MEMS & Microsystems
Prof. Santiram Kal
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur
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Evolution of MEMS & Microsensors & Market Survey

I will continue for some time. Lecture 2 contain that is the microsensor introduction. I was discussing on the characteristics of sensor. There are certain parameters which are known as dynamic characteristics of sensor.

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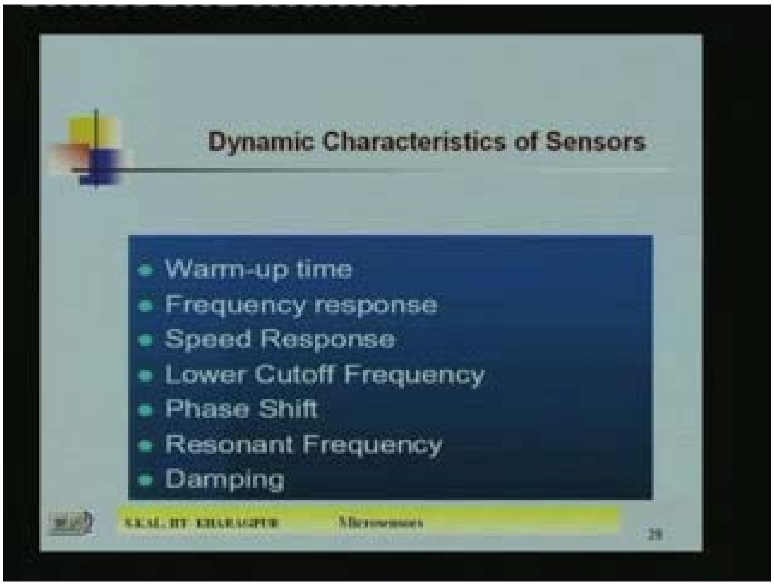

They are namely: the warm-up time, frequency response, speed response, lower cutoff frequency, phase shift, resonant frequency and damping. So these parameters also you have to take care of which are not mentioned in lecture 2. That means a resonant frequency and damping is a critical parameter when you go for designing an inertial sensor. For example: accelerometers or gyros. Speed response is important for any kind of transient phenomena if you want to detect, then is very important and frequency response is important for any of the sensors which deals with electrical signal. So these are basically the dynamic characteristics and all these characteristics how the sensor is behaving with all these dynamic parameters that one should know before he or she uses those sensors in actual application.

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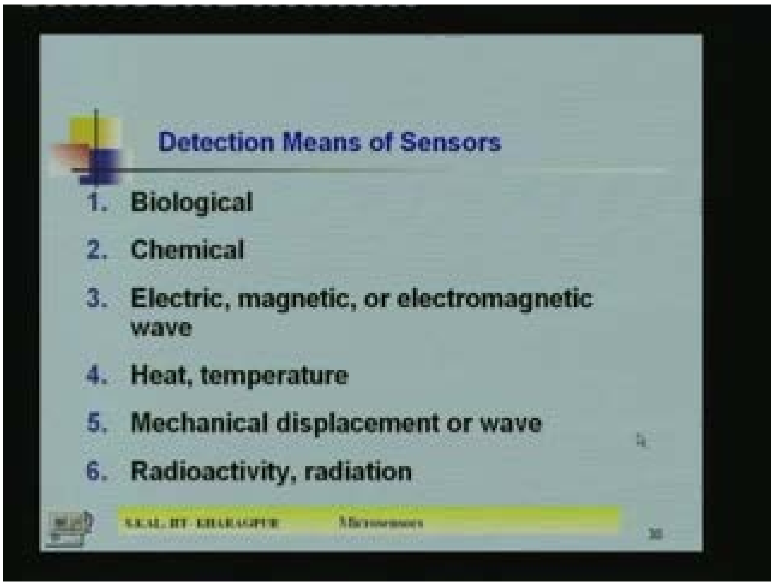

Now what are the detection means of sensors? Detection means may be biological, may be chemical, electric, magnetic or electromagnetic. Detection means may be heat or temperature, mechanical displacement or wave, radioactivity, radiation. These are various kinds of detection means.

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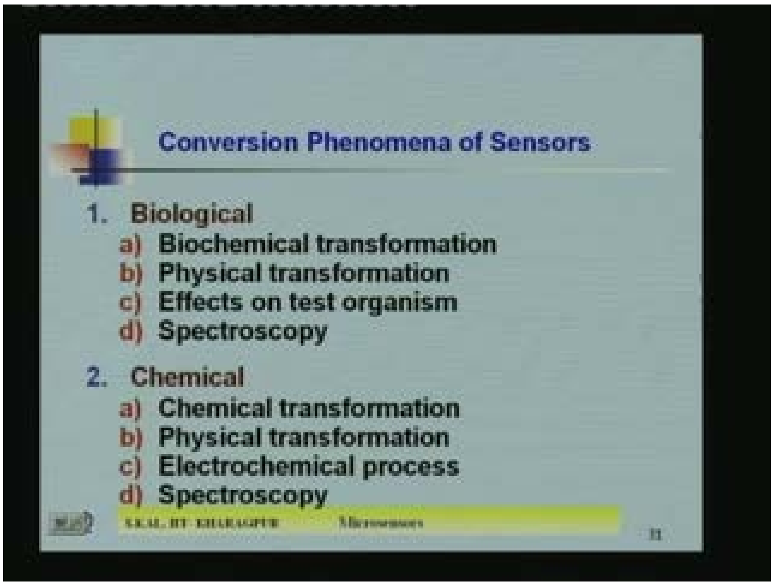

And now, the conversion phenomena. So what physical reaction or what physical change is going to take place inside the sensor because of which you are getting output with the variation of the input stimulus. What are those conversion phenomena? In case of biological, the conversion phenomena may be biochemical transformation, may be physical transformation, and may be effects on test organism. That means some biological phenomena may take place if we apply certain chemical into that biological spaces or body. That is effects on different test organism. Then spectroscopy. So these are the conversion phenomena.

In case of the chemical sensors so what are the conversion phenomena? They are namely, chemical transformation, physical transformation, electrochemical process and spectroscopy. Spectroscopy means frequency change or if the electrical signal if you take at the output, it is a fixed frequency spectrum or the band changes that is the basically spectroscopic change.

