Indian Institute of Science

Photonic Integrated Circuits

Lecture – 11
MOEMS

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NPTEL online certification course

This topic is called MOEMS, micro opto electro mechanical systems.

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This also call sometimes optical MOEMS, so MOEMS is subject where you integrate mechanical and electrical components on a small the effects like silicon effect, so in this module this discussion I am trying to bring in optical events on to also on to mention see how we can integrate mechanical optical and electrical element on to the chip. We will focus more on the optical and mechanical slide.

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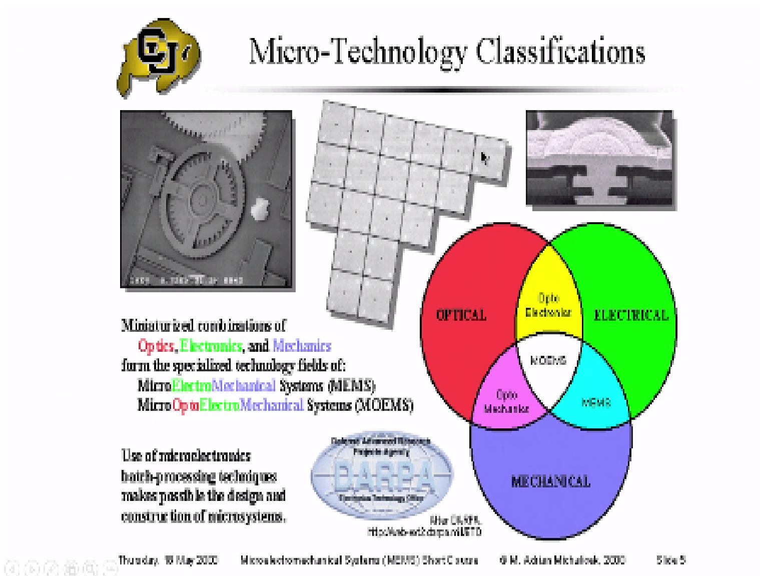

So MOEMS is a technology where as I mentioned you can have lot of miniaturized. Components obviously can the effort for that you think started with the VLSI technology where you integrate several of electronic components on to your small silicon vapor. And then people found that silicon is a very good material for mechanical application also, so that what it started many, many components like them elements like mechanical elements. Started with the cantilever being should have some up to sophisticated components like a motor subway in fabricate long to this silicon vapor.

This is like the vertical from the corroded investee website in collaboration with dharpaa about 20 years ago this technology has started growing and this when diagram shows the definition for MOEMS. So it can be set to be w combination of electrical mechanical and optical components in the miniaturized form, and let us go ahead and then as we go long I will discuss many other things.

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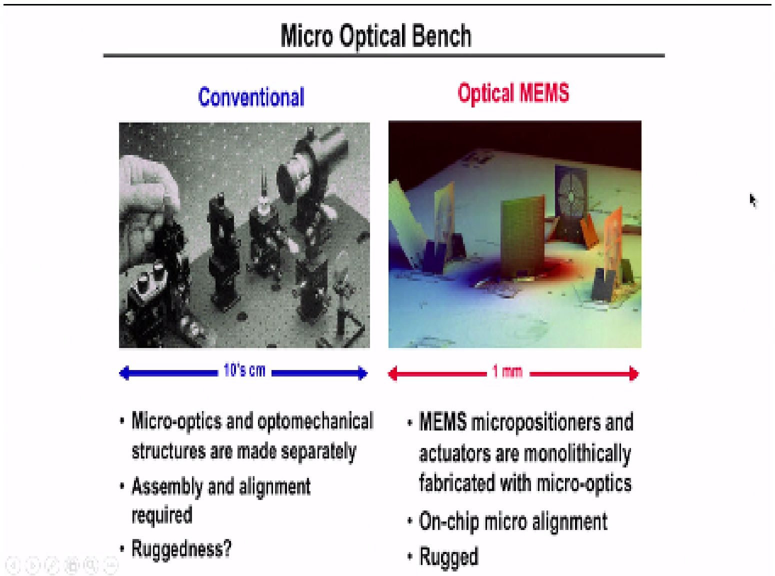

So this one if the dramatic development and by the end of flaws century in one of the i-table papers this particular device has been demonstrated called micro optical bench. On the left hand side you see a conventional optical bench containing lenses, mirrors, presumes, laser beam splitter and all the conventional optical elements that you find in a physics lab as you know that his typically of the RM for few meters and you can reconfigure all these elements you can arrange them such that to achieve a function like an interferometer or a paleographic recording system or what not.

