Microsystem Fabrication with Advanced Manufacturing Techniques
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Lecture – 1

Good morning or good evening depending on wherever you are; I am a Prof. Shanthanu Bhattacharya, and I am in associate professor at the department of Mechanical Engineering at the Indian Institute of Technology, Kanpur. So, today I will be actually teaching you about this very fantastic area of Microsystems fabrication by using advanced manufacturing process. So, to begin with I would just like to say a few lines about what really Microsystems are or how this Microsystems technology has emerged over the years.

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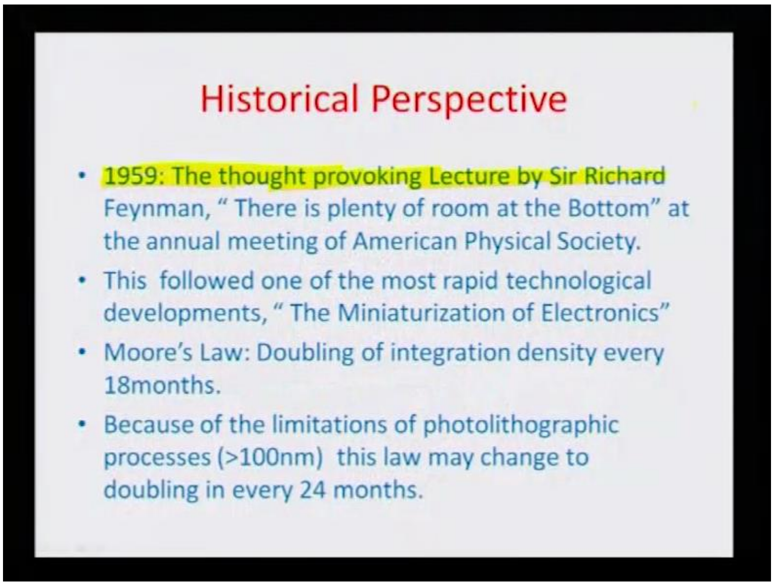

So, if you look at this particular slide, it kind of gives you a historical prospector of Microsystems research on the way, and here specially this highlighted region as you can see talks about this the very famous lecture, by Sir Richard Feynman called, "There is plenty of room at the Bottom". So, it all started really from this particular lecture which incidentally was presented at the annual meeting of the American physical society way far back in 1959. So, at this time really the research in the Microsystems engineering area was a fledgling or add it fledgling state, and there were some very interesting ideas which were pointed out by Dr. Feynman about what can happen really when one can goes to smaller, and smaller for example, in one instance you really pointed out that if you can right the whole lords in the on the tip of a simple ball point tip or ball point or ball point pen how small can the letters b and. So, he talked at length about different scales, and how they would look at when you really do them, and some of the very fundamental concepts like scanning electron microscope transmission electron microscope etcetera, and the power of high energy beams have really emerged from this lecture. So, this really followed one of the most rapid technological developments which is also known as the miniaturization of electronics microelectronics as we call now a days, and there was this very famous law called Moore's law, which came to being from our business prospective were it was pointed out that this miniaturization density. If you look at every eighteen months for a period of 18 months would be a essentially doubly which means that the amount of circuits that you can really print on to a small square area would go twice exactly with the passage about eighteen months also.

So, this law really also tells you about how how small the miniaturization drive of electronics can take you two it kind of gives you time scale estimate for that. So, this law when its start at looked very good, and you know people really had about eighteen months time period for approximately doubling of the integration density; however, because of the limitations posed by photolithographic process as a I am going to describe in this details little bit later what photolithographic means really. So, because of the limitation posed by this photolithographic process of being able to go more than hundred nanometer of… So, this law may eventually change to doubling in every twenty four month now, and now a days increasingly it has been seen that instead of the eighteen month period the period of integration density doubling itself has shifted to about twenty four months also. So, this is sort of brief overview of where the microsystems drive or microsystems revolution really started from…