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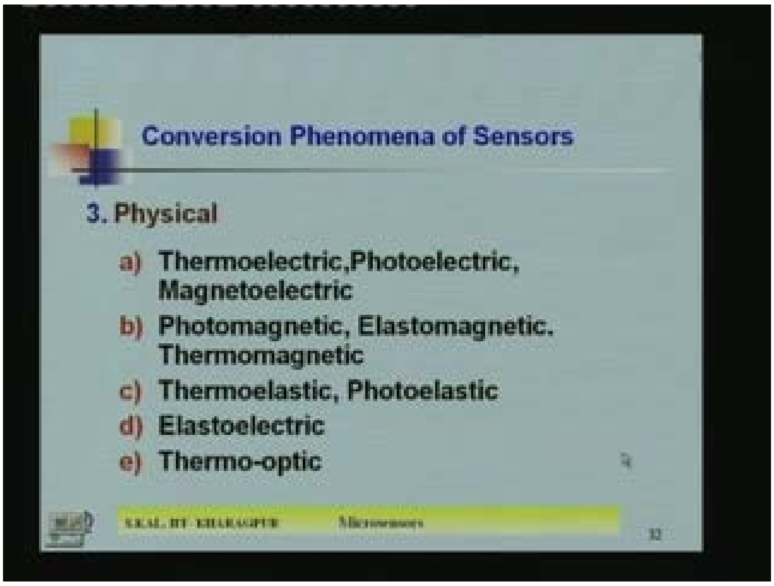

Now, in case of physical sensors, what are the conversion phenomena? They are thermoelectric, photoelectric and magnetoelectric. That means you see from physical means here the thermal energy, optical energy and magnetic energy. So thermal energy you are getting at output electric, optical energy photon you are getting at the output electric or magnetic energy or magnetic flux is changed into electric energy. All these are the conversion and they all belong to the physical and that is a thermoelectric, photoelectric and magnetoelectric. Now other conversion phenomena is output is magnetic. So change of magnetic flux. So that can be changed, if you incident some light on that body that is known as photomagnetic. If elastic properties change of the body then magnetic energy may change.

There are certain materials if you change its elastic properties magnetic flux, magnetic behavior, magnetic property of that particular will be changed. Say permeability may change by changing the elastic energy for application or elastic energy into that material. Thermomagnetic, if you change the temperature of that particular material its magnetic property or permeability of that particular body may change. So those are one kind of conversion phenomena. Thermoelastic and photoelastic is another that means elastic property will change. That means what is elastic property stain components will change different stain components may change and then with the effect of the thermal energy or photoenergy. Photoenergy means radiation by optical energy or light.

So if it is radiated on thermal energy or the optical energy incident its elastic coefficients or elastic property of that particular material may change that is one kind of conversion. Then elastoelectric means if the elastic properties are changed, its electrical behavior will change. What are the electric behaviors? Permittivity and permeability of material may change? If you apply elastic energy or that mean elastic energy strain or stress should be applied that deformation. Or if we apply some stress on that body and we elongate that particular material, then what happens so the electric property means its dipole moment may be change. For example, its permittivity may change.

So this is basically the change of the electric property for the change of the elastic energy onto the body. Then thermo optic is another conversion phenomenon that is the thermal energy is incident on a body, it's optical property may change or the optical energies is a body is exposed to optical radiation, it's thermal property will change. Its temperature may change or its kinetic energy of the molecules may change and then automatically it will lead to the change of temperature. These are the conversion phenomena in case of physical sensors.

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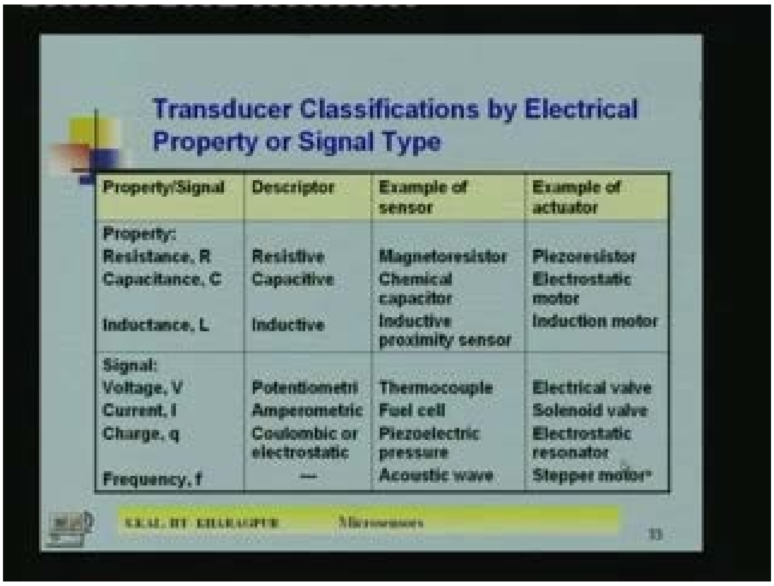

Now the transducer classifications by electrical property or signal type. This table basically the given this table gives you the property of the signal descriptor and example along with the actuator examples also. That means classifications of transducer. So property, for example the resistance descriptor is resistive, example of the sensor is the magnetoresistors and example of the actuator resist piezoresitor. So the sensor is magneoresistants and actuator is piezoresitor may that means piezo means it is a displacement or mechanical property is going to change of the particular crystal. That is with a change of resistance so that is a piezoresistance or if we apply mechanical stains or stain a resistance may change. Capacitance if you look into is descriptor is the capacity and sensor is a chemical capacitor and its actuator is electrostatic motor. In case of inductance, then descriptor is inductive and sensor is inductive proximity sensor and example of the actuator is induction motor.

On the other hand if you see the signal, then voltage signal deals with the sensor which is thermocouple and it is suppose descriptor is potentiometric, current change the descriptor is amperometric and its example of the sensor is fuel cell and actuator is solenoid valve. Charge if you concentrate, the signal as a charge electronic charge then its descriptor is coulombic and sensor example is piezoelectric and the actuator is electrostatic resonator. Similarly frequency you can get acoustic wave as the sensor and the stepper motor is basically the example of the actuator. So these with this, actually I give you some introduction of the microsensors what are its basic blocks in a sensor, its characteristics, its properties and when you select a particular sensor, what are the parameters one should look into for judge a sensor good or bad. So these are the things which I discussed in this lecture.

