Lecture 20
Fabrication of MEMS based Catheter Contact Force Sensor

Hi, welcome to this module. And in this module, what we are looking at, we are looking at, how to design a strain gauge, right for understanding the catheter contact force and I'll show you, how this same strain gauge, can also be used for lessening, the change in the mechanical properties of tissue. Now, you have already seen in the, not, in the last module. How the photolithography process? What are the steps for the photolithography process? And what kinds of photo resist are there? What kind of masks are there? I have taken an example as well. Right? So, let us see here, how can we design the strain gauge. Okay?

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So, if you see the screen, what you see here is a, 3d maps based strain gauge or at the tip of the catheter.

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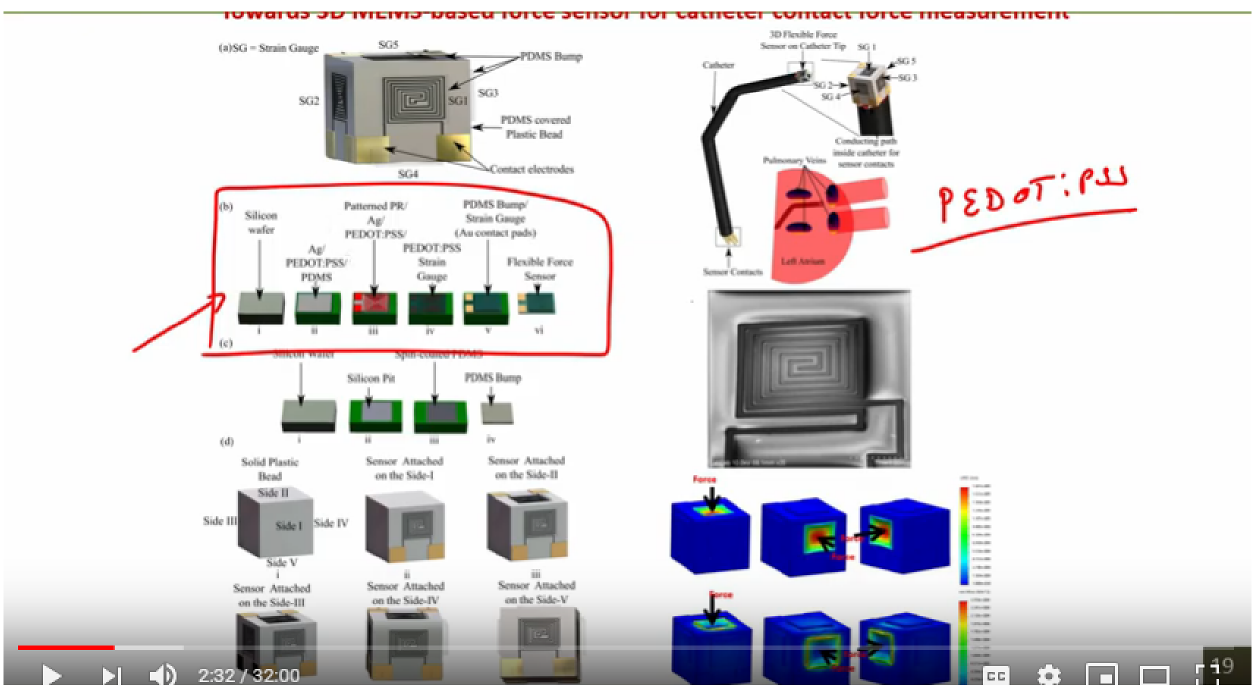

And we want to understand, how we can design this, MEMS based, sensor for catheter contact force. Right? So, this is a memory sensor and as you can see, we are using a square bit, so you have how many surfaces? You have six surfaces. But, one surface is used to connect to the creditor. So, we have now five surfaces on which we can stick the sensor. What kind of sensor we are using? We are using strain gauge. So, now as you know how the lithography is done. Right? I will, I will show you, this particular process and also I'll show you, step files how we can go from step one to step six. So here, if you focus this particular section. Right? What is it the first one is that you take a oxidize silicon substrate. Right? The next one is, you have to deposit PE dot PSS, PE dot P SS is a conducting polymer, PE dot P SS, PE dot P SS is a conducting polymer. Okay? So, conducting polymer we have to deposit on, which there is a thin layer of silver. Right? The there is a, reason behind using silver is that you have a better, addition of the PE dot P SS on the substrate. Then so and that PE dot P SS is on PDMS, you see, what is the process? Let me; just show you, to you in this slide.

