Compliant Mechanisms: Principles and Design
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Lecture – 62
Compliant suspension mechanism in microsystems (MEMS)

Hello, in the last lecture we looked at a number of compliant mechanisms rather a catalogue of compliant mechanisms. There are still, if you left and that pertains to what we call compliant suspensions and these suspensions are particularly useful for micro systems components and devices or rather what we call micro mechanical parts, that are used a lot in the field of MEMS that stands for Micro Electro Mechanical Systems. So, let us look at what the suspension compliant mechanisms actually mean and how they could be used in micro applications.

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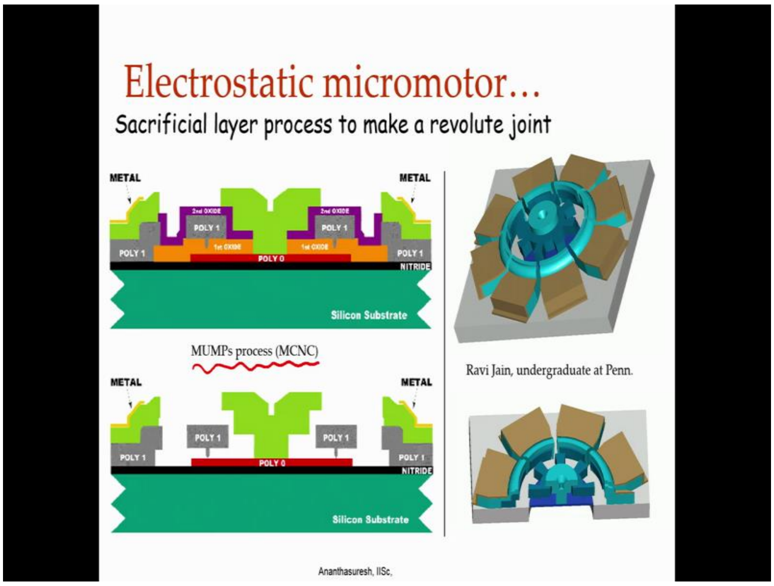

When micro electro mechanic systems field developed, people tried to develop elaborate processes to make such a simple thing as a hinge. What is shown here is what is known as the MUMPs process which is still actually available in commercial form as S Y MUMPs and the other polymumps process that was started at (Refer Time: 01:28) centre of (Refer Time: 01:30) in the USA in CNC like a foundry, at the time they developed this process to make actually electrostatic motors, that was a process developed by MIT, Berkeley and ATNT; the labs. So, it was very elaborate process with many layers; three sacrificial layers and it was quite complicated.

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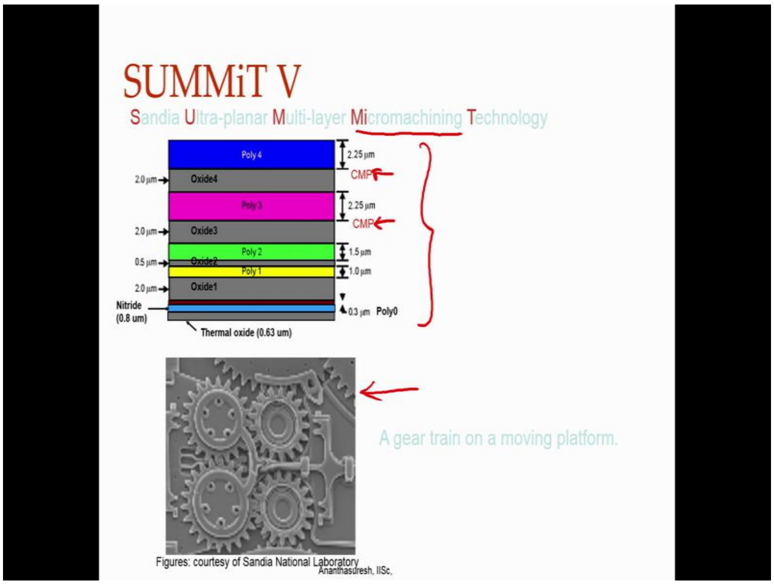

And later Sandia labs developed in even more elaborate process, where there were four structural layers and three sacrificial layers and two CMP steps that is chemical, mechanical polishing a very elaborate process which they called summit in many ways it was a summit of the peak of micro machining or micro fabrication techniques.

They could make things like this; there was a gear train which is on a moving platform in order to make such complicated things, they needed to develop such a complicated process.

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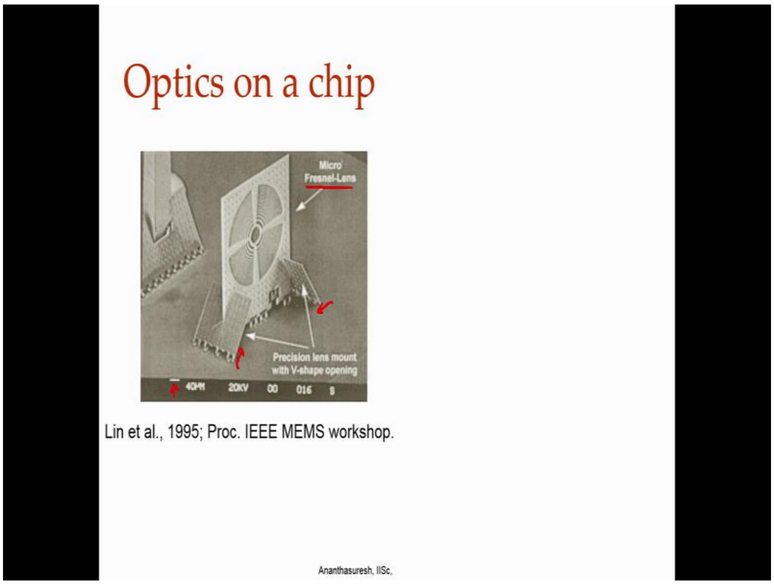

But or they could make optics on a chip here is a Fresnel lens that is actually made to stand upright on a chip and this little thing here is says this is 40 micron. So, this little bar over there we see a little bar was 40 micron second, you can see how small it is. Gradually there are some locks here and there all done on the chips so that what is made flat to be planar is actually pushed up to become 90 degrees or perpendicular to the chip.

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So, all of this required sophisticated micro fabrication process, and here is a zoomed in view of the gears and slider and pings and so forth that came from Sandia national labs.

Very nice processes and this actually a micro lock, you can see lock is a very complicated mechanical or mechanism and that was possible to realize that in micro fabricated form.

