Fabrication Techniques for Mems-based Sensors: Clinical Perspective
Prof. Hardik J Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture - 31
Smart Catheter- Flexible Force Sensor

Hi, welcome to this particular module. And in last module what we have seen? We have seen atrial fibrillation right. And now, we know what exactly atrial fibrillation is right, it is a heart disease, where your heart starts pumping unevenly. So, actually that unevenness of pumping or heart beating is due to misfiring of signals. And then we have seen through video right that what is a procedure or what are procedures to cure this particular problem.

Through this interaction and through the videos and through the notes, we understood that tool that is called catheter is used to cure this particular disease, and that is how it is done? That when there is a misfiring of signal first a catheter through a small incision is insert into the body of a patient, and that catheter goes to the area within the heart, where the electrical signals are misfiring that catheter we call it as a electrical mapping catheter right, so that we can know which area within the heart is misfiring.

Now, once we have this electrical mapping, then the clinician will insert or a surgeon will insert another catheter for ablating that particular portion. So, when you talk about ablation, ablation is burning. Burning of tissue that it is a heart tissue, where the misfiring of signals are occurring, so that is the ablation process, so that ablation can be using cryo, there is a cryo ablation or it can be used it can be done using RF. So, RF is what radiofrequency ablation.

Now, in both the cases, you are heating the tissue. So, when you heat the tissue, tissue will burn right. If you if you burn the tissue, the current cannot pass that means, the signals will not pass that means, we think that the misfiring of signals has been cured. But, it is very important to know the source of the signal, because it is not a uniform directional signal or large number of signals that is coming like index in the case of arrhythmia right. In this particular case, the formation of signals is extremely non-uniform, it is very difficult to find a source of the signal.

So, if you can burn that source of the signal, then the recurrence would be extremely low. Recurrence means a patient would have the same episode after going through surgery within few days right. So, another way there are several parameters that we observed right last time, including power density, what is a (Refer Time: 03:09) size right, what is the contact force, whether it is a irrigate irrigation catheter or non-irrigation catheter. So, a lot of parameters are involved, when you are talking about atrial fibrillation.

We are interested in contact force, because contact force is very important. Why, it is contact force. So, when the catheter touches the heart or touches the tissue of the heart right, how much force the a surgeon is applying is very important. If the force is less, then the ablation will not be proper. If the force is more, then the other areas, which were not misfiring will got will get burned right. So, if the force is less, recurrence rate is higher. If the force is more, the burning of the unwanted region will happen.

So, to have the optimized force, there are catheter force sensing techniques. And we have used we have seen yesterday tacticath catheter and thermocool right thermicool or thermocool. Actually is thermocool thermocool catheter. We have seen both these catheter, which are right now used in surgery.

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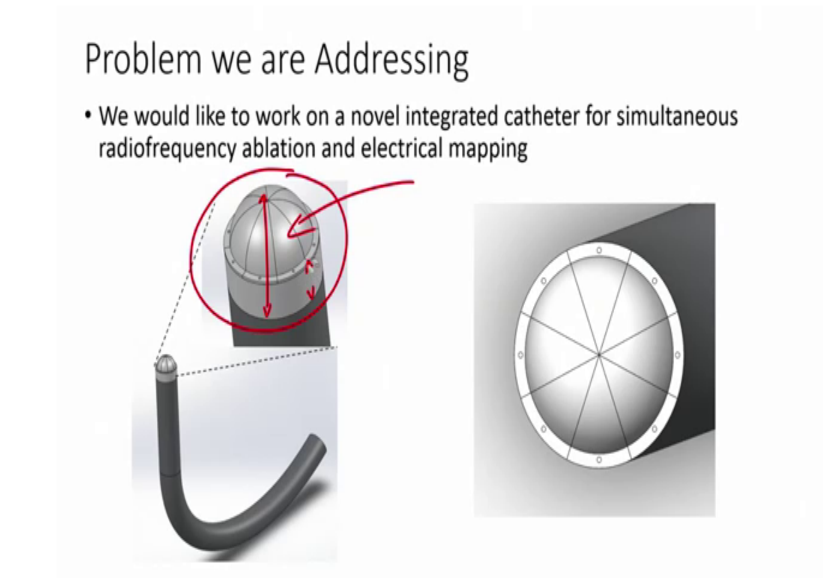

Now, our idea is to design a catheter that can perform electrical mapping as well as ablation together. So, yesterday we discussed sorry we discussed this catheter right and your design, where it will open the tome will open an catheter within it. So, this external this tome will have if through this tome, we can give the RF frequency right. We can also have make it conductive, so the length of the tip increases right.

So, this particular section can give the can be used for RF ablation. While when this tome opens this thing opens right opens up, at that time the another catheter from within will come out, and there will be used for electrical mapping that is our idea anyway. So, you can design your own catheter. So, you see this is open problem.