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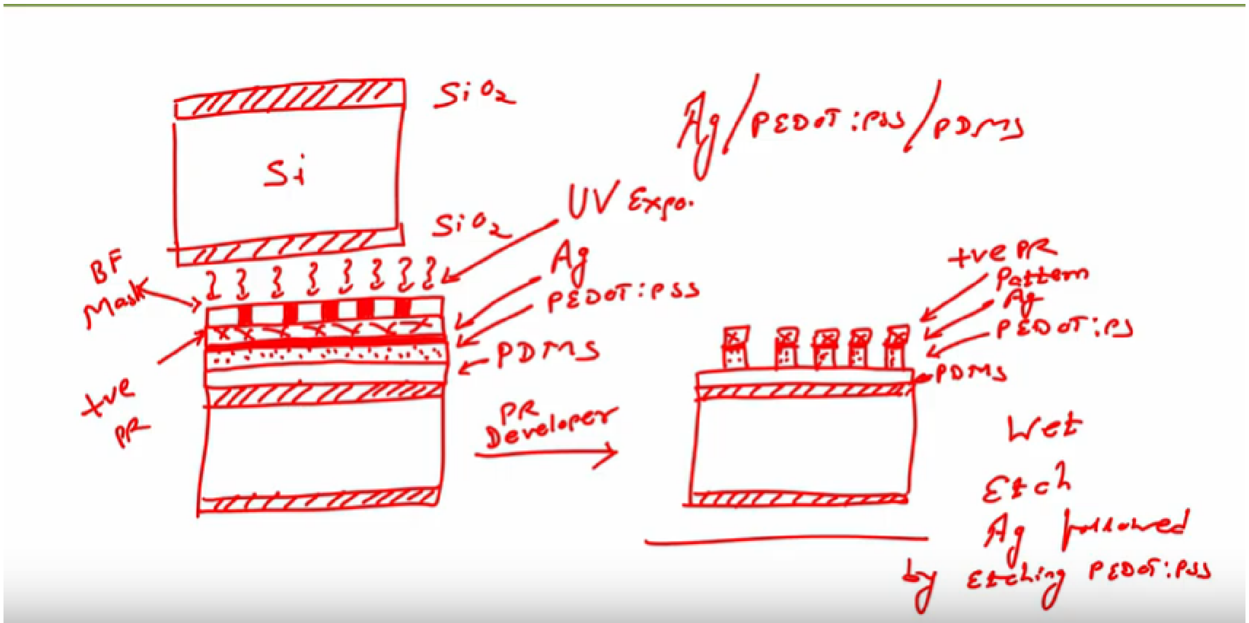

You take a, silicon. Right? And this is your silicon wafer, grow oxide. So, I have grown, silicon dioxide, this is silicon dioxide, silicon dioxide and then, the next step is, on this oxidized silicon wafer, you pour PDMS. You have to pour PDMS, all right. On this PDMS, on this PDMS, we will spin coat, we will spin coat, PE dot P SS, PE dot P SS, on which there is a thin layer of silver, thin layer of silver. So what we have written is? You have silver, over PE dot P SS, over PDMS. Right? This is what we have written? Now, if you go to backs, then you will understand, in this slide that we are written AG, with a silver on PE dot P SS, on PDMS. Next step is you pattern photo resist. Right? On this particular, on, on PE dot P SS, so as to get the strain gauge. So how you will do patterning? So for that, what you have to do? You have to spin coat, you have to spin coat, photo resist. So, this is our positive photo resist, then you do perform soft baking. Right? And then, we go for exposure, what exposure we will go for? You go for UV exposure. Because, it is a photography. Right? Out and now we know, what is you lithography? Right. So, you have a mask, what kind of mass it looks like? It looks like a bright field mask. Right? So, this one is my bright field mask. Right? And then, next step would be UV exposure. UV exposure, after this, next step is, you dip the wafer, you of course unload the mask and dip the wafer, in photo resist developer, Photo resist developer. When you do that, what you will have? You will have oxidized silicon substrate. Or with there is a PDMS. Right? PDMS over which, there is a thin layer of silver, this is correct. It is correct, it is not correct. Because, on PDMS what will have? When PDMS we have, PE dot P SS. And PDMS we have conducting polymer. Right? So, we have PE dot P SS. On PE dot P SS what we have? We have thin layer of silver, thin layer of silver. On silver now you had on the lithography and you develop your photo resist, so what you will have? You will have, positive photo resist, patterned and right. Positive add resist, which is pattern. Now, so this is what we see here, see this particular step, we see here, which is pattern photo resist, on silver, on PE dot P SS, on PDMS. Next step is that, you etch silver, this one is silver. and then etch, u etch this is a wet etching silver, followed by, followed by, etching PE dot P SS, followed by etching PE dot P SS. So what you will have? You will have, you will have AG, N PE dot PSS, AG is a silver, silver and PE dot PSS, on PDMS over which, there is positive Photo resist .right? So, of course after P for this positive for this developing, you have to go for, hard bake and then you have to, do the etching step. So, don't skip that. Right? The, the process you should know that, when you depose, when you spin coat photo resist, first step is you to go for soft baking. And soft baking is done at 90 degree for one hour, followed by, loading the mask, UV exposure ,then developer, then hard bake which is done at 100 120 degree centigrade, for 1 minute on hot plate. And then, you had to go for etching. Right? After etching we have to, step up the positive Photo resist.