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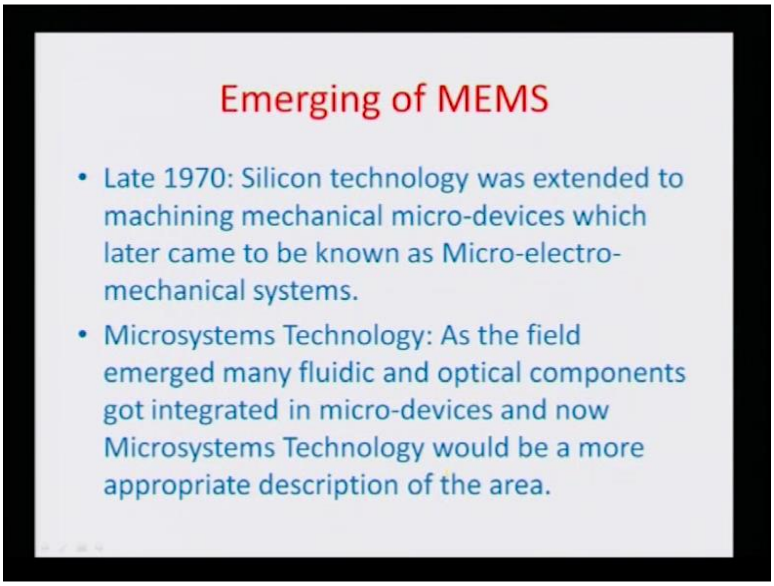

So, you know, because of this limitation posed by the Moore's law to the business of the microelectronic industry there were some processes really, which fell out, because they were no longer capable to handle the integration density which was offered by microelectronics. So, in the late seventies these technologies were kind of gathered to gather, and the silicon technology was extended to what you call machined mechanical micro devices or mems as the term is known micro electro mechanical systems which came in to being, because of the fall out to the process from the micro electronic industry.

So, this feel really was very exciting, because it had a component of mechanical motion or mechanical synthesis of small miniaturized structures or feature it also had a component of electronics were whatever signals it would be able to process can be transduced in to corresponding electronic signals, and, then of course, it was add the micro scale. So, thus the name micro electro mechanical systems. So, as this field emerged Microsystems technology increasingly got applied to many fields like fluidic, and optical industry or components, and these sort of synergies with the mems technology, and got integrated in to this whole you know micro devices the concept of devices actually came up were variety of techniques likes fluidics, optical components microelectronic systems micro mechanical systems could be all integrated in to one platform, and together these. So, called micro devices were, and the way that it was realised or built were known as the micro systems technology.

So, our course really would focus more on this microsystems technology, and some of the very instead of the art processes of fabrication which should be used for relying these systems as would see in details later on.

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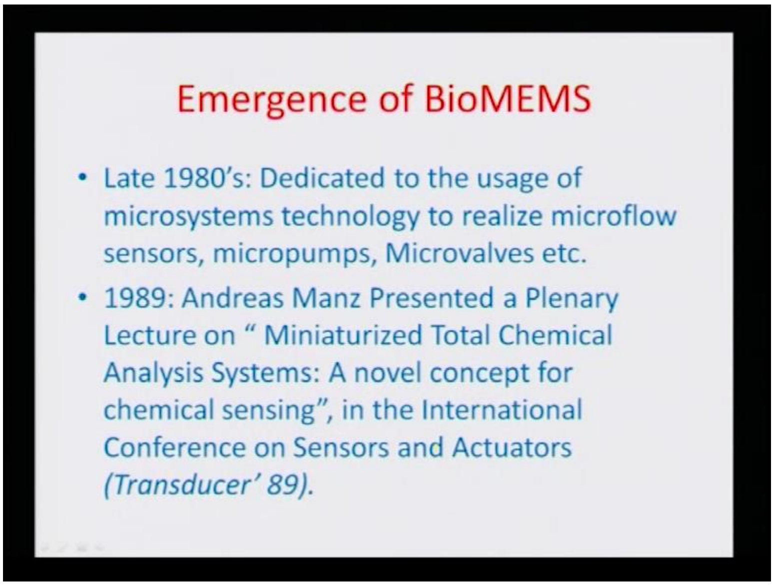

So, let us look at little more of historical perspective as to how the mems or micro electro mechanical systems really got integrated into biological or you know bio medical mems. So, really when the mems started in the nineteen seventies, it was dedicated mostly to physical systems like realization of temperature or measuring measurement of temperature acceleration velocity, and so on and so forth, but towards the late nineteen eighties there were increasing amount of usage of this micro system technology to realize micro flow sensors micro pumps micro valves were fluidic motion at the micro scale certainly became very important I would also like to point out to this one famous paper by sir andreas manz, which was presented at a plenary lecture on miniaturized total chemical analysis systems a novel concept for chemical sensing, and this is presented at the international conference on sensors, and actuators which really change the dimension for these micro electro mechanical systems, and slowly increasingly the field emerged in to the bio medical micro devices or bio medical mems systems.