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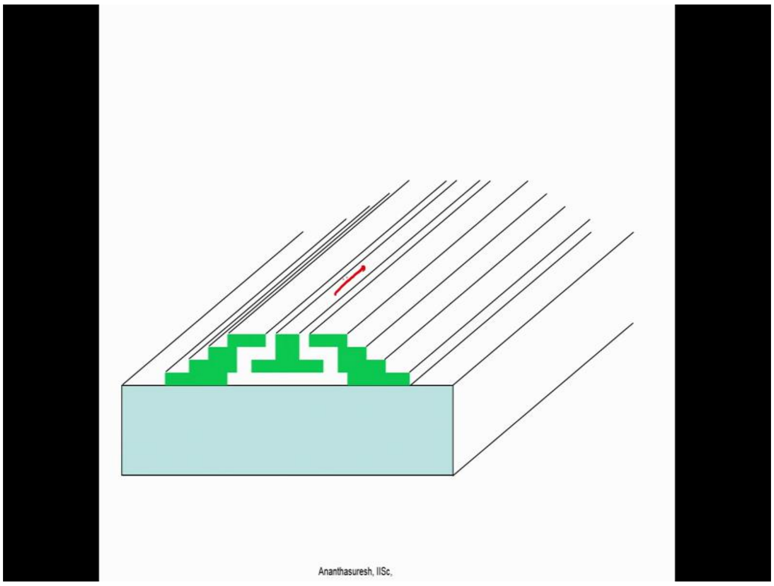

And the process used for such a simple thing as a slider, one can make something like this where this green portion can simply slide in that direction. If you think about that in order to make it free, you need to have the sacrificial layer; the yellow layer when you sacrifice it that becomes free, it can move along the direction that we showed.

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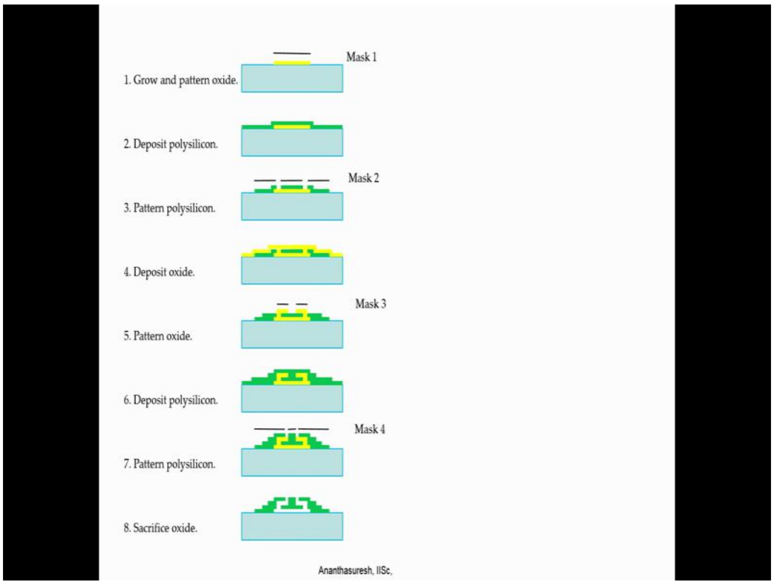

So, process for that is re-elaborate; you need four lithographic masks so make it, instead what people very quickly in the MEMS field realize is that; instead of making a slider that can go in and out now as we showed in the previous slide that can slide like this. Instead of that one can go for a compliant slider.

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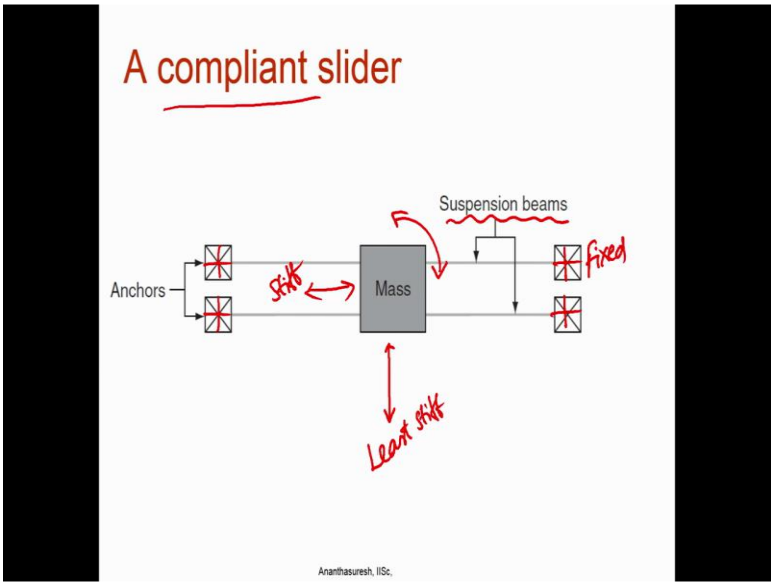

What do you mean by compliant slider? It is a mass which can be slide up and down like this; in this two directions. So, when it does, there are no guide ways for it; which is a good thing because at micro scale the friction and where are really problematic and you do not want to have rubbing surfaces. So, we suspend the mass with what can be called suspension beams and here is where it is fixed, it is fixed here and here and here and here, the other beams are now suspended, so that this mass elastic surfing of the beams.

Now, in this direction it will be least stiff or most flexible whereas in this direction, it will be very stiff and with some effort we can make it stiff in the out of plane direction and notation and so forth. This is what we had discussed the very beginning of the course where we said the suspensions when you design them or elastic pairs as we had called, they have to be design in a way that in the direction of interest they should have most flexibility and the other directions, they should be most stiff. And compliant slider is one which duplicates the motion of a sliding joint or a prismatic joint using this beam suspension.

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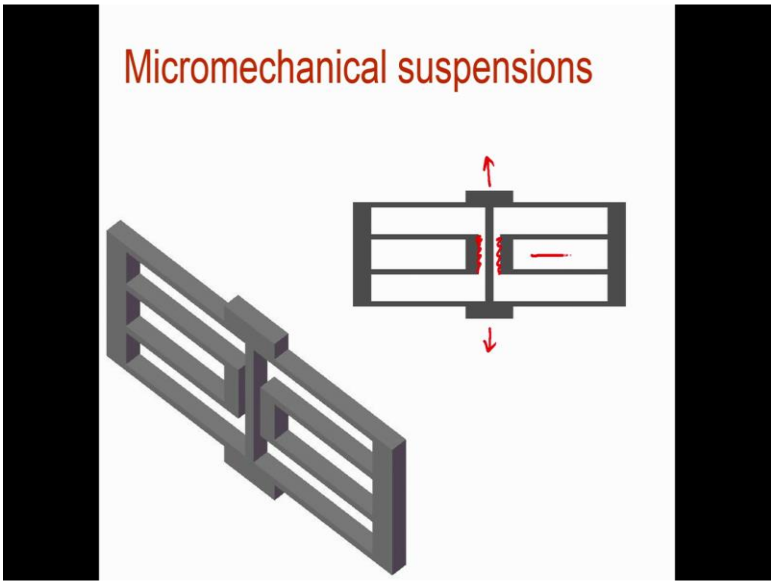

And there are number of suspensions, this is a folded beam suspension which is fixed over here and this one will be very flexible with that direction this direction, but very stiff in these direction.