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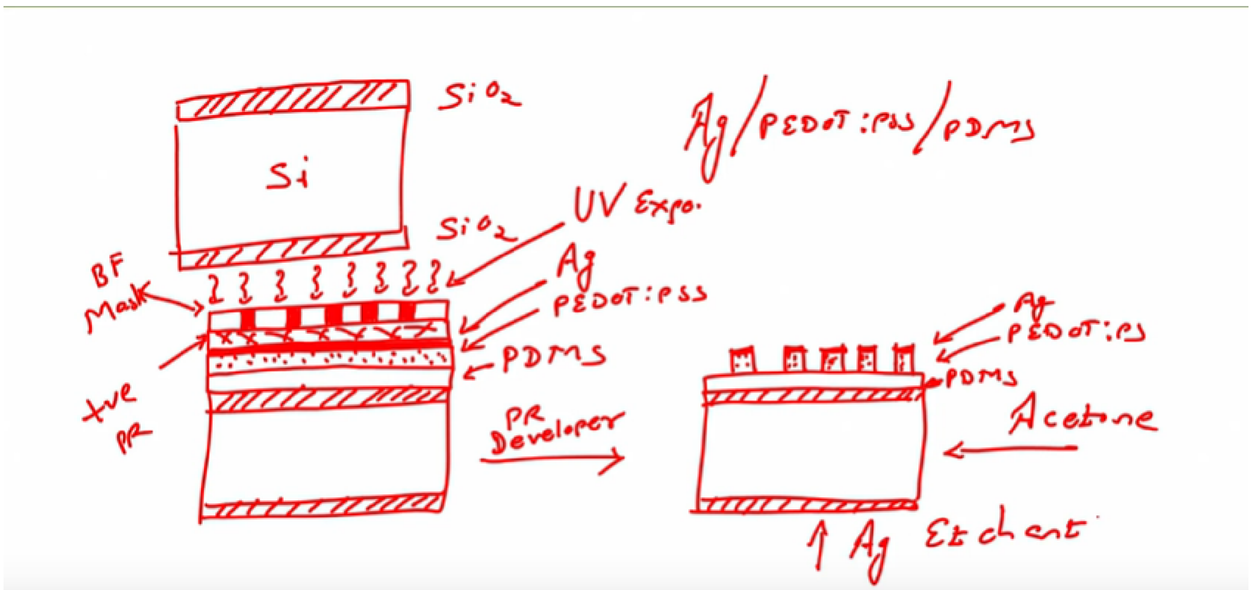

So, for stripping of positive Photo resist, what we will do? We will dip this wafer in, acetone. If I dip the safer in acetone what will happen? My positive Photoresist will be stripped off, positive, positive for that this is, stripped off. So, my positive for this is gone. Now, what I have? I have silver and PE dot P SS. Right? Do I require silver? I don't require silver. Right? So what will I do? I will etch, silver now. So, after this acetone ad dipping, will dip this wafer in, Ag etchant, Ag etchant. So silver etching and if I go for silver etching, what will I have? I will have only PDMS on which, PE dot P SS, strain gages pattern, PE dot P SS strain gages pattern. This step, this step, right is shown here, alright. this these are the steps that, you have to follow, so as to get the particular pattern of PE dot P SS, why we are used PE dot p SS. Because, we want to make us train gates and PE dot PSS is not only conductive, but it's a piezoelectric material, piezoresistive material and your user understanding the piezoresistive versus piezoelectric. Right? You apply pressures then in the distance, piezoresistive these two applications in this voltage piezoelectric. Okay? So, strain gauge, once you have the strain gauge, the next step that you see in the glass in the, in the schematic is that you have to have, PDMS bump. Right? That you edit on the strain gauge, that means, if you go through this slide.

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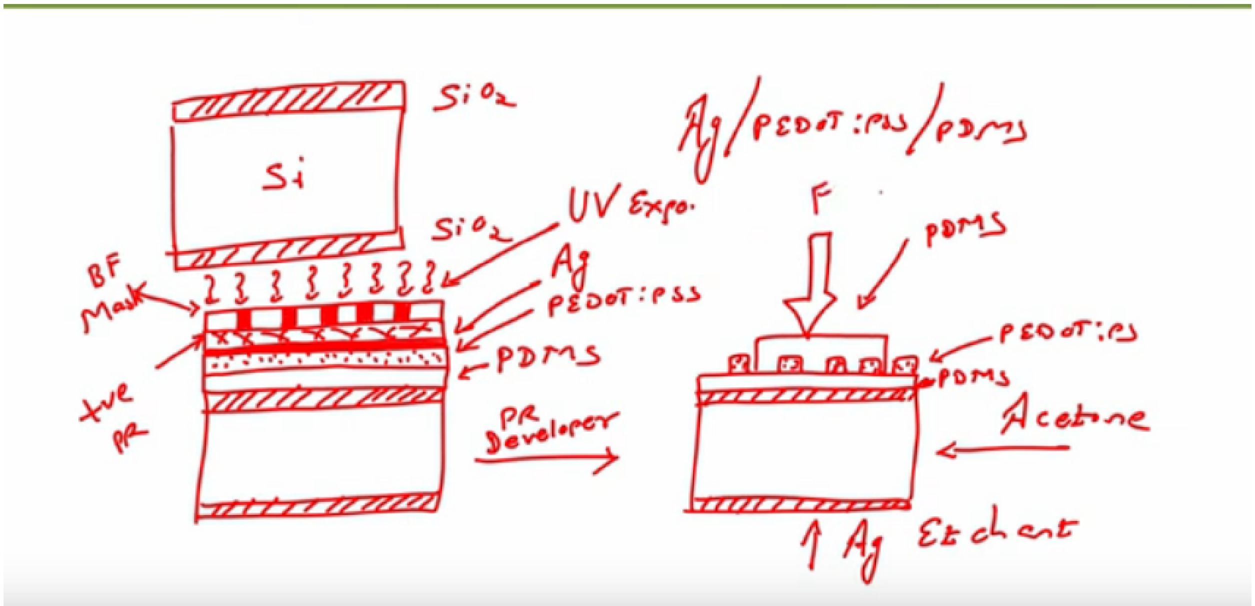

What you want to have? You want to have, P DMS bump on the strain gauge. So that, this bump will help us or will facilitate, the force that we apply on the strain gauge to, to transfer the force that we apply, externally to the strain gauge, alright. So, PDMS bump, how can we create this PDMS pump? For creating this PDMS pump, we have to perform again a lithography.

