Micro and Smart Systems
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Lecture - 01
Glimpses of Microsystems: Scaling Effects

So welcome to the world of micro and smart systems. We have 4 experts giving this presentation. I just give a brief highlight of my colleagues.

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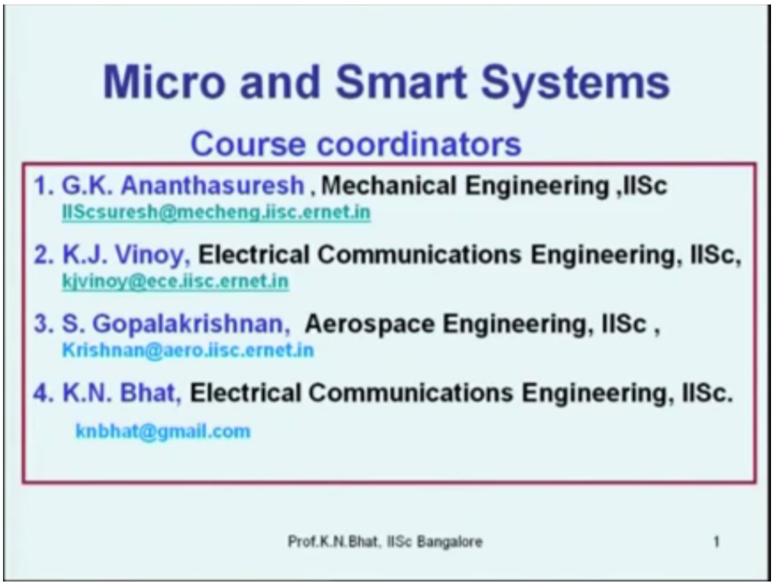

My name is professor K.N. Bhat. I am from the Indian Institute of Science, Bangalore. Originally, I was a professor in IIT Madras and I retired from there and I come over to IISC in 2006. My expertise is on devices and MEMS, this is the fourth person here and other 3 people who are very important in this program are professor G.K Ananthasuresh. He is a professor in Mechanical Engineering in the Indian Institute of Science.

He has a PhD from the University of Michigan and he was also an associate professor there. He has come back and he is now a full professor in the institute. He works on MEMS, lot of work on mechanical modeling etc he has done. So he has hands on in this area very much and he will be giving a major number of lectures here. Professor K.J. Vinoy is in the Electrical Communication Engineering at IISC.

He is a PhD from Penn State University. He has written couple of books in the related area of MEMS along with the professor Varadan and he has been here for about 5 or 6 years in the institute. He is an expert in RF MEMS, microwaves and also in technology. So he will be talks on the technology related area whereas professor Ananthasuresh will be giving presentation to deal with mechanics of solids.

Professor Gopalakrishnan is in the Aerospace Engineering at IISC. He has a PhD from Purdue University and he is expert in finite element methods. He has been teaching this course and also he is working using these MEMS devices for health monitoring. So all in all you have people giving this course who have been working in this area talking about these topics okay.

So I welcome you to this particular program on this micro and smart systems. Mostly, we may be dealing with MEMS area to start with and go on to the micro systems.

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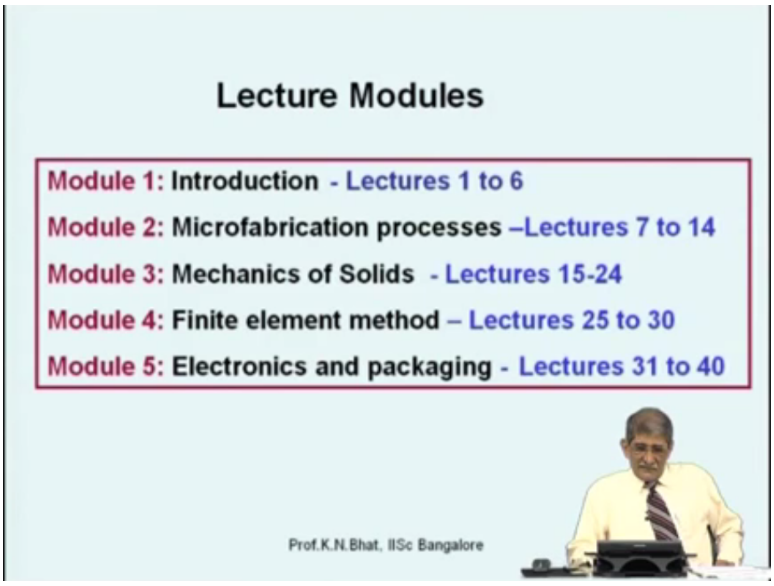

We have 5 modules in this program and module 1 is introduction. In fact, today is the first lecture on this topic which I began. Lecture 1 to 6 will cover the glimpses of microsystems mainly introducing the topic to you people to the audience here, glimpses of microsystmes scaling effects etc, miniaturization necessary, smart materials and systems and overview and then you have microsensors.

Some examples we will be dealing with you in the third session. In the fourth session, we will have microactuators, some examples then microsystems examples in the lecture of 5, which I will be dealing. Then other 3 will be dealt by professor Gopalakrishnan and professor Ananthasuresh. Lecture 6 on examples of smart systems and professor Gopalakrishnan will deal with that which deals also with the health monitoring the topic in which he is working very much.

Module 2 is microfabrication processes. There are lectures 7 to lecture 14, professor Vinoy from EC Department will give all these lectures, which will deal with bulk micromachining, structure of silicon and other materials, wafer processing, various micromachining techniques and soft lithography, smart material processing all those things he will be discussing. Then we have the module 3, which deals with mechanics of solids.

Lecture 15 to 24, this part will be dealt with by professor Ananthasuresh from Mechanical Engineering Department. So this will deal with stresses, deformation, micro device suspension, residual stress, Poisson effect. All those dealing with the mechanics of solids and which will bring you up to date in that area, which is required for doing any device design for micromechanical systems.

We have the module 4 on finite element methods, which professor Gopalakrishnan from Aerospace will deal, discuss. Here, it will give you a complete exposure starting from fundamentals on the types of numerical methods for solving partial differential equations, which are very important in any system in engineering. What is the finite element method, variation of principles then the shape functions? These are the topics which will be dealt with.