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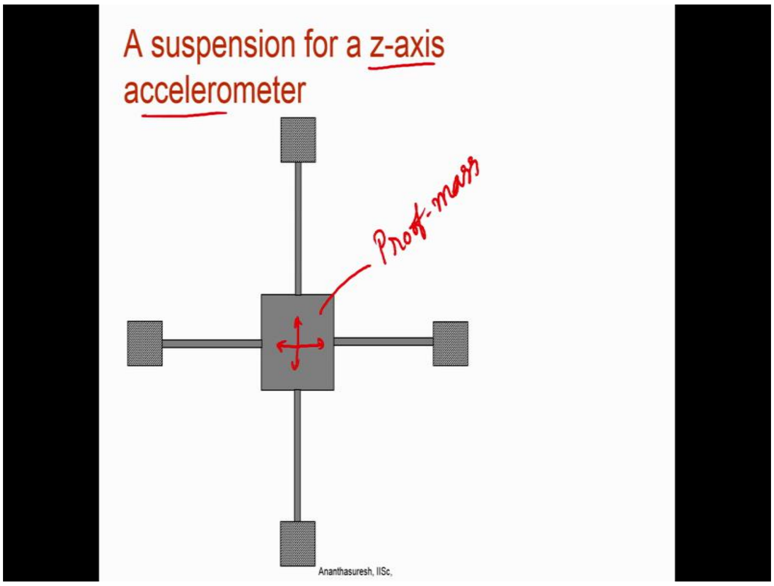

So, very popular suspension mechanism with basically replicates the prismatic joint without having to have rubbing surfaces or assembly or where or friction. A suspension for a z axis accelerometer because this one will be very stiff in the in plane directions, but flexible in the out of plane direction so that becomes is z axis accelerometer, where this mass sometimes it is actually not sometimes, it is actually widely called a proof mass of an accelerometer or a gyroscope and we have many suspensions like this.

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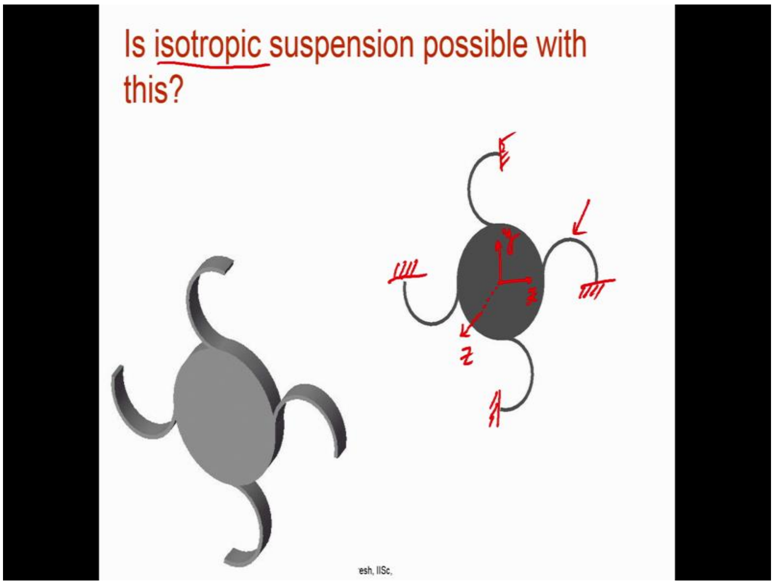

And here is one what can be called an isotropic suspension, so where you want to have in this direction, in this direction as well as out of plane direction you want to have the same stiffness. So, we can play with a shape of this and fix them over here like this whether they are moved in the x direction, y direction or out of plane z direction will have the same stiffness; there are number of designs that give you this isotropic behaviour.

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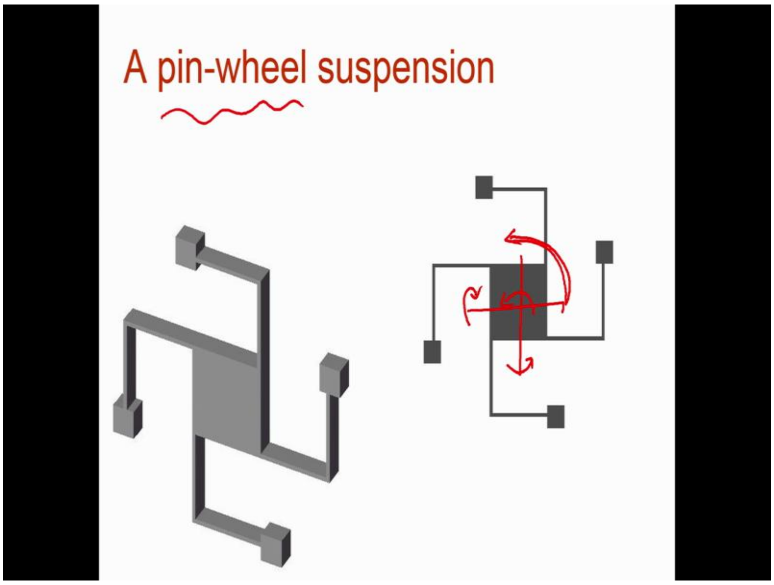

Here is something called a pin wheel suspension that also has the little bit of isotropic nature, you can say what stiffness you want or even rotation stiffness rotation this way and then tilt about that axis and tilt about this axis all of those and in of course, this what I have written rotation is tilt about the z axis. For all of those one can design the suspensions to make this prove mass suspended with some stiffness; multi axial stiffness in the weather tube want for the application, a lot of sensors in actuators use these suspension.

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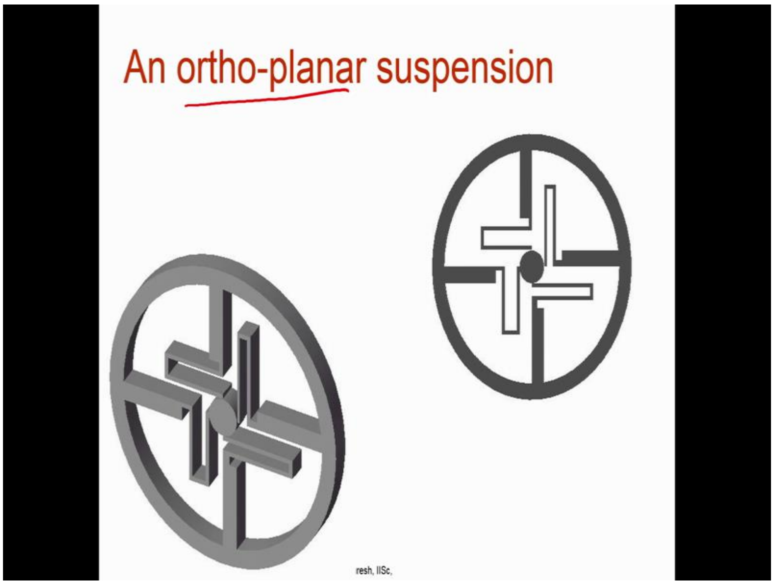

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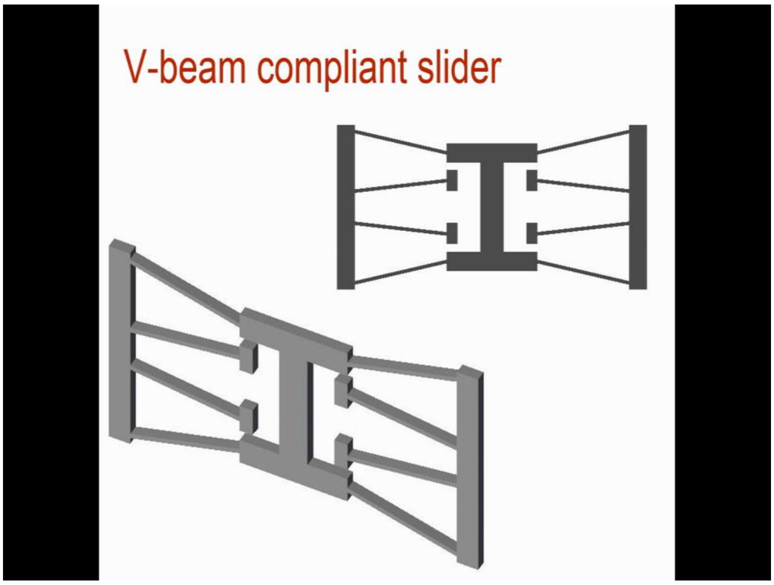

Here is a folded beam suspension and, but that is for ortho planar motion; that is some that lifts out of the plane with certain stiffness characteristic. Here is a variant of the folded beam suspension where there are V-beams instead of parallel beams and this is a very interesting two axis micro mirror mechanism, which was done by a gear which was spin off from 8 into bell labs and bell labs was closed down.

