time the equipments are going to change and if you go below say 1 nanometer level, then physics of devices is going to change.

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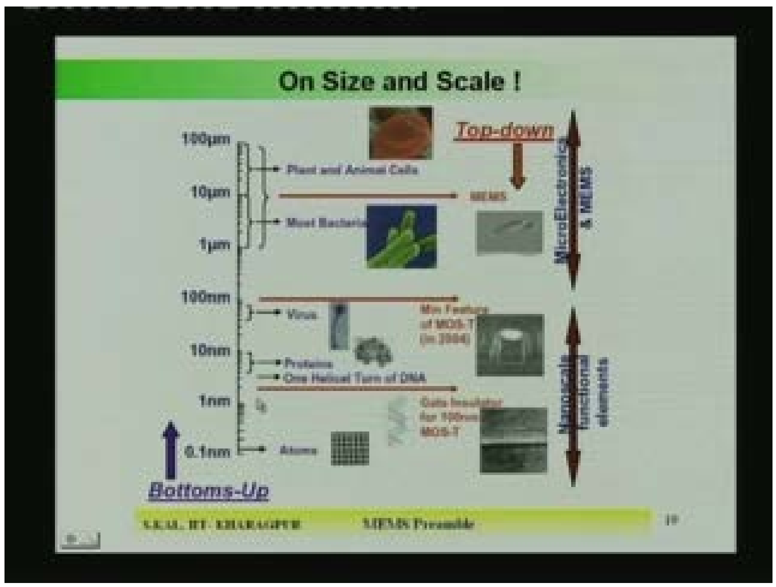

So now, if you look here, the size also on the scale that is bottoms up and here it stops down. So both are shown, here the few areas are is basically plant and animal cell and this is the bacteria size is the 1 micrometer to 10 micrometer and 10 to 100 micrometers are plant and animal cell. This is the area where basically the MEMS are made and now if you go beyond that, which is not microelectronics that is basically coming nano scales or nano electronic their size comes below the 100 nanometer to say here is say 1 nanometer. And below 1 nanometer the different area so that 100 nanometer to 1 nanometer, that the size of the virus, proteins and the helical turn of the DNA and this is the minimum feature size of a MOS transistor in 2004 you can see here. So people are working so 10 nanometer or 15 nanometer level, obviously, that is the nano scale for the nano and these are 100 nanometers MOS transistor you can see the gate dielectric is from here to here.

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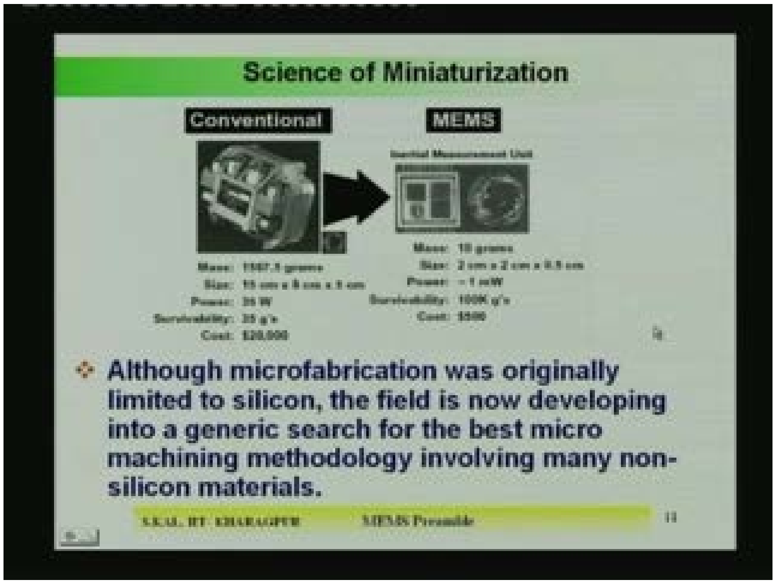

So now, the science of miniaturization with that you can see in case of machine, how the size is going to reduce. And here the size is basically an accelerometer and here is a MEMS accelerometer. Now, side by side if you compare you see initially, the conventional, the accelerometer, the mass was nearly 1.5 Kilo more than that and its size is 15 centimeters by 8 by 5 centimeter and it requires power of the order of 35 Watts. And on the other side you can see that, if a MEMS accelerometer if you use so that mass is only 10 grams so instead of 1587, it has reduced to 10 gram and size is very small compared to these. Power instead of 35 Watts, is only 1 Milli watt and cost instead of 20,000 Dollars, it has come down to only 500 Dollars. So, at present the price is further down and you can get nearly 10 or 50 or 100 Dollars to have MEMS devices.

So, although the microfabrication was originally limited to silicon, now the field is open people have started using some other materials than silicon particularly the polymers and ceramics and composite materials and also coming into the picture and people are using those materials for the MEMS devices and microsystem fabrication. Why people are sticking at the beginning only on silicon? There are certain reasons. Because silicon technology is fully mature and there is no new research to be done for the processing of silicon. That is why they do not want to deviate from the silicon. But later, on the other material particularly polymer and organic material has some other advantage in certain areas, so they are going to switch from the silicon to other nonconventional materials also non-silicon materials also for making MEMS.

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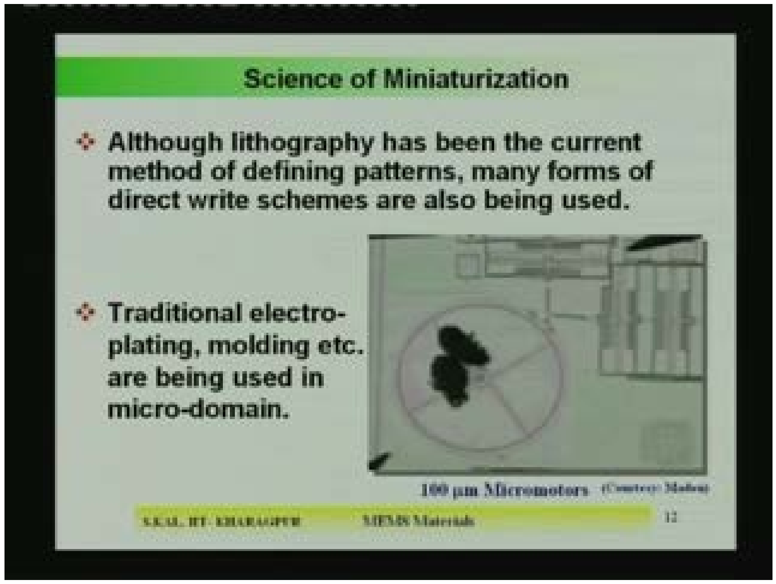

So now, the science of miniaturization, if you look into that, although lithography has been the current method of defining patterns, many forms of direct right schemes are also being used now a days. Traditional electroplating molding is being used in micro-domain. This is not used in case of this normal microelectronics. But in case of MEMS we are going to use the electroplating micro molding and in this liga, all these are coming into the picture and all the techniques, I will discuss in detail in the future classes.