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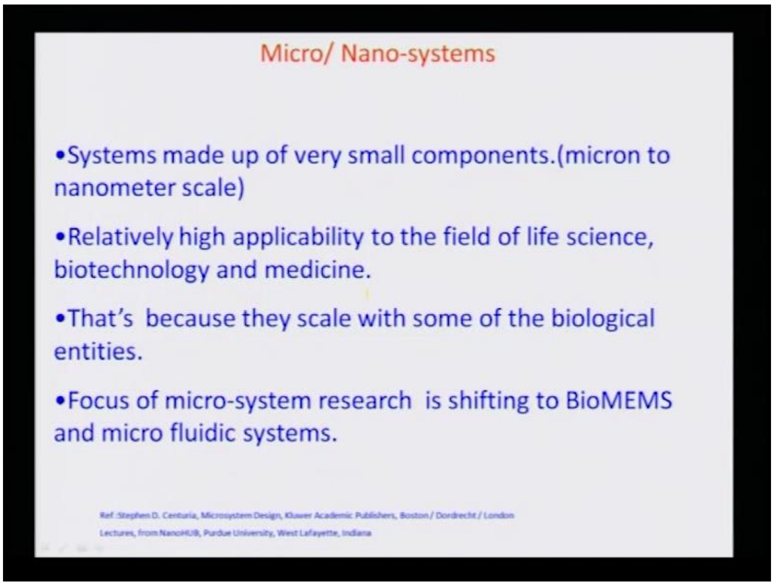

So, what these biomems devices are or what they do really they are having relatively very high applicability to the field of life science bio technology, and medicine, and of course they are system made up of very very small micron to nanometer size component, and this is, because primarily these mems features scale very well with some out the biological entity's which are available. So, therefore, this concept of mems which emerged from physical mems, and went into biomedical mems really has taken a lot of steps, and researches emerged in this particular area.

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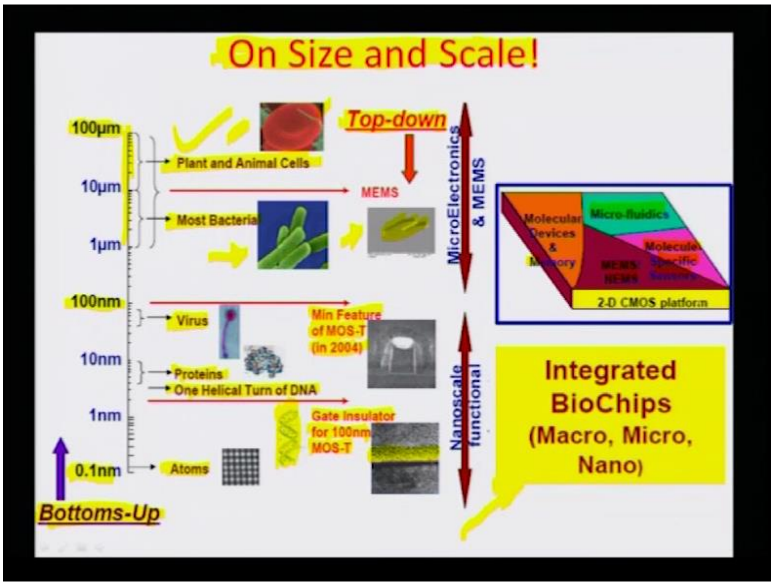

So, this really shows why memes can be applied to biological world, and this is one slide which mentions some something about the sizes, and the scales in the comparisons of the various mems devices with respect to the biological entities. So, here if you look really a towards this left side of the scale its starts from about zero point one nanometer as you can see, and it can go all the way to about hundred microns or. So, and just to give you few example on the sized domain hundred microns typically size of human here, and these entities here, you can see are the biological entities which are very commonly available in different forms of life in the nature. For example, most plants, and animal cells if you really look at the size domain are about ten micron plus region. So, this is an illustration of red blood cell you it is like a inverted button from shirt it is a small sack which contains various chemicals, and are very good oxygen transporter within the human system this.