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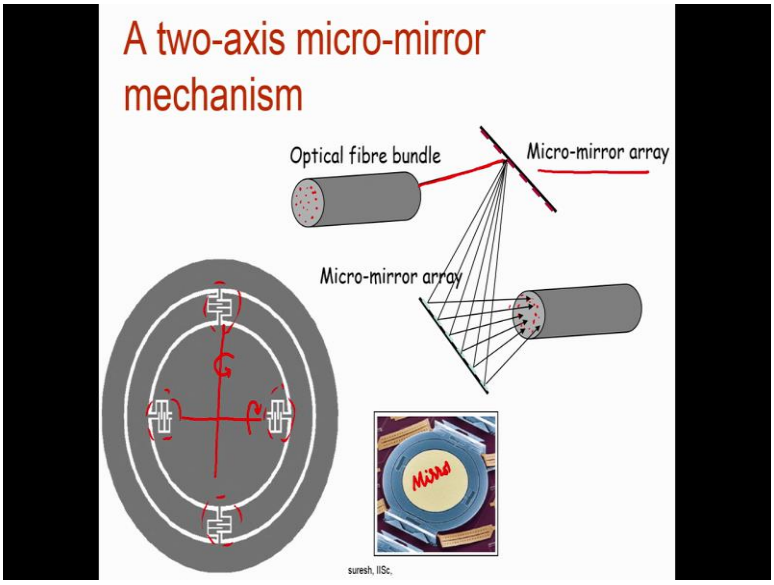

What we have here is a mirror which is shown here, it can tilt about this axis; it can also tilt about that axis. So, it can tilt like this and like that which is used for optical fibre aligning now in the sense that there are many fibres in a bundle, each of them carries different signals there also need to go to different points over here in other bundle. So, you have an array of micro mirrors over there and here, they will take one thing that can go to any point here.

So, it is more like exchange a post office where let us come to one post office and there we have to go to different post office around the world or country. So, this thing is done for writing the optical fibre signals; what is n is mechanical because you can do it very fast with not so much of loss and in a very flexible way, this can suddenly this signal that is convert of one fibre here can be configure to go to any of these in a matter of few micro seconds and milliseconds.

So, this is a suspension where you see; these are the actually compliant beams arranged in a particular way to make this happen.

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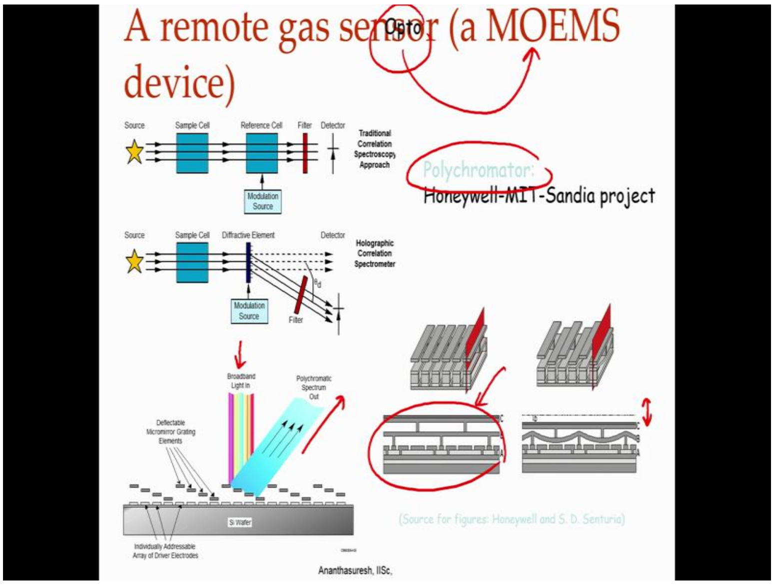

And here is another one; it is a remote gas sensor is a micro opto electro mechanical system as what we do call MOEMS. This is the very interesting thing where a beam would actually move without any deformation, any beam we take it will not go straight down like this, it will have a deformation bend shape. This one actually go straight up and down in a very interesting design or a suspension that this has, now this is called a polychromator which is a correlation spectra meter device, where remotely we can identify a gas or even a solid material liquid material by using this modulation source which is what this does, what this array of beams with a suspend in a particular manner they is the take broad band light and then produce a spectrum of any colour that is why it is called a polychromator, but what you have is basically beams configured in a particular way to get this.

Actually a topologist algorithm giving such a design would be very nice, but it will be very tough, it is a very engineers design to make a beam go up and down without bending.

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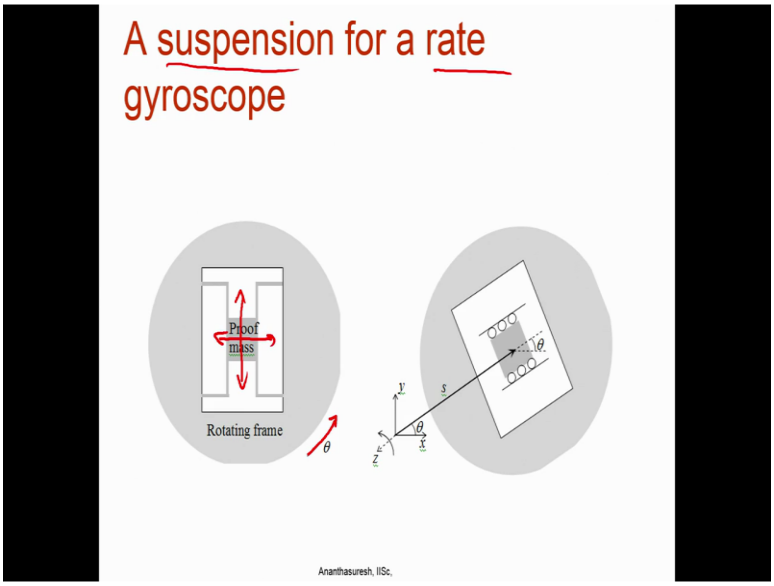

And here is a suspension for a rate gyroscope, where we need to have a proof mass be accelerating one direction when the rotating frame, this rotation happens here it is start moving the other direction it (Refer Time: 11:54) force that needs to be suspended so that it has two natural frequencies that are designate meaning the same natural frequency for two different modes of it (Refer Time: 12:04) Foucault pendulum that is a suspension for it, these a Foucault pendulum their equations.

