A Brief Introduction to Micro Sensors
Dr. Santanu Talukder
Department of Electrical Engineering and Computer Science
Indian Institute of Science Education and Research, Bhopal

Lecture – 20
Accelerometer – I

So, today we will be talking on Accelerometer. And, what is an accelerometer? It is like a acceleration sensor, like an acceleration sensor and this sensor actually measure acceleration. Like, while you are in a car and car suddenly accelerating.

Now, if you need to measure that how much is acceleration because, from acceleration you can measure how much is the velocity, you can calculate actually how much will be the velocity and, how much will be the what will be the distance travelled right. So, let us discuss on accelerometer or acceleration sensor and this is our case study 2. Let us say we have this springmass system.

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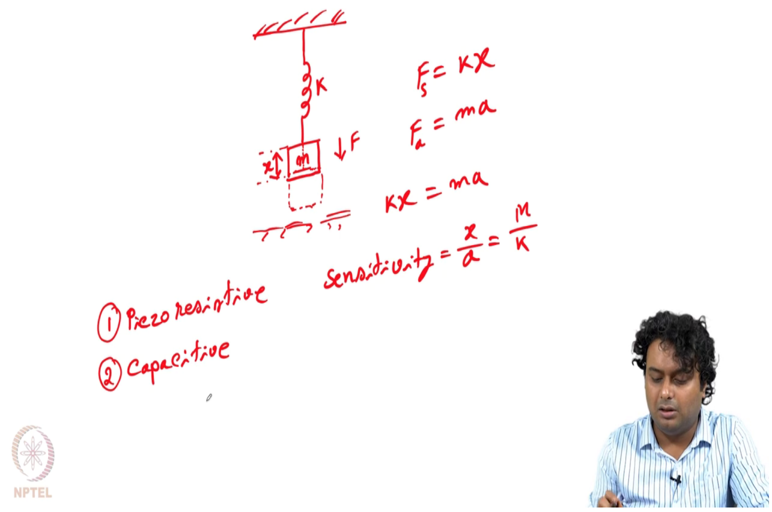

So, here is a fixed plain right, and then you have a spring, and then a mass is hanging from it right ok. Now, you apply some amount of force. So, let us say mass is m you apply some amount of force, let us say F. And, because of that the mass deflate, because of that the mass deflate by x amount ok.

Now, what is the force on the spring? If the spring is K a K, then the force or a spring force is equals to K x, and at steady state so, this is the spring force correct. And, that steady state, the applied force, if the mass has an acceleration of a then we know that F is equal to ma right and that steady state these two forces will be same and K x is equals to m a. Actually, accelerometer where acceleration sensor uses this principle.

So, as soon as now assume that this is our sensor this spring is our sensing, it has the some it some kind of structure and it has the sensing element etcetera ok. And, this mass is actually applied with like some force is applied on this mass or this mass is suddenly accelerated and that will measure with this sensor. So, how we can measure? This is the same phenomena we will use, which we have been discussing from module 1 itself right, that if we apply some amount of force, then there is this reflection, then we can measure the deflection and accordingly we can measure that how much is the force of the acceleration.

So, here also this is a deflection and this deflection is of the spring. So, in our case, let us see if we while we are using some kind of sensor this deflection of will be of that particular membrane or cantilever and accordingly we can measure the acceleration. And, what will be the sensitivity?

. So, sensitivity equals to x by a per unit change in the acceleration, how much will be the change in the deflection? And, that is M by K, this small M capital M are same ok. So, then if we get M by K ratio higher than we get higher sensitivity ok. What are different technique by which we can actually measure acceleration. So, one we have already seen during while discussing the recess sensor that is Piezo resistive, [Piezo resistive.

So, then what we will do we will put some kind of piezo resistive element here in the spring. So, as soon as some stress or strain is applied on the piezo resistive material, it will it is distance will change and accordingly we can measure that how much is the deflection or how much is a force. And, number 2 is like capacitive.

So, there will be some baseplate, there will be some baseplate here and with that baseplate we will measure that how much is the let us say, if this is another plate type the top plate this mass, the top plate then, how much is the capacitance in between the top plate and the bottom plate. And, accordingly we can measure that what is the distance or what is the deflection of the mass?