For example, equalie it is small you know cylindrical two to three micron length about one point five microns diameter object, and this is a bacteria, and most of these bacteria are in the size range of about one microns to ten microns, and if you look at this particular here it is a virus it is a cap set made up proteins with enclosing few genetic is a information of material, and most of the virus are in the hundred plus nanometer domain size range if we go one step further this for example, is a protein molecule, and this here you can illustrate here d n a deoxyribonucleic acid, and one helical turn of the d n a is about y w o to three nanometers twenty thirty armstrong. So, you can think of that mother nature kind of builds these systems up the bottom of technology assembling atom, and atom, and molecules in a particular fashion.

So, that you can generate these smaller entities biological entity's, and these together would realize one of the very highest, and complicated most complicated forms of life you know using bottom of fabrication technique on the other side you can see some of these fracture, and features from the common micro system domain this for example, is a micro cantilever you can see this lips taking out of this structure, and this whole pool here as you can see is a is a sort of cavity in to which the slip is ticking out. So, you can recall this is a diving board in a swimming pool kind of structure the only difference here is that, because it is micro scale this lip is about close to about tens of microns, and the thickness could be about two to three hundred nanometers, and the depth in to which this cavity is placed is can be close to about one two microns. So, the reason why am illustrating all this is that these some of these features, and structures rain very wells size wise with this biological entity for example, this is an again another very interesting example it is a polysilicon gate with nitride spacing, and the minimum feature of m o s transistor which has been declared by the I t r s road map in the year two thousand four is less than hundred nanometers, and for such a such a hundred nanometer device the gate insulator region which may be this region is as low as few nanometers about two three nanometers or. So, and so you can see that even at the molecular level there are these features, and structures which are created which rine very well size wise with these molecules.

So, it gives you an opportunity to sort of you know interact with the biological world more appropriately by building micro size features an objects, and therefore, the mems changed its direction mostly in to bio medical mems, and it had immense utility, and some of the very interesting projects develop by the human civilization like the human genome project so on so far as... So, there was a huge class of materials called integrated bio chips which got formulated, and this one of the major area of mems were some of these components could be fluidics or could be with molecules specific sensors could be mems, and mems systems, and molecules devices, and memory structures etceteraetera they got integrated to the two d see most platforms, and they could do integrated sensing detection diagnostic very rapidly.

So, therefore, I have kind of illustrated or walk you through the history of these micro systems technology. So, called you know started in nineteen seventies as a fall out the microelectronic revolution, and then basically went to realize some of the physical micro devices which would sense physical velocity, and acceleration pressure, so on so for some physical parameters, and, then finally, emerged into this biological micro systems or bio medical micro devices which could do sensing diagnostics very very rapidly. So, it has been a very useful area of research, and work. So, far and what we will learn in this course really is how to make some of these micro systems devices using conventional or most of the time advanced machining process or machining technology.

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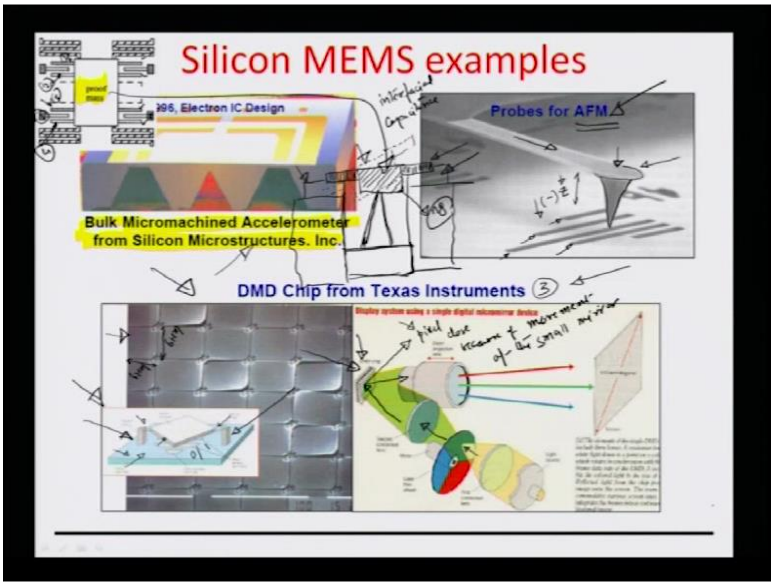