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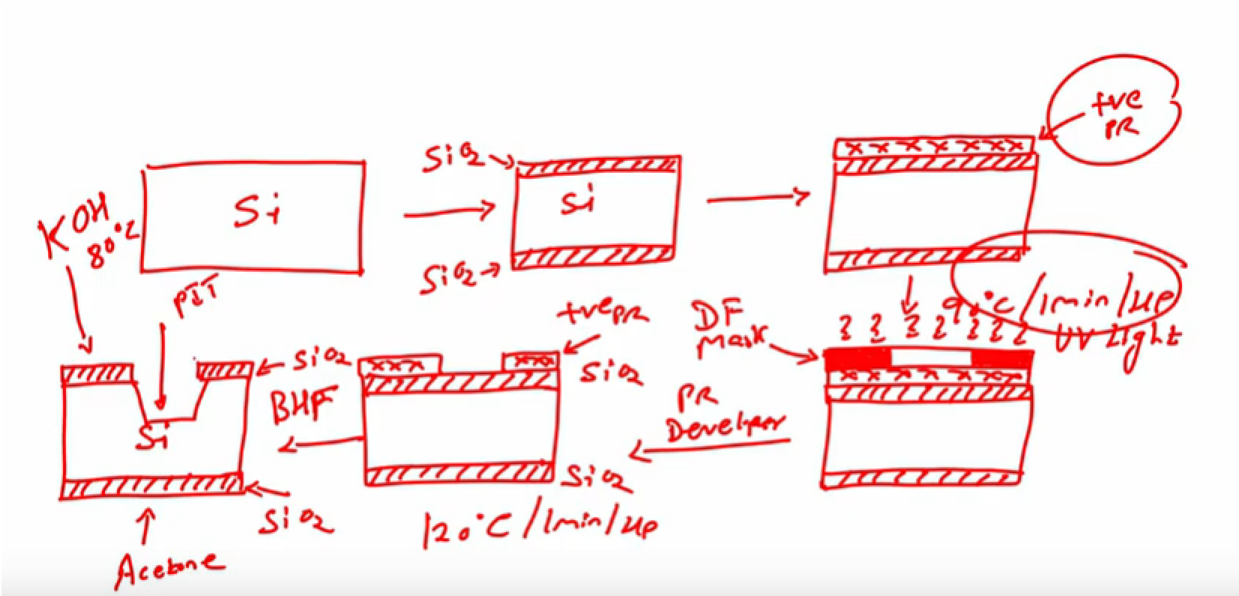

So what we'll do? We'll have a silicon wafer, we'll have a silicon wafer, next step will be, to grow oxide. Next step would be, spin coating positive Photo resist, alright. Next step is, you have to do a soft bake, at 90 degrees centigrade, one minute, on hot plate and then, you can lower the mask and expose the wafer. Throughout the mask, we'll be a dark field mask and expose the wafer, with UV light. So this is silicon, this is silicon dioxide, silicon, silicon dioxide, this one is positive photo resist, this one is your dark field mask. After exposure, you have to go for photo resist, developer. When you do photo resist developing, what you will have? You will have, oxidized wafer, positive photo resist, sio2, sio2. Then you have to go for Harvick after Harvick, Harvick is done, it 120 degrees centigrade, one minute, on hot plane. After her baking, you have to dip this paper, in buffer hydrofluoric acid; buffer hydrofluoric acid is BHF, when you dip the wafer in BHF, what will have? You will have, oxidize silicon wafer, where your oxide is etched, oxide is etched, alright. So, if the oxide is etched and this is your positive Photo resist, this is your silicon dioxide, silicon, silicon dioxide. Right? Now, if you dip this wafer in acetone, this will dip this wafer in acetone, what will happen? The photo resist will be stripped off, photo resist etch stripped off .so, you'll have, this particular pattern. Right? Now, after this, I will dip this wafer in, in potassium hydroxide, at 80 degree centigrade, this will, when I do this, what will happen? I will have a pit. Right? This pit should be equivalent to the height of the bomb that we want. So, now you understand this much process, if you go back, you will see, so you take a silicon wafer and you create a silicon pit, this is where we are, right. This is what we have seen here? You take a say, oxide silicon wafer, grow oxide, spin coat photo resist, right. load mask, expose the wafer, I'd go for photo resist developer, hard baked, soft baked, everything we are done after, after photo resist, you go for soft baked, which is right over here, then you go for mask, you lithography, on exposure photo resist, developer then hard make and then you are dipping this for in silicon, in BHF, which is silicon dioxide etch and what will happen the silicon dioxide will get, edge ,you remove the photo resist with the help of acetone and then you, dip this for in hugged to get your pit, which is pit in silicon and this pit, the, the depth of this bit is equivalent to the height of the bump that we want.