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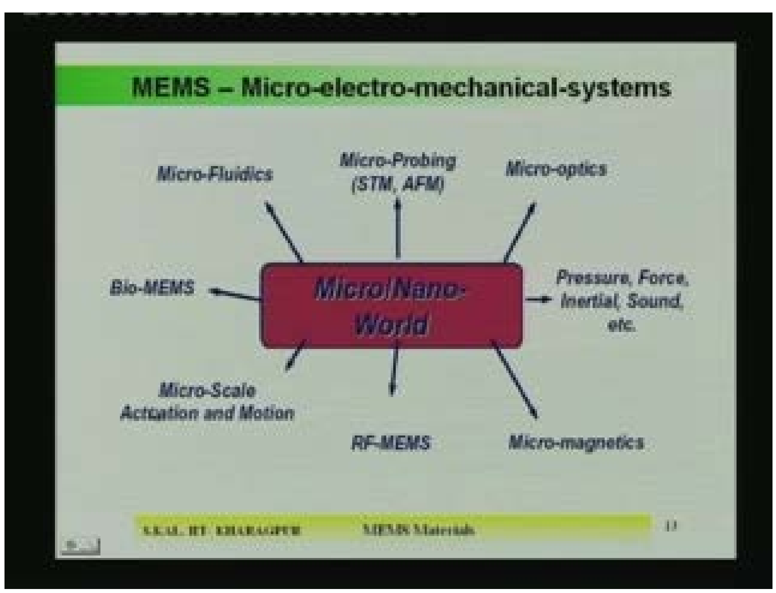

Now, this is a Micro or Nano world. If you look here, you can see various application areas. Those application areas are basically, one is the say the physical MEMS or physical sensors which deals with pressure sensor, force, inertial, sound means that these are the area where MEMS devices are made. Other area is micro-optics, optical areas which we call it as MOEMS Micro-Optical Electromechanical Systems. So there is the optical domain, there are lots of devices made using mircomachining technology. Then another is micro-probing, the STM and AFM. The AFM components are being made using the MEMS. Others are the micro-fluidics. Micro-fluidics is a major application in the biology and not only the biological application, there are others in flow of gas and flow of fluid in a micro channel, that dynamics is a is a very interesting and there lot of devices are being made now. This is another area of micro-fluidics. In Bio-MEMS, lot of work is going and one emerging area of research at present Bio-MEMS area.

And by the actuation and motion that is basically the actuators are also very important. If you want to make a microsystem, what do you need? You need the sensor, you need actuator and you need the signal conditioning circuits or processing circuits. So actuator is one part of the microsystem. So if you look into all the microsensor development that will not complete the microsystem development. If you want to have some microsystem, you have to see how the actuators can be made. And it cannot only make how it can be integrated with the sensor and also the signal condition circuit. So that is why this is another area of Micro Nano world, how can you make the actuator a precisely working actuator and is very important which is integrable with the micro sensor.

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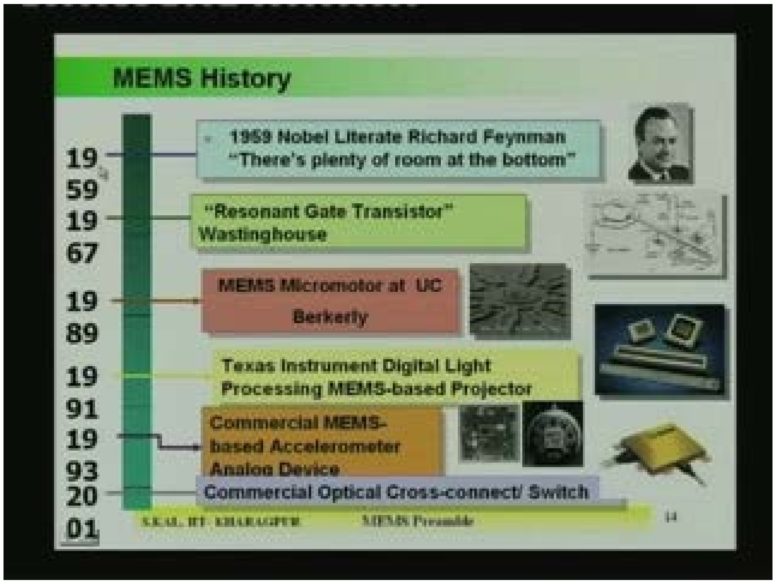

Now let us look into the MEMS history and if you look there, the gentleman is a fine man you know, and he basically got a Nobel Prize in 1959. In physics, again he had a vision and at that time he declared that there is plenty of room at the bottom. That means on silicon inside you can make lot of small miniature devices and that means there are a lot of spaces available which people are not utilizing. That vision has come through in 1959 that has been basically announced. In 1967, if you look that transistor basically Resonant Gate Transistors came from Wastinghouse, and then in 1989 is another thing that is basically MEMS device started. This is the picture which is basically 1 micromotor and has been developed in UC Berkeley.

And then in 1991, you can see the MEMS device which is one digital light processing chip that is used in DLP projector machine. And in 1993, these are the accelerometer, if you see commercial MEMS accelerometers coming from analog devices, ADXL series accelerometers and if you look here that is where actually a chip inside. And not only is the chip, if I enlarge the picture you see the signal conditioning circuit is also inside. And then the commerce in 2001 commercial optical cross-connect and switches as coming to the market, that is a MOEMS devices optical MEMS. So these are basically from 1959 to 2001, the history of MEMS.

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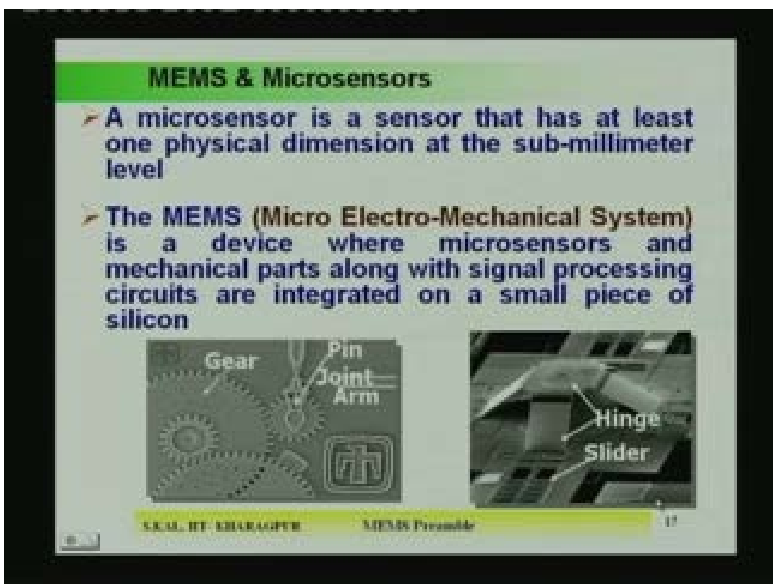

At present, if you see the micro structures made out of the silicon and other materials, some of the structures are shown: the hinge slider, and this is the one gear, this is a pin joint, so this is all this made using the micromachining technology. Now there are two things, one is the MEMS and Microsensors. Sensor is a very important device. Now-a-days, no system can be made without use of sensor. Lot of sensors is there in any of these microsystems. So that is basically the difference between sensor and micro is nothing but, the physical dimension is very very small in case micro sensor and in the range of the sub-millimeter level.

On the other hand, the M E M S or MEMS microelectromechanical system is a device where microsensors and mechanical parts, along with signal processing circuits are integrated on a small piece of silicon. In earlier days, sensors and circuits are not integrated on silicon. But if you integrate both the devices, then it is known as the microelectromechanical system. Mechanical means they are basically the mechanical part which means actuation parts. Actuators will be there, as well as the sensor parts along with the circuits, that is the MEMS.

