Design Practice - 2
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Lecture - 11
Introduction to Micro-Electro Mechanical Systems (MEMS)

Hello and welcome to this Design Practice 2 module 11. Today we will be taking up a new topic on micro-electro mechanical systems or MEMS as we call it and then follow it by sensors and actuators. So let us understand about you know a little bit about the history of how this whole new area of MEMS evolved and let us also understand how you know MEMS was a fallout of the microelectronic revolution because of the whole slowing down of the parameter which is otherwise better known as integration density.

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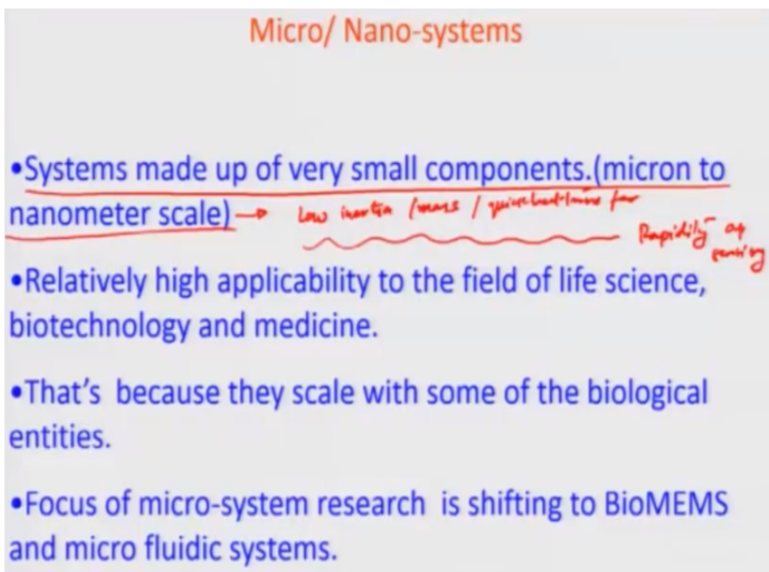

So when we talk about you know micro and nano systems, typically they are systems made up of very small components mostly micron to nanometer scale and such components or such systems find very good applications primarily because these systems have an overall low intertia and mass associated with them and also they have some very interesting properties like for example quick heat transfer as well as because of because of prominence of area the surface area as well as very peculiar characteristics when we talk about fluid flows in such case.

For example if fluids are made to pass through small orifices and capillaries typically there the flow regime happens to be that of laminar flow regime and therefore some very peculiar behavior comes up when we talk about such small dimensions or such small components. So the systems which are micro or nano have found tremendous utility because of all these different properties that they have in several modes related to sensing and actuation.

The question that is being repeatedly raised is the rapidity, the rapidity of sensing because there is hardly any component of its own which can add up to the total time scales. Therefore they are fast responding as systems and they can quickly diagnose something or detect something or even actuate although you have to somehow magnify the effort of such a system to feel that actuation on a scale which is more realistic for components or systems in the normal engineering realm of arena.

So MEMS systems can go into typically sensing of all physical chemical as well as biological entities. It all depends on how you can apply the MEMS sensors and what are the purposes for applying the MEMS sensors. For example a MEMS sensor can be used to detect temperature or rapid temperature rise or you know cooling temperatures. It can be used to detect quick acceleration deceleration.

A MEMS sensor can also be used to find out trace gases which are in the ambience and which otherwise are very difficult to sense. So there can be some characteristic change in the sensors element in terms of its electrical property or optical property which can give you an idea of the presence or absence of certain gases at very small concentration within the environment so on so forth.

So there are diversely defined sensors of that kind which operate mostly at the micron scale and are otherwise better known as MEMS sensors. So initially starting with physical MEMS the MEMS area has now gone into a very different dimension. There is a relatively high applicability of these sensors to the field of life sciences, diagnostics, medicine, biotechnology.

And therefore there is another term which is coiled up with MEMS which is also known as bio MEMS or biological MEMS which talks about how you know systems or how aspects of human body and how they are affected through attack from external organism can quickly be detected using small platforms and typically such MEMS would handle the porous borders between an otherwise human system.