Now in the next lecture I will switch over to the sensor evolutions. Microsensor evolutions and at the same time I will discuss on the market survey. So as an engineer, you should always see how the market behaves or how much is the market or a particular product or quantity. So that is very important aspect and before production of a particular device.

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So for that I will switch over to the new topic and that is the evolution of microsensors and MEMS and its market survey.

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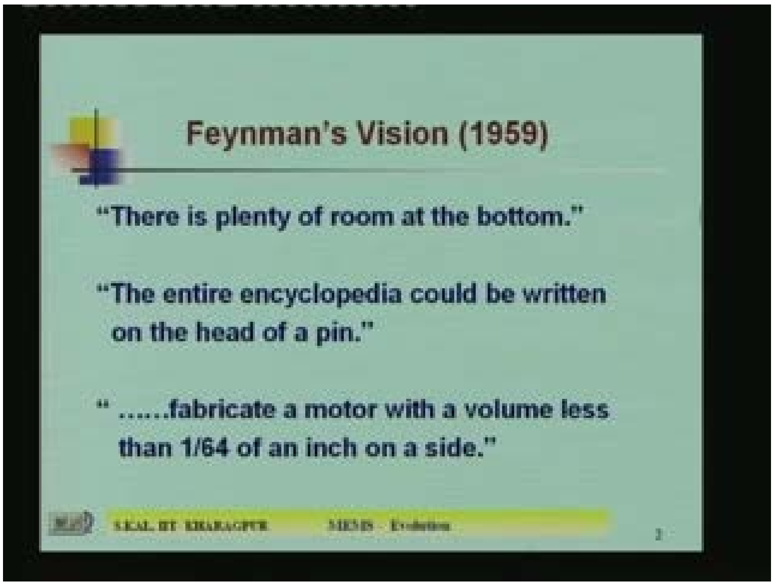

Now here, again I start with Feynman's vision in 1959, when Feynman visionary is a great visionary and he told us that there is a plenty of room at the bottom. At the same time he predicted that the entire encyclopedia could be written on the head of a pin. And his vision in 1959 is close to the reality in 2004. Because of the miniaturization of the devices, miniaturization of the systems, at the same time the miniaturization of the sensors has made successful of the dream of Feynman which was published in 1959 in a famous paper by Feynman. And at that time he also predicted that it is possible to fabricate a motor with a volume less than 164th of an inch. That mean at that time one could not foresee the mechanical things can be miniaturized. But now it is also possible because of the evolution of the MEMS. Now micromotors are available whose dimension are few millimeter by few millimeter and obviously it can be reduce still further with innovations of new technologies new processes new materials. And then Sir Feynman's vision will be successful obviously in the near future and is close to the reality.

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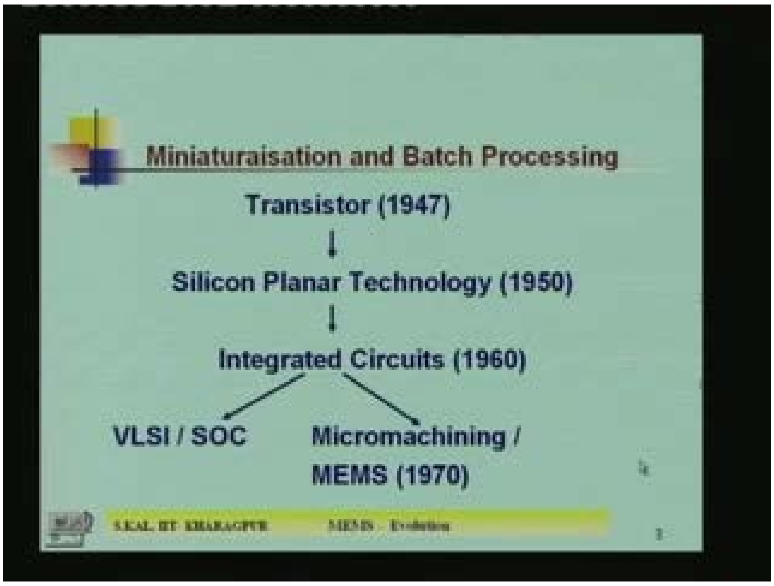

Now, if you look back from the transistor discovery which is 1947, then comes planar silicon technologies 1950 then comes integrated circuits 1960 and after that there are two areas; one area is meant for the silicon VLSI and another area is micromechanics or micromachining and on the other hand MEMS. So it has basically got importance in 1970 and from there in 1982 when Peterson paper came and people thought extensively and how to improve, how to progress with that particular area, that is MEMS or micromachining area.

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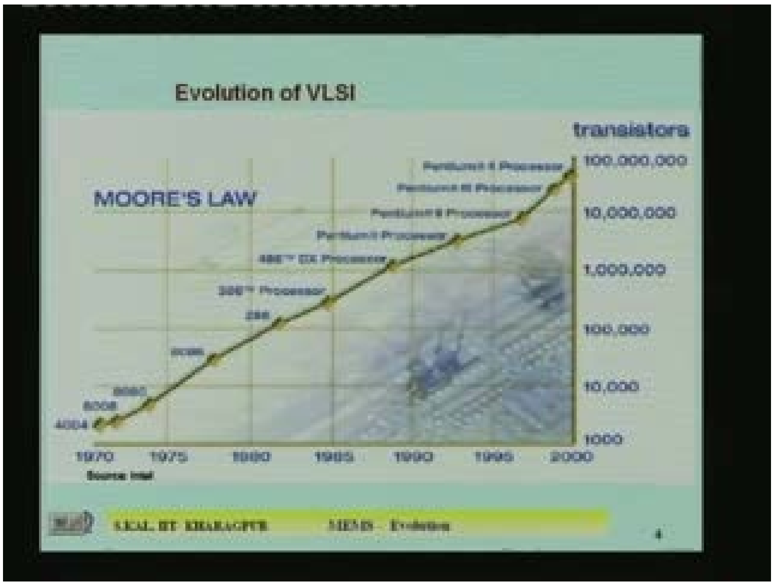

So now, again I am giving you the Moore's law and the Moore's law here it shows the evolution of the computers with miniaturization of the components. Now here is the microprocessor is the 4 0 0 4 which is basically transistor count is 1000 in 1970 and then a 2 8 6 processor or 3 8 6 processor is nearly 1985 and whose transistor count is 100 thousand in a chip, in the processor. Then next generation is 4 8 6 DX processor that is nearly 1990 and it's 10 to the power 6 number of transistors means, 1 million. 1 million transistor in 4 8 6 that is nearly 1990 then comes pentium processor, then pentium 2, now pentium 3, now pentium 4 at present.