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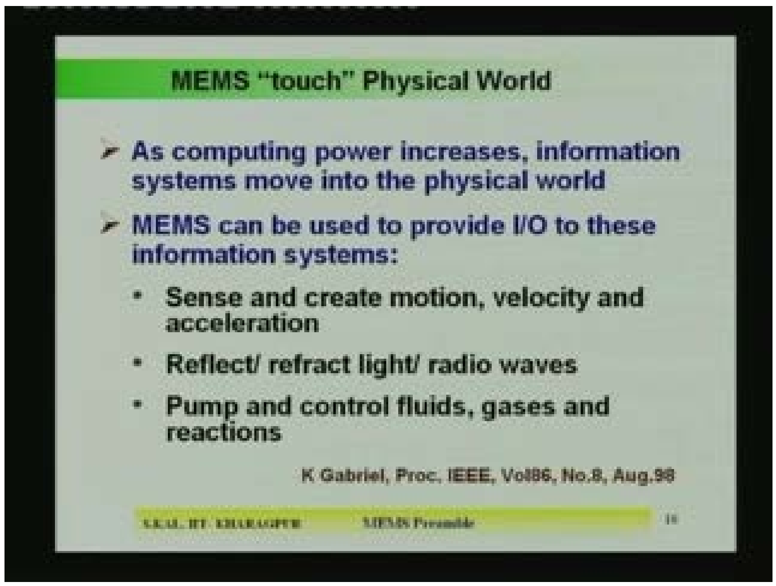

Now, as the computing power increases, the information systems also move into the physical world. Lot of the application in physical world using the MEMS and where the MEMS is playing a major role, that is in particular in case of I/O of input output device of any of the information system. And they can sense and create motion, velocity, acceleration they can produce and at the same time in the optical side these devices can reflect or refract light or radio waves also. And at the moment, the pumps and control fluids gases reactions gases and reactions are also done with the help of MEMS devices and these are integrated any of the information system now a days.

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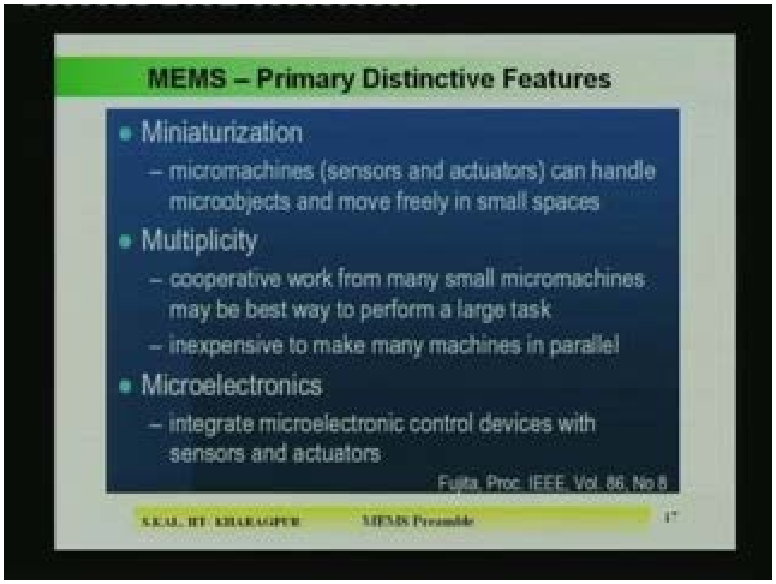

Now, the distinctive features of the MEMS are threefold. One is miniaturization, second is the multiplicity and third is the microelectronics. The miniaturization, i already told you how the size is bringing down both sensors and actuators, and they are integrated together. Multiplicity is basically the multiple functions that are being made in a system. If you want to have a large machine large task, you have to have some small micromachines and those micromachines are coupled together, integrated together to get best performance on a single chip that is the multiplicity.

And at the same time, the other advantage is that if you are going to integrate, not only integrate you are also going to fabricate those devices in batch production. That means if you make many of the devices from the same chip, automatically cost will be reduced. At the same time, many machines if you integrate together, they work in parallel, so the total system if you can think then its cost will also reduce so that means it is inexpensive. On the other hand, another thing is microelectronics. It integrates microelectronic control device with sensors and actuators. So these are the three primary distinct feature namely miniaturization, multiplicity and microelectronics.

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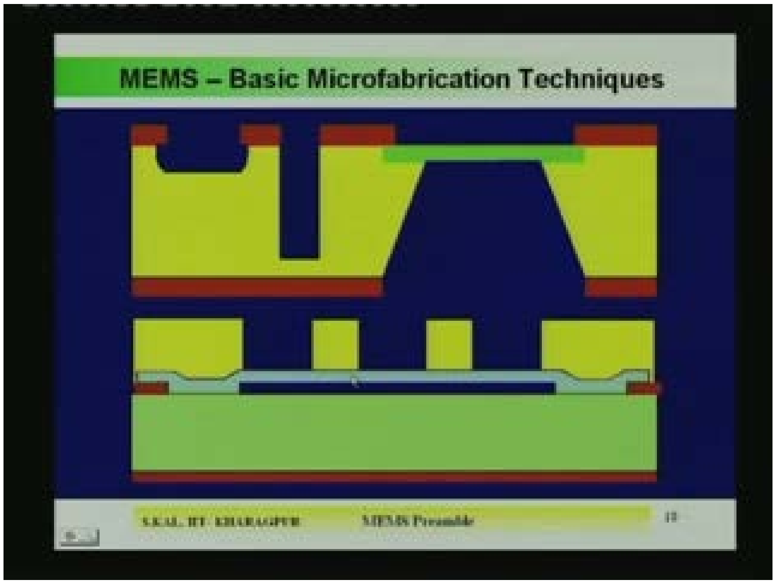

Now, the basic microfabrication techniques in case of MEMS are two. One is known, as I told you machining is the key feature of any of the MEMS devices and there are two kinds of machining, one is known as the bulk micromachining other is a surface micromachining. So in bulk micromachining, the first picture you can see the bulk silicon is edged to have different kinds of shape so depending on the techniques used in fabrication, you can create a membrane, you can create a rectangular hole or you can create a feature like this. So here, the yellow color piece is basically silicon and the red color is the passivation layer and the green color thing here is the stop layer. So, that means there are techniques used by which the edge can be stopped automatically. That I will discuss in detail in micromachining lecture.

Now, depending on the size of the opening of passivation layer, you can get different kind of structure from silicon itself. And the bottom picture is taken after surface micromachining of silicon. Now here, you can see is one kind of the cantilever and this in a bottom, is basically vacant. You can see here is a hanging kind of thing and that whole structure is on the surface of the silicon. So, that means if you can edge with a controlled manner to remove some of the material, either it is a structural material or it is a sacrificial material to have different kind of structure at the surface. So that is why it is known as a surface micromachining and this particular process is fully compatible with the VLSI process and the VLSI chips can be made on the sense silicon along with these the microsensor, if you go for surface micromachining technology.