It may appear to be a bit complicated initially, but he has dealt it in such a nice way that everything will become very familiar to you and clear to you by the end of the program. Then the formulation of numerical integration, implementation of finite element method all these things will be discussed in that module. Then the last module 5 will deal with electronics and packaging.

I will deal most of the lectures here on semiconductor device basics, Op-Amps and Op-Amp circuits, signal conditioning for microsystem devices. These I will discuss then we will have integration of microsystems and microelectronics because after all when you need mechanical elements, mechanical devices you have to deal with the real world, you need to convert those signals into electrical signals, which can be made useful to deal with external world.

Then the packaging, it is not enough if you have the device was standing over there, you should have system with which you can put together, package it suitable for the particular application. We will discuss also flip chip and ball grid etc and the reliability. Finally, the last 2 lectures will deal case studies. One case study is on the pressure sensor. I will discuss that dealing with the complete design processing and also packaging part of it for various applications.

Then case study 2 will be accelerometers. Professor Ananthasuresh will have a nice presentation on that dealing in the various aspects of accelerometers including design and some of their applications etc. So that is about the lecture modules.

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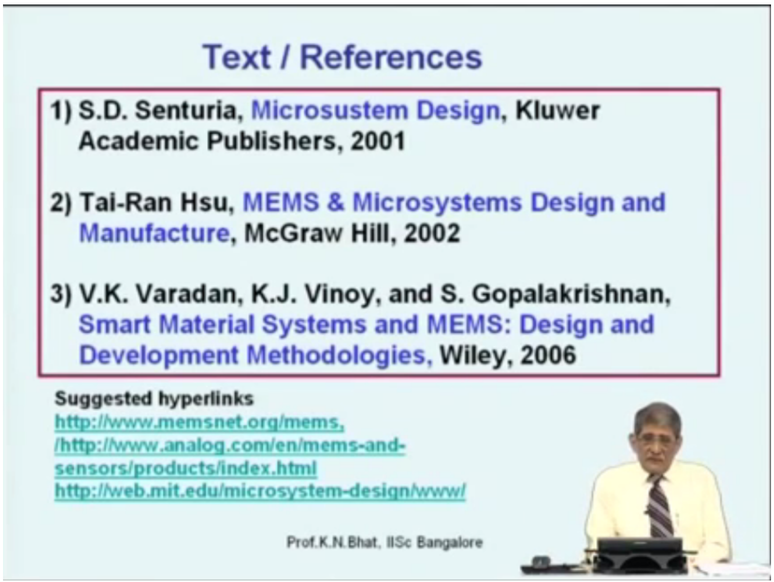

Now the text books and reference books for this I have listed out here. One of the important books or all the 3 are important. Professor Senturia, he has written a book on microsystem design, Kluwer Academic Publishers, 2001. It actually has come in cheap edition some time back, it is just cost only around some 400 rupees or so. It is affordable for all of us. Tai-Ran Hsu is the author. His book title is MEMS and Microsystems Design and Manufacture.

It is McGraw Hill and cheap edition is available, which is just about 250 rupees. I am not trying to advertise that, but what I am trying to point out is it is affordable for all of us one can buy, many of the interesting things, fundamentals have been discussed in that book. Another text book that will be very useful is author by professor Varadan, professor Vinoy and professor Gopalakrishnan.

Professor Vinoy and Gopalakrishnan, you will hear from them subsequently in some of the lectures. So their book is on smart material systems and MEMS, Design and Development Methodologies, Wiley 2006. So you can have your hands on, on these books that will be useful. Apart from that you can have several hyperlinks to which you can go and I am not going to read out this. These are available in the websites.

Additional reading if you want to do, there is micromachined transducers source book by professor Kovacs from Stanford, it is a McGraw Hill edition, it is not available in cheap edition, but it deals with various aspects of transducers etc. It is very well written book and you can also take a look at microsensors, principles and applications author by Gardner, John Wiley and Sons.

The third one is a very famous book written by Madou, Principles of Microfabrication, CRC Press published in 1998. Lot of technological details are given in that book. It is a sort of bible for many people to what to follow the technology.

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So we begin our lecture 1 on the microsystems and the title of this particular lecture is glimpses of microsystems and miniaturization. I am professor K. N. Bhat from EC Department, IISc at Bangalore. My email is knbhat@gmail.com. Anytime you have any doubts you can always send an email to me or any one of the speakers here.

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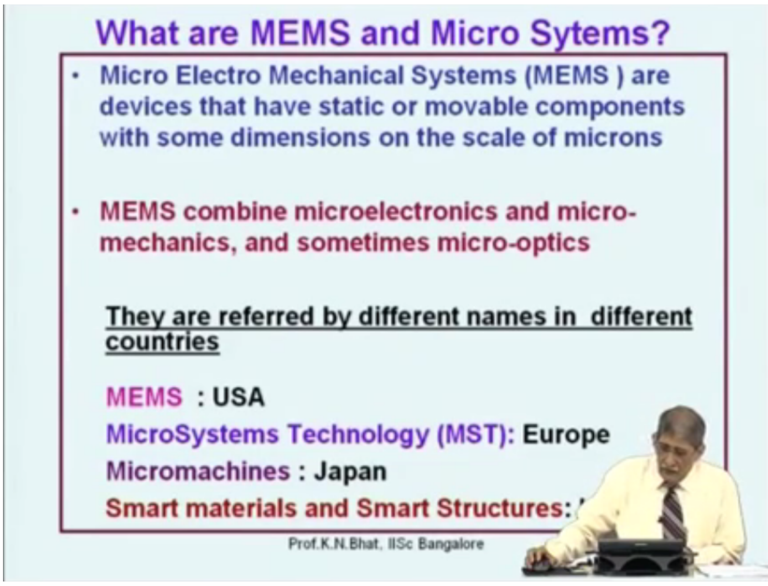

So first we will begin with what are these microsystems and MEMS? MEMS is catchword today, everyone talks about MEMS that is microelectromechanical systems and already talk has begun on NEMS, which is nanoelectromechanical systems. So these MEMS or microelectromechanical systems are devices that have static and movable components with some dimensions in the scale of microns.