And pentium 4 you see a 100 million transistors are there in pentium 4 and at present the people at thinking of 1 billion transistor in a chip, in a processor. So these are the evolutions of the VLSI as per the Moore's law. But the MEMS evolution does not exactly follow the Moore's law. It is a different phase. It is advancing and lead to find certain law which is which satisfy the evolution of the MEMS or microsystems. Now if you look into the evolution of MEMS, the actual thing started in 1954 by paper by C J. Smith. And that is the property of the silicon a unique property of silicon which is piezoresistive property and that has been observed by C S Smith.

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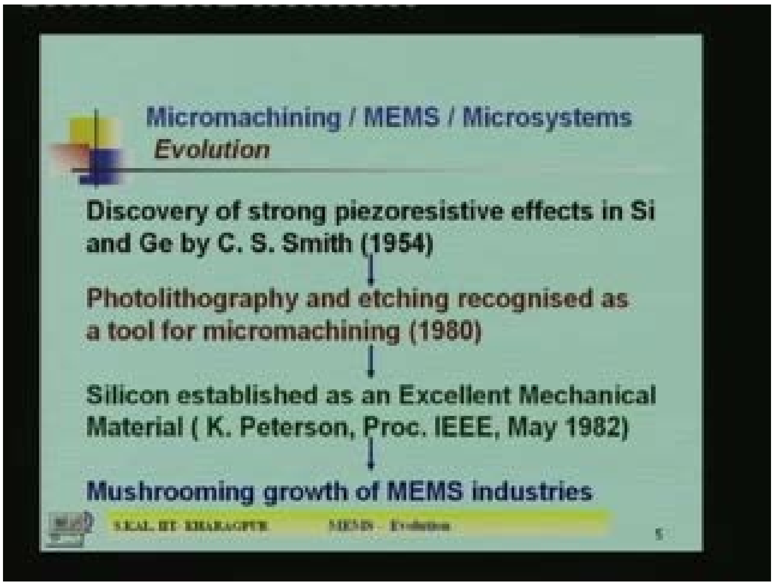

And the paper came out in 1954. Then people started thinking the why not silicon can be used for the sensors or MEMS, why this silicon is giving importance is clear to you because it is compatible with the integrated circuits and VLSI. Then in 1980, the micromachining technology evolved and photolithography etching recognized as a tool of micromachining. Because all the other photolithography etching was used in case of patterning of VLSI, VLSI components or VLSI fabrication photolithography technique and etching technique was used. And in a micromachining means, here the same technology but little bit difference is there. Here the aspect ratio may be different, which is used in case of VLSI is not used in case of micromachining. If you change the aspect ratio, then many cases you have to machine a particular material whose protective layer was not known that time. That mean passivation layer was not known. That you have to do some research. But people started thinking that it is possible that is now from 1980.

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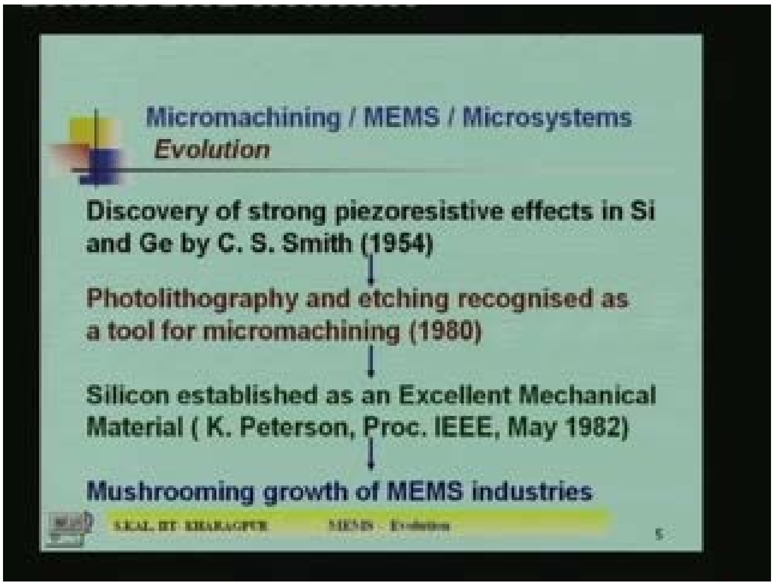

The micromachining came into limelight and then the lot of research has been taking place in micromachining. And at present, this field is very promising. And one can foresee various kinds of sensors using the micromachining which is basically a photolithography and etching technique employed in case of VLSI fabrication. In 1982 the famous paper which is published in Processing IEEE, which is the silicon as an excellent material. Silicon was known to be excellent material for integrated circuits in VLSI. But later on they found, it is also excellent mechanical material. Because, silicon's mechanical properties are also excellent. So, it can be used for sensor which will sense the mechanical behavior of any anybody or any system. So that is why the silicone is entered into the MEMS area in a big way. And after that there is a mushrooming growth of the MEMS industries has taken place because it has very good market potential. So, lots of companies, small size big size companies are coming up to initiate the MEMS research and to market or to produce MEMS device commercially.