And you know the diagnostic wall which is all the body fluids. So things like for example blood or sputum or urine can very quickly be diagnosed and the advantage that MEMS provides or microsystems provide is that those diagnostics can be carried out really quickly when we talk about such applications. So why there is a relative high applicability of micro and nano systems to this field of life sciences principle.

Because the elements that we are talking about their size and scale with some of the biological entities and also the focus of such systems is typically and the research in such systems is typically shifting to bio MEMS and micro fluidic systems. So we will actually cover a variety of these different systems more on a information basis right now but then later on more from a applicative standpoint or a design standpoint when we discuss some of issues related to micro fluidic sensors, electrochemical sensors and detectors.

Actuators which can do small scale fluid transport or small scale fluid mixing so on so forth and we will give a very nicely presented manner you know what are the some of the challenges which you will face operating things at this particular scale. So when we talk about micro nano systems and historically look into where it all started from.

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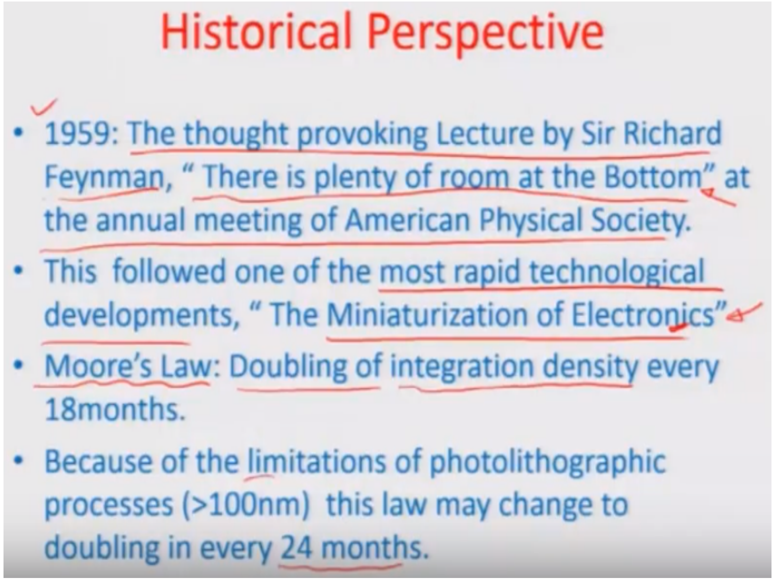

It really actually started from this very though provoking lecture all the way back in 1959 by none other than the great physicist Sir Richard Feynman. The name of the lecture is, There is plenty of room at the bottom. This is very commonly available. It is a American Physical Society lecture which was delivered at the annual meeting by Dr. Feynman and some of the ideas which are mentioned in this lecture right from the way that the whole lot sprayer can be written in a tip of a pin to something related to how visualization can be made possible at such scales and how resolution issues can be handled at such scales.

Really promulgated a lot of scientists around the world to you know follow one of the most rapid technological developments which is otherwise known as the miniaturization revolution okay. So this typically affected the electronics to begin with because this was the most commonly available area which could have direct benefits in terms of small sizes for example look at how computers have scaled down or cell phones have scaled down.

So therefore it was widely applicable to the miniaturization of electronics to begin with and while doing this miniaturization people came across a very natural hurdle which is very appropriately described by Moore whose who has studied and given a hypothesis that the there is a certain rate at which the integration density changes as a function of time.

Because obviously the processes which are used for laying down circuits together or small features together are quite limited in terms of how small they can go and so what Moore describes is a doubling of the integration density every 18 months and obviously this got changed to about 24 months because of limitations imposed by a process which is very important in outlaying some of these small components and features which is known as photolithography.