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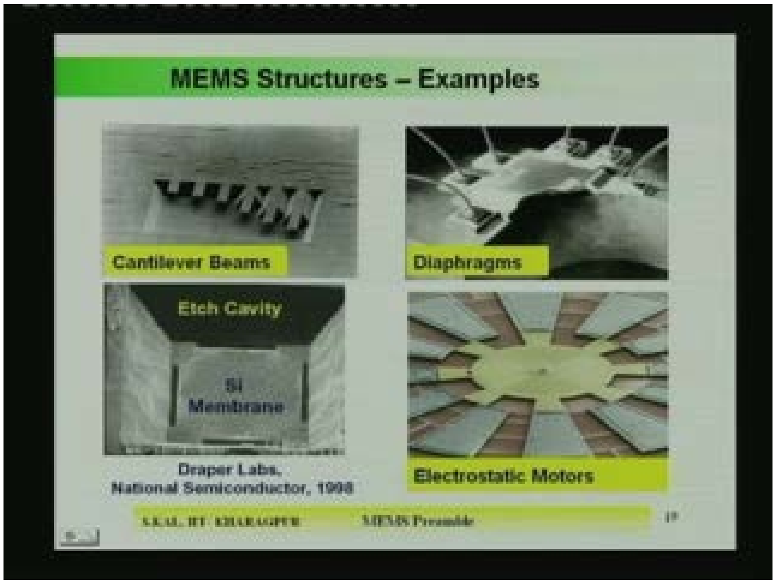

Now, I will just give some of the examples of the structures, so those are one structure you can see here. So this is basically some of the cantilever beams. Different size of the cantilever beams you can make out of the silicon and those are hanging and below silicon has been edged and you see this is another kind of structure the side walls are kept and a bottom is vacant is removed so these are the various kinds of the microstructure which is used in many of the devices. On the other hand, here you can see these are diaphragm. And this is one kind of diaphragm. On the diaphragm, some devices are made and this is the bonding pads and from where the wires are taken out and these diaphragms is used for many of the vibrator. In some cases, the diaphragm is used or the membrane is used and in case of sensors like the temperature sensors or IR detectors. So here is another structure which is silicon membrane at the bottom of the silicon and this membrane is basically held by 4 cantilevers.

And this is one fixture of cantilever another fixture and these fixtures are positioned in such a fashion that the whole membrane is held properly and this on the membrane, either you can make active devices or also you can make some passive components, or for actuation also you use the membrane. This side you can see is an electrostatic motor. This is another MEMS devices and that is another challenge people had solved, that is, motor which has big size people earlier they had an idea how it can be miniaturized is not possible now. In the last few years, the R and D had gone in such a level so that a micromotor of the size of few millimeter you can have that is basically electrostatic motor, and this is the basically rotor and this is the stator in a side this color is stator this is a rotor. Now by using the electrostatic field, this rotor can be rotated, just you can maintain a gradient of the field in the stator so that because of electrostatic attraction, the rotor can can move from one of the line to another line and again if the gradient is maintained, it will come here, then it will come here, in this way it started rotating and this sort of the motors are a very useful to any of the miniature devices. Particularly, in case of biological application these micromotors are used for microsurgery or knife etcetera for reviewing some of the biological spaces from the body.

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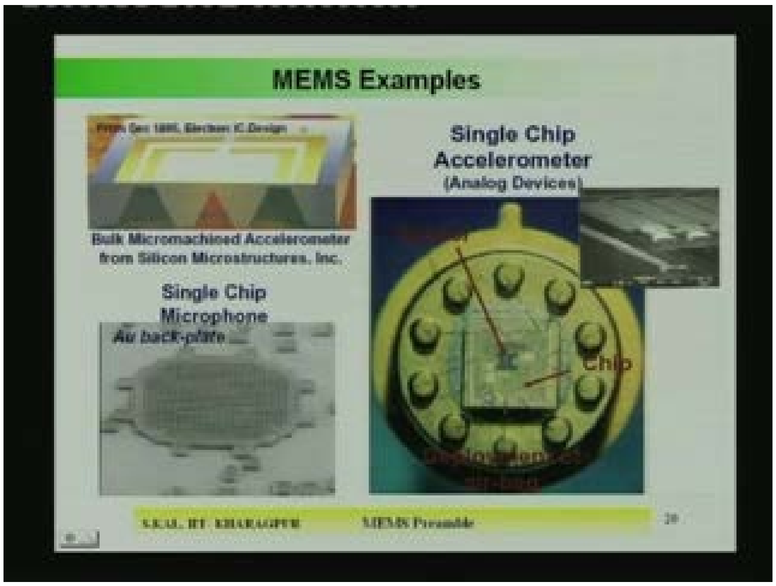

So now, other few examples I am showing here, that is the bulk micromachine accelerometer from silicon microstructure. So here you can see this kind is a bulk thing, this is a bulk and this here is some kind of the membrane and from there some structure has been made. So this is another single chip microphone and that is the back plate, is the gold coated back plate and here this is the structure, basically vibrator and then the other circuits. Because in a microphone the first the acoustic signal is received and that is converted into electrical signal and that signal again amplified later on so, the whole thing can be made out of silicon, the single chip microphone can be made using the MEMS technology. These are the some holes; those holes are basically some (Refer Slide Time: 35:49) on the silicon that can be also made by using the micromachining technology.

Here I showed you earlier one accelerometer chip. There is another accelerometer from analog devices and here you can see this is basically the acceleration sensor and this sensor has been enlarged the picture has been enlarged here. In this particular portion, you can see some pins are there and so because of the acceleration, the movements of these cantilevers will be either as it is basically the capacity of the surface micromachining accelerometer. So because of the acceleration, the capacitance will change and that capacitance change can induce the change in electrical signal and that signal can be processed by the circuit which are developed side by side, so that no further noise will be introduced into the system and at the same time there is no loss of signal, so you can get maximum efficiency of that particular chip and that is the airbag, the accelerometer chip and lot of applications are there in airbag. I will discuss the applications of the microsensor in automobile. Then again I will highlight what are the various kinds of the micro sensor used presently in the automobile industry.

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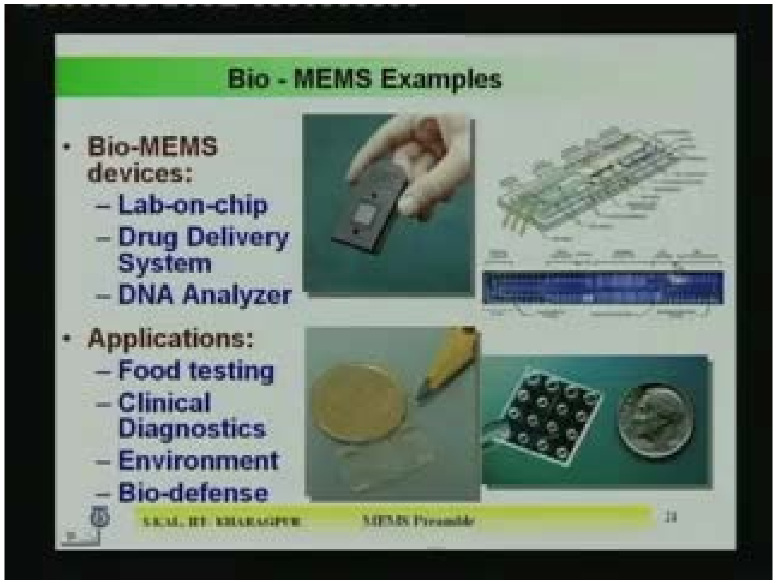

Now, another area is biological application of the MEMS and there, if you see, many devices are made out of the silicon or the polymer. You can see lab-on-chip, this is the lab-on-chip and here basically lab means where the diagnostic is being made. That means you see your blood culture or you want to have your lipid profile. So, blood sample is taken and there are a lot of chemicals are made and then the after reaction, the regions are analyzed reaction by production are analyzed. From there they can come to a conclusion that the composition of the blood like cholesterol level, like creatinine level or the sugar level etcetera. So now in a chip itself if you have lot of micro cavities and each cavities having some of the regions, so then automatically if there are certain channel, a small amount of blood is pushed into a small channel and then it will flow through the microchannel into the different cavities. The reaction will take place and their sensors are there to know the different composition, different levels of blood constituents. So at the same time if we are using small amount of blood, you can have total diagnostic of your blood or lipid profile you can get it so that is known as a laboratory on a chip.