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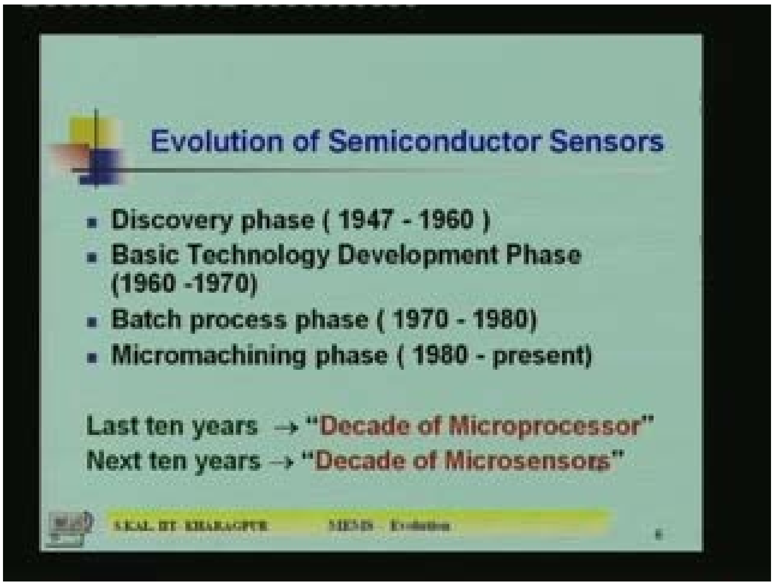

Now, semiconductor sensors discovery phase if I see it's 1947 to 1960, is a discovery phase then technology development phase I have mentioned is 1960 to 1970 is a basic technology development phase. Then batch process phase is 70 to 80, in case of semiconductor sensor. Then micro machining phase 1980 to till date. So these are the different phases of evolution of semiconductor micro sensors. Now, last 10 years people call the decade of microprocessor because we have seen the evolution of microprocessor from the Moore's law card that lot of evolution and lot of improvement has been taking place in last 10 years. That is why that was known as the decade of microprocessors. And next 10 years people are predicting, so that will be decade of microsensors and MEMS.

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And now the if you look at the chronology of the MEMS development then we can see, from 1975 to 1989 basically micro machining silicon MEMS and microsystems 79 the first MEMS accelerometer was reported and 1993 it has been commercialized. By Stanford University research effort has enabled analog devices to commercialize some MEMS accelerometer nearly 1993. In 1990, surface micromachining advance MEMS technology compatible with CMOS process came and which has lot of application in automotive medical IT and industry military and aerospace.

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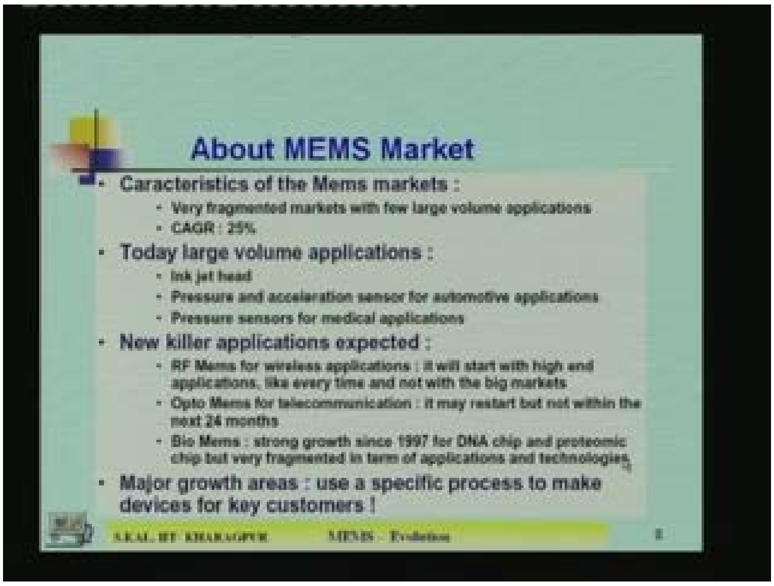

So then market. So let us now discuss little bit on MEMS market in different area. The characteristics of the MEMS markets are fragmented. Because of different amount of application in different areas. Even then the cumulative annual growth rate of the MEMS market is nearly 25 percent. Today large volume applications of MEMS device or in the area of ink jet head in case of pressure and acceleration sensors for automobile application and pressure sensors for medical application. These three area, big market at present one is the ink jet head other is basically pressure sensors and acceleration sensors. Application areas are automotive application and medical application. Now new killer applications expected. Those at present, this market is not very big but within 1or 2years, it will be the killer application.

What are those areas? One is RMMs for wireless communication you know at present lot of wireless devices are coming up. Because one example is your mobile handset. So for that lot of RAF MEMS components are required and mobile handset, they use lot of miniaturized components. Then opto MEMS for telecommunication application. It may restart but not within the next 24 months people are predicting. Other is a killer applications is bioMEMS. A strong growth since 1997 for DNA chip and proteomic chip but very fragmented in terms of applications and technologies. Major growth areas of MEMS, they use a specific process to make devices for key customers that is the applications specific.

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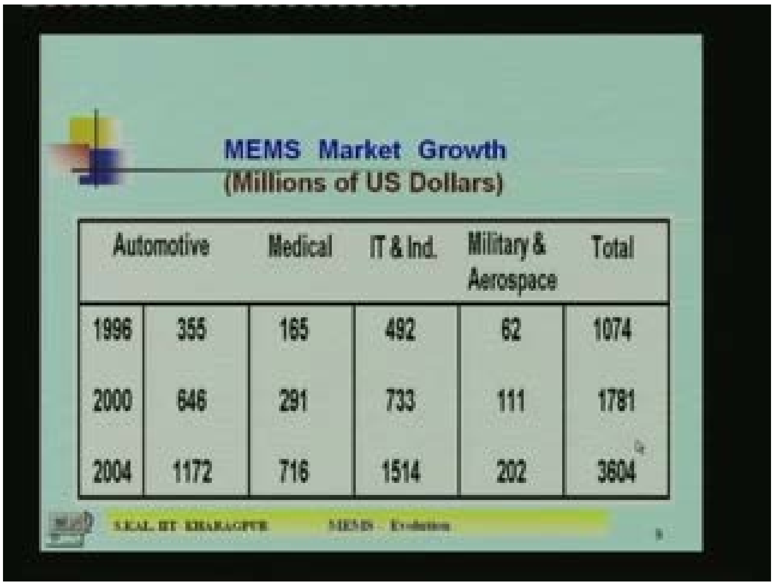

	Automotive	Medical	IT & Ind.	Military & Aerospace	Total
1996	355	165	492	62	1074
2000	646	291	733	111	1781
2004	1172	716	1514	202	3604

Now if we look the market growth in terms of US dollar. Then this table gives that automotive, medical, IT and industrial application, military and aerospace and the total market of MEMS in terms of millions of US dollar. You see 1996, automotive is 355 million US dollar, medical 165, information technology and industrial control is 492 million US dollar market and military application is defense is 62 million US dollar, total is 1074. Now in 2000 and 2004 if you look these two years, the market in comparison with 1996 then you can see here that in every 4 years the market has almost doubled. So here 355 to 646 from 646 it is nearly 1172. So almost double the total growth you can see here 1074 in 1996 is 3604 million US dollar in 2004 so that means market is picking up.