If you want to talk of NEMS, those devices will have dimensions in the scale of nano. So it depends upon your ability to shrink these device sizes to the nano and the microsystmes combine micromechanics with microelectronics. You will have the mechanical components and devices along with the microelectronics. If you want to like you can call NEMS with nanoelectronics.

I am just putting out that term also because that is catching up very much everywhere. Sometimes you can have these micromechanics along with micro-optics. Then you will not call it as MEMS. You will call it as MOEMS, micro-opto-electro-mechanical system. These microsystem or MEMS are referred by different names in different countries. This is just to keep you informed that whatever name you by which you address it, it is a same thing that you are talking.

So finally what it matters what is there in the name, it is after all what matters is what you are dealing with. So you call MEMS for this microelectromechanical system in United States and many parts of the world. You call it as Microsystems Technology, MST in Europe and if you talk to colleagues or professors from industries in Japan, they will address this as micromachines and of course we also have a term in India that is smart materials and smart structures okay.

So overall today more than talking about it as MEMS, people prefer to talk about it as microsystems because which will involve not only the micromechanical systems, it will also include electronics and a complete system will be there with which you can deal with entire process or entire activity.

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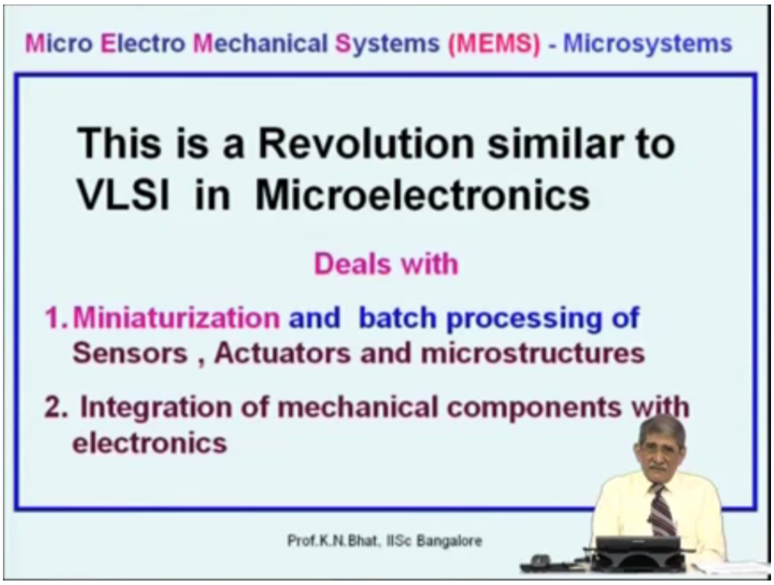

Now these microsystems or microelectromechanical systems is actually a revolution, which is similar to the VLSI in microelectronics and as you know that the VLSI began with a single transistor in 1947 when it was invented by Bardeen, Brattain and Shockley who won the noble prize for transistors. At the time, it was in large size single devices. Later on, the miniaturization of those devices was possible and that was possible in a big way.

So the integrated circuits came into picture and then integrated circuits in large scale very large scale all these came into picture. They call it as VLSI. This has become omnipresent. The VLSI has become omnipresent in every walk of life, civilian, automobile, defense everywhere it is used and the cost has come down from year to year, that has been possible because of miniaturization.

So the revolution in VLSI has happened because of the ability to miniaturize okay and this has been possible or this has been further possible because of the batch processing of the devices. So you could process when you say batch processing what is implied is when you make one device or one process, you do that simultaneously on number of devices. To give an example, when I want to make one integrated circuit process say like diffusion or oxidation.

I can do it on number of wafers simultaneously on a single furnace that is because in each load in the furnace, you can load 50 to 100 wafers simultaneously and because of the process called photolithography in each wafer there will be 100s of devices. So you can see that one go you process 1000s of devices that is called batch processing. So if you can think of if you can use that process batch processing and if you can do miniaturization or that batch processing with photolithography enables you to do miniaturization.

So if you can adapt that to mechanical systems nothing like that, you can make the mechanical devices smaller by miniaturization if it is possible, you can do the batch processing if you use some specific materials, which you really use for integrated circuits that is the silicon. So silicon has become very popular even with mechanical devices today. You will have subsequent lectures coming on that, which will tell you how silicon is very powerful material for making mechanical components like sensors, actuators etc.

And MEMS which not only deals with miniaturization, batch processing of sensors, actuators and microstructures it also should have the capability to integrate mechanical components with electronics. So this is actually the marriage between the 2 systems completely, 2 aspects, 2 departments should say. You will have not only mechanical you will have all the department put together interacting with this particular microsystem activity.

So when today if you refer to VLSI it is not nearly very large scale integrated circuits, it is very large scale integration of department activities of different streams. So you will see that in this activity not just electrical or mechanical you will have chemical materials people, physics people okay, fluidics people, all systems all areas of people participating in that very actively.

So integration of mechanical components with electronics is very important activity here, so you can see that you can put all these things in various small package to form a microsystem what may occupy if you recall the era of computers. If you go back to many of your youngsters would not have seen that, but we were thinking of computers way back. A computer used to occupy the entire room and it was a big thing to even watch the computer from the window from outside.

Today, you have the computer in your palmtop. The whole thing has been possible because you could reduce the entire system into a small package. So if you can do the same thing for mechanical components, mechanical systems you can have it on your palmtop, you can have a micropump on your fingertip with using this miniaturization system. I will highlight some of them today as you go on.