So in this particular example in this particular paper people are demonstrated on a small silicon vapor of the size of a mm all the elements that we usually found that means we usually found on the conventional optical bench. So you see that there are mirrors there are flannel lenses there are many other components on the silicon vapor they could be activated by several means you can raise the component up or make it life lap based on the voltage that you apply to this.

So that the process is called the activation and you can configure this such that you can such a certain function, so the major difference is that this is very small and this could be made on the silicon vapor. So there are as I show in the next few slides there are people are made several components on to a small vapor. So other advantage s that you can obtain from such a approach can be the compactness then you have very small size and by proper packaging all the alignment problems could be handled you can control in particular you can say that you can control the elements the way you want electrical is rather than mechanically or by manually and they would be more rugged this all the advantage this one of the dramatic examples of optical MEMS devices.

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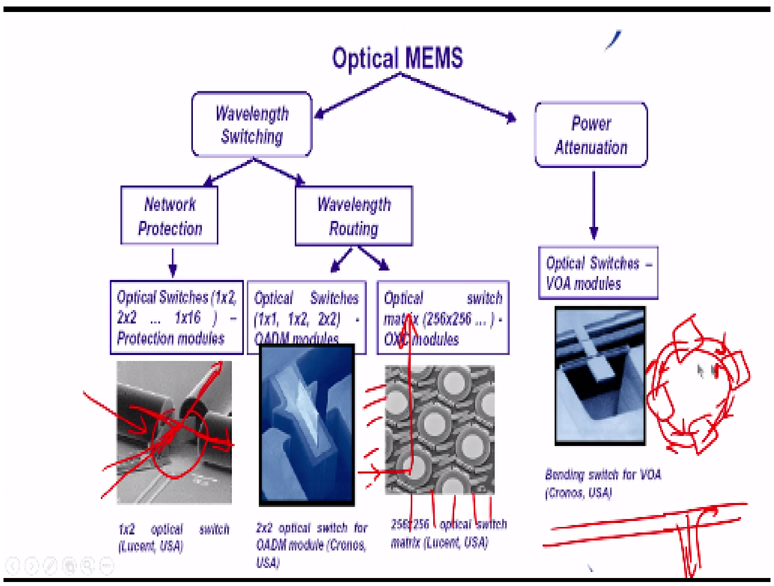

So this are all the way that component that you can think of the people are formed on the silicon vapor. So there are two broad categories of applications one for power applications one for the networking applications for application typically I have given an example of what is called the variable optical modulator so we can control the amplitude of light emanating out of this module in also switch depending on the requirement. On the left side you have all the elements which will useful for networking applications for example if there are, if the elements are depending it on the wavelength.

You can switch between different elements you can provide protection in a network for example I just give you one example of network protection you have a optical network consisting of a four elements like this configured in the form of I think and typically there are two or four optical fibers connecting them, there one of the optical first zinc will take the signal in the clockwise direction and other in the anti clockwise direction and you can configure these elements and exchange the information and cross check them. So if any of the links is faulty or any of the notes is faulty we can redo the signals by using these optical signals and elements that is important application of optical mems.

You observe that the first one is ½ optical switches, there is a mirror here and there are 3 optical fibers aligned this two are straight and this perpendicular to that, this is small micro mirror which could be actuate into this path of light wave. Suppose the light wave is coming from this fiber and entering into this fiber, normal coats, then you insert this mirror the light could be deflected 90 degrees into this. so you can have ½ optical switching by using these mechanism, of course this is a actuated electrical.

So these electrical signal will push this into this, then there is the example of a drop multiplexer where you can drop the signal, if the fiber is bringing in the fiber this signal, so at this point you can drop a part of the signal or you can add as signal path of light be, so you can this is called air drop multiplexer. The 3rd example is of optical switch matrix, where you have 100 of elements which are micro mirrors, light could be deflected using these micro mirrors.

So these mirrors could be actuate to either flat or pop up and the earlier example in the previous model what I showed with the switches lounge like fiber on to this mirror and deflected into some port like this, so we can configure the switch matrix through the signals from some of the import ports to some of the output ports, these are various categories to broad categories to optical memes devices, there are many applications which we may see as we go along.