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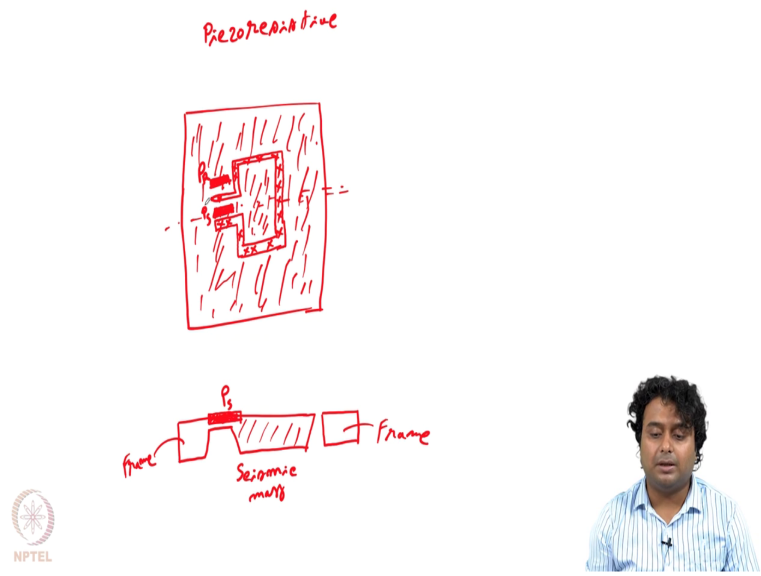

Now, let us discuss a bit about piezo resistive one. So, we let us say we have a structure like this. So, this is like a membrane that this inside plate is like a membrane and this is in between these two this cross region is like gap ok. So, this is like a membrane or the some kind of cantilever plate, which can move or vibrate, which can deflect. So, this cross region is a gap ok.

So, this is region it is not connected. So, this is like a this is like a flapper or flapping wing kind of thing, which can move up and down ok. If, I draw the cross sectional image, then it will look like something like this. So, this is the flapping part actually, this is the flapping part is moving and this is the frame, this is both at the part of the frame, taking the cross section in this direction.

So, we have this, so, this is the frame and on between that so, this is called kind of seismic mass, this can be called as seismic mass. What do we do we put two piezo resistor; one piezo resistor here and another piezo resister let us say here. So, one is on the moving part or the seismic mass junction and another is the what is called this is P sensing and this is P reference.

So, see initially while the membrane, initially while the membrane is not deflecting. Then P r and P s will have the same resistance both are at the same position and let us say they are fabricated similarly so, both are of same resistance. So, here also it will I will draw the P s. So, this is the piezo resistor, sensing piezo resistor P s and this is the reference.

So, as soon as there will be some acceleration or there will be some acceleration like let us say this cantilever. Now, this is fixed to this to my hand right. Now, if my hand move up and down accordingly this also starts vibrating right. And, because of that if there is a piezo resistor then there will be some stress or strain on that piezo resistor. And, that will change it is resistance and that resistance change will measure in compared to the P r of the reference resistance. Because, the P r or the reference resistance is at the frame this is not on the moving part of the sensor, this is on the frame.

So, this will be constant this will not change whereas, P s will be changed and the advantage of having these kind of reference register is let us say there is some change because of the temperature, or applied voltage, or any other parameter, which is not like which is common to both of the case like the reference resistor as well as the sensing resistor. So, those effects will get cancelled out. Because, if that because of the temperature, if the resistance is changing then that will change, similarly for both of them.

So, P r and P s will increase or decrease by same amount for temperature, but the acceleration effect is only on the sensing liquid, because the reference element or reference piezo resistor is not moving at all.

So, ultimately we can measure the resistance change at the sensing element and we can measure the acceleration. Now, while making the actual structure, while making the actual structure we just delete it seismic mass, we need to package it and in while packaging, we use a bottom cap and the top cap.