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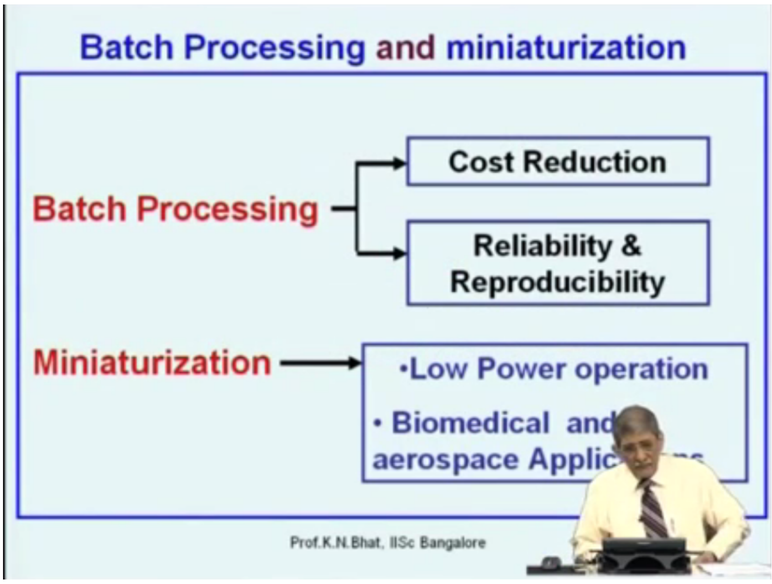

So the batch processing, what are things which makes it possible for you? I hope you understand by now what is batch processing is. The batch processing as it is evident from the VLSI enables you cost reduction because in one process you are able to process number of devices, you shall even when you want to make a mechanical device you will use a lithe or some other process to shape the material like steel or some other material.

It has to be done one by one, but if I am using a material like silicon or similar materials which can be used for batch processing then with one process you get number of devices simultaneously so that leads to cost reduction okay. So you can see the classical example of the memory chips that you have. What of costing when terms of dollars earlier, now it has gone fractions of dollars, fractions of rupee, one bit of memory.

So memory size has become bigger and bigger, it is available very cheap for you. Few years back if you say 500 MB, they will look (()) (21:07), but today even if you say several GB then you wonder that is all what you have so that is the kind of (()) (21:13) that has taken place because of cost reduction and batch processing. Further the batch processing gives you reliability and reproducibility.

What do you mean by that? When you are processing individual devices one by one, it is very difficult to have reproducibility even this minute change in the process will make changes in the properties of the device, functioning of the device to some extent, but if you are batch processing what is happening is all the devices undergo the same treatment. As a result, all of them will perform identically and all of them are placed close by when integrate.

So performance is exactly same in all those cases. Reliability, so once these sort of things are achieved this reproducibility it becomes highly reliable particularly when you make the size smaller and smaller the chance of the flaw that is available in that portion of the material is reduced if it is bigger or larger area of the material that is a good chance that there will be flaw in the parts of the material.

So the reliability of that particular device, which depends upon the large volume will improve if I shirk the size of the device and this is possible with the well processing. Further to these advantages of using this batch processing and miniaturization, we will talk of miniaturization. When you miniaturize the devices or the system, the consumption of power is low, very good example is any actuator if you make it small, you do not need much power to make it move.

For example, if you have a huge pump, you need large amount of power to run that, but if you have a very small pump, which can pump microliters of fluid, you need very little power. So very good example is that micropump for low power operation. Similarly, there are several other examples which we will see as you go on in the microsystems where the power consumption will be reduced.

And when the power consumption is reduced, you can use it anywhere in the remote areas, you can run it with the battery. If the power consumption is more, if you start running with the battery, will run out of the battery very soon okay. So that is the main advantage of that and miniaturization allows you to use this for biomedical aerospace applications. You do not want to carry a big payload into your system when you are dealing with space vehicles etc.

So you would like to reduce the size of the entire system and miniaturization helps you to use it for aerospace applications and also biomedical applications. You will see soon why you need to miniaturize these devices for biomedical applications. For example, if I want to insert some device into a human body, you cannot afford to have big size. It should be very, very small.

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A very good example of that I will illustrate with some devices, which would be inserted into the head vein to monitor the pressure. Now let us just take a quick look at a comparison before I go into the details of the microsystems. Conventional micromachining and silicon micromachining. I will talk of silicon because silicon is the one, which is very popular in microsystems.

No doubt other materials also are gaining popularity, material like polymer, which are very much biocompatible are getting popularity, but when you want to really integrate electronics with mechanical components, one has to take a look at silicon related materials.

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Conventional micromachining techniques whatever I have said I have summarized it here. Each component must be made piece by piece. Low price for large production volumes are the result of mechanization. It is because of mechanization automatic process (()) (26:00) etc, you will be able to reduce price some extent, but otherwise it has to go through piece by piece and some of the micromachining technique in conventional micromachining are ultrasonic machining, sandblasting to shape the material, laser ablation, spark erosion, etc have aided in miniaturization.

These are just most of them are not really batch processing okay. So you will be able to do miniaturization with this up to certain limit. The finest details that can be machined are 1 to 2 orders of larger than what you can do with photolithography using silicon. You may deal with several microns size. You may not be able to go really to micron level. So that is possible with silicon micromachining.

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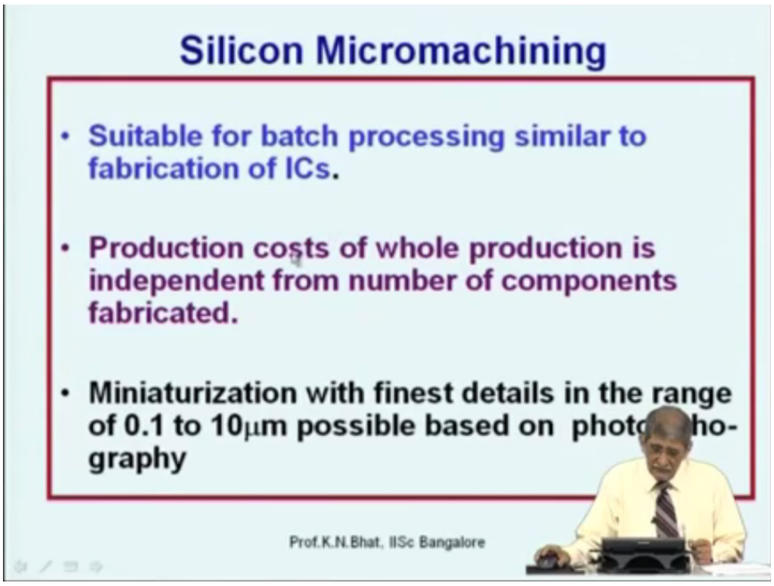

Why I am harping on silicon is silicon is useful for making integrated circuits. Silicon is suitable for batch processing, well known processes are established why not we use it for realizing in mechanical components and you can use the processes similar to the fabrication of ICs integrated circuits that is very large scale integrated circuits. Then because of this batch processing production cost of the whole production is independent of number of components fabricated.