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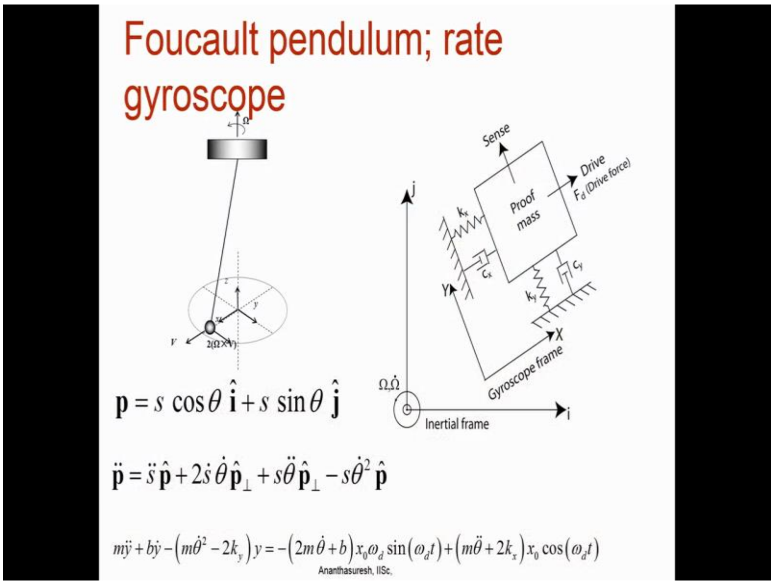

So, you can look at that, so you can have a pendulum suspended can have motion like this or motion like this in a perpendicular way. So, you put energy into this when the frame starts rotating then it will change the plane.

So, what is oscillating like this will start oscillating at a inclined angle, so would have seen some museums where this a Foucault pendulum, our gyroscopes are actually based on that principle.

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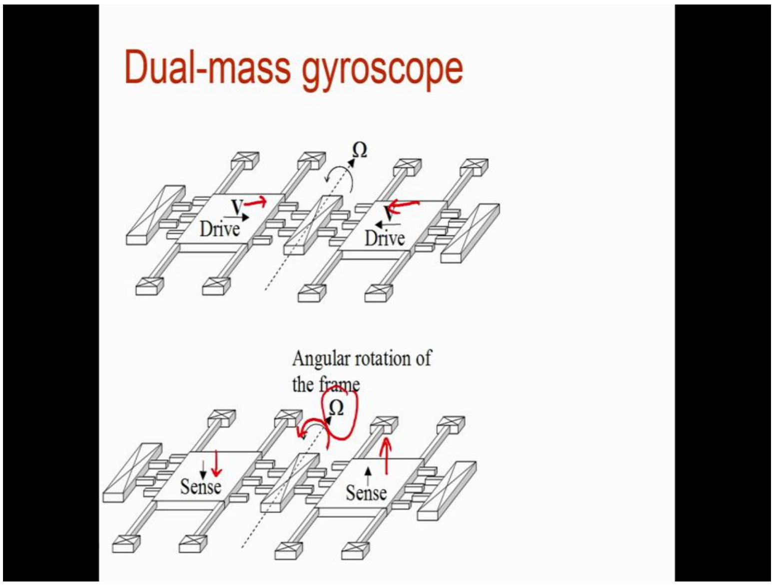

So, if there is a drive in this direction for two of this one goes like this, other goes like that you drive them. When there is a angular rotation about this axis as it is shown, one of them will be moving down other will be moving up; these two because the direction (Refer Time: 12:59) is force mega cross v. So, one of them will go down; other will go up in capacitance between the moving proof mass and the electrode underneath will tell you what the angular rate is; we can measure that. There all interesting suspension mechanisms with compliant things, here is one of those and another one.

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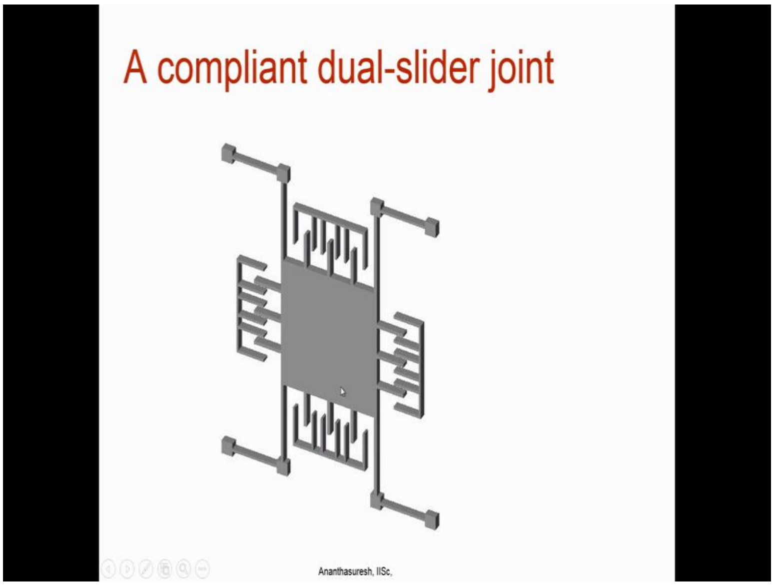

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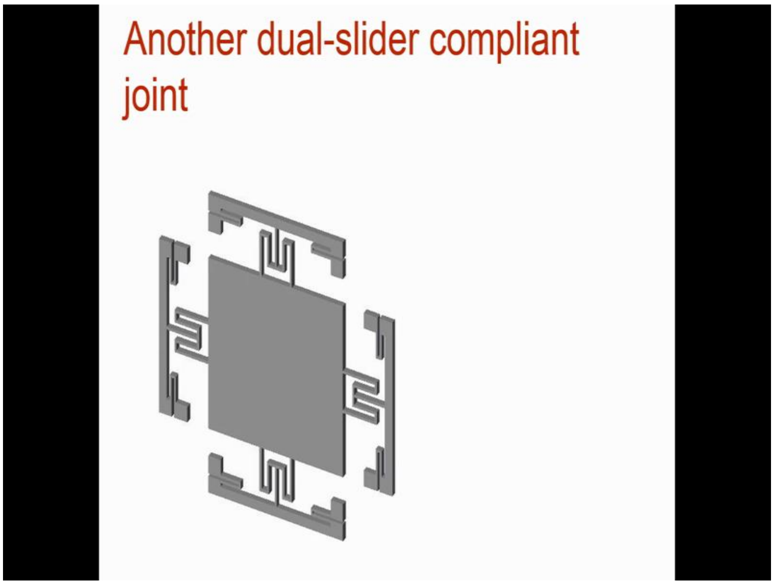