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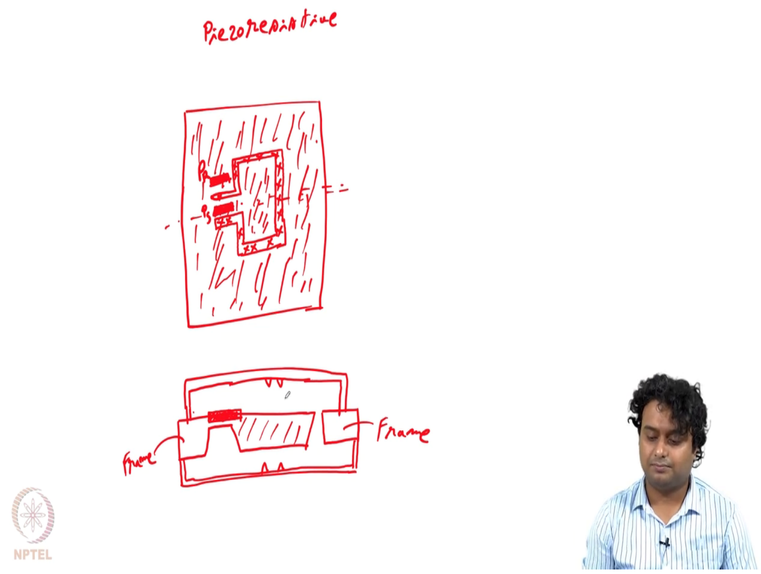

So, this is like the bottom cap and a top cap. So, bottom cap and top cap and you will see that the this is the membrane this is the not the membrane rather, it is like the seismic mass, which is actually moving slight cantilever, but the head is much in geometry, the head is much bigger than it is anchor region. So, as it is moving there is to get rid of stiction or any of inused stiction on those kind of effect, but we can put in a top cap or bottom cap, we put this kind of dimples or anti stiction tips.

So, even though it moves top and up top and bottom, it will not get stuck to the top cap or to the bottom cap. And, another point I would like to mention here is if we are using capacitive technique then we can measure the capacitance between the seismic mass and the top plate or in the at the bottom plate.

And, accordingly you can see that if it is moving down. So, the gap between the top plate, the gap between the top plate and the mass is increasing whereas, bottom plate and then the mass is decreasing. So, we can measure that one side capacitance will increase another side it will decrease. So, accordingly we can measure that, how much is the change in the capacitance of what is the deflection. So, that also can be done, if we are using capacitive technique ok.

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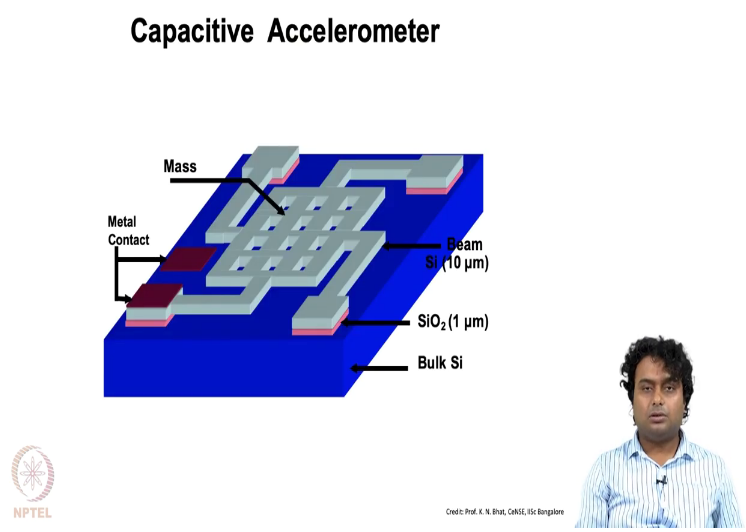

So, now let us move to the second type of accelerometer that is capacitive accelerometer. And, here I am showing you the structure am showing you the structure, which is a suspended structure.

So, you see that they are this is the substrate this blue is the substrate which is silicon, bulk silicon, then on top of that there is this sacrificial layer or ankle layer this is SiO_2. So, this pink side you can see here this is SiO_2 of on micron. And, then we have the floating structure or actual proof mass, which we call proof mass is the or the beam or the moving structure, that is again silicon this can be polysilicon also single crystal silicon, and it is it is said 10 micron of thickness ok.

And, then we have two different metal contacts; one contact is from the like this suspended structure and another contact is on the substrate. So, substrate is fixed right. Substrate is fixed and on top of the substrate this membrane is vibrating. And, in between them we will measure the we can measure the capacitance and we can measure that how much is a change in the capacitance and accordingly we can measure that, what is the acceleration?