What I am implying by that is whether you make 100 devices or 1000 devices, the cost difference will not be much, so more you make you gain your cost really goes down that way. So making cost for the batch process at a time you make 1000s of devices so the cost is drastically reduced because of that. Cost of the whole production is independent of number of components fabricated.

It is miniaturization with finest details in the range 0.1 to 10 micrometers is possible based on photolithography. I will not deal with that today, that will be dealt with by professor Vinoy in his lectures in module number 2 on microfabrication processes okay.

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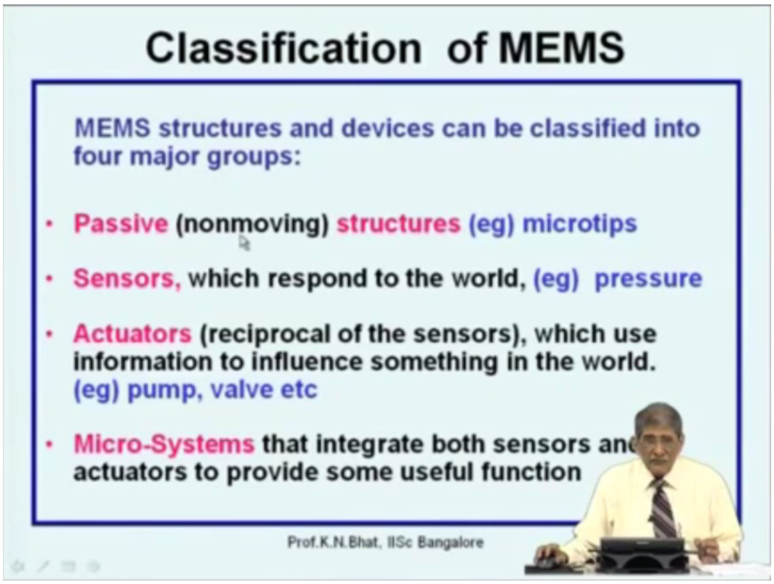

Now before you go any further just a general classification of MEMS when it is MEMS it is also microsystems. It can be classified as MEMS structures and devices that can be classified as 4 major groups. Passive structures, for example microtips with the finest tip, which will be useful in several applications including high frequency vacuum tubes including some of the atomic force microscopes that those passive structures like microtips can be fabricated in the MEMS process that is passive, they are just structures.

You can make microfluidic channels, very fine channel you can make for fluid flow in microliters or nanoliters that sort of you can do with this MEMS technology. How you do you will definitely see during the course of these lectures. Then you can make mechanical components like sensors, which deal with pressure sensors, accelerometers, gyro and several other things whatever gas sensors all those which respond to the world convert it to electrical signals that can be realized with the MEMS technology or in the microsystems.

Example of the sensor, pressure sensor. Actually survey says that about 60% of the market for microsystems or MEMS is pressure sensors. The remaining 40 for all other sensors and other actuators. So sensors convert mechanical signals into electrical or any other signal into electrical signal. Actuators, reciprocal of sensors which use information to influence something in the world.

For example, pump is a good example of actuator, use electrical signal to run the pump, convert it into mechanical energy, so from electrical or whatever information you have convert it to mechanical energy mostly that is actuator. Microsystems though we are calling this course as microsystems that has all these things passive sensor, component sensor, actuators etc. Microsystem integrate both sensors, actuators maybe passive structures to provide some usual function that means it will also have electronics embedded into that.

And in the microsystem you can have 2 approaches, one is the mechanical component, for example let us say a micropump, it is there as a one chip, in a small chip width maybe 2 to 3 millimeter size or couple of millimeter size, one cannot just imagine 1 millimeter size pump. You are not talking of liters of fluid pumping being pumped, you are talking of microliters or nanoliters of fluid being pumped mainly for biomedical applications and in also in space applications also they are useful okay.

So you can have a micropump as a separate chip. To try this micropump you need electric signal and this electrical signal can come in the separate chip and in the microsystem you may have this mechanical component and also the electronic circuit on separate chips how is under one umbrella, when I say umbrella on one it is packed in one package.

So from outside world you will see the system, which has electronics as well as mechanical component that is one way that is hybrid approach or if you do not like it, if you want to make it even more compact, you should have the ability to integrate mechanical component along with electronics in one chip in one process you must be able to realize both of them that is the ultimate.

In fact, in some one of those lectures in lecture number 39, I will have an occasion to discuss with you one of the forces, which has been realized at the university level in India on integration of pressure sensor with electronics using an approach called silicon insulator approach. We will have occasion to discuss that. You will have to wait till almost towards the end okay.

So that sort of microsystem is the one that one really looks into ultimately though today many of them are hybrid systems. Integrated systems are available commercially, the most popular one or the most famous one is the accelerometer fabricated by analogue devices in United States, which is used for deploying airbag in the car. As you know in the car, we do not need airbag here in the sense the speeds are not that high, but in highways etc in United States where the speeds are very high.

If for some reason there is some desertion or some accident that happens, the first thing that would happen will be the people in the front seat will get affected, it could be fatal. The reason is because when you suddenly decelerate or you will move forward and you get hit in the front. So this airbag will deploy, it will trigger due to this acceleration or deceleration and it will just open a balloon and it will just come and hit against you, so that it will prevent you from falling forward.

This is a classical example of microsystem in which the accelerometer is integrated on the same chip containing electronics to convert the acceleration into electric signal and that electrical signal is used to activate this airbag or the balloon that is the very good example of that. So it was not very easy for analogue devices to do it. It was several years almost a decade or more was spent in realizing that.

So the technology was not that well known to use the mechanical and electrons integrated together, but today it is more available for all of us to work on okay.