Let us look at some of the example of physical mems as I told you before, and these are some of the commercially evaluable mems structures, and devices as on date in the industry. So, this mostly is in area which is realised using silicon, and let us see example one here it is a bulk micro machined, and accelerometer, and this comes from a company called silicon micro structures, and typically this accelerometer is having a basic principle as illustrated here the concept of proof mass. So, if you look at this top left corner we have semantically show now this accelerometer works. So, this proof mas here is essentially a very small feature which can be about twenties of microns by fifties of microns, and this is pivoted typically. So, if you look at this domain cut.

So, if you look at this proof mas in the way it is pivoted it is illustrated here by this small cartoon which am making in this screen. So, essentially this mass is pivoted like this on surface, and surface here is actually is inside cavity or it is edged inside cavity inside is edged, and the remaining part of the wafer like this. So, you have the pivoted proof mass here by this shaded region which is nothing as, but this illustrated here, and you have a cavity here around, and typically what happens is that there are metal structures which are coming out from this proof mark on both sides.

So, these are some of metal structures which are coming out on both side, and be illustrated here as one this one in this one two, and this is again we this for, and similarly there are other four indicated by this arrow here on the right side. So, these metal structure are coming out as you can see by the vertical shaded lines on both side, and, then there are certain other metal structures which are actually present on the top of this surface which has been micro machine an out of which the cavity has been made, and these structures are present in a inter degitated manner were as you can see. So, you have one structure, this one present between component three, and component four. So, it is sort of inter digitated, and which place in that manner. So, whenever there is movement of this particular mems housing there is a change in the angle of this proof mask here. So, the proof mask may actually become something like this as you can illustrate, and can be illustrated in this diagram, but the dotted line and. So, therefore, there is always a change in the interfacial area between these wings which are there are on the bass proof mass, and the metal structure which are printed on to the otherwise plain surface, and, because of the change in the interfacial area there is always a change in interfacial capacitance and because of this capacitance change there is a signal there is a electronic signal.

So, if I can really a calibrate this this capacitance change with respect to the acceleration role pitch your different physical parameters that is really what an accelerometer measures these accelerometer are increasingly use now a days in auto wheel sector for airbag based actuation and. In fact, very small acceleration. So, can be recorded very easily using some of these structures the advantages that this kind of accelerometer would have a very miniscule list count or the accuracy of measurement would be higher, because this proof mass may only be a few maybe about nanograms or. So, it wait. So, it is a very small amount of mask that you are really carving out.

So, that you can check physical parameter with great accuracy example two is this very interesting tool which is also the corner stone of nanotechnology, it is called an atomic force microscope or we can see here is a silicon structure coming out it is like cantilever, and the tip of this cantilevers atomically sharp. So, you can this tip here it is a sharp to the size of few atoms, and this again is used extensively for thopological measurement of surfaces were this cantilever tip is move to over a ruff surface, and whatever cress, and tuffs are present on the surface are being monitored by means of the deflection a monitoring the deflection in the z direction of this particular cantilever. So, therefore, if suppose I were to monitor these small valleys which are present over the surface I would simply scan this cantilever of on the top of these valleys, and wherever there is a valleys, and if we have some positive pressure on to the stop of the cantilever it would go, and going to the valley, and there would be a zee direction displacement in the negative zee direction, and if we can record that we can really take also which data point, and reconstruct the image of the surface is based on some of these points. So, an a from can really we use in the in the touching mode or the tap taping mode, and again silicon micromachining micro manufacturing using some of these advance manufacturing techniques are used for building some of these systems. So, along the course we might have example problem were why were we might see how to develop or device these tips using non conventional or advanced manufacturing example three here is very interesting example is one of the commercially evaluable devices which are available in the powerpoint in the in the multimedia projectors, and this is something called digital micro mirror device chip from texas instruments.