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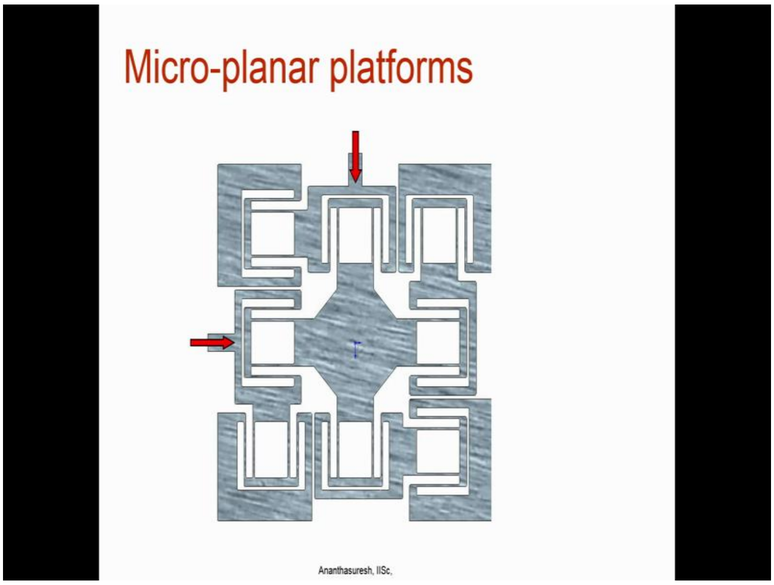

And another one; this one is a very interesting one actually we should actually see this. So, this one has 8 of the same building block by building block I mean one of these. So, such things 1, 2, 3, 4, 5, 6, 7, 8 are there for central thing here; if I move it let us say I push on this one, it moves purely in the y direction. We are applying force in the y direction see which was the four building blocks are actually moving. So, what are moving when I do this, this, this and then this and this others are not moving; there is absolutely no motion in the x direction. In other hand, when I push in the x direction; the other four that one not moving or now moving, so this, this and this and this are moving and there is no motion of y. So, this is a perfectly decoupled x y compliant suspension.

So, there are a number of suspensions like this with different characteristics and here is one which looks complicated.

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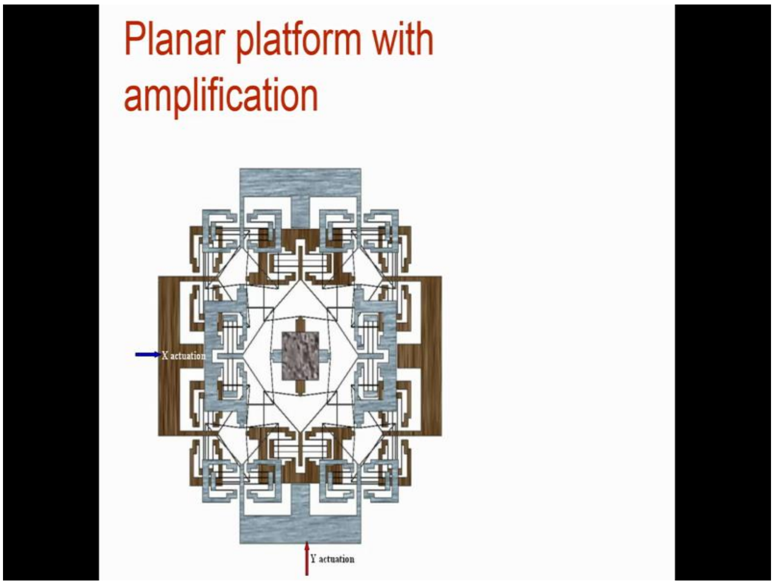

I do not have a device for you to see today, but that is in two layers; this is like the one that I showed, but this one has amplifying compliant mechanism added to it that is, when you move this one direction it will amplify the motion of the stage, but it will still written the decoupling feature that we talked about that moves only in x direction y direction. You put something in x, something in y; this will move only that much in x only that much in y will relate to it to how much you have applied and of course, there is a amplification feature in this particular mechanisms that you see on the screen, this particular one in two layers.

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So, moving on to another mechanism we have lot of grippers, so that was the mechanism with two layers and we have this grippers; we have a separate lecture on micro machine grippers so I will not elaborate on that. So, it can see how we can make with different materials spring steel grippers, we can see our one rupee coin and well you will see the motion of these things later on.

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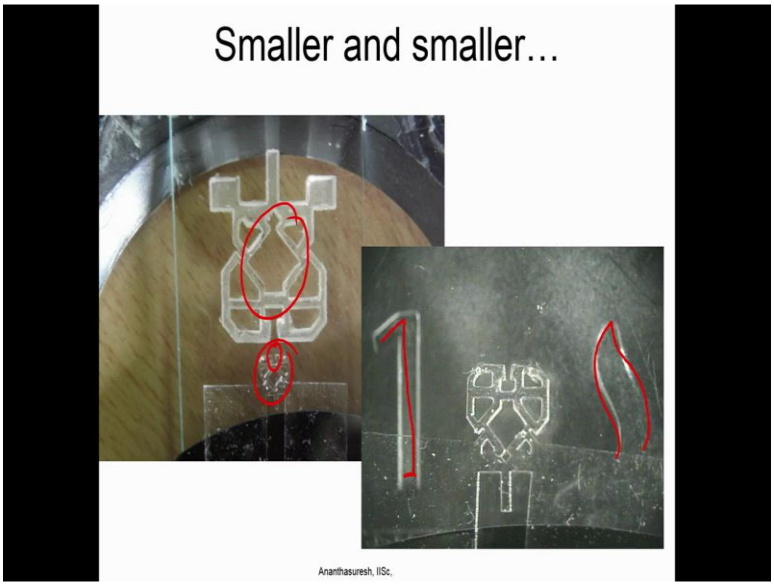

And we can also use smaller and smaller of this grippers with in this case p d m s material. Now that was a coin next to it, but now what we have is actually one in the one rupee coin things started becoming and this is the thumps up on our one rupee coin so we can make things we make this and then we make this we make something that goes here.

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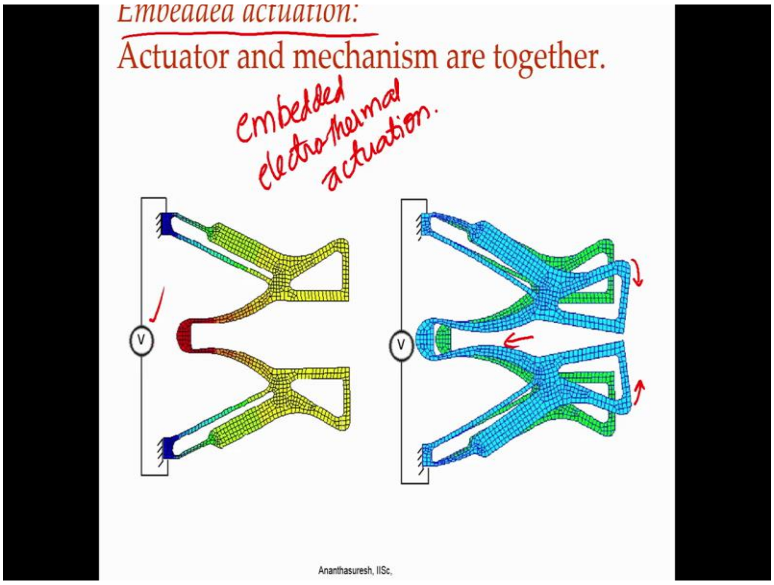

So, we will talk about how small we can make smaller enough that we can actually handled biological cells in division biological cells using compliant grippers and moving on to in (Refer Time: 16:20) suspensions. Now we have a number of devices let me see there is an interesting one that I can show you quickly, I think folded beam suspension is something that I think so I useful to see.