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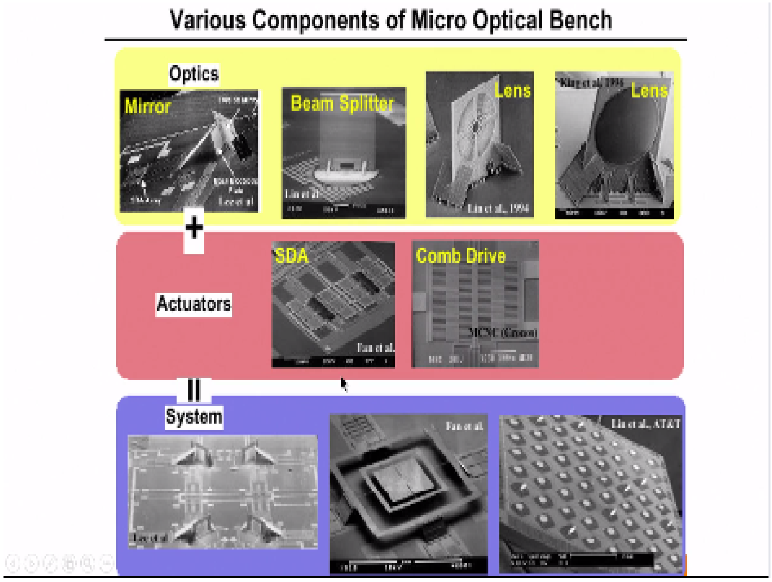

So these slide shows various components that have been fabricated by the way all these are fabricated devices from the general lecture, please look at the lecture given in the end to notes to get more information about the elements. So the various components that have been made on a memes or micro optical bench are like this, mirrors there are glitters there are lenses, there are home drives and so on. So these two are actuates to move these elements and there are several system like the micro mirror erase for sorting applications and so on. There are various components and system that have been fabricated on micro optical bench.

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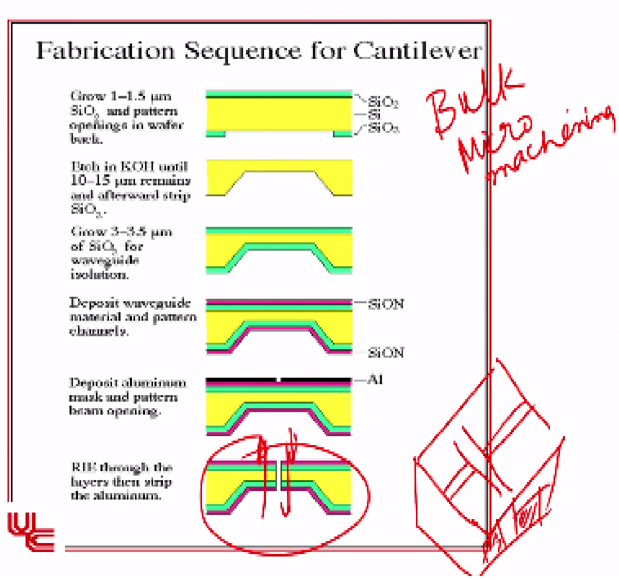

So I would like to give you a brief idea how such memes devices could be fabricated just the 2 examples, this is not a discussion for going details about the fabrication but just to give you the idea, we think of this particular method call the bulk micro machining, this technique I am describing is called the bulk micro machining where the silicon vapor itself is used and it is properties to achieve this function. So just to give an idea is the cross section what you are seeing is the cross divisional, let us focus on this device, cross function device may be you would like to make a 3D picture, something like this.

Where one portion you have I will cut at this point, one portion you have the wave weight, I will draw wave weight, that is the wave weight, terminating at this point there is another vapor on this and the region below this is etched out, let m say here. So this is etched out here so this portion is removed, so this is the floating I have shown over here, so the two beams are fixed at the end but their flexible to move around like this, so by applying 4 or other mechanism you can move this, for example you can put the force on top of this and move this down.

So the idea here is, let us say this greenish region is the wave guard region and the light is launched into this region and substitute the output ant based on the gap the amount of light goes from the input portion to output portion varies and if there is any miss alignment between them the amount of the power that comes out reduces, so we can calibrate this device as a force sensors force on n axis and the amount of light output on the other axis and you can measure what is the amount of the force of the odds of few micro new tons to mille new tons.