So, let us look at the basic principle of how this system works. So, you can see here in this particular figure an array of plates which are shiny, and they are probly made up of metal, and they very teeny tiny. So, therefore, it actually a blown up image and each of this plates we something like about six micron into six micron. So, here this dimension may be about six micrometers. We can similarly this dimension may also be another six micro meters at each of these plates are arranged, then array format in very complex manner as can be illustrated in this figure. So, these plates are really pivoted on both ends, and they are like a simple supported been configuration, and these plats also are electrically actuated from the bottom structure which is indicated him blue here, and they have these electrodes.

So, if there is a electric field applied between this blue base, and the bottom of this plate which is hanging the plate reflects, and, because of the reflection if this plate was shiny on the surface, and a suppose light was falling on to this plate light would go out of focus. So, here for example, is the d m b chip which actually is carved out of this array of different plats, and here for instants you suppose this light been falls in a certain direction from the focus the optical focus, and there is some preprocessing done like passing it through r g b filters, and then optical chopper etceteraetera, and let say it were supposed to go in a direction towards the focus or the focusing length. So, typically the plate get reflected the bean who would go out of focus and so typically the pixel which was being represented by the plate which reflected.

Who would close? So, you have a pixel close, because of movement of the small mirror. So, you may able to realize that the image which is projected is really a function of such pixels it is in array of pixels. So, a pixel illustrated by a certain color or brightness or intensity would be the presented of a creating some impression on on the surface which is corresponding to the image simultaneously a pixel which is closed or a pixel which is top would represent dark region of the particular image.

So, it is really a array of these pixels which would be able to demonstrate an image, and you can do suitable amount of optical magnification etcetera to this particular image to transmitted and. So, if you have a signal in form of zero or a one it can drive the angle defection of several of these mirror in unison thus closing several pixels in opening several pixels, and that can be used to translate the digital information of an image that is recorded in a computed or in to the projector. So, it is one of very fantastic examples of what mems structures can do in terms of image projection.

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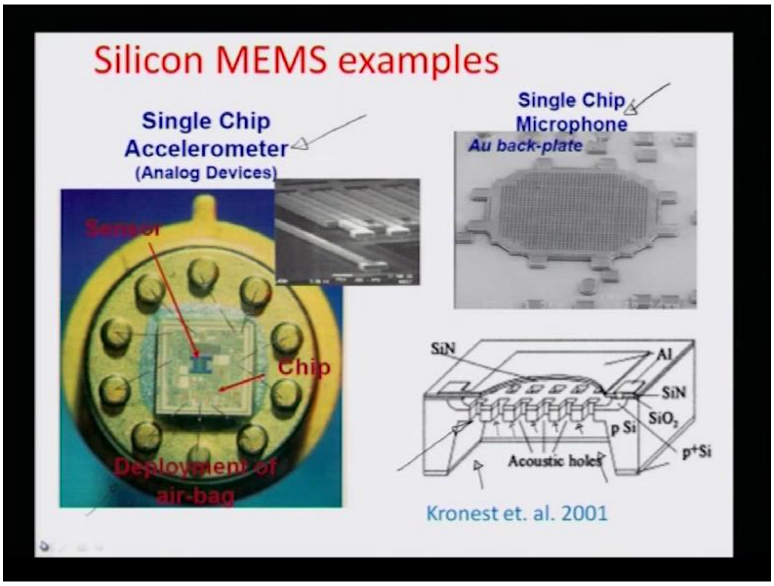

Let us look at some of the other examples of mems; these are two very interesting examples of silicon mems again an accelerometer device from analog devices which is used at typically for the deployment of airbags has mentioning. And this is again the single chip microphone which is again the principle is based on this vibrating membrane which is highly perforated as you can see on the bottom, and you have a layer of piezoelectric material coated on the top. So, whatever you're speaking in to this small micro phone basically were as, and vibrates this perforated membrane, and it creates in electrical signal which can be process or magnified, and that is how you can here sound transmitted electronically over distances. So, typically all speaker base systems like telephones cell phones microphones etcetera are based on some of this miniaturized of super miniaturized principles at work. So, that is some of the examples of silicon mems I would now like to also illustrate some other examples.