So this law has now changed to a level which says that the doubling can take place almost every 2 years. So there is a definite fallout you know in the technology advancement because of this constraint which has been added on to the system which is about rate at which the miniaturization density must happen and or may happen because of limitations of the technology. And so because of that a lot of processes which were directly used as fabrication processes in microelectronics got shelved off and these processes were taken up together and put into a new domain which is actually known as micro-electro mechanical domain of systems.

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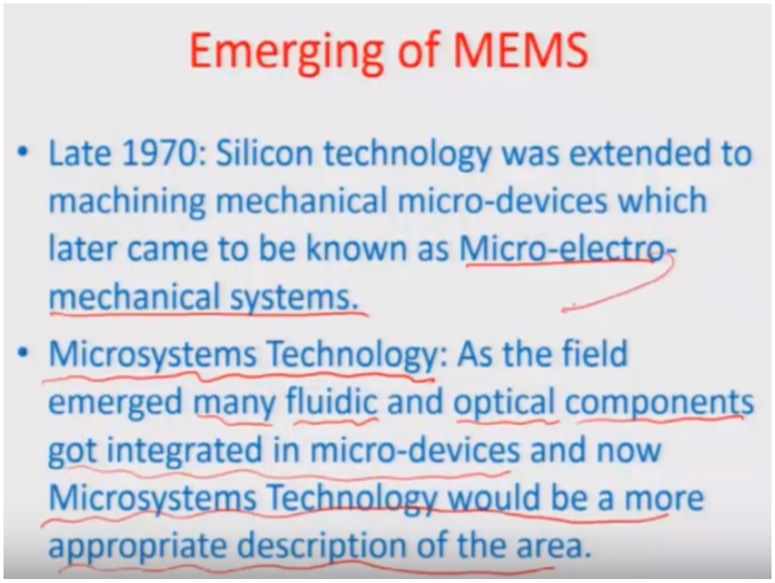

So typically a MEMS system is well known to have one part which is electronic or electrical and a part which is also mechanical. So there is a small component which probably mechanically oscillates or it changes in its way that it bends for example or it changes the surface stress distribution and such a change in signal is because of some happening which happens around that small component.

And that happening could be in terms of maybe change in the overall chemical atmosphere in which such system rests or it could be something because of the temperature at you know of the environment where such a system rests and because of such change in the mechanical aspect of a material if we can somehow be able to translate that or transduce that in form of a change of electronic signal that is what a MEMS system would typically do.

So a mechanical signal being translated into an electrical signal and so the electrical signal obviously is of quite great importance because when we talk about electrical signals they are comparable with machines. They can be more easily integrated through electronic machines and so whatever advancements have been made in terms of displays and readouts can easily come and get added to that technology.

So therefore the advantage of transducing into electronic signal is always highly felt and because of which these micro-electro mechanical systems supposed to deliver very accurately measurements in terms of change in electronic signals. So the whole area of micro-electro mechanical systems can be typically brought under this domain, a unified domain of microsystems technology.

And obviously the mechanical aspect is one but then you know the field has emerged into many other aspects for example fluidic or optical components and together they have all got integrated into micro devices. Now microsystems technology would be a more appropriate description of the area rather than only micro-electro mechanical system. So it is sort of merged into you know systems which are micron sized and do something useful and important.

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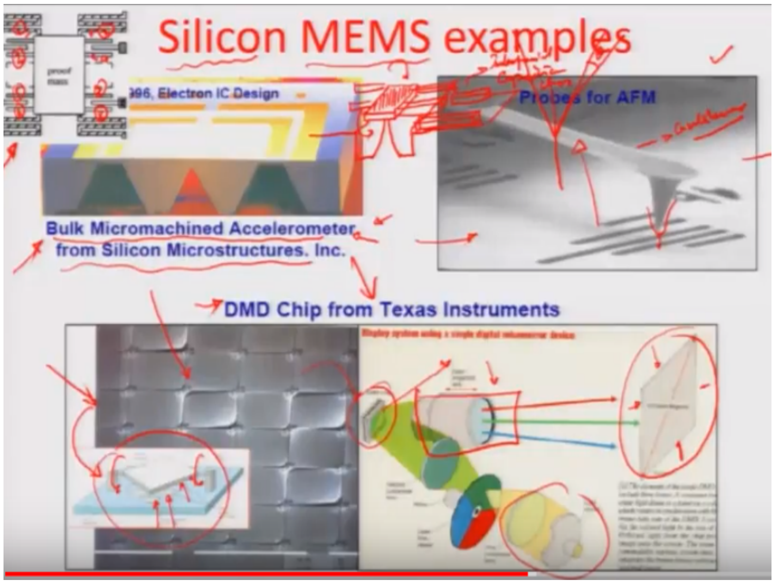