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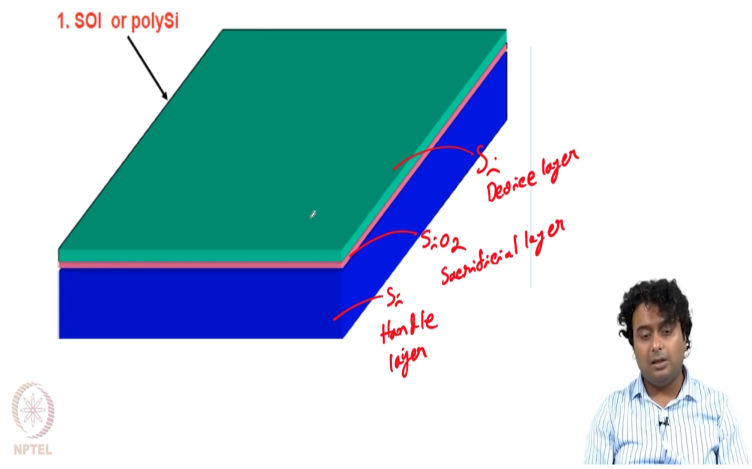

Now, for making this we start with a SOI layer or a Silicon on Insulator.

So, you see there are three different, three different layers ok. So, first top one is the silicon layer, but in the middle or the sandwich layer is same silicon dioxide layer and the bottom is also silicon, which is like single crystal silicon. Now, you see the basic difference. So, all are silicon here right, all are silicon. This is silicon, this is sorry not all are silicon rather this is silicon and this one is SiO 2 and the top one is against silicon, but there are some specific different between the top silicon and bottom silica that you can see here that the thickness is not same.

So, the bottom layer is called bottom silicon is called that is a (Refer Time: 16:12) that is a platform or the substrate, this is called handle layer ok. The bottom layer, bottom silicon can be called handle layer. And, the top silicon is much thinner compared to the bottom silicon.

So, it can be 10 micron 20 micron whereas, the bottom layer of the handle layer is like 500 micron.

So, this is called also device layer. And, in between SiO 2 is sacrificial layer. Another important point is this top silicon layer can be single crystal silicon, or even poly polycrystalline silicon. If, it is poly crystalline silicon then on the SiO 2, we just grow the silicon film ok, then it will become it will be a poly silicon.

Whereas, if we add another like on the bottom silicon we connect or on the bottom silicon, we actually grow silicon dioxide and then from top we actually connect another silicon wafer completely, we bond another silicon wafer, then we each from the other side. So, let us say this one was 500 micron, this is let us say 1 or 2 micron and the top was also about 500 micron, then the top silicon is aged till this point. So, that it will become thinner and this silicon will become like the device layer ok.

So, this in that case that silicon a single crystal silicon, because single crystal silicon wafer is like, if we are using a silicon wafer cut from a silicon in lot or single crystal silicon piece, then this silicon will be single crystal silicon. Whereas, if it is grown using like CVD or any other technique, then it will be, then it will be like polycrystalline silicon. And, this kind of silicon wafers are very much popular in means device fabrication.

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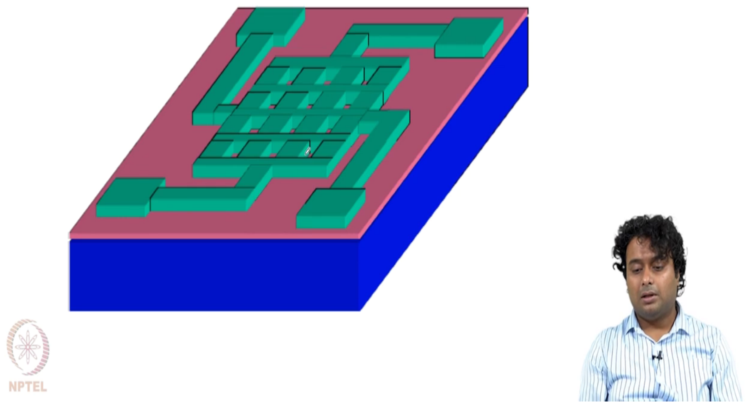

Now, we have discussed lithography in like in module 3, here we saw that how we can make a pattern on the on the silicon or on any substrate using photolithography and (Refer Time: 18:45) lithography. And, here you see that using lithography, we have from this structure, we have aged the silicon according to our requirement or our design and we have got this structure. And, after that if we give this sample into buffered HF or VHF, then that will etch away the SiO 2 part, that will etch away the SiO 2 part wherever it is exposed.