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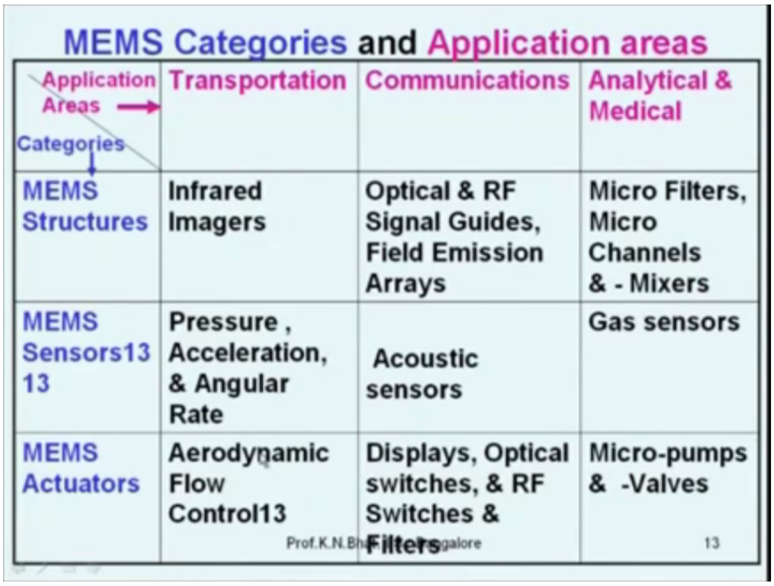

MEMS Categories and Application areas

Application Areas → / Categories ↓	Transportation	Communications	Analytical & Medical
MEMS Structures	Infrared Imagers	Optical & RF Signal Guides, Field Emission Arrays	Micro Filters, Micro Channels & - Mixers
MEMS Sensors13 13	Pressure , Acceleration, & Angular Rate	Acoustic sensors	Gas sensors
MEMS Actuators	Aerodynamic Flow Control13	Displays, Optical switches, & RF Switches & Filters	Micro-pumps & -Valves

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So now I think just again I will just see this is the summary of what we have said MEMS categories, structures; sensors; actuators. Used applications, transportation; infrared images; pressure; acceleration; angular rate all these are used and then aerodynamics flow control that is all transportation applications. Communications, you can see this microsystems or MEMS are useful in everywhere.

Communications, MEM structures; RF signal guides; field emission arrays for vacuum tubes. You may wonder why we are talking about vacuum tubes. I will have occasion to talk to you about that little bit. Vacuum tube is coming back with vengeance because of its high performance at high frequencies, which are useful for several defense applications and biomedical applications.

Acoustic sensors, displays, optical switches, RF switches all these come under communication. If not in this lecture in the next session, I will touch of some of those things. Analytical and medical okay micro channels, micro filters, mixers all those things are there under which are structures. Then gas sensors are there for medical applications or analytical applications, actuators, micro pumps and micro valves these are very good examples of that.

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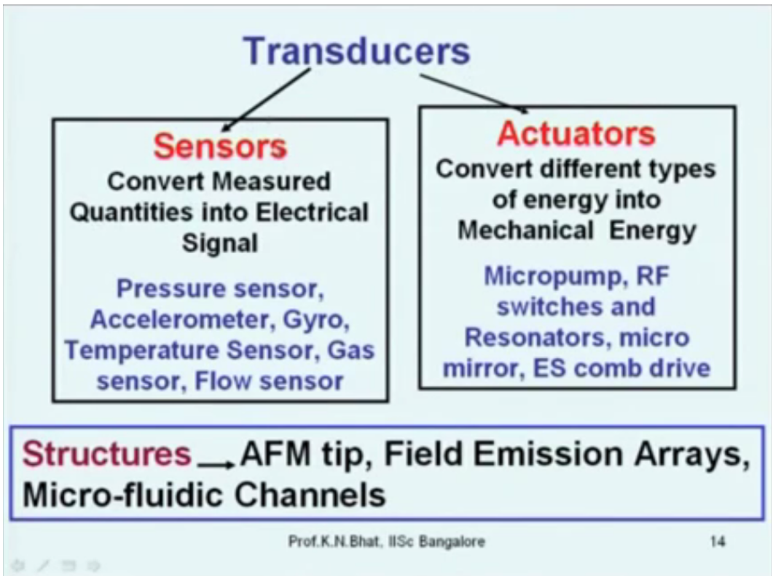

Now once again, I am touching upon this topic. Generally, you can classify it as sensors, actuators and structures, the MEMS and as I already pointed out sensors convert measured quantities into electrical signal to reiterate pressure sensors, accelerometers, gyro, temperature sensor, gas sensor, flow sensor all these come under this category and possibility of making them in micron size at least some dimensions in microns.

Miniaturization is possible with this MEMS technology. Actuators which convert different types of energy into mechanical energy that is the correct definition of actuators. Micropump, RF switches, resonators, micro mirror okay very small mirrors, comb drives all these are actuators and will discuss some of those aspects also in the subsequent lectures. Structures as I pointed out AFM tip, field emission arrays, micro-fluidic channels.

Field emission arrays are nothing, but number of fine tips arranged together side by side to make use of in electronics.

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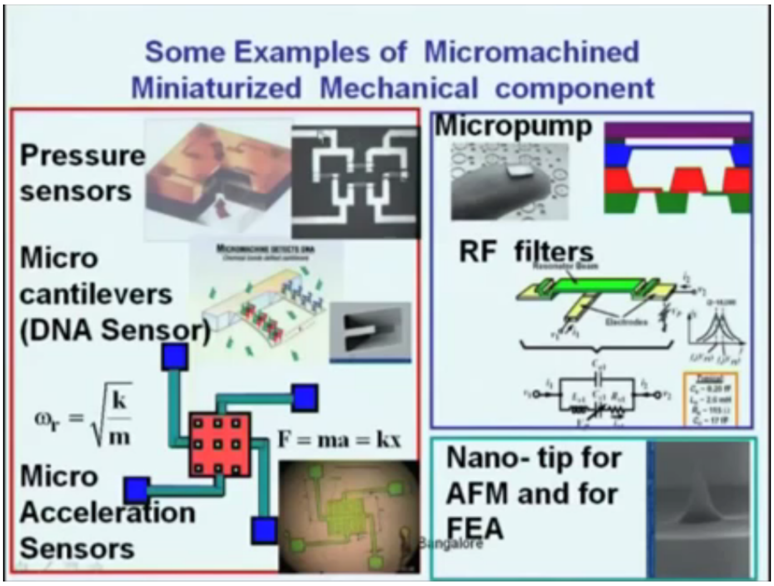

Now some examples of micromachined miniaturized mechanical components. I am just showing this in one slide to give a glimpse of some of these devices. For example, here, you have just a 3 dimensional schematic of a pressure sensor and here you have a photograph of the pressure sensor chip part of that shown here. The white what you see is the aluminium interconnection and there are 4 resistor located here 1, 2, 3, 4.