So let us look at some of the concept, some of the products which are available as on today where directly MEMES technology is applied. These are some very interesting features of some products probably some of you probably already know some of these products. So when we talk about the first product it is one of the corner stones of nano technology today which is known as the AFM or the atomic force microscope.

Now this atomic force microscope is a small cantilever beam as you can see right here. This is a structure which is you know scanned under in a cm and the cantilever beam gets projected in shape. It has an atomically sharp tip and the idea is that this tip is able to scan on a surface which basically deflects and bends the particular tip. And so if this understanding of bending can happen maybe in terms of a light beam which is falling in otherwise shiny surface in the top of this cantilever beam and subjects to deflection because of such bending okay.

Let us say for example the beam deflects by theta. So obviously the mirror would deflect by theta by 2 and so based on this such bending what can really map what is the progression of the tip in terms of the z direction and such a z direction can then be topologically mapped as a reconstructed image which would give you an idea of how the surface looks like.

So depending on the resolution of the scanning on a surface one can get a very good perspective of almost a domestic scale features on the surface by an instrument like this. So that is what

AFM or atomic force microscope is. It is again a material or a device which comes under the realm of the micro-electro mechanical systems. Think of it as change in an optical signal because of a bending process which happens right here at this small cantilever tip.

So a mechanical signal being converted into an optical signal and then because of that optical signal an algorithm computing the exact topology over which such a tip scans is what is directly visible out of the probe of such an AFM. We have other examples. For example this right here is a very interesting application of MEMS, particularly physical MEMS. This is the digital micromirror device, a chip that Texas Instrument makes and is very common place with screen projectors.

So this particular chip is again based on principle of microsystems if I looked at this surface right here it is an array of mirrors. All these mirrors are probably a few microns by few microns in width and each of them are capable to twist and deflect in a manner so that the cross-section of the mirror is represented somewhere here okay. So each of this mirror is actually pivoted and it is standing on 2 pillars as you can see.

And these mirrors are being able to get deflected through electrical fields which again formulate as a function of the electrodes, the discrete electrodes which are there on the base surface on which this particular mirror assembly is standing. So therefore there is a tendency of this mirror to rotate about this pivot point and the mirror of course is a reflector. So let us say there is a beam of light which falls on such a chip which is an array of such mirrors again and you know one of the beams rotate out of focus.

This is where the beam gets guided into this particular lens here which projects it on a bigger screen by magnifying the particular image. Now supposing there is a beam which goes out of place and goes out of this focus so the small micron by micron dot which is formulated as a result of otherwise reflected light into this focus and now it is away from the focus comes as a dark pixel and so therefore there are series of dark and bright pixels which could make an image.

And such an image could be then projected on to a particular projector screen okay and this can be one of the very fantastic examples of how you can digitize an image okay with respect to electrical signals. There is another, yet another example which is very commonly used in all you know safety devices mounted with an automotives and this is the bulk micromachined accelerometer from silicon microstructure which is a company which was formulated to address this issue of airbag actuation within automotive.

So in this particular example in the you know the accelerometers there is a proof mass and if I looked at sectionally how this proof mass would like it is something like this. It is a small structure which is mounted and pivoted on a surface and basically it is capable of rolling, pitching you know or yawing different motions can be executed by this proof mass. Further this proof mass also contains certain structures which span like wings.