So, all of these regions will get etched away, but whichever region is below the anchor as this is much bigger. So, here one point to note is this beams are much smaller than the anchor just for the drawing we have made it like that, but it is much smaller than the actual beam so, which is not on inch scale ok. So, these anchors are much bigger than the beam size or this size or the proof mass size ok. And, not exactly is actually the proof mass is much bigger, but there are holes. So, in up through the proof mass this whole circuit for that purpose that the BHF solution can go in and it can etch it can etch all the SiO 2 below it.

So, through these holes through this holes HF solution can go in and can etch away this material. So, this region let us say this region where SiO 2 below this region. So, to below this region we will get etch from the site as well as from this. Accordingly, SiO 2 below these region will get age from these hole and this hole also from this hole also these 2 holes also, some amount will come and also from this side.

Ultimately at the anchor region only SiO 2 will be left all the other regions it will be gone. And, we will get a suspended structures like this and then using again lithography then we can make this metal contact at this two particular position.

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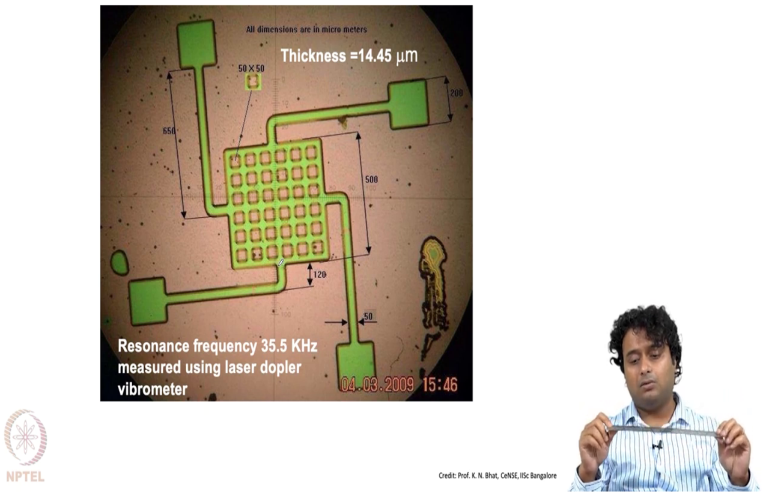

And, this is the real optical micrograph image of the capacitive accelerometer and here you can see that. So, there is this particular system we call laser dopler vibrometer.

So, using that system the frequency of vibration can be measured. So, as we know that all the us all the structures have a have a resonance frequency. And, what is that resonance frequency, let us say I have this cantilever. Let us say I have this cantilever, then I bend it and leave it, then it starts to vibrate with a particular frequency. I deflect it and leave it starts to vibrate with a particular frequency that is it is natural frequency.

Now, let us say while we are actually vibrating; that means, I am not leaving let that the force itself is vibrating. I mean giving a vibrating force. Then, if this frequency what is the applied force, that frequency and it is natural frequency, if it matches, then it is called resonance and in that resonance the amplitude is maximum. So, let us say if I am if I am applying some force and it is vibrating with some with some amount of amplitude. As, I am changing the frequency, then as particular frequency the amplitude will be maximum, because then the natural frequency and the natural frequency and the first frequency are same, in that case amplitude will be maximum ok.

So, that is called resonance frequency. So, this structure while measured using this laser doppler vibrometer system, where we use actually a laser source and then using doppler effect we can measure the how much is the vibration frequency of this of a particular structure, using that system we got it 35.5 kilohertz.