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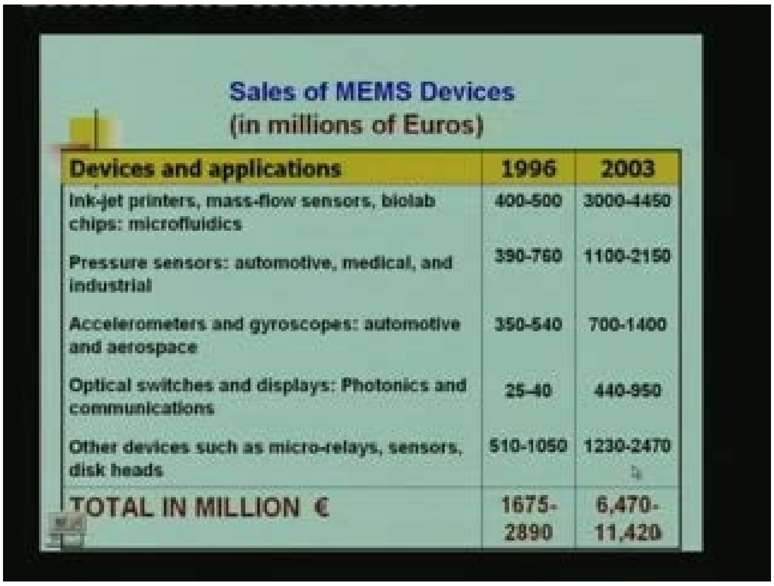

Sales of MEMS Devices
(in millions of Euros)

Devices and applications	1996	2003
Ink-jet printers, mass-flow sensors, biolab chips: microfluidics	400-500	3000-4450
Pressure sensors: automotive, medical, and industrial	390-760	1100-2150
Accelerometers and gyroscopes: automotive and aerospace	350-540	700-1400
Optical switches and displays: Photonics and communications	25-40	440-950
Other devices such as micro-relays, sensors, disk heads	510-1050	1230-2470
TOTAL IN MILLION €	1675-2890	6,470-11,420

Now the sales of MEMS device in term MEMS device particular application wise are compared in this table in 1996 and 2003. So inkjet printer heads mass flow sensors biolab chips which is microfluidics chips in 1996 is a 400 to 500 euros million euros and 2003 it is 3000 to 4450 million Euros. You can see the change. Pressure sensors automotive and medical which is unique device is pressure sensor it application wise automotive medical or industrial from nearly 400 to 800 in 1996 and it is 1100 to 2150 million euros in 2003. Accelerometer and gyros it basically inertial sensor, application areas are automotive and aerospace. You see 350 to 540 in 1996 and 2003, 700 to 1400 million Euros. Now optical switch and displays, it is optical MEMS optical applicatio was very small in 1996 now slowly it is picking up and in 2003, 440 to 950 million of Euros. And other application areas are micro-relays, sensors, disk heads, and etcetera. So total in the device level, total the market from 1675 to 2890 million Euros to now it is becoming 12000 million Euros if you include all the devices.

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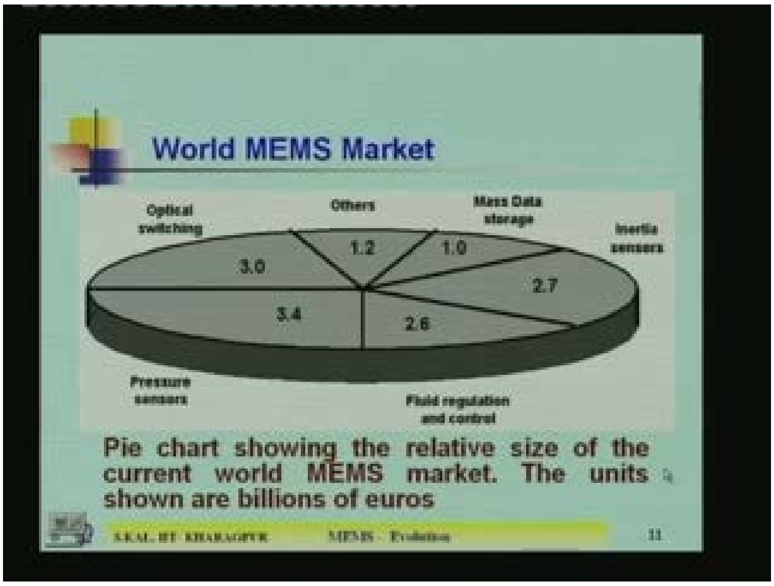

Now the pie chart shows here the relative size of the current world MEMS market in terms of application areas. So here, you can see here that pressure sensor, the total pie area if you see the major application areas one is the pressure which is 3.4 major applications. Then comes, the optical switching area, and then is a inertial sensors 2.7, mass data storage is 1 and others are 1.2. These are the proportionate the application areas for different applications.

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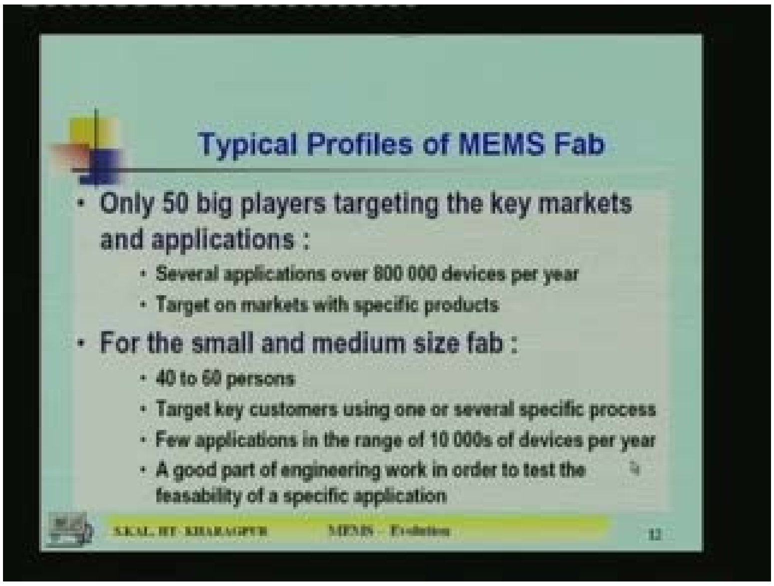