So on based on the design we can achieve this is the functionality of this is device say you can call it has force sensor and you have the optical waveguide fabricated and there is a gap and this is the nine features of this, if you want to achieve this if you want to fabricate this device how to do? What are the steps involved? What I have been describing this particular slide. You started with double coated oxide silicon vapor, we have silicon here and oxide on both sides, you can also decide what is the thickness of the oxide that you want to have but you can coat additional layers like the reddish one that you are showing here.

Oxide nitrate to change the properties of these wave guiding elements, as we have seen by using the effective index we can load the waveguide and change the refractive index, so as first step let us draw a diagram or slot below for example, if this is the bottom portion, you would like to etch out a region like this and not so much you get etch out you like to retain this region and maybe I would say etch out this region and then oxide layer for the various purposes, then oxinated layer top of it and then in the next step I would like to deep etch out this region.

So you make an aluminum mask and using several HN are there for oxides and silicon you can deep etch, this is called deep etching, the RIE stands for reactive iron etching, so the important feature of this bulk micro machine process is the silicon itself is used the mechanical properties of silicon will be important and typical dimensions of the orders of a few microns for the beam this can be called as can clever beam, beam thickness of the orders of few microns say it 20 microns.

Waveguides as you know hour of the arts of micron sometimes on silicon vapor there where the half of the fraction of micron of that is half micro meters and so on. So typical force rangers and pressures rangers that we can talk about are other of a mille neutron to micro neutron, so this is the example of our we called as a bulk micro amch8ine process for making optical MOMES devices.

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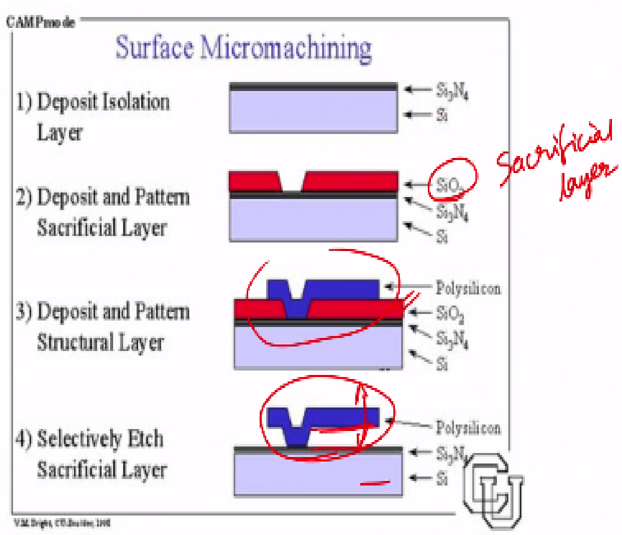

I will take one more method of fabrication more sophisticated method of fabricating MOEMS called surface micro machine. So in this particular method once we will use silicon as the base but the structures are made of poly silicon, so poly silicon could be pattern on to such that you can have a beam and so on and once again you start with the silicon vapor coat nitrate toward here to the base and then use oxide.

This reddish region is oxide silicon oxide which can which used as a sacrificial layer to hold this poly layer on top of that you coat another layer deposit and pattern layer of poly silicon and all this whatever shape you want and then h out this oxide layer, so this it piglet in a very crude way this is the surface micro machining process.

So this is typical in a very good way this is the surface micro machining process, so it uses repeatedly the quoting of the oxide layer and depositing in pattern, several types depending on this structure. This particular case we are showing a policy on cant liver beam made by surface micro machining process. So you can make optical cases on top of this and then control their property by deflecting these beam by you can use electrodes and electrical forces between these silicon layer and base so that they can deflect. So I am just using this to illustrate surface micro machining process.