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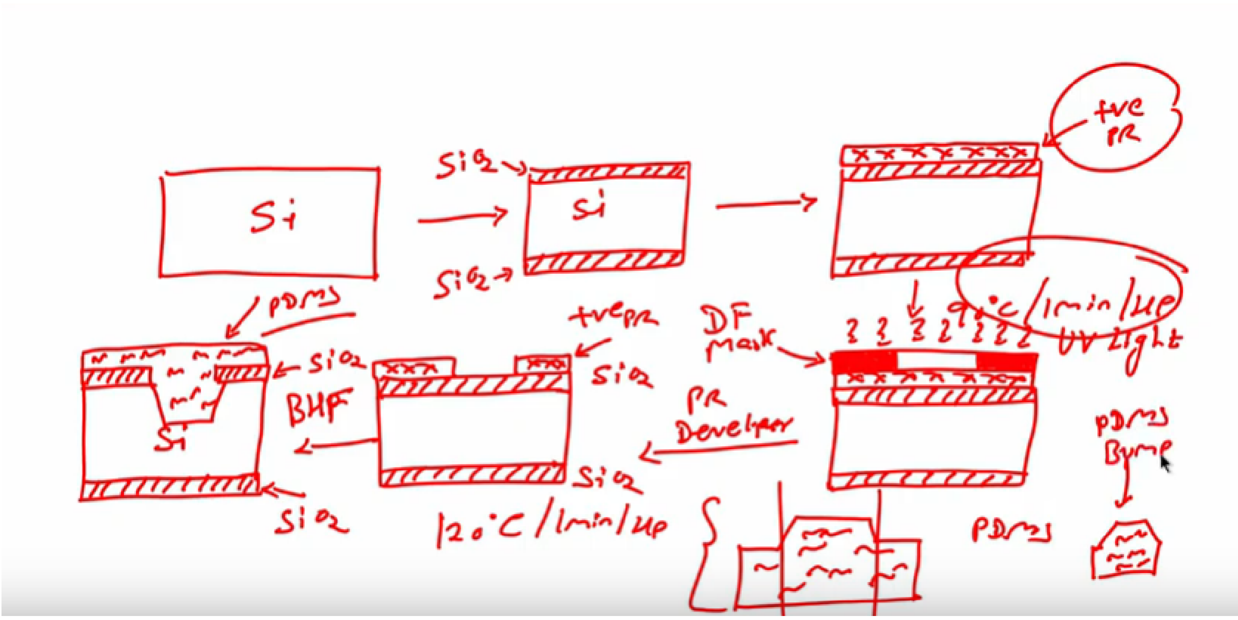

Now, after this what I will do? I will I will pour, PDMS, I will pour PDMS, on this particular pit. and then, I will cure it, this is PDMS, I'll pour PDMS on this pit and then I will cure it, when I cure it, I can strip it off, if I strip it off what will I have? I will have PDMS like this. Right? Now, if I cut this then, what will I have? I have PDMS bump. Okay? This PDMS bump, I have to attach on, strain gauge, I have to stick it on strain gauge. Right? So, how we can create this PDMS bump is using a lithography technique that is what is shown here, that you have, silicon wafer, this one, you have silicon wafer, grow oxide create a silicon pit, then pour PDMS and then cure it, to form the PDMS pump, this pump you take it and attach it to the silicon, to the strain garage that you have fabricated, earlier. So, this entire PDMS that is here, you can step it off from the oxidized silicon wafer. So this is what you get, PDMS then PE dot PSS strain gauge, strain gauge and then the PDMS on the top. Right? This is your sensor; this is your sensor, how? Let us see,

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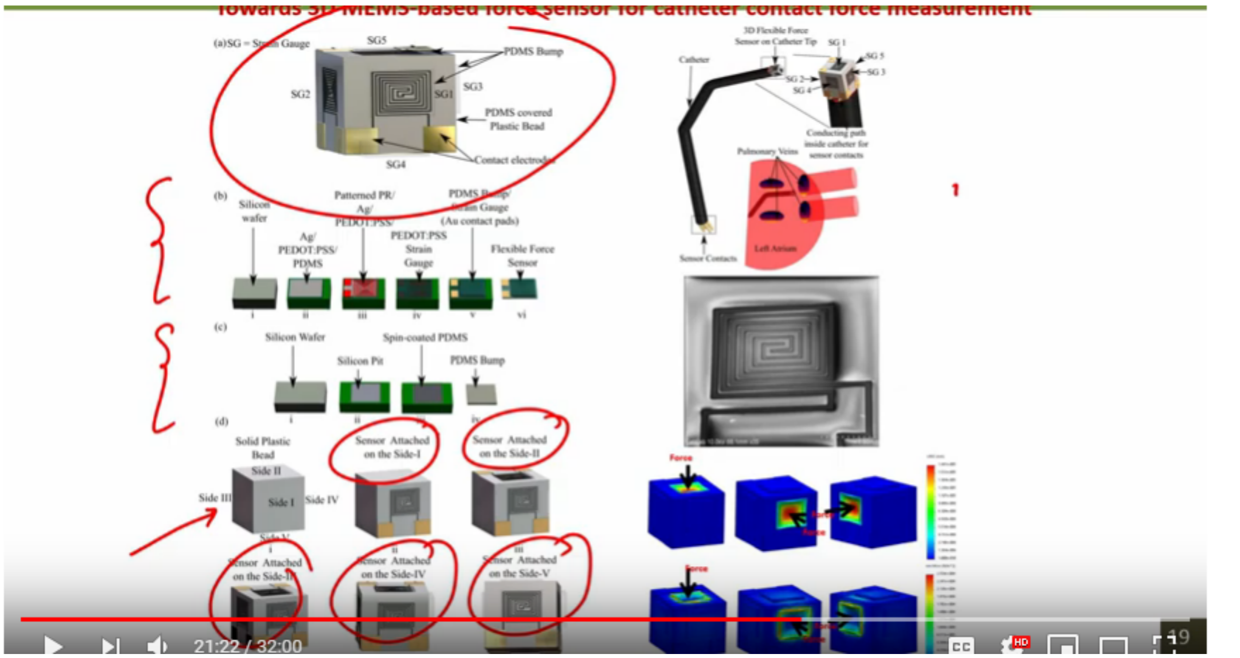