Which are on both sides and as you can see these structures here let us say this 1 and 2, similarly 3 and 4 and when I am talking about a structure I am talking about these structures okay; similarly, 5, 6, 7, 8. There are 8 such wing-like structures which are an integral part of the proof mass and simultaneously there are certain structures which are outlaid on the surface itself okay.

So there are structures printed in metal which are outlaid here on the surfaces and whenever there is a motion in terms of rolling, pitching, yawing etc. of these proof masses there are going to be interfacial capacitance change. So interfacial capacitance change which can be then calibrated with respect to the acceleration deceleration which goes around and that results in actuating signal which can open up an nitrogen bottle which can otherwise fill up the airbag.

So this is a pretty interesting product you know the silicon MEMS foundries are able to do such a complex fabrication process. They are able to handle it through a multimasking process step. We will talk briefly about the processes later on in the particular MEMS domain that we are talking about. So these are some very nice examples of physical MEMS which can you know lead to sensing of topology, sensing of acceleration deceleration and also light guidance etc.

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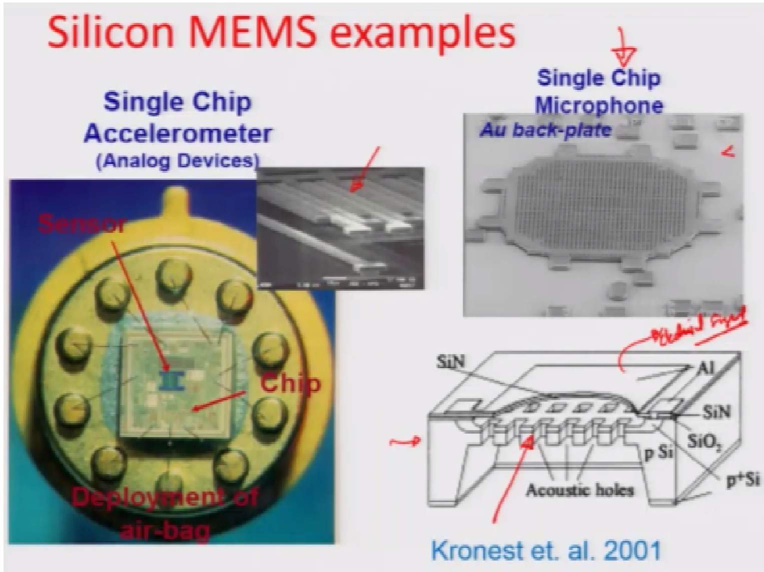

There are couple of other examples which I would like to show. These again are single chip microphones based on a small perforated film which has a piezo layer and there are acoustic holes on this film because of the perforation and so whenever there is a sound wave which strikes this structure from one side there is a response in terms of a electrical signal which happens and which relates to the transducing of the acoustic waves into electrical signals.

And so the idea is that whatever electrical signals are generated with respect to the compression and rarefaction waves which are emitted from somebody who is speaking has passed through a set of amplifier network so that it amplifies and then that amplified electrical signal can be sent to the bass and tweeter of a speaker which can give a larger amount of you know or a larger magnitude of the sound waves and so therefore a small button microphone as is available these days is typically based on such principle.

So this is again another very nice example of silicon MEMS. This again is a capacitive accelerometer fabricated by Analog Devices. This is also based on the structure of interdigitated electrodes or com drive based orientations which would sense very accurately any change in the acceleration deceleration etc. So these are some silicon MEMS examples.