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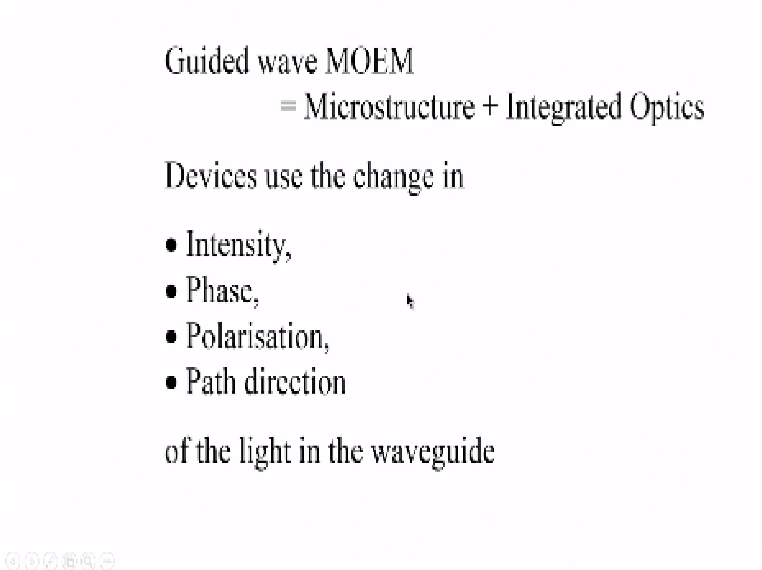

So now we will see what could be called as MOEM devices combined with integrated optics, so earlier whatever I have shown the bulk devices controlled by bulk memes devices optical memes controlled by electrical signals and other ways. Here we would like to see how a waveguide based optical elements could be controlled by using the structures. So we have at a disposal, intensity of the light, the phase of the light, the polarization, the direction of the propagation and so on so forth that can be controlled by memes structures.

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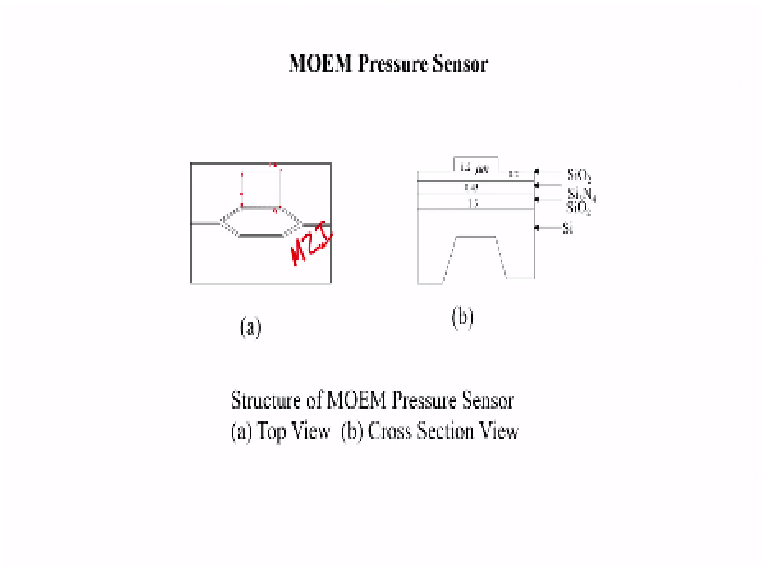

So this is the example of a pressure sensor where you have the configuration of device you have the top view containing and you are stating the principles not final details but some technological issues also I will highlight later on. So you have the magzerante interferometer as a top view and just below the.

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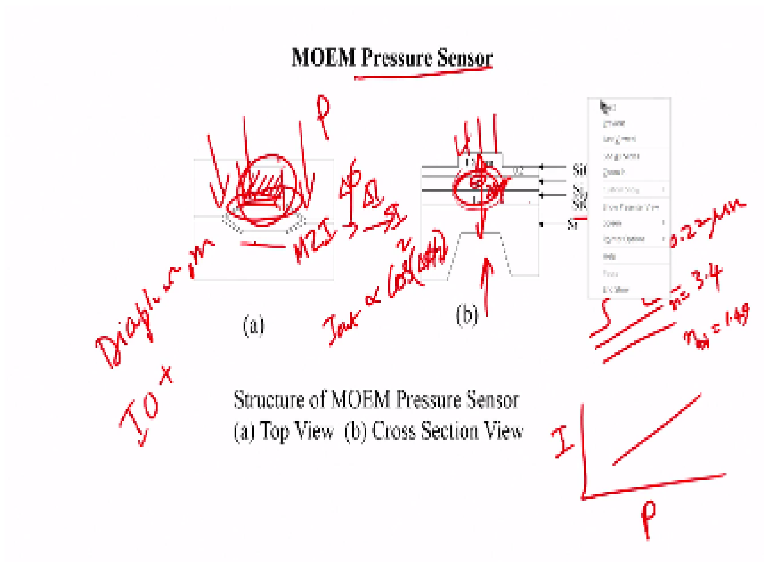

Arm of the one arm of the imagine for a meter high h outer diaphragm, so the configuration of the diaphragm is one here so from the top e know visible easy anything but H out from the bottom show you can assume this is line from the diaphragm for the typical diaphragm from it is and the typical thickness including consisting of the wave guide etc could be the hours of the few micron 20 microns and the wave guide you know use in the silicon when the hours of the fraction of the micron after the micron the typical dimension is 0.5 micron 5.22 micron is the typical dimension of optical waveguide .