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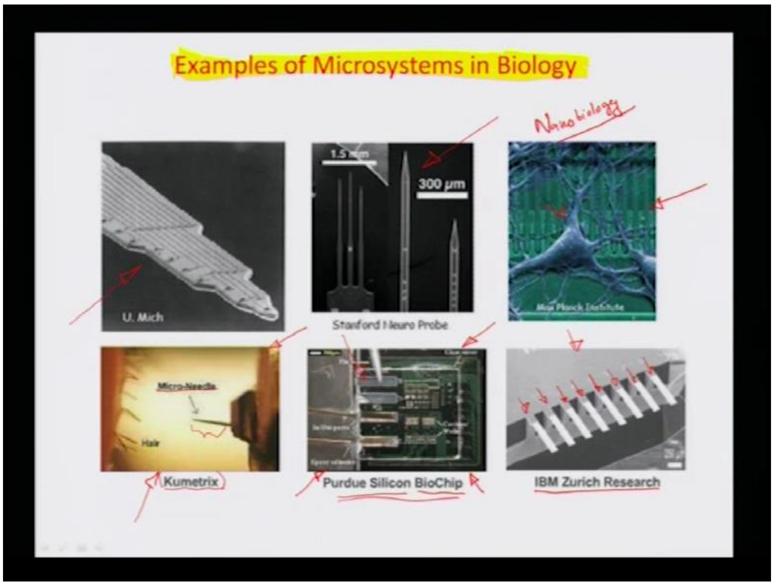

So, let us now see some more illustrations on application of mems or micro systems in biology, and here I have for you about six different illustrations of how micro systems can be really used in biology, and as you can see here the first example is very widely refer to in red is basically this set of micro electrodes which were developed at the university of meshi gun by doctor wise wise a steam actually. So, essentially this was used for monitoring the electrical activity of brain tissue, and these electrodes here as you can see are printed, and they are in plain, and this needle here needle like structure here may be only few tens of microns in width in a few hundred s of microns in length, and they are all oriented with these. So, called electronically place or for electrical identification of signals at there all coated metal prints or in prints place from the top of these electrodes on this we can this again another very fascinating example from research group at stand for, and this is a new, and it is used for providing stimulation to patient suffering from decease were these stimulations are medically advise sometimes for proper operations or you know the the sort of routinizing the functionality of any human being suffering from these decreases.

So, again a very fantastic example of micro systems at work slender like tall needles which may be about twenty to thirty microns in width wise, and few hundred microns tall, and these are quiet excellent example of micro systems in biology this is another example of micro systems can do for monitoring the cross tog between neurons these are some neurons cells going oven an array of, and this area is also known I nano biology, and it is recently come out very well sometimes. If physiological monitoring of cells using this signals is electronic signals becomes very critical to understanding their cross talks. So, essentially the idea is that these neurons are growing over the the gait region of these moss transistor arrays, and if there is a change in the the surface protein expression of these cells its recorded in terms of change surface potential and. So, if you can keep on monitoring the current based on the change in surface potential it can give your idea of what cross talk is going on a single cell level between many cells growing together on the top of this array example four here is again very interesting, and very fascinating example of mems in biology this is a micro needle, and this is based on the this sting or the needle of a mosquito.

So, when mosquito bites you you hardly feel the pain because the needle is not able to really damage or deflect the pain receptors which are placed underneath the the human skin. So, of course, there is swelling which comes, but that swelling is more, because of an that it releases. So, that it can thin out the plug sample that it is taking,, but otherwise this needles are about twenty microns, and again about hundred eight or two hundred microns in length twenty microns in diameter. So, it is a high aspect ratio a slender structure, and such structures. If we can fabricate arrays or groups, and fabricated over let us say pads which can be mounted on the figure or different regions of the body you can think of or an vision a system of painless strug delivery to the human body so. In fact, this slide has been borrowed.

This picture has been borrowed from this company call kumetrix which commissionaire the some of these micro needles technologies for dug delivery applications this again is an example of very fascinating area of micro systems called integrated by bio chips, and senses, and now this area also got in to picture, because of need dictated by the human gynome project again were analysis of samples became very critical at a very rapid phase of fast is. So, typically these bio chips integrated bio chips are made up of some channels in chambers in architectures which can handle minuscule amount of volumes of fluid of a certain target, and they can be mixed in proportions define proportions with their analites of intrest.