So the entire trick here is to realize some resistors 4 resistors on a membrane. For example, here you have got this block of silicon, which you have shaped by removing the material from below using a technique called as bulk micromachining, which professor Vinoy will discuss later to realize a membrane. The membrane thickness maybe or it will be in the micron size, 10 micron, 20 micron of that order depending upon the pressure that you want to monitor or sense.

And on that membrane you will have this or the 1, 2, 3, 4 resistors located on the membrane and these resistors experience whatever stress the membrane will undergo when it is subjected to pressure. So if it is put in an environment there is pressure, the membrane senses the pressure and this stress experienced by the membrane is transferred on to this resistor whose resistance value will change and you monitor the change in the resistance of that resistor, calibrate it to measure or estimate the pressure.

More of that will come later, this is the idea and this entire size of this structure that I have shown here will be 1 to 2 millimeter size. You cannot afford to have that bigger if I want to use it for biomedical applications then okay. You have also I will come back to this subsequently. You can have cantilever beams, which are used for DNA detection. We will discuss that little later on these individual things.

So here a small molecule also can be detected if it sits on this cantilever. Cantilever is nothing but a beam it maybe micro or nano structure, which is anchored at this edge here onto its anchored at that portion so that only the beam is the one which moves up and down. So if any molecule goes and resides on that beam, the beam should deflect. So you should be able to measure that deflection.

You will be able to realize the beam, which is such a small one, which is possible by miniaturization and which is possible by the MEMS technology that is what we are just going to deal with that. So in a system you will have this mechanical component plus the one which will convert that deflection into electrical signal microsystem.

This one what you see here is this red color here with the holes there is a plate or a structure, which is supported by means these 4 beams here which is also above the ground level all these which are hanging all these are anchored on to this 4 green pads anchored so this entire structure is anchored on the 4 blue structures this is not green, blue okay. So they are anchored there.

So this system can move up and down like this. So if there is acceleration in that direction, this particular plate will move down or up depending upon the acceleration and this moves with respect to another plate so there will be change in the capacitance between this moving plate and the stationary substrate. If you sense that capacitance you can actually estimate or use that acceleration that is experienced by this mass.

This you can call this as a mass, they are after all accelerometer contains a spring and a mass. Spring here is these 4 beams, which are holding that mass and this is a mass. So the principle of that etc will discuss later not right today. Then this is what I showed here so this is the example of the sensor. These 3 are the sensors and the 1 that I am showing here is the actuator.

You can see here on the thumb you have the micropump on schematic diagram I have shown here. So this is the micropump, which has 1, 2, 3, 4, 5 layers, which are pointed together. To realize the chamber of the micropump, which will allow the fluid to throw into this chamber through this valve when it opens and it will also let the fluid outer when this valve opens and the ability to open this valve into and out is enabled by means of by applying voltage between this electrode and this electrode.

When we apply voltage between these 2 electrodes, this membrane which is thin will deflect upwards due to electrostatic actuation, electrostatic force after all when you apply a voltage between 2 electrodes, there is force of attraction between them. Normally, when you have a capacitor, capacitor does not move because both are rigidly held, but here you have got this bottom plate, which is very thin.

So if there is force of attraction between the top and bottom electrodes that will deflect up. The thinner one will deflect up increasing the volume of the chamber, that way the pressure in the chamber will be reduced. When the pressure in the chamber is reduced, this valve will move up so that the door is opened and the fluid if it is in contact with the fluid, the fluid will enter through this.

Now if you drop the voltage to 0, this membrane will come down increasing the pressure inside to a fluid already has entered then this valve will close because this cannot go down, but this can open outward that will let the fluid outside that is one stroke. In one stroke, you may be able to pump a fluid, which is maybe nanoliter or microliter depending upon this chamber volume and this stroke volume.

Stroke volume is the extent up to which membrane deflects okay so you can use these for pumping fluid from a reservoir to a source region where you want pump. You can use it for biomedical applications where you can mount it on the finger and along if you have it have a needle which is connected, it can inject insulin to the human body right away. This is required because today particularly in India, we have lot of people who are diabetic.

Therefore, you can inject controlled quantities of insulin by using this micropump. If you have a sensor, which senses the sugar level in the blood okay, the system will include a sensor which is sense of fluid the sugar level and once the sugar level reaches some level you will have a voltage generated, that voltage will activate this pump and that will let in this fluid through that controlled quantities of fluid at that time when the sugar level comes up and it is injected into the system through this needle that is the microsystem actually. You do not have it back this is one goal of this microsystem activity.

Then I will also discuss not to dwell upon this because there is something which I want to discuss the biomedical application of pressure sensor, nanotip. This I will bring in my next lecture on systems. We will go to this now.