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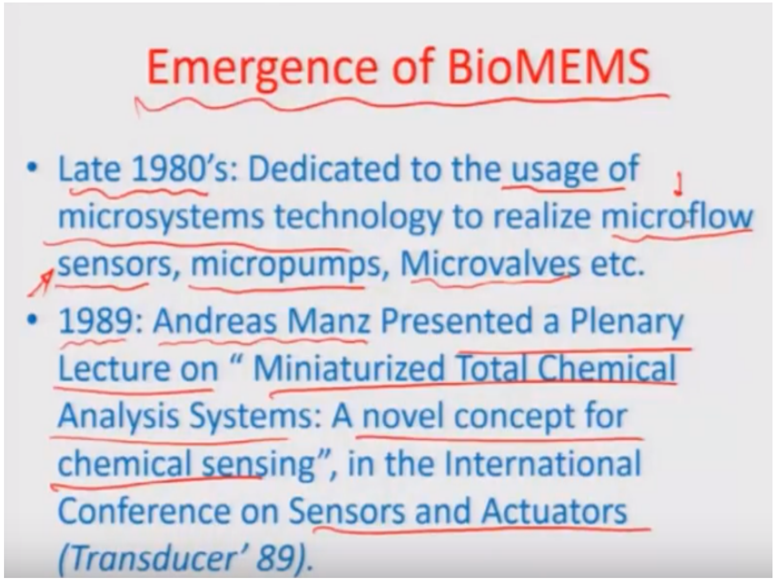

As I told you earlier briefly that the MEMS kind of emerged into the chemical domain in the late 1980s and people realized increasingly that whatever was used in the physical measurement system and because of smaller inertia or smaller you know contribution of its own mass would sensitively detect. There can be an increased usage of this technology to realize very small flows which are otherwise known as microscale flows.

It can also be used for designing sensors which are related to some of the body fluids. It can be used to control flows, for example you could mix or valve or pumpflows at a small scale using such small structures and features and so by small structures and features we are referring to smaller channels, smaller actuating systems you know smaller topologies within which flows can be confined.

So the very seminal paper which you know kind of change the dimension of the thinking of people who are in this area of micro-electro mechanical systems. So Andreas Manz presented this Plenary lecture on Miniaturized Total Chemical Analysis Systems, a novel concept of chemical systems or sensing and this was presented at the international conference on sensors and actuators in as far back as 1989 beyond which this new area of the integration of microsystems into biological diagnostics biomedical you know engineering etc. started.

And there was the emergence of this new area which was known as the BioMEMS area and in fact immediately after this there was a another initiative by the US UOE towards mapping the whole human genome and it was a seven nations initiative funded by again department of energy where the utility of such small miniaturized platforms to do rapid analysis was greatly felt and lot of technologies were developed around this time to address issues related to gene analysis, gene sequencing so on so forth.

So that created a merger between both these areas. So MEMS emerged into what you otherwise know as BioMEMS.

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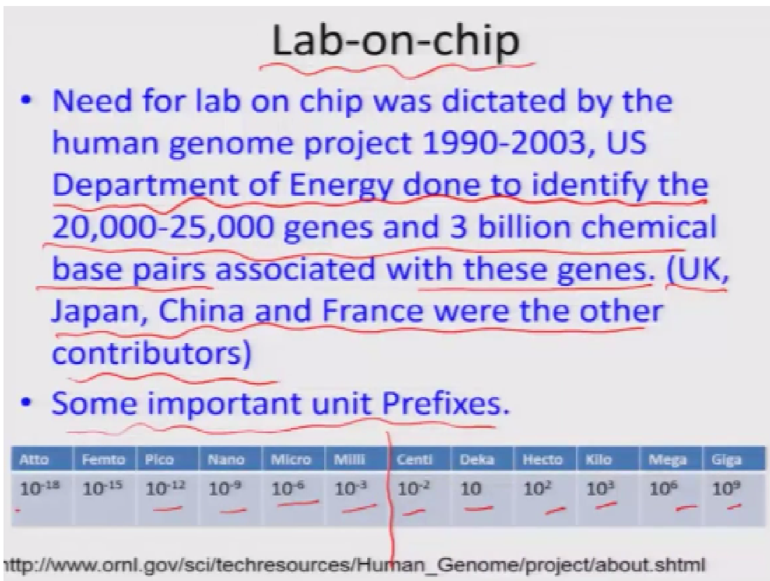

So you know there was another initiative which was carried out you know which we call you know again the lab-on-chip technology which is again a fallout of MEMS where microflows are actuated within small platforms miniaturized platforms and with those flows on board you are able to sense some of the biofluids, some things related to you know the 3 billion chemical base pairs associated with various genes.