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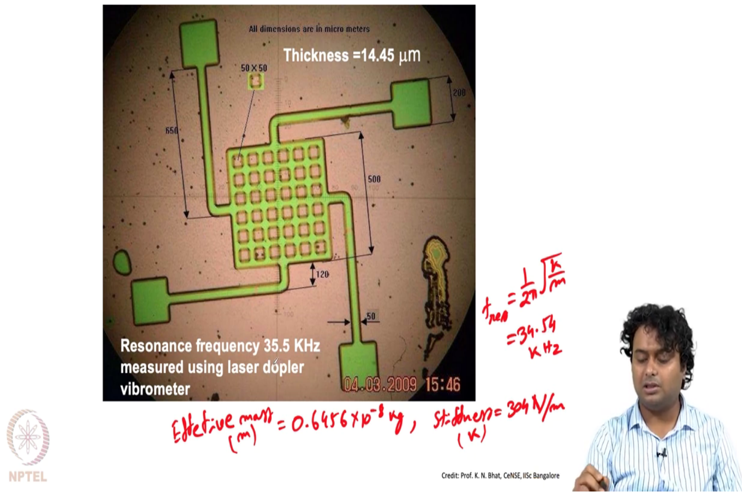

Whereas, if we only calculated the effective mass of this particular suspended such as was a 0.10 to the power minus 8 kg, and it is stiffness as we have seen in module 1 and 2 that we can calculate the stiffness for this all the 4 beams and then a like for a single beam then, we can calculate it for all the 4 beams right. And, effective stiffness equal to 3 0 4 Newton, Newton per meter so, this is K and this is M.

And, actually from this dynamic system from the dynamic system we can show, that frequency of a dynamic system or resonance frequency will be should be equal to 1 by 2 pi into root over K y M. And, that is equals to 34.54 Kilohertz. So, according to our design and the material properties another thing it should come as 34.54 Kilo Hertz whereas, we have we measured we got 35.5 Kilohertz. So, 1 Kilohertz it is off from it is design frequency.

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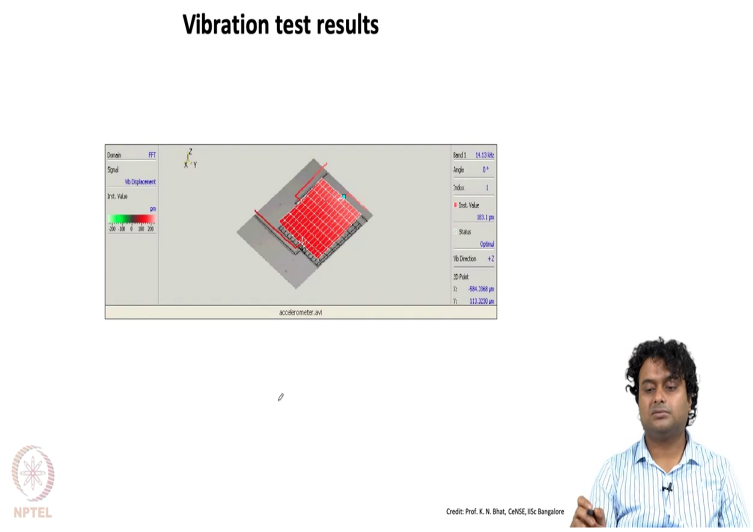

And, this is from the laser doppler vibrometer the actual like vibrating image, which is actually kind of reconstructed image, and here you can see that the beams are much thinner than the than the proof mass.

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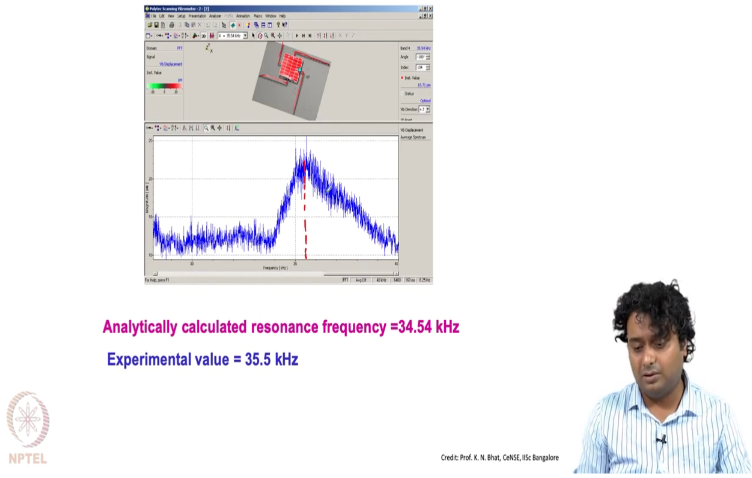

And, we will see the frequency response and you can see that the initially there is some amplitude. Initially there is some amplitude, which is like much lesser about even below 15. And, as we are switching the frequency it is almost same.