So, that they can be recognized. So, there is some kind of transduction of signal which changes the chemical information on to the analite to the interest in to electrical signal, and an optical signal, and the whole integration of how to change the signal or how do process a signal or how to infer from the signal is a done together on this integrated by a chip. So, these technology is are this group technology is of this group of technologies are also known as lab on chip kind of technologies, and they are very useful for the diagnostic the clinical diagnostics world again a very fascinating application of mems again this example six here illustrates a bunch of different cantilevers, and I have already mentioned about this cantilevers extensively while talking about afm, and the technology of afm. So, these cantilevers can be very easily used for recognizing d n a molecules.

In fact this work done for the first time at a I b m zuric research indicated that deflection on this cantilever scan with some of the binding events, that may happen on to the top of these cantilevers between capture probes which are very intelligently placed on the top of each cantilever in the target molecules which may come in bine and. So, this reflection can be recorded with certainty to indicate whether there is a bining action which is happened, and this can be used for typically for application like micro etcetera. So, this is again another very fantastic example of micro systems in biology, and it is applications.

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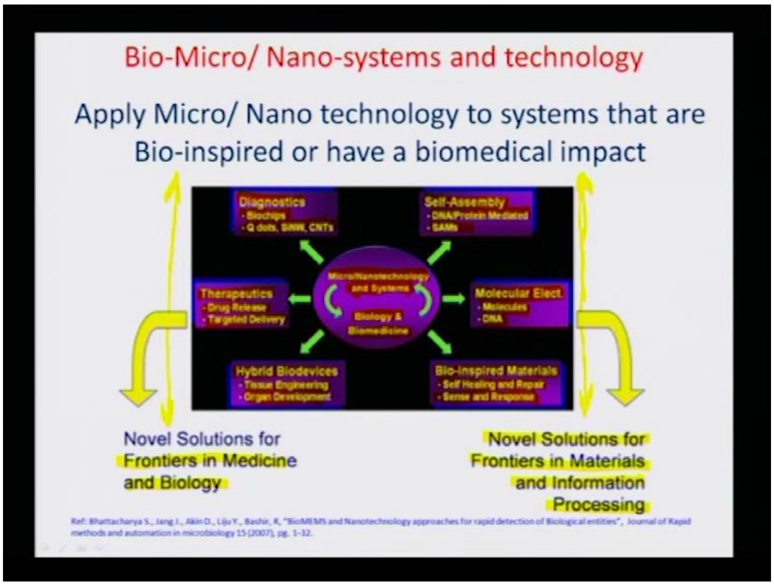

So, if you really a look at a bunch of these technology is sort of micro, and nano systems, and the way that they apply to the biological world. So, I would try to classify these technologies as once which have a biological impact or a bio inspired, and its synergistic learning process were on on the on the left side these three boxes are representative of learning experiences from micro nano systems which would result in some novel solutions frontiers in medicine in biology, and these can use example like diagnostics have we have discussed about bio chips they can be nano micro structures like quantum dots silicon nano wires carbon nano tubes so on so forth.

They can be some therapeutic application targeted drug delivery painless drug delivery or drug release systems again were micro nano systems can be used for some developing some solutions or frontier in medicine in biology, and, then you have these hybrid bio devices were you can develop through tissue engineering a complete organ,, but again keeping the principles of micro nano fabrication or in advanced manufacturing of such processes as applied to the biology, and medicine the boxes on right here illustrative of reverse learning experience which you get through what biology in medicine has to offer, and how you can apply on to some system which would be useful for developing micro nano technology. For example, let us consider self assembly which can be d n a protein mediator are in a mediated the sams of self assembled monolayers.

Again something which naturally available, and you can directly apply this to do some very novel work of maybe nano scale inter connects or micro scale interconnects, which can be part also molecular electronics were single molecule d n a can be used as a basis of conducting wires nano wires between more than two pose; that is another very fantastic example of developing this bio inspired materials like for example, the human skin. So, if you look at skin it such a wonderful instrument can selfi, it can respond it can repair un it can sense, and learning from what mother nature has to offer in terms of this scheme, and trying to innumerate the fabrication technology. So, that you can develop these advance machine in processes is another way of looking to develop this novel solutions or in materials or information processing. So, therefore, it is a synergistic learning experience on the left you have learning from micro nano systems as applied to a biological world, and on the right you .have learning from biological world as applied to micro nanotechnology systems.