And the large the refractive index is the another important tropic of the silicon of that is 3.4 refractive index of the we can oxide of the silicon you have the 7.49 also so this typical parameter also of the silicon for the all the devices.

So this particular structure has the multilayer of the layer of the oxide of the nitrate of the oxide and the light could be guided in this higher refractive index and the try of the refractive index to the index light could be guided in the structure and this pattern structure is the channel wave guide effectively can find mode in this region by effective refractive index so when you apply pressure that is uniformly top of this in the perimeter .so in the stress in they used refractive index changes larger here the other arm is not interferrment effect much there is various of the refractive index in this region in the wave form region particular on the wave guide region and so there is the different face sift.

There is the different face variation between two ever and we can do nil the face shift of that end of the inter perimeter which is converted in to intensity change so the intensity of the output is dependent on the face change at this point typically($COS^2 \Delta 1/2$) and the lightning there and the Z I.

So you can calibrate device for the pressure as the function of the light intensity output with the pressure typically I show you a few pictures, so this example were use mines diaphragm is a means device diaphragm typical deceive which is used to control the optical property the day of the light property and this wave guide we have combined the integrate in the optics +diaphragm further application to pressure and the sensing will you show more details in the next Full flights.

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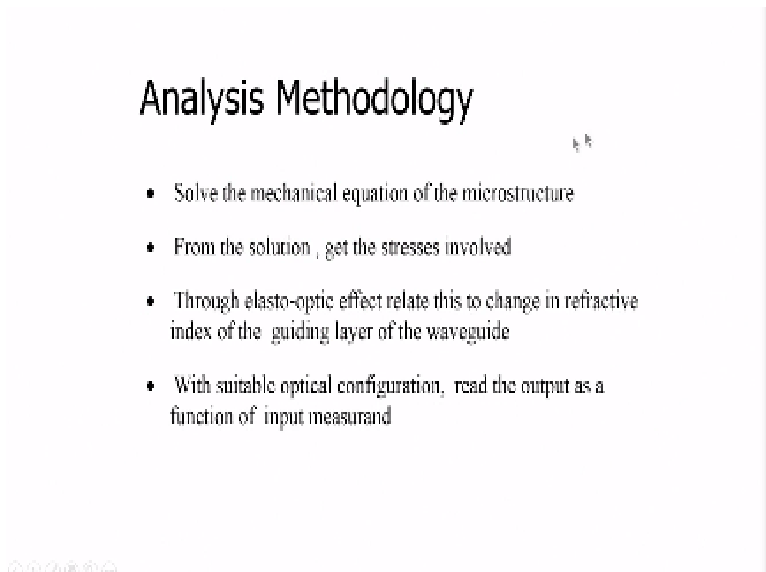

So if you want to study such optical memes device late we the optical wave guide devices with the mechanical equation means the optical equation and there any electrical device electrical equation are combined in all in the single here it so you solve mechanically equation of the diaphragm then from the solution in the distressed various induced as we have seen in the case of the optic effect in this particular case is what is called the electro optic effect and the stress is involved then using you can relate these electro optic effect so we refractive index variation of the waveguide and you can chooses property optical congregation of the magnetic in the particular case and then the input signals. So the broad meter logy I will show you the equation of the electroplate how this is been done of the case of the region sensor.