Now profiles of MEMS fab around the globe. So who are working on MEMS nearly 50 big players are there around the globe. They are controlling the whole market and they are producing nearly 800 000 devices per year and target on the market with specific product products is picking up. For small and medium size fabs nearly 40 to 60 persons we call it is a medium size fab. Lot of medium size fabs are there in Europe or Taiwan in Japan also. Their target key customers are specific because they produce a particular sensor for typical application, not very large quantity some medium size and this market is picking up tremendously. And if you look into the medium size fab, total investment is not enormous but profit is more if you concentrate on some specific products. Not in all fields. So here, the application in the range of 10000s of devices per year not like 800 000 devices per year. And a good part of engineering work in order to start, in order to test the feasibility of a specific application is required for small and medium size fabs.

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Now typical profiles of the MEMS fab and total fab at present is 350 MEMS fab worldwide and the business is still growing and as I mentioned the cumulative annual growth rate is nearly 25 percent. Specific products within medium volume or big part of the business are there. The number of manufacturing facilities is growing fast with a strong investment in Europe, Taiwan and China. Now we will see the country wise what are the distribution of the fabs.

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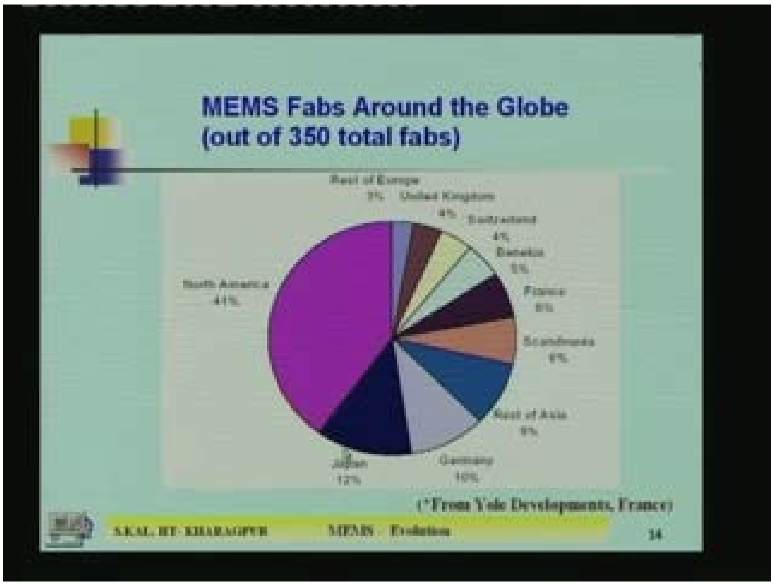

Now here, if you look this diagram, major portion is taken by North America. It is about 41 percent of the total fabs are in North America. Next share is in Japan. It is about 12 percent of the total fab is in Japan. Next is the Europe. And in Europe, if you divide different countries, then comes first is Germany it's a 10 percent, then comes say the 6 percent both France and Scandinavian countries, then Benelux is 5 percent, Switzerland 4 percent, and UK 4 percent, rest of the Europe means east European countries they contribute 3 percent of the total fab. But here if you see the picture of Asia so there Japan is separated out from rest of Asia because they are the major fabs or major R and D activities is going in Japan, that is why Japan itself is 12 percent and rest of Asia is only 9 percent. So this is the county wise distribution.

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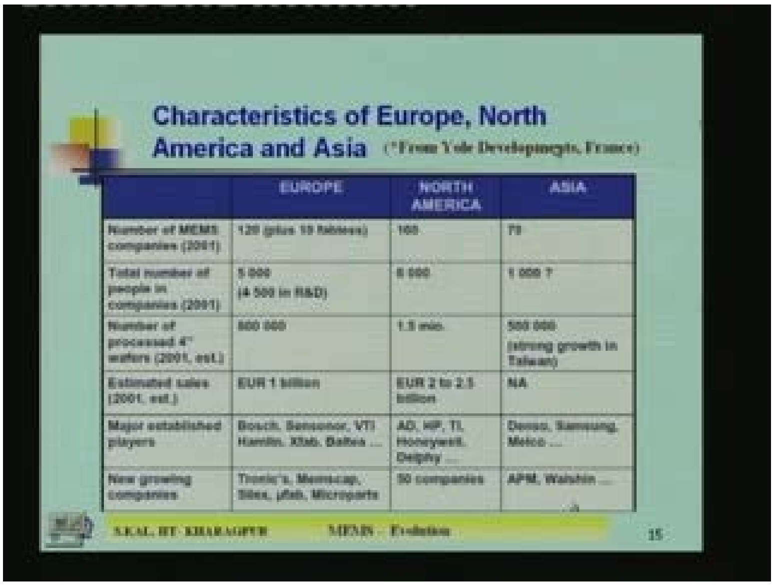

And now the characteristics of Europe, North America and Asia in terms of the fabs, in terms of the number of people, in terms of the device production and in terms of the companies are shown in this table. So in 2001 in Europe 120 companies are there. North America were 160, in Asia 70 people working in the company, in Europe it is nearly 5000 out of that 4500 is R and D. so North America nearly 6000 people and Asia very small amount of people is a 1000 that is basically, I am taking about in fab. So now, number of processed 4 inch wafers is 800 000 in Europe, 1.5 million in North America and 500 000 in Asia, there is a strong growth in Taiwan.

Estimated sales 1 billion Euro Europe is selling North America 2 to 2.5 billion Euros and Asian data are not available. Major established player in Europe are Bosch, Sensonor, VTI, Hamlin, Xfab and Baltea and North America is analog devices AD Hewlett Packard, TI Texas Instruments, Honeywell and Delphy. In Asia, Denso, Samsung is a Korean company you know and Melco these are the Asian players. Now some of the companies are growing. In case of Europe, you can see Tronics, Memscap and the Silex, Microfab, Microparts, they are coming in a big way in Europe. North America similarly, similar 50 companies are there and Asia the growing companies are APM and Walshin and some others in Korea.