now, if I do that, then this becomes a flexible for sensor. So, if i press this particular sensor, it will bend and at bending or so strain in the sensor will cause change in the resistance, because Pizza resistive sensor. Right? This is what is shown right in the figure that once, you know lithography, it becomes easy for you to understand, how you can create a different sensors, of abaca different sensors. This is a recipe, all right. This is a recipe. Now, how to create this particular sensor. Right? the first step is to take the cube, you take the cube, then the second step is to create flexible force sensor and to attach it, on each side of the tube, of the cube, see here, slide, slide 2, slide 3, slide 4, slide 5, why slide 6 the side sixth we are not doing anything, because the side sixth is the side, which we have to attach on the character. Right? So, all six sides, side one from side six, we are used side one to side five, we are using for editing the Posadas is too flexible for sensor, after that, you can perform the simulation, it's very easy to perform a simulation, so as to understand that, when I apply a normal force, on to this particular sensor ,how the strain will be there and how what is the effect of stress and strain on the overall performance of the sensor, on applying a force from zero Newton to one Newton, alright. So, we are done ,this study right and we can understand, what are the different simulation results, this is the actual photo offers to engage, made out of PE dot P SS on PDMS material. Okay?

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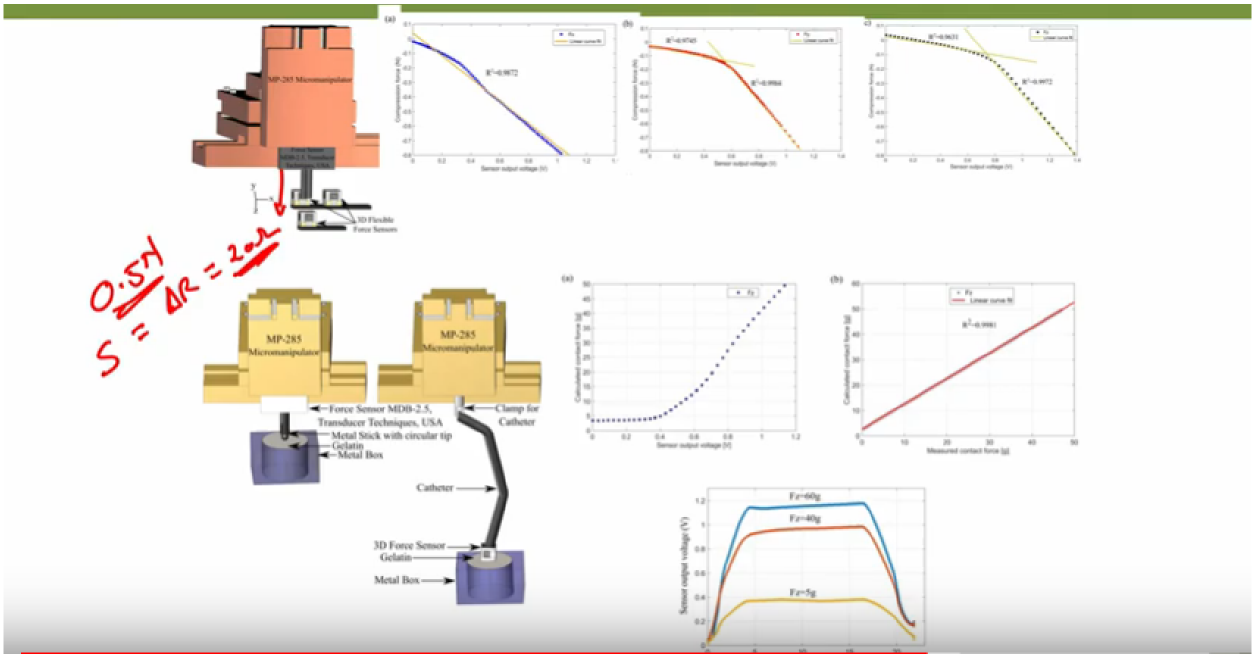

Now, if I perform the experiments then first point is, I had to understand, what is the change in the distance on applying a certain force? So, I had to connect a commercial force sensor or commercial load cell. Or and then, I will apply a known amount of force, on to the sensor, onto the sensor. So, if I know, that point 5 Newton of force I am applying and my sensor is, showing change of resistance from the base value s 20 ohms, then I will know that, every time when it saw change in 20 ohms, it is point 5 Newton, you got it. That's why we are applying a force through, the load cell or a commercial force sensor. Once I have the data, then I will, so this is what it is shown here. Right? and if I connect the sensor, to a proper electronic indistinct circuit, I'll show it you, in the, in the next module, then what will happen, you can see the chain on applying compression force, from zero to zero point one, Newton minuses so from minus interval power point eight, to zero point one compression force, what we'll have is, a different sensor output voltage. same thing when you are applying on the y direction and z direction, so XY and z and every time you are to fit it and the fitting value is, close to point ninety, eight point ninety, nine and point ninety, nine seven that is a square value and this is a linear fit.