But, as we are increasing more and more the frequency the at certain after certain frequency it starts increasing and it reaches a maximum at this point and that is that 35.5 whatever we have got from experiment right. So, this is the peak frequency whereas, or the peak of the amplitude is maximum.

So, this is our resonant frequency. This is our resonance frequency that is about 35.5. And, again if we increase more than if we increase our frequency or the first vibration mode than the resonance frequency and again it decreases. So, while the structure is under, while the structure is under some kind of force or some kind of applied force, then what happens is this frequency changes.

So, initially the structure is this membrane or this proof mass is vibrated with some basic frequency or some force frequency. As soon as some acceleration change occurs, then we will change will see that change in the frequency response, because this frequency changes. And, accordingly we can measure that how much is the acceleration.

Now, let us discuss one of the impinge accelerometer we will discuss this in different context which we have already seen this image still I will draw it once more.

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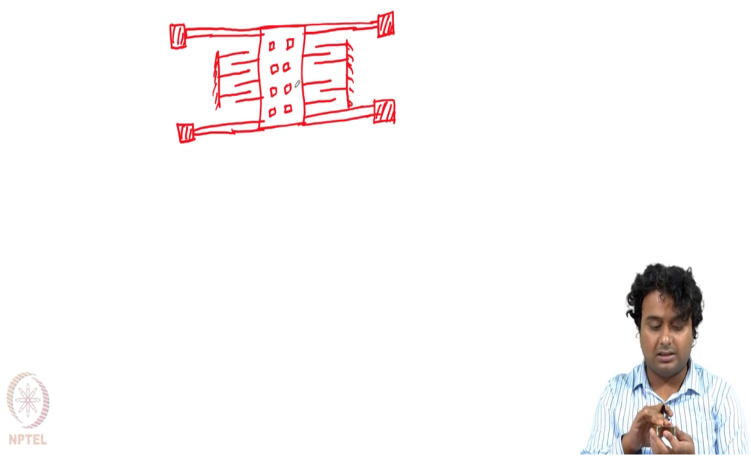

So, let us say this is a proof mass, which is actually vibrating in plane. Now, we measure the capacitor in between the fixed plates and the moving plates or the or this membrane right or this proof mass. So, this is the proof mass and as some force comes as some acceleration of force comes.

So, let us say this let us say this sensor is put on this body. Now, as this will move and if it experiences some kind of a change in the acceleration and if it experiences any kind of change in the acceleration, then this structure will like move, in this direction or in this direction right.

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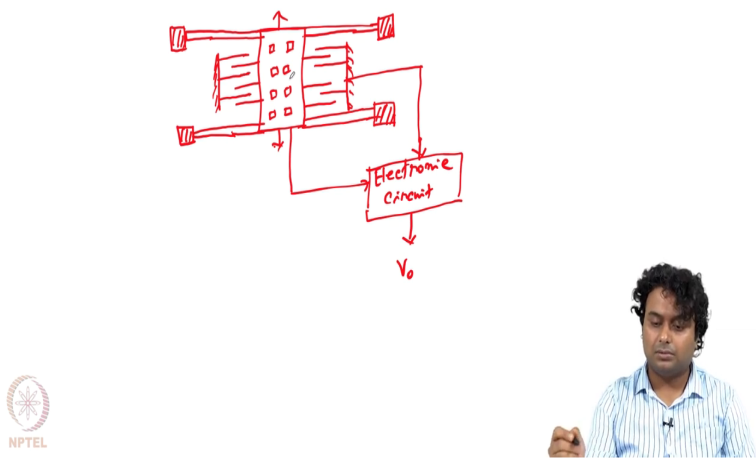

So, this is in plane movement. And, according to that the gap between the gap between the fixed electrode and the moving electrode will change and according to that the capacitance will change and by measuring. So, this will be connected to an electronic circuit and this will be connected to an electronic circuit. And, that will give an output voltage, V 0, which will be related to the change in the capacitance, which is in term related to how much is the deflection or how much is the acceleration and accordingly, we can measure the acceleration using this kind of accelerometer.