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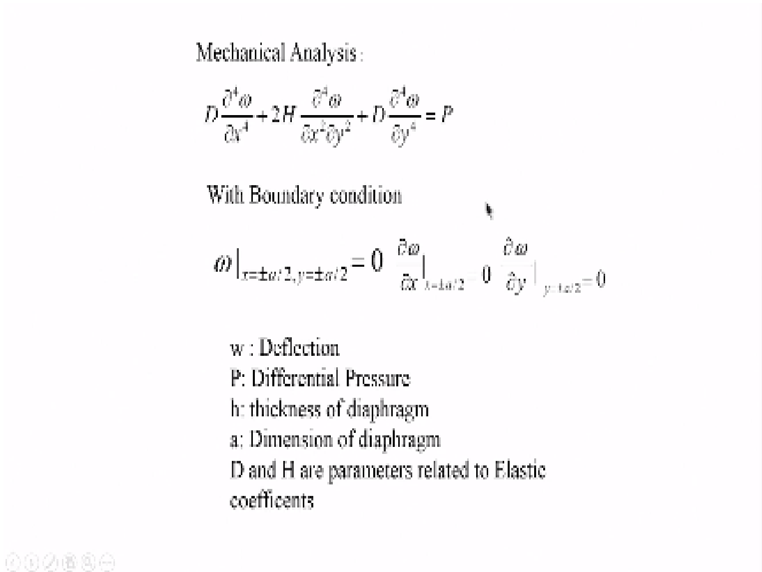

So it is atypical case we can do the current literature for the more details we have the mechanical equation of motion so on the right hand side we have the pressure this is the motion of the diaphragm and have been given in the several bounder condition to determine the displacement function of the diaphragm and also of course we can relate it to the stress variation of the diaphragm from the stress variation is typically earlier device of stress could be consider as derived to as for displacement and the another feature that is elastic.

That is that elastic by this elastic is the stress variation or tense for the even though how really form the pressure or the scalar values and the pressure and the diaphragm the induced this is the optical change as well as the mechanical change could be Victoria of tense or the nature the idea in this particular slides to solve in the mechanic called quantity ratio and obtain the displacement function and the distressed variation so the stress will be rearrested to the optical property.

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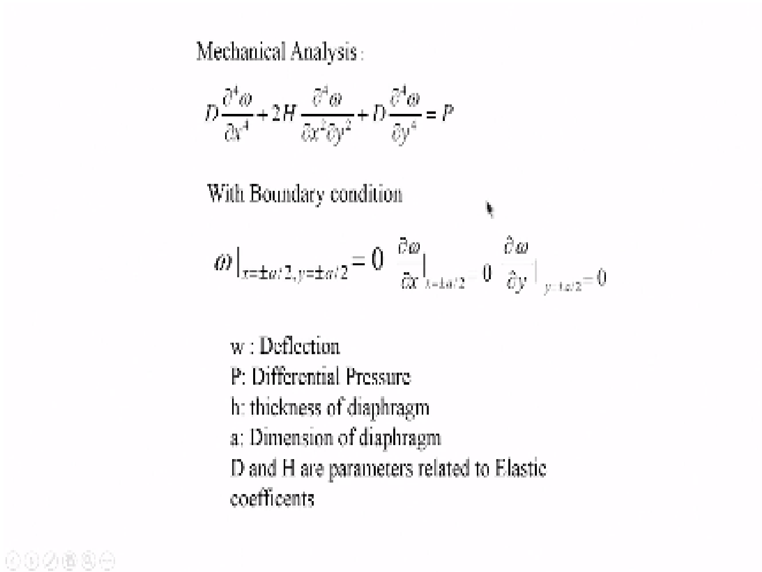

so using optical mechanical cupping expression you can relate the refractive index variation with the stress variation . So stress variations I am showing you as different values and different directions with co efficiency and there also different for a different modes. TE and TM modes of light propagation different co-efficiency these two are different, for example $C_2{}'C_1{}'$ so we have to reflects to its variation also along with this chess. So Δn is depending on the function of the test. This is the important features of these elastic optic devices.

For then of course define the sensitivity of this sensor as face it the input perturbation. For example the particular P is perturbation of pressure the resulting which in the phase. So you can correct literature for more exact relation between Δn and the stress induces and which is different for different types materials type like silicon depend on the drop concentration it. So you can use to control the mechanical and optical properties not only electrical properties of the silicon junctions and ways.