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Now, once you know this particular parameter. The next step is, to understand the change in the phantom tissue, change or in the elasticity of a phantom, phantom is not real ghost. Okay? Phantom tissue, phantom tissue you can make, with the help of gelatin in, phantom tissue can easily make the help of gelatin. if you have eight jelly, jelly is what it looks like a tissue and that's why, the jelly would have different elasticity. Right? If you eat a jelly bar, you will understand that, it's very flexible. So can I, measure the elasticity of the jelly, because it's a phantom tissue. Right? So, do that if I have a fabricated sensor and if I apply force, on the jelly, I will see the change in resistance, depending on how much force I'm applying. Now, I am not, I don't know, what is the force I'm applying, but because there is a change in resistance, I will use this value, which I have already, have a table, with the help of commercial force sensor if you remember, we are applying different force to the our fabricator sensor, from that we have four forces resistance value. Now, with the fabricator sensor, I am applying force to the tissue and that I, whatever change in resistance is that, that will correspond to the earlier force. Do I have a, force and resistance correlation? So, let me, let me show it to you here, if it is too confusing for you. So, if I have the commercial, commercial for sensor, CF this is fabricated for sensor FF. right? Now, what I am showing you here is that, there is a electronic on listing circuit, so every time the registrant changes, let us keep resistance as a point now. I am applying different force 0.4, 0.1 to 0.4 Newton's. Okay? This is commercial for sensor, applying force on the fabric for sensing. Now, when I am applying point 1 Newton, I am looking at, a change in the distance, so that's the base resistance is 1 kilo ohm, the change in resistance is 1 point 1 kilo, of now the newel is 1 point 1 kilo ohm and applying, point 1 Newton. So, what is the change in resistance? about 0.1 kilohm, if it's a, if it's a linear, then I have changed resistance like for 0.0, 0.2 I'll have change point 2 kilo ohm point 3 Newton, I'll have point 3 kilo ohm point, for it and I have, point 4 kilo ohm values. Now, I know that, whenever my sensor is changing from 1 to 1 point 1 kilo ohm that means, the force that it is experiencing is point 1, this was easy. Now, what I am doing, I have fabricated sensor, for sensor. Right? With 1 kilo ohm base resistance and I am applying a force, on to a gelatin, gelatin, gelatin is a phantom tissue. When I apply certain force, I see that, my sensor is showing one point two kilo, from this value, I can listen one point two kilo ohm, there is one plus point 2 this is Delta R what we are showing, this is overall resistance, so this point, one point two corresponds to point two kilo ohm and that's why, it is point two Newton. If it is changing from 1 kilo ohm to, one point four kilohm, one point four kilo ohm, when I apply a force on the gelatin, then the change from 1 kilo ohm to one point four kilo ohm, will be of 0.4 kilo ohm, this point four kilo ohm, corresponds to point four Newton and thus I know , I am applying power point 4 Newton of force, on to gelatin, that is what I want mint, when I was telling you about the, force versus change in resistance and how to correlate it, with the help of a commercial for sensor or a load cell and then go back and press the gelatin tissue and from there we can get the results.

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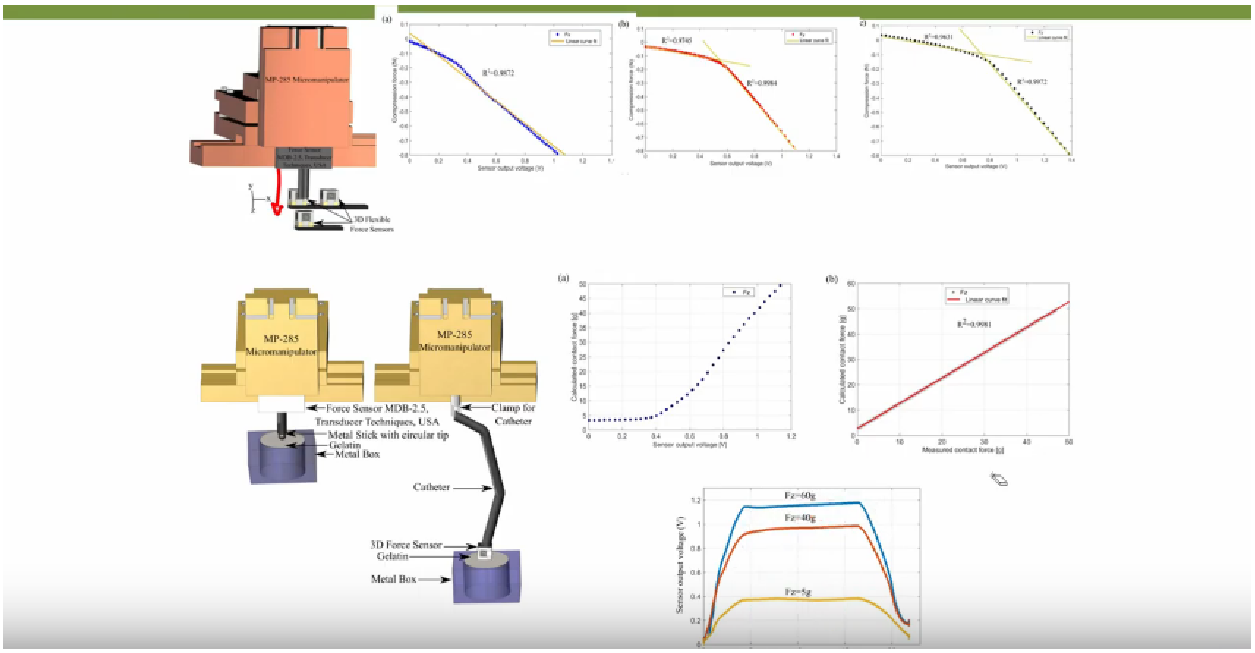

So, this is a mp285 my micro manipulator. you have seen the MP 285 micro ml micro manipulator, you will see probably in the in the class, but if not, then it is a, it is a, it is used to manipulate the, the, the rod that we are attaching or the catheter tip that we are attaching, in terms of few microns. You can move it, x y&z with a precision of few microns. So, now you when you apply a force. Right? Onto gelatin with the help of the catheter, then what you get, that you have a sensor output voltage versus calculated contact force and sensor out measure contact force was is the calculator contact force. So, you can see that it's extremely linear and thus the sensor, can act to as a force sensor, now when we apply different grams of force, from Phi gram to, 40 gram to, 60 gram. You can see the change in the, sensor voltage, then one, so a photograph is our optimum force for the ablation, we have seen that.