And another picture you can see these are drug delivery system so drug delivery system is automatic drug delivery system. That means in many cases you know, particularly in a hospital or nursing home when the patient is admitted and in the night if the attendant is not there if he have severe pain, and so if you need some drug for releasing his pain and if no attendant is available, then there is a lot chaos and problem. So if a small chip has been developed, so if you fix the chip on his hand, so automatically some pain is there and some pain killer in a liquid form would be automatically injected into the body so there is no continuous monitoring is required, the chip itself is a taking care of. On the other hand a lot of people is having blood sugar, so when to put the insulin into his body can be diagnosed by particular chip and the chip continuously monitoring the health and the sugar level of a body and then whenever required the insulin is injected into the body.

So that is the drug delivery systems that mean there you have to have certain diagnostic feature as well as delivery feature. So it's a very intelligent module or chip and that is coming now days in many of the advanced hospitals or in patient take care of places. So, these are drug delivery system, is another solution in the place of continuous monitoring by some sisters or doctors. So in DNA analyzer, a lot of DNA research is taking place, gene research is taking place and there also these um the MEMS is playing a major role. And application wise, others are the food testing, clinical diagnostic as I mentioned, environment, and bio defense, these are other application areas. These are some of the pictures of the bio MEMS devices.

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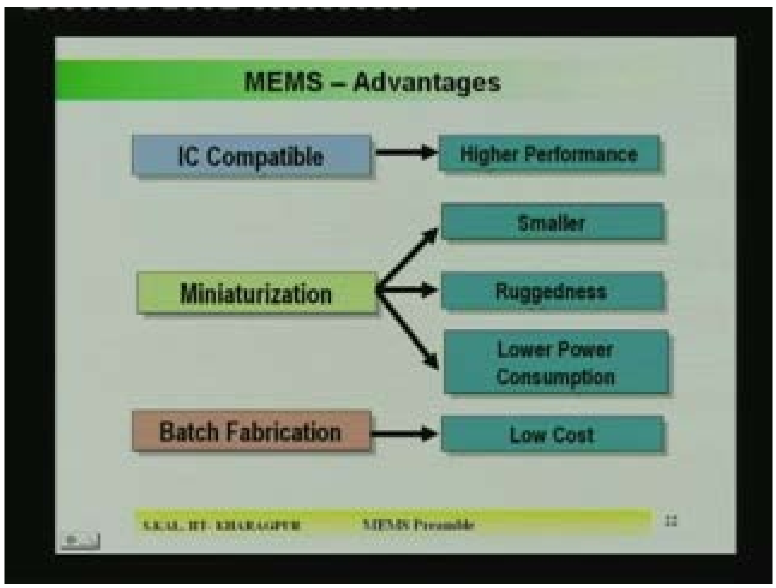

Now, the advantages of the MEMS are many fold. And particularly, these MEMS devices now days which are coming are IC compatible. As I mentioned, if it is IC compatible its performance is very good and miniaturization has got three fold advantage. Not only size is small, it is a rugged and at the same time if you reduce the size, then power consumption are also low. That is another demand of the day so whatever the system or chip you made it, power consumption should be low as minimum as possible. Because everybody wants the system should be battery driven. And battery driven means, the voltage level if the whole system should 1 volt, 2 volts or 1.5 volts in that range. So for that you need that the power consumption should be less so that the life of the battery will be higher. So you have to make innovation in circuits so that low voltage, low power circuits are added into the feature at the same time you have to have the miniature device whose power consumption will be extremely small. And the third one is a batch fabrication. Batch fabrication means the low cost. So automatically it is obvious if the same batch you can fabricate millions of devices, so cost parts will be reduced drastically. So these are the three major advantages.

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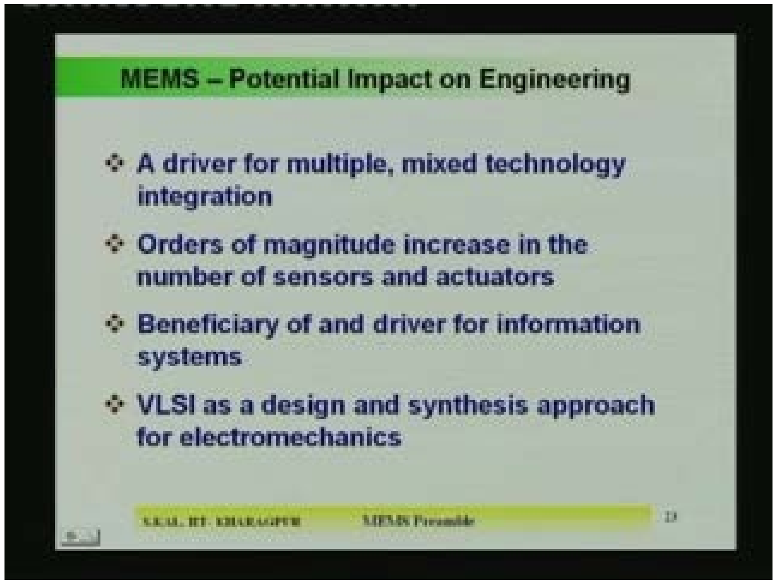

Now the impact on engineering, the MEMS devices and what are its impacts on engineering? So it is basically a driver for multiple and mixed technology integration. What is mixed technology and multiple technologies? That means, here technology is not only electronic technology. So here, they are combining materials technology, electronic technology and mechanical. Because as i told you, the MEMS means motion is involved. That means the mechanical movement is involved, so lot of mechanical engineering applications are integrated with electronic application.

That means, technology is a mechanical technology, materials technology and electronic technology, all are integrated together. So that is the driver for integration of those and orders of magnitude increase in the number of sensors and actuators. So that is another potential impact and the third one is beneficiary of and driver for information systems. So in a present information age, so MEMS and microsystems are driver for taking the information technology ahead, many folds in a forward direction. Others are the VLSI, as a design and synthesis approach for electromechanics, so it is electromechanics. So these are the different impacts on engineering.

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Now, again a multiple and mixed technology integration, you require in this particular area is interdisciplinary research. Because, VLSI is basically the research area where only electronics and electrical engineering people are involved. But here, in the MEMS or microsystem technology, the interdisciplinary research and people from different disciplines are required; physics, chemistry is also, people are also involved in lot of etching here is a micromachining or etching either it is a liquid or gas etching, lot of knowledge of chemistry of the materials and devices and gases are also necessary. So knowledge of chemistry is very much involved here, physics is everywhere, material research is required, so interdisciplinary team is required for R and D on MEMS and microsystems. So MEMS will counter the technology for narrow specialization. So people are working narrowly in different aspects, so in a device simulation design a group of electronic or electrical engineering people are working only.