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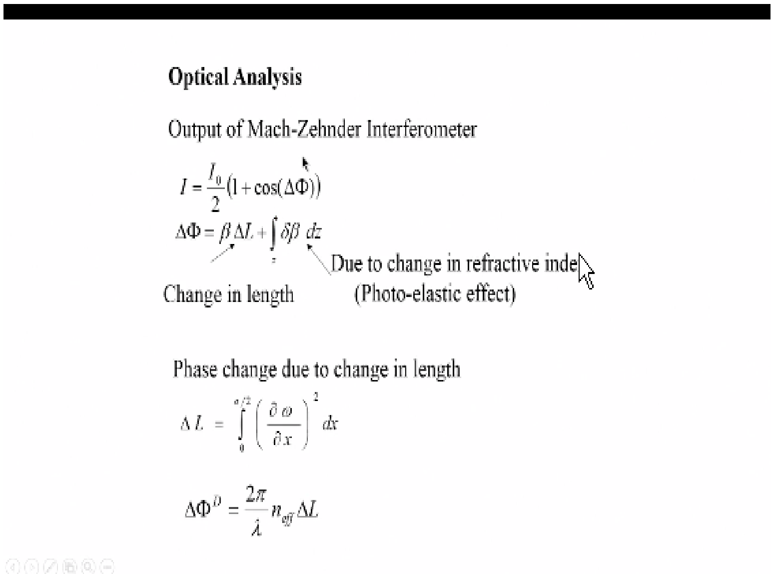

So once the mechanical analyses and put it in the coupling the expressions in it will optical analyses. An important feature that we inverted here is Δn should diffract to changes or function of the stress which are the functions of z. So the diagram like this on varies or experiencing the replacements, so the refractive is varying the long result as. The important features many of the structures. Δn is equal to z, we have seen such analyses for tapered wave race like branches and cup lox analyses.

So in this particular case I am showing you the very simple analyses and for ensure and if you using ensured I a optical structure we can relate the intensity with the phase it. And phase it with the changes with the placements or changes in the displacement or changes in the propagation constant due to the change in the refractive index. Erasing in the electro optic effect, and we finally calculate with there are the phase its.

So the phase change due to changes in the length could be estimated and finalize all these living sensitivity especially. So you can finally relate the properties with the sensitive probes and sensitivity properties with the change in the phase in the function of the change in the calculation so this is about description of how optical means devices based on the optical wave race could be analyzed. So first mechanical analyses are relate that mechanical analyses with the optical properties by using the electro optic effect and then use the optical analyses to study the propagation of light in a optical wave race of the function input contribution parameters and which one of the propagation properties.

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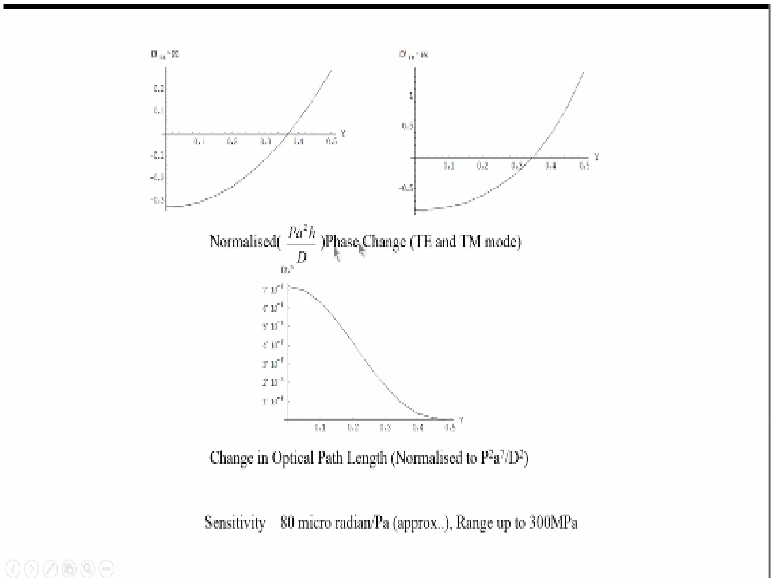

So this is a simple path that we have done, in our lab. For various values of the this was various surface changes for different modes across different variations. O in the optical path length and as the function of the distance. Now days a lot of from numerical analyses tools with can help us to solve this tapered wave length like being propagation method we have seen. From the new techniques are can be used to measure these to analyze the properties.

Typical sensitive are of the orders of a few micro radians per Pascal and typical range can go of to several mega Pascal. So these chart will shown just to elastrator that such an analyses could be done and very, very useful because the currently literature for more exact description of the devices and technologies and their functions. So just to highlight summarize and show you the device which consists of a mechanical element that I from an optical element the magazine from it base to the optical wave gates study earlier and then interrelating them to achieve the functionalize scenic. So thank you very much for this module.