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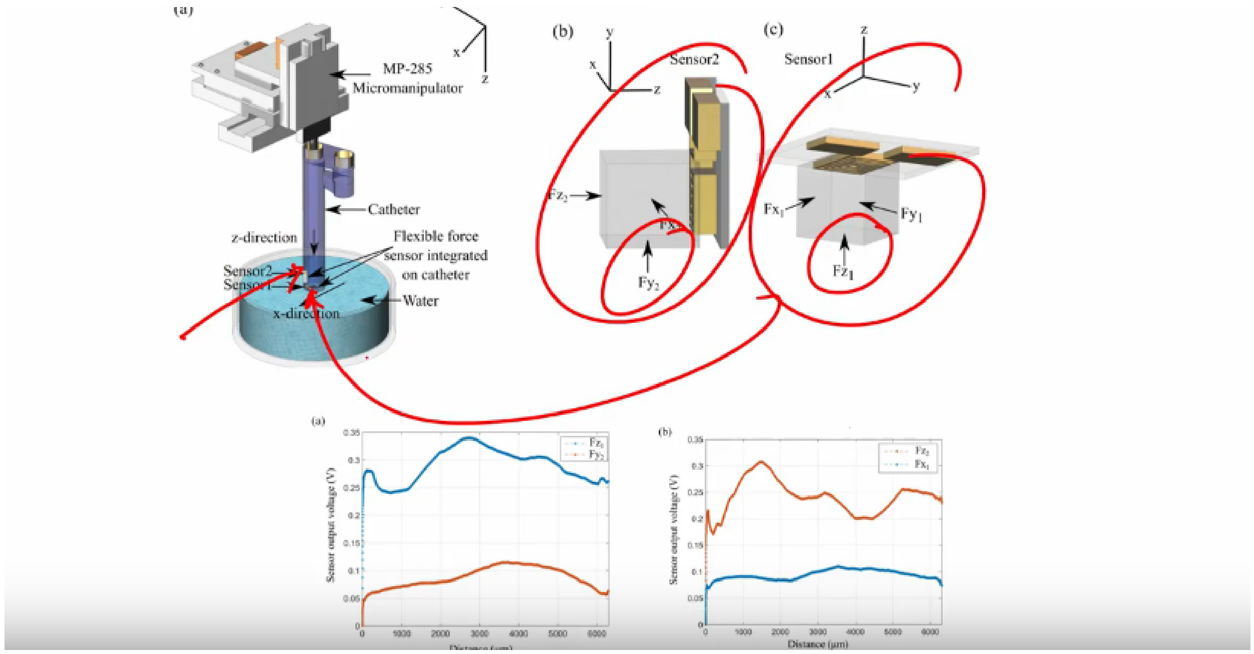

Similarly, if I want to use the sensor in water and I can, I can move the sensor in XY and z direction and for that, I have different sensor output voltage, depending on the distance that I'm moving, for, for each side, I will have. So, for in this particular case, you have seen sensor 2 and sensor 1. Right? The, the FZ 1 and f Y 2 would be the force acting on the z direction, like right here. and when it is acting in this direction, the force acting on FY 2, y 2 will also be there because of the way we have it is the sensor one, sense that is at the tip, of the, of the creditor, one sensor is on the side of the creditor. So, when you are applying a force, which is FZ one, then a correspondingly f Y 2 will be affected, same way, when we are applying of, because you can see here, you see what I am saying is this sensor is connected, on this side; this sensor is connected at the bottom, all right. So, when I am applying F z1, this one force is acting on F z1 surface, for this sensor 2, which is on the side, I will have force on FY 2 and when I have force on F Z 2, which is right over here, right I will have corresponding for Z, F x1, all right. These are it is related, so f, f z1 is ready to F y 2, FZ 2 is related to F X 1. Z is Z. Okay? F z1, as I said z, but you can also say Z, it is how you are comfortable with, so but the point is here, we can measure the change in the voltage, which is the sensor output voltage, when we move the sensor in the water. So, this is how we can do the experiments. And this is the last slide for this particular module.

But, what I want to say is that with the help of lithography system, you can design, a several micro, several sensors, one of the sensor I have taught you, in this particular module, we can use electronic un listing system, using operational amplifier and connect it with this kind of sensors, so that we can see the corresponding change in the force values, at the display terminal, alright. So, then you have to take care, alright, please focus on the slides, the notes that I have given you, the videos that you can see and also try to see the experiments, because experiments are extremely useful. If I take talk about ECG, you can also find ECG from lots of PPTs is available online. Right? You can, you can learn books on PCB, on the ECGs. But, if we are showing you in a real time, how the ECG is performed is very different, than what you find from the, what you can learn from the books. Right? So, please focus also on the experiment part and in the next module, we will continue the, further in the topics of the this particular course. So I'll see in the next class. Bye for now.