Material is that material science people are working now this nano specialization, people have to come out of that narrow specialization and has to see how we can different knowledge can be coupled together to have a good system which improves the information, which takes forward the information system or information age. Teams that best integrate multiple disciplines will be best positioned for future opportunities. And new materials are also necessary now days because of different applications. What are those materials? As I mentioned, that polymer is coming in a big way in MEMS devices, because lot of polymer materials are biocompatible. On the other hand, silicon devices are not always biocompatible, so that is why lot of emphasis is given now days in polymer MEMS research. And lots of composite and ceramic materials are also coming into the picture.

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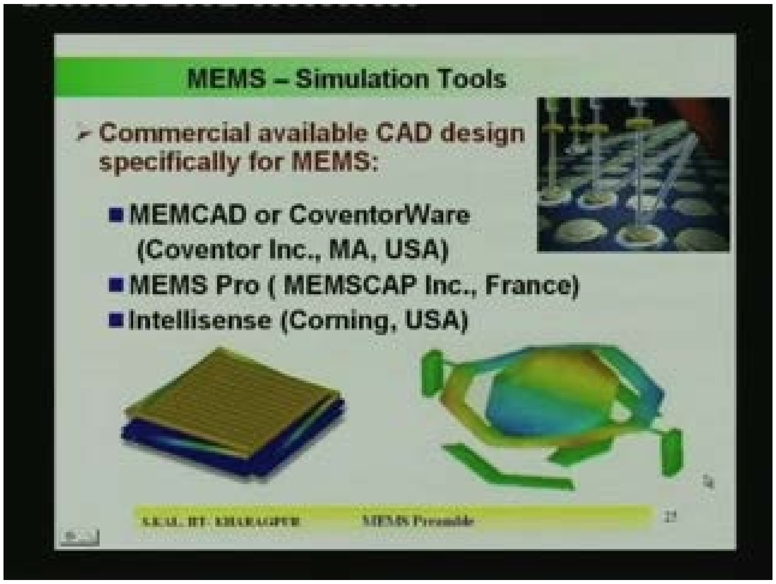

And now for making the MEMS devices, first you have to design the MEMS devices. For design, earlier we used to get some software tools for the VLSI devices. MEMS device tools that mean stimulation tools were not available. But it gradually the MEMS device simulation tools or MEMS design tools are available and those are namely MEMCAD or CoventorWare from Coventor Incorporated USA, another is a MEMS Pro MEMSCAP from France and Intellisense from Corning USA. These are the three major simulation tools for MEMS design. And other than this, there are other device simulate not device the design tools are used.

Those are the ANSYS are also being use now days because ANSYS is a basically finite element analysis simulation tool and is a MEMS and microstructures, has not regular structures there is a lot the irregularity is there for analysis of simulation of those structures, you have to go for numerical techniques. And for numerical techniques either finite difference or finite element tools are very much useful and they are based on those finite element or finite division difference method these software are developed. And these are some of the structures obtained from the simulation tools and the mechanical analysis, thermomechanical analysis, electrothermal analysis; all analysis can be made using that software.

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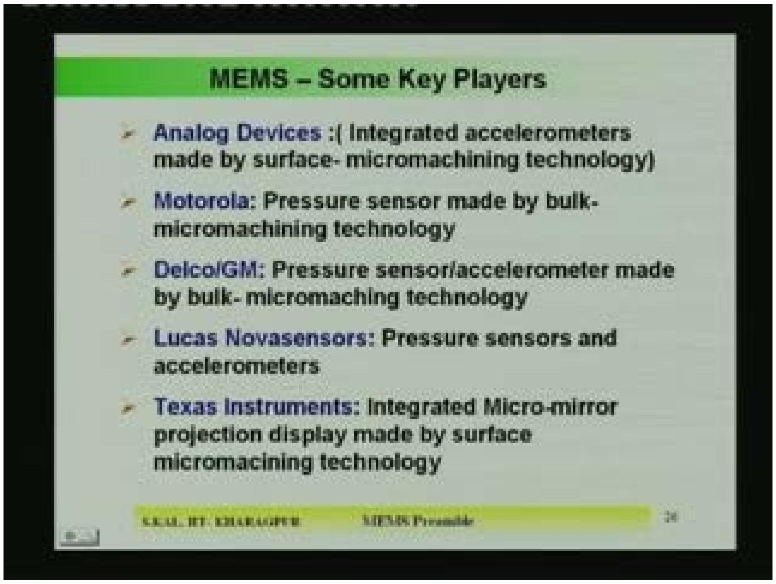

Now I will spend sometimes on the players on the MEMS and microsystem. Some key players around the globe who are working on this particular area, at the same time who are producing commercial MEMS devices. So namely, the first is coming into this area is analog device company. They are concentrated on integrated accelerometers made by surface and micromachining technology. Their major product is micro accelerometers. Another player is a Motorola. They are concentrated on pressure sensor made by bulk-micromachining technology. Others are Delco/GM, again the pressure sensors and accelerometers made by bulk-micromachining technology. The other one is Lucas Novasensors, they concentrate on pressure sensors and accelerometers and Texas Instruments integrated micro-mirror projection display made by surface micromachining technology. The DLP projectors basic technology is coming from the TI. So these are the major players.

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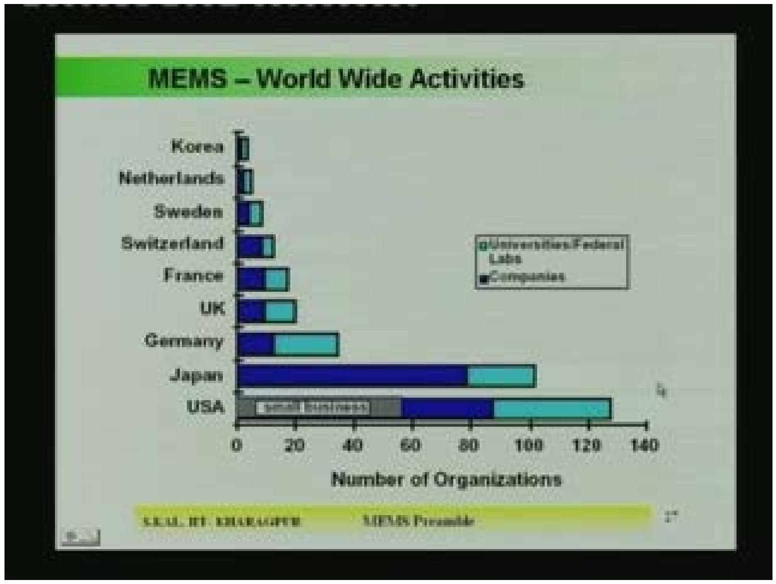

Now worldwide activities if you look, you can see this picture here. So you see the major activities going on around the globe and just from different countries particularly. You can see USA and Japan they are far ahead from other countries and here the blue color represents the companies, number of companies who are involved in MEMS activities and this color is basically universities or research laboratories involved in R and D on MEMS. So you can see here the Germany, UK, France, Switzerland, Sweden, Netherland and Korea. Those countries are involved but industrial or major players in industry are basically coming from 2 countries which are USA and Germany. And in the Asia, you can see, other than Japan, Korea is also little bit involved on the MEMS and microsystem R and D as well as the production level.

So in the major players are from Europe. Particularly Germany, UK, France, Switzerland and Sweden, Netherland there the major R and D locations are there.