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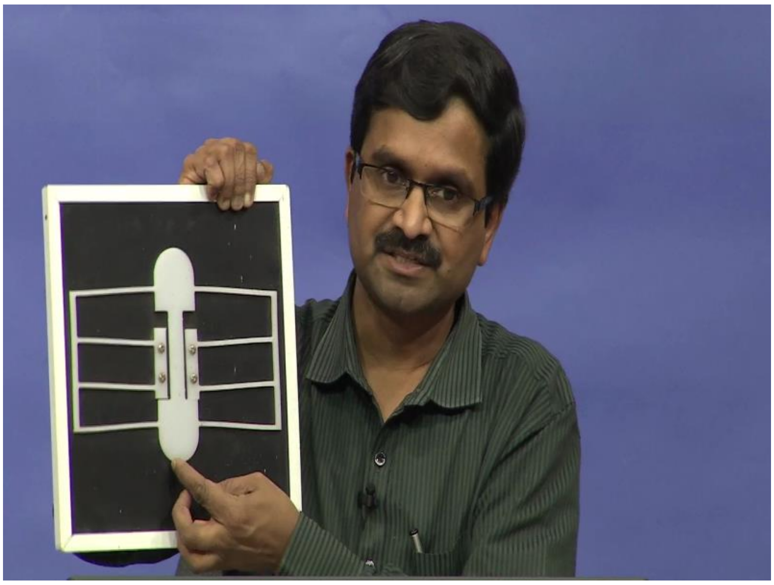

So, here is the folded beam suspension, so it is fixed over here and here and very easily there is not that much stiffness here and if I start moving it here its actually quite difficult I cannot actually move in the x direction it very stiff I can I cannot move it.

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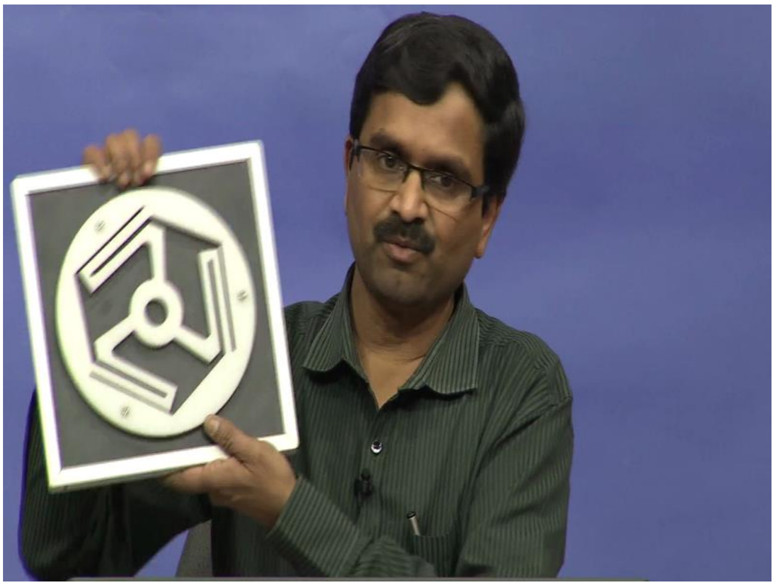

It is very stiff in x direction very flexible in the y direction. Let me show in ortho planar suspension that we talked about, this particular one. This is something to move up and down, so if I keep it like this I can raise it here. So, if let me put it; it can be raised, so this suspension actually is useful for moving things up and down very precisely; all of these are very useful precision mechanisms. So, that is another important application of compliant mechanisms, where you can have very precise motion because there are no joints there are is no back clash, there is no friction you can have very precise motion with compliant mechanisms and the suspension that we are talking about also application in precision mechanisms.

Now, let us actually move on to actuators; micro actuators. This particular one is an actuator it is called actually embedded actuation, this is embedded actuation; embedded electro thermal actuation that is mechanism and actuator need not be separate as it is at the macro scale most often. Here all we are doing is; we are applying a voltage between two points and that creates a differential thermal expansion device and it will deform like it you shown, here we do not need to apply force here that is in at necessary we can just apply voltage and that creates the actuation; that is the electro thermal actuation.

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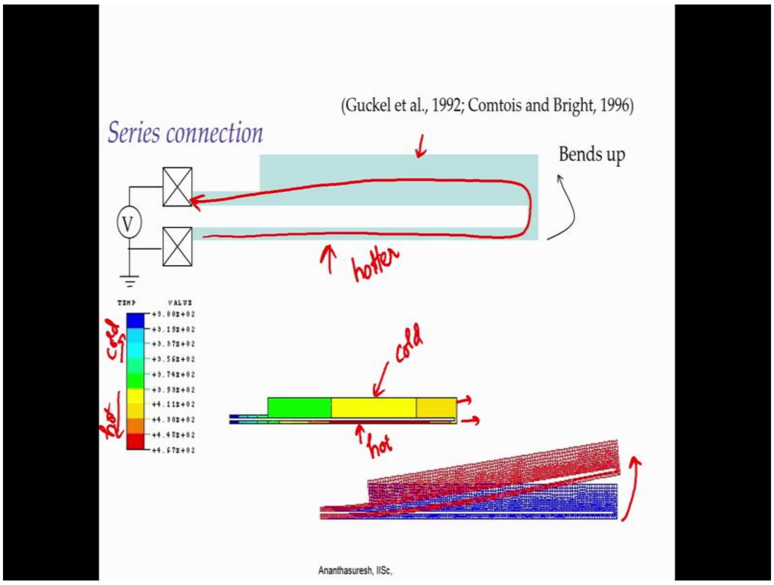

So, when you have a folded beam like this, if you pass electric current by applying voltage as it is shown here then it would simply expand. So, there will not be anything interesting happening with that; you simply expand here. The movement you make it slightly a symmetric, so something like this, now the current goes through this and then comes back here. The current density here will be not higher than current density here, so this gets hotter as we can see here; red colour means hot, the other colours lower colours here; this is hot and this is cold colours here. So, this is literally cold then this expands more than that, so the best way for it achieve equilibrium is by rotating as it is shown they are called heat actuators or sometimes called for fun (Refer Time: 19:52).

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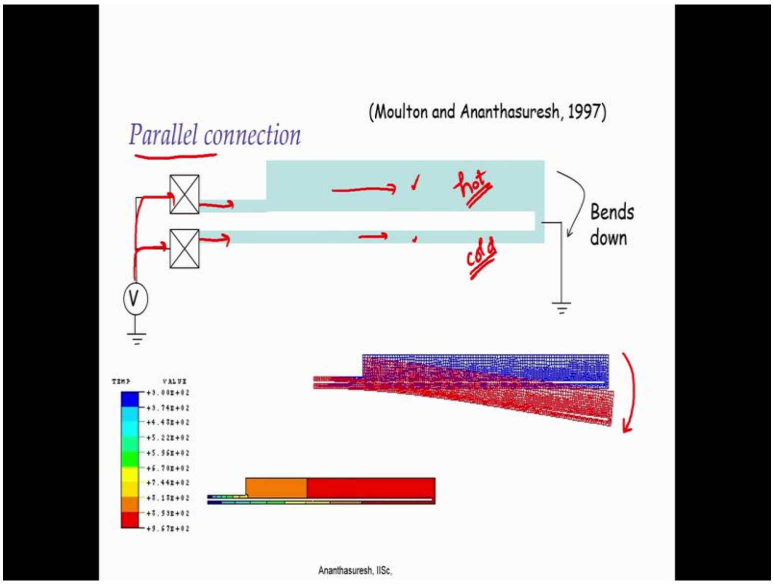

If you connect them in parallel instead of series then the current here that comes gets distributed between this and this and more current flows through this then this because this has less resistance compared to this one. So, this now gets hotter than this; this becomes the hot on and this becomes the cold on and it will start moving like this.