Obviously UK, Japan, China, France were some of the major contributors in this zone. And when we talk about such device, lab on chip devices, they are basically small systems, miniaturized systems which would perform some chemical operations and they would b able to give out immediate transaction from a chemical to electrical or chemical to optical you know change in the signal and it would be then identified as a diagnostic tool.

So based on this initiative there had been many research work carried out around the world and today the whole area of biomedical devices are resting on this one very important technology or finding which happened around the late 80s and proceeded since then and lab on chip is now to a scale where there is a dedicated journal by the name of lab chip which publishes material, research material around the world of initiatives in this particular area.

So while understanding the various scales across which such devices work, some important units which would typically come as we go along are this Atto 10 to the power -18, Femto -15, Pico -12, Nano -9, Micro -6, Mini -3 and then you have Centi, Deka, Hecto, Kilo, Mega and Giga. So these units are of relevance particularly ones which are sub millimeter scale as far as the lab on chip or microflow based sensors are considered.

And what we are going to do or what we are going to learn in this particular set of modules in this particular week is about such sensors and actuators which has microflows in picture and is able to run on lab on chip devices.

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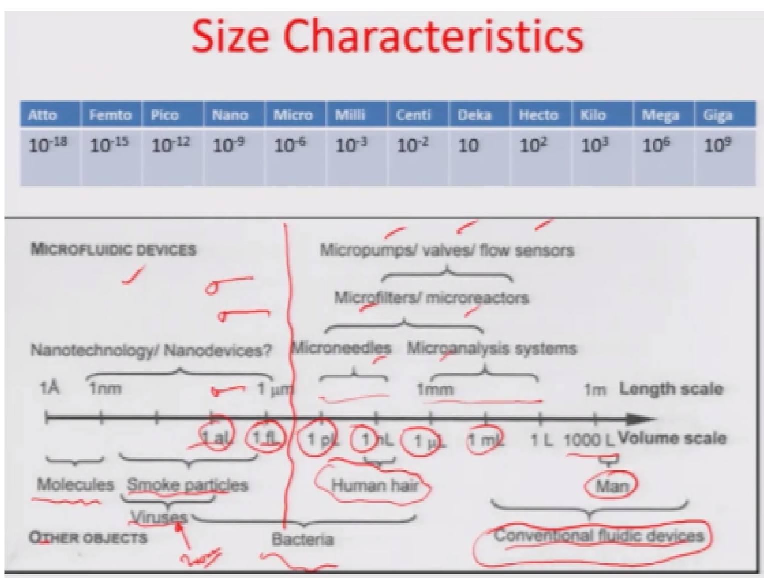

When we look at size characteristics of various microfluidic devices there are micropumps, valves, flow sensors, microfilters, microreactors, microneedles, microanalysis systems so on so forth and they all fall within the you know the length zones which are mostly starting from the millimeter range going into the submillimeter region and if I consider what are the kind of volumes they handle they go from one millimeter onwards downwards to almost about 1 Pico liters.

When we compare some of the objects which are of real life and which probably may be of known nature to all of you. Man for example is around 1000 liters by volume of the total confinement of fluid that he has within the human body. So are convention fluidic devices. But when we talk about such devices as micropumps, valves, flow sensors they typically have dimensions of that volume that a human hair would typically have okay or some of the bacteria would typically have. Bacteria of course goes much smaller all the way to the Atto liter scale.

All the micron devices kind of end here and then you know to the further left you have devices where one or more dimensions are in the nanometric length scale which means this is a submicron domain and you have volumes of the order of Femto liters or Atto liters hit upon where you are talking about objects like molecules, smoke particles, viruses.

Typically all these viruses are about few hundred nanometers in diameter, you know 200 nano meters upwards maybe and so this scale here right here is what we know as the nano scale for such fluid existence. So I would like to end this particular module in the interest of time and in the next module we will look into some other aspects related to MEMS and sensors. Thank you very much.