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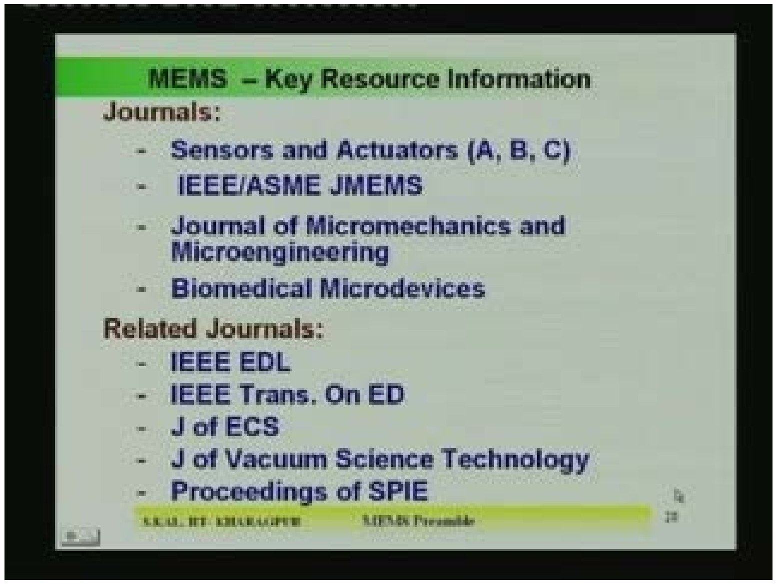

And now, at the end I will give you some of the information or resource information. So those are very important as we continue this course, so you need some information for further study and some of the journals which deals with MEMS papers and MEMS research activities are published. Those are:

Sensors and Actuators (A, B, C)
IEEE/ASME Journal of Microelctormechanical system IEEE journal
Journal of Micromechanics and Microengineering
This journals are focused only on MEMS.
Biomedical Microdevices

BioMEMS lot of papers are coming there and the related journals were not only MEMS other devices and VLSI papers are also available. Those are:
IEEE Electron Device Latest
IEEE Transactions On ED
Journal of ECS
Journal of Vacuum Science Technology
Proceedings of SPIE

So these are the journals.

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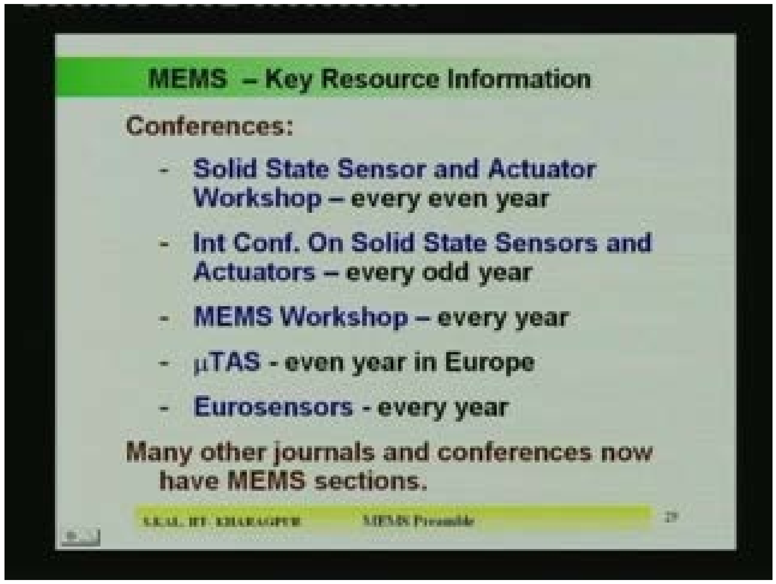

Now I will give some of the conference regularly, organizing on MEMS and microsensors and microsystems. They are:
Solid State Sensors and Actuator Workshop every even year is taking place.
International Conferences Solid State Sensors and Actuators every odd year is taking place.
MEMS workshop every year is annual event.
MicroTAS even year it is in Europe this conference.
Eurosensors it is also every year.
Many other journals and conferences now have MEMS sections.

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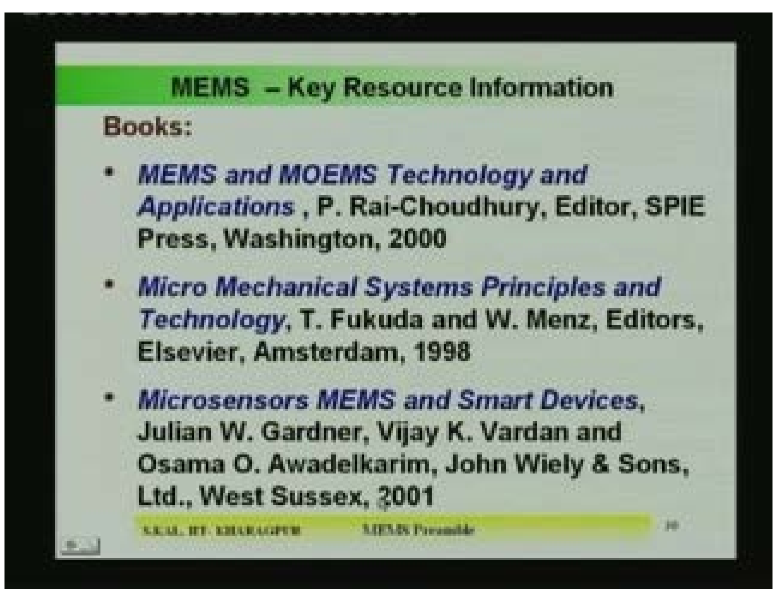

Now I will give some of the books which are important for further study. Those are
MEMS and MOEMS Technology and Application by Rai-Choudhury and is SPIE publication.
Micro Mehcanical Systems Principles and Technology T. Fukuda and Menz from Elsevier.
Microsensors MEMS and Smart Devices it is a Gardener and Vardan that is again John Wiely publication in 2001 it came. It is a very good book and deals with all aspects of microsensors and MEMS are Gardener and Vardan.

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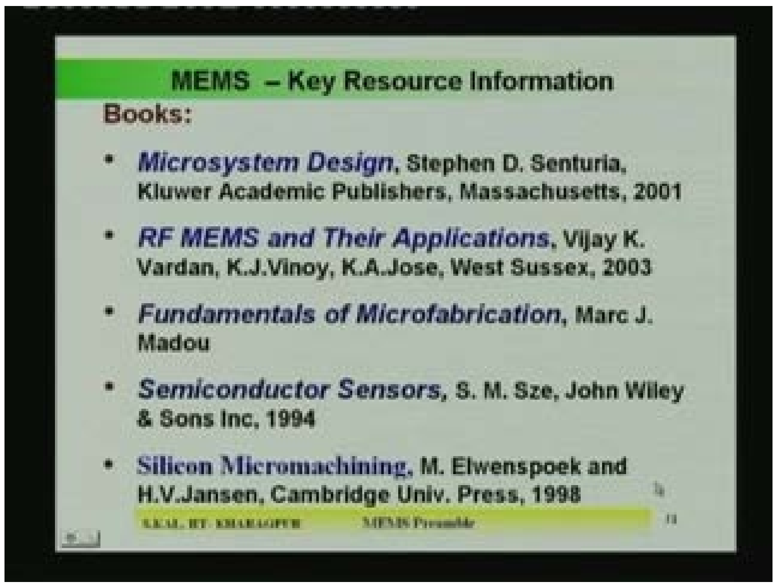

Other than these three books, there are other books available and those are the
Microsystems Design by Senturia,
RF MEMS and Their Applications by again Vardan and
Fundamentals of Microfabarication Marc J Madou, it is also CRC press book
Semiconductor Sensors by S.M. Sze,it is also John Wiley publication and
Silicone Micromechining by the Elwenspoek and the Jansen, is a Cambridge University Press.
So these are few books which are available now a days in print and you can have some of the books in our library also you can borrow those books for further study and other than this journals and books, lot websites are available now a days and I will give you some of the websites addresses also, where you can have lot of information on MEMS research as well as for the present developments of the MEMS and that those websites are very important.