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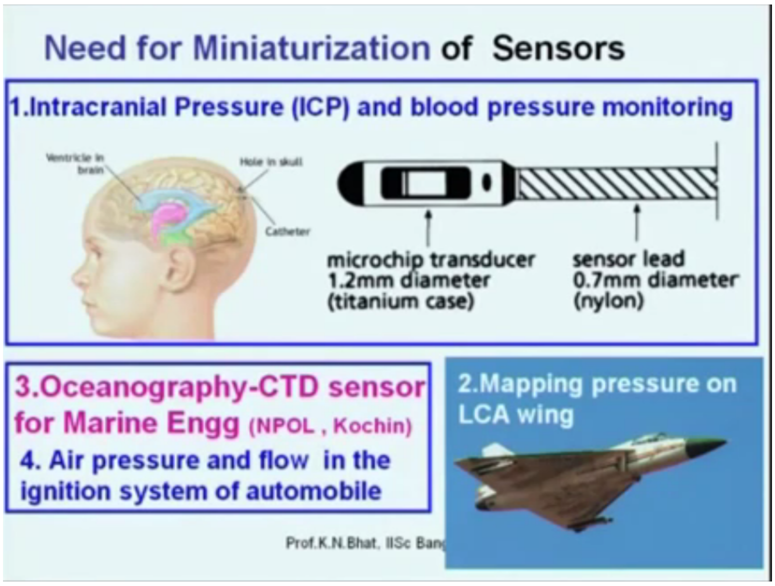

So I will have just a brief discussion on this before we wind up our discussion today that is why we should need the pressure sensor which is miniaturized? In Bangalore, we have this NIMHANS okay where lot of patients go after suffering from severe headache due to a tumor on the head or due to a head injury during an accident. I was told that at least 15 to 20 patients go to NIMHANS after a head injury in road accident.

Now the patient will have severe headache because the brain swells due to this head injury. The headache as it develops and becomes more and more ultimately the patient will go into coma. So when the patient goes there what they want to do is they want to monitor the pressure in the brain. If the pressure builds up too much they want to siphon out some of the fluid in the ventricle in the brain.

So this is actually the picture where you want to interact with this portion of the brain there that is invasive. What you have to do would be you should want to monitor the pressure, you want to have a pressure sensor, pressure sensor directly located inside here. How do you reach there? The only way you can reach there is you drill a hole. You cannot drill a big hole into the brain.

It has got to be a millimeter or maximum I was told about a millimeter and a half because after all entire operation is over that hole in the skull has to heal by itself so that has to be very small. So if you want to make it invasive, you must have miniaturized pressure sensor whose size even after packaging can be about a millimeter or 2. So that has to be inserted into this.

So this is called intracranial pressure monitoring. You can do that by introducing that into this brain and this pressure sensor when you insert you get one of this, this is available commercially abroad, but very expensive and you cannot afford to use them again and again. You have one thing insert it into one human body you cannot reuse it, it has to be thrown out. So you cannot afford to have several 1000s or 30,000 or 40,000 of rupees for this.

So we are working on this, professor Ananthasuresh, myself and professor Navakanta Bhat, we are working on developing a micro miniaturized pressure sensor for this application for biomedical application. It has been going on for some time you know about few months so we have made some progress on that. The most important thing here is you cannot insert the pressure sensor in the wafer form.

You must have wire connections done to that and all these should be biocompatible. You must package them in the sense when you insert it, it is in a package form and the package cannot be a metallic package because a metallic package will be harmful to a person and you must use it biocompatible. So that is one of the big activities here.

You may have pressure sensor for different applications, but key thing to see is the chip may be of similar type, but the package will be different from one application to another application. This is the major difference between the package for integrated circuits and the package for the MEMS or the microsystems. If you want to use this pressure sensor for application like mapping the pressure of the wing of light combat aircraft then you must have flat package.

If I want to use it for this intracranial pressure sensing, you must have a package which is biocompatible. If you want to use it for measuring the pressure, use it in oceanography okay. There is conductivity temperature and depth measurement in the ocean. Then the package must withstand that corrosive fluid of this liquid of the ocean. You can see what all challenges are there in this microsystem packaging.

Then you can use also for air pressure and flow in the ignition system of automobile then you must have the device, which should be capable of withstanding those temperatures, which may exceed 100 degree centigrade. You can see the requirements are tremendous on reliability, environment of operation all these are very important. So you have to take care of those things in the packaging and the device design all those things are part and partial of microsystems okay.

We will have occasion to discuss about these structure of the pressure sensor maybe I will bring in my next lecture. So what I am trying to point out here is just I will skip some of these and come back.

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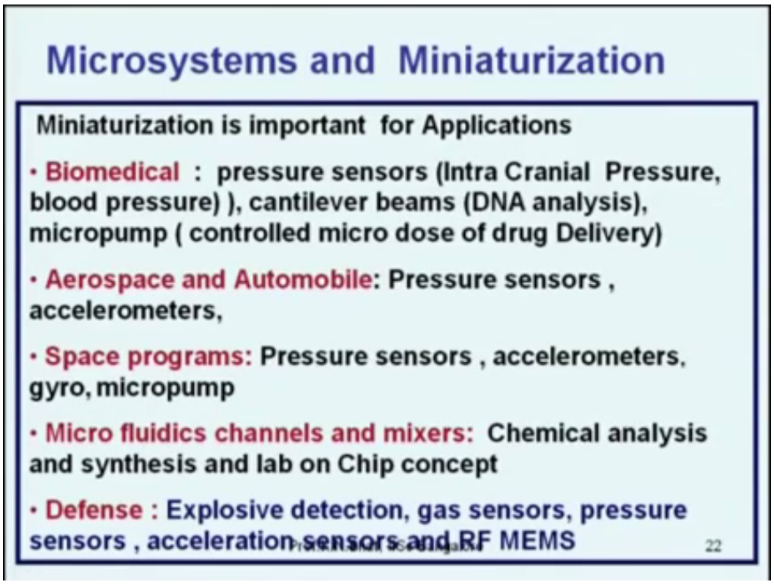

Microsystems need miniaturization to sum up. You need miniaturization for all the many applications biomedical, pressure sensor, cantilever etc need miniaturization. Aerospace the application in pressure sensors and accelerometers. Space programs, pressure sensor, accelerometers, gyro, micropump all these are useful. You need micropump in space applications because the gyro has a motor, which has bearing.

You need the lubrication for the bearing and very small quantities you need a micropump to deliver that. Then for defense applications explosive detection etc you need many of the sensors. So that we conclude with this particular thing now and we will continue on more details of this microsystems in subsequent lectures.

I think next lecture will be given by professor Ananthasuresh on smart materials and systems and overview with the lecture number 2 and after that we will have lecture number 3 on microsensors and some examples and micro actuators. My lecture next will be on microsystems some examples. I will touch upon the remaining things in my lecture in that lecture. Thank you very much.