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Now you saw the same device by switching the electrical connection series to parallel, you can actually make it go that way or this way that gives you a way of designing complicated things. This movie may not play, but it was made with silicon because I do not have the new file here, but it will show that the it will move like this and this portion actually gets little red hot and silicon can take high temperature like 500, 600, 800 without any problem and what you see here of the two probes that apply the electrical power supply and electrical potential voltage.

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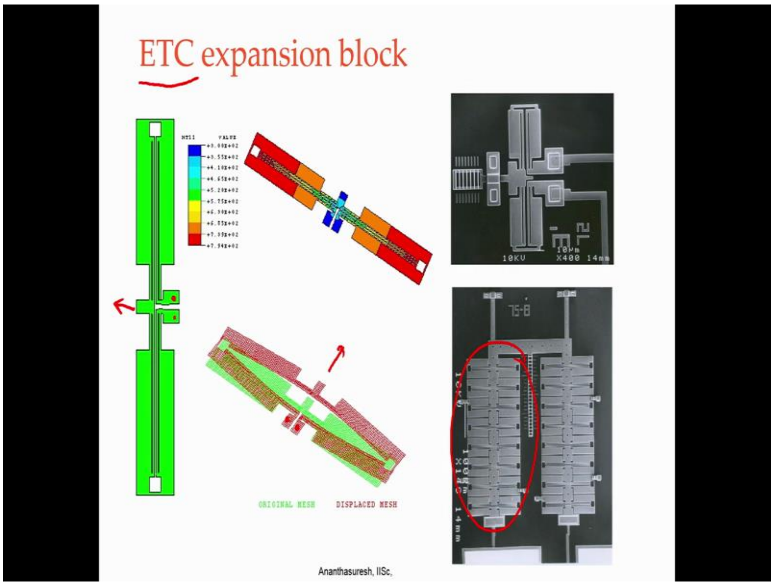

This is a electro thermal compliant expansion block as you see here this particular one has a simulation shows is going to move like this upon applying voltage between two points that is this and this if I do, this will move like that if I put in a ray of them; it actually acts like a linear activator. So, micro activators can be done again what is here these all our compliant mechanisms principles being there it may not appear that way that it is essentially a compliant mechanism, but now actuated using electro thermal method.

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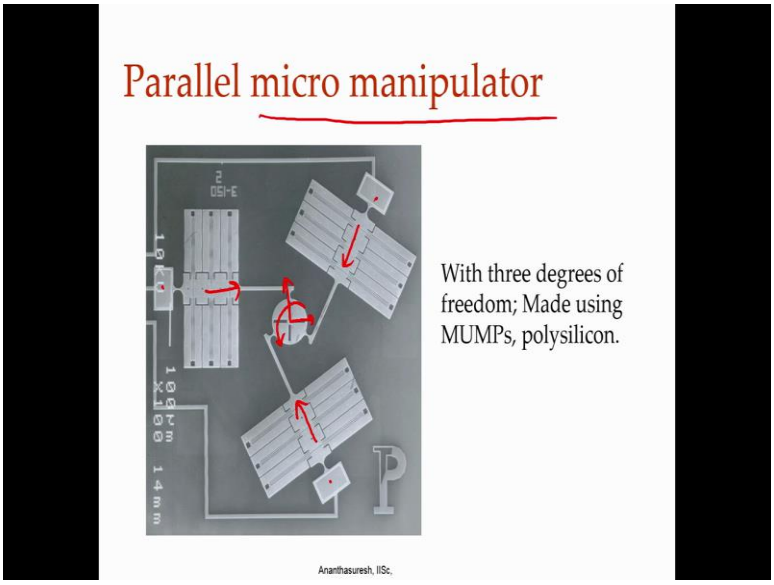

And one can make a parallel micro manipulator which has three degrees of freedom; x motion y motion and rotation by changing voltage here and these are like parallel (Refer Time: 22:08) that will expand and contract and you can actually make it like a parallel planar parallel manipulator.

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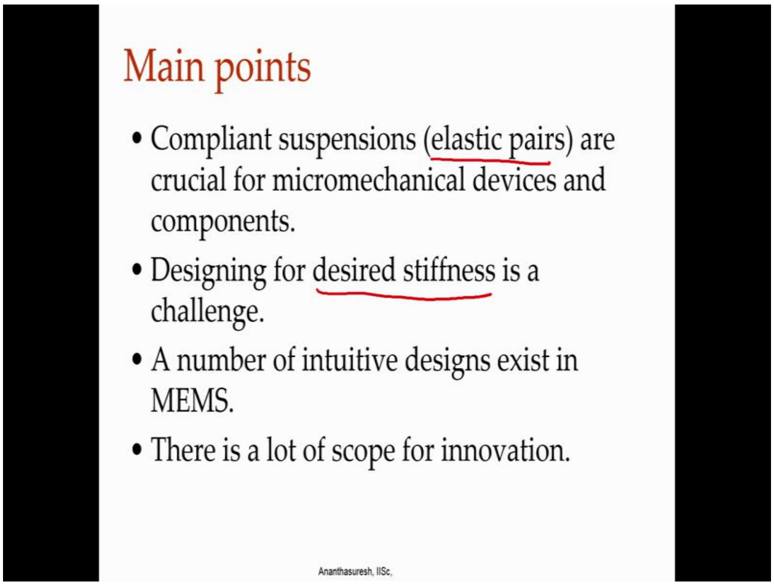

So, the main point of this particular lecture is that we have a number of compliant suspensions which we can call elastic pairs. They are crucial for micro mechanical devices and components and in fact many of the MEMS that we talk about. Finally, as far a mechanical engineer who is working the field of MEMS, it boils down to designing this compliant suspensions of suitable stiffness or multi axial stiffness in different directions you need to have different stiffness's and compact with regard to being amenable for various micro fabricant techniques with fewer masks as much as possible a single layer and that is all mechanical engineers can contribute to are that is a most important way mechanical engineers can contribute to micro electro mechanical systems by making newer and newer suspensions.

And as I have already mentioned, designing this suspensions for desired stiffness is the key challenge in this. Once you do that everything else follows from it and in the field of MEMS, a number of intuitive designs exist, but are also number of design that are systematically design all of this is because of compliant design that MEMS (Refer Time: 23:42) naturally embrace. So, what we will discuss in the next lecture on compliant mechanisms with micro systems is what we can do using compliant mechanisms for signal processing. Signal processing using mechanical elements as an idea that existed long time ago, but micro fabrication and all the innovations that have come in micro systems and to some extend even in the nano electro mechanical systems field make wave for novel way of even processing signals that also we can call is an important application of compliant mechanisms as we will discuss in the next lecture.

Thank you.