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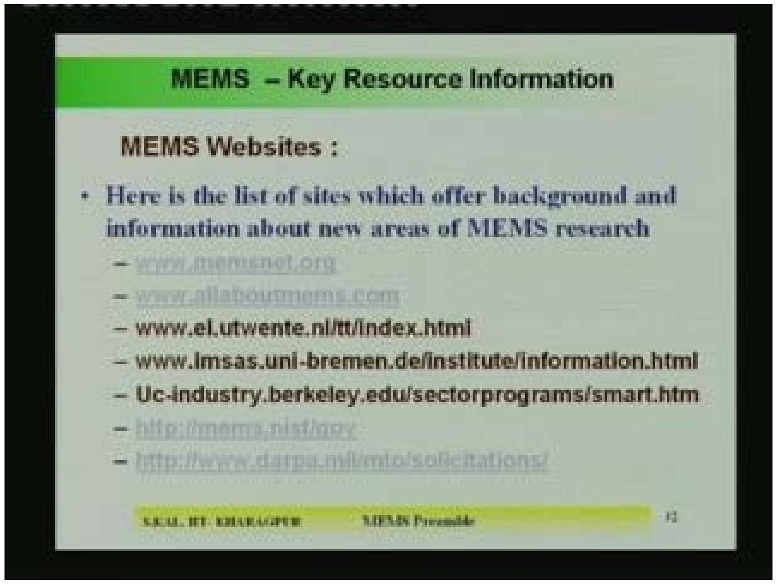

You can just open this website and you can see what progress is going on. There are certain websites the MEMS stock website where you have some queries you and push that query and in the future you can get answer of those queries also. And like all other subject MEMS books are not plenty I just mentioned few books may be 10, 20 books are only available and out of those books few are available in the library, others are not available. So I would request you to find some of the text books and go through that so for further study and advance research you can get from website and from the journals. Thank you very much.

Preview of Next Lecture
Introduction to Microsensors

So in my last lecture, I have introduced the course MEMS and microsystems. So by now you know that in MEMS and microsystems one of the important blocks is the sensor block and today's lecture I will highlight the sensor and I will introduce sensor then will go to the microsensor and different aspects of sensor its specification required and its technological aspects, all these things I will discuss in today's lecture. And sensor is a very important device and now in microsystem we use microsensors and I will discuss what is microsensor and in particular in MEMS and microsystem we normally use semiconductor sensors. And again why semiconductor sensors? Because semiconductor materials are used in many ICs and so if I can make the sensor out of the semiconductor material then it will be easy for us to integrate both the sensor part and circuit part together and that's why lots or sensors are coming out making use of semiconductor materials. And in the first, let us see what sensor means. And sensor basically is a word it is coming from a Latin word sentire.

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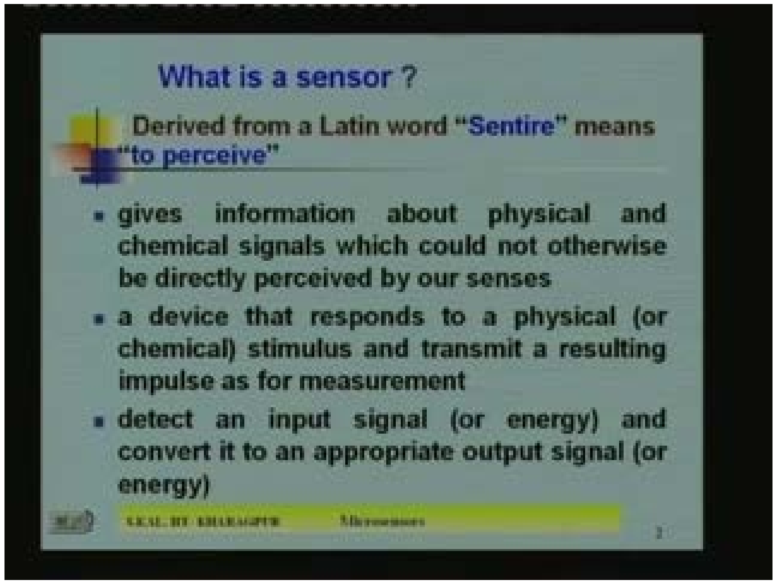

And that means to perceive that is derived from Latin word sentire. A lot of definitions are given for sensors. Basically it gives information about the physical and chemical signals which could not otherwise be directly perceived by our senses.

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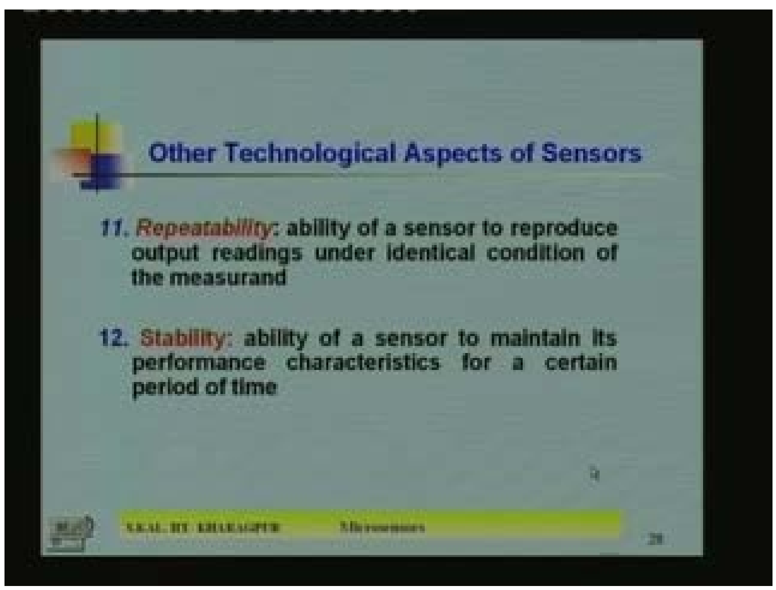

Or other parameters which you have to take into account when you are selecting or designing a particular sensor. Repeatability means, ability of a sensor to reproduce output readings under identical condition of the measurand that is repeatability. Same conditions you are applying, the output of the sensors should be same. If it is not same it is not repeatable and repeatability may lose because of different problems in your designs, different problems you have made choosing on materials of the sensor and different problems of your environment condition also. And the stability is another important aspect and that is ability of a sensor to maintain its performance characteristics for a certain period of time. So that means, how long your sensor is performing well, that is the stability. So with this, I just gave an introduction to the microsensors and something I will continue on this topic in the next lecture also. And then I will discuss on the evolution of this MEMS sensors as well as market survey

Thank you. Let me stop here.