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Now the country wise picture Europe, if you look here, then very fragmented markets with few large volume application in MEMS products mainly automotive and inkjet heads they are concentrating. If you look into microfluidics and microarrays activities that is, in Europe is doing service oriented work in microfluidics some company is telling they need microfluidic sensor in this area at this much amount they are 1 lakh not in mass scale production. Polymer micro replication is an emerging strongly in Europe. Strong presence in DNA microarrays and protein arrays that is also coming up in Europe. In optical site, yet to start they are beginning the optical MEMS R and D is there, but in fabrication finished product, they are yet to restart the production. Strong R and D in some new companies is getting a momentum now a days in Europe.

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Now look into the North America. So here strong presence in high volume markets such as automotive and IT in case of North America. In microfluidics and microarrays arrays strong position of the USA, 40 percent market share in DNA chip business 40 percent mark 40 percent market share in DNA chip. So that is basically in bioMEMS the USA is going ahead among many other countries. Very low level of activities in the polymer MEMS field. As I mentioned earlier also the polymer MEMS is getting importance very recently with the discovery of the active devices using the polymer material like field effect transistor is now being produced in using the polymer and it has been demonstrated, if it is so, then the MEMS devices particularly the bioMEMS device polymer is also biocompatible so bioMEMS can easily be fabricated using the polymer material so you can easily integrate the active devices as well as the sensors and actuators totally using the polymer.

That is why not in production level but R and D level, people are interested much at present to do the polymer MEMS research. And that is why very low level of the activities in polymer MEMS field but it is getting importance day by day. Very big stop in the opto business. Because although people are predicting that optical area lot of MEMS applications will be there in case of the optical switches and power splitter couplers optical. So, but there are lot of technological barriers and problems. So that is why the companies at present are not coming up and most of the work is in R and D level fields so that is why is written very big stop in the opto business until and unless R and D is mature in the laboratory skill so company may not invest the fund into the opto MEMS research or MEMS production or R and D, business R and D whatever you call.

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Now coming to the Asia. Asia actually divided into 2 parts one is Japan another is outside Japan. See in Japan, lot of regional research efforts is there and lot of cohesiveness among the different companies are there and they are in Asia they are the they may the one of the important country who looks ahead in terms of business compared to other Asian countries. So that is why lot of commercial commercialization is taking place under the roof of big companies in Japan in MEMS and microsystem area. But in microarrays and microfluidics the initiative has launched in 2001 and they are picking up slowly in this particular field which has large tremendous potential in biomedical application.

Outside Japan if you look, there are lot of players there. Particularly in three countries: one is in Korea, other is Taiwan and other one is China. So many startup companies has come up in Korea and they are yet to produce the commercial products into the market. Large investments are there in Taiwan in MEMS foundries. And in China, they have initiated R and D investment and lot of R and D institutes has come up there and large investments are being made in R and D in China. May be within few years they will also start production of the MEMS sensors and devices and microsystem which may be compatible to Japan or any other countries. They are very emerging R and D is there in case in China. These are the three major player outside Japan in the in Asian region.

If you talk about the Indian scenario, here lot of R and D is going on under the umbrella of government funding. But industry has not come up so far aggressively because here the microelectronics market, microelectronics foundry was not that much progressing. In India you know not many fabs or microelectronic fabs are there. Actually the MEMS fab emerges from the microelectronics fab. So that is why the MEMS industry has not come up till now but R and D effort is there. May be in future some companies come up, may be in small level not in big level to produce the MEMS devices in some specific application.

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Now this the last slide in this lecture. It is a worldwide major players in MEMS along with the application areas. Now here, application areas are shown one is aeronautics and aerospace, process control and instrumentation, defense, medical and biomedical, telecommunication, automotive, home appliance and IT and entertainment these are the different application areas. And some companies are given important in some area, those company names are mentioned here. For example, aeronautics and aerospace the companies are BAE Systems, Systrans, Donnar, Aeronautics and Honeywell, and in case of process control and instrumentation Collibrys, Tronics and Microsystems theses are they are involved mainly on this products. In defense area, BAE Systems, Silicon Sensing Systems, Schopradir, Systron, Donnar and other many companies are coming up here. In medical and biomedical area Affymetrix, Agilent, Corning, Nanogen, Debioteck, Toshiba, Gyros, Caliper and so on they are concentrating on medical and biomedical.

And IT and entertainment sector if you look here, the companies like HP and Olivetti from Italy, Panasonic Japan, Texas Instrument USA, Sony from Japan, Olympus there are lot of companies in IT and entertainment there you will find lot of companies from Japan also. In telecommunication areas Analog Device it is one of the major contender here. The Applied MEMS Collibrys, Cronnos, Intellisense, MEMS Optical and so on. There, ST Microelectronics is also one of the important foundry company who is producing MEMS and micro MEMS devices which will be used for telecommunication application. And automotive application which is major market in major MEMS market, they are Analog Devices, Bosch and DALSA Semiconductor, Delphi, Denso are there in case of automotive application.

Mainly the sensors used in automobile applications are the acceleration sensors, pressure sensors and some cases the mechanical sensors are also there and temperature sensors in a limited facilities are there. Home appliance you can see the companies are Analog Device, MET, METU and HL Planar Technique. there are there the they are are in home appliance Home appliance means lot of the household electronic machines are using now a days MEMS sensor. One application area in case of the washing machine, dish washer, these are some home appliance. So there people have started using the MEMS based the acceleration sensors, pressure sensors and other things. Position sensors, displacement sensors, these are being used in home appliances and other equipment.

So I gave some of the important figures deals with the markets of the MEMS and in conclusion I can say although the MEMS market is not similar to the VLSI market, but it is picking up slowly, people have identified the application areas, people have seen the advantages of MEMS and micromachining devices compared to bulk devices used in early cases. And utmost people have seen the cost or the cost performance ratio of those MEMS devices. It has shown an important a very specific potential in future Microsystems. It has lot of promise, so R and D is picking up day by day in a major way and may be within a few years you will find that MEMS market will nearly touch the VLSI market also. So with this let me stop here, this lecture. In the next lecture I will discuss on the application areas with examples. Applications I discussed a little bit today’s lecture and first lecture also. But specific areas of application with little bit principle of application, I will discuss in the next lecture. So let me stop here today.