I want you guys to not only learn micro engineering or in a clinical applications, but I also want to think right, think novelty the things that we are learning this subject in this particular course or the things that are most of the things are open problem right. You can design, you can start working on this, you can start performing research. And if the idea is novel, you can have your startup right. We there are beautiful schemes from government like making India scheme right.

So use these kind of initiatives to design and to come up with a novel idea, the novel technologies that can be implemented, not only in clinics, but everywhere else with the with the knowledge of your this particular subject. Now, this particular subject is a part of the knowledge, you had to acquire other subjects knowledge from other subjects as well to form a complete set up right.

But, like I said if you know micro engineering, if you know micro technology, then you can collaborate, you can integrate with lot of subject experts right. Starting from clinicians to a chemical engineer to a mechanical engineer to a robotics engineer, there is to a biologist, there is a unlimited you know access to you right. Learning this course, learning micro fabrication, learning MEMS, learning the FAB lab technology, will give you unlimited access to collaborate right.

We will not make you an experts in all the subject, but we will help you to work with someone right. Working together, you can you can make cool devices. Working alone you can, but working together, it will be it will be a really nice experience try sometime right to work together. Of course, I am sure that till now you guys have tried working together concept right. Other when we are preparing the homework or assignments or it is about preparing for exams right, we read together, we shared ideas. So, when you work on a research problems together with a interdisciplinary ideas, the results would be amazing So, coming back to our catheter problem. So, this this a design that we have been talking about.

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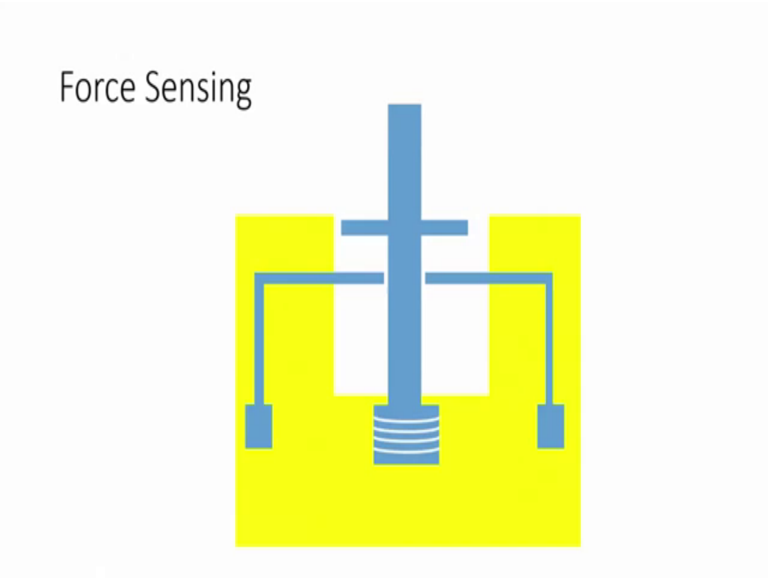

What kind of force sensor you can used right. This is one example of a force sensor, so and how this force sensing mechanism would work right.

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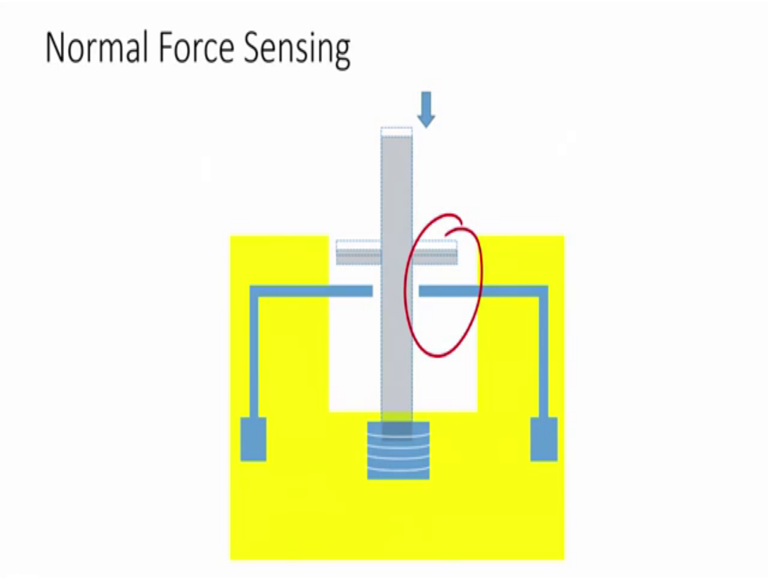

So, what you can see is if I apply a normal force, then there will be displacement because of which you can you can measure the change in the capacitance, you can see the change in the capacitance. So, one way of measuring the force would be to have this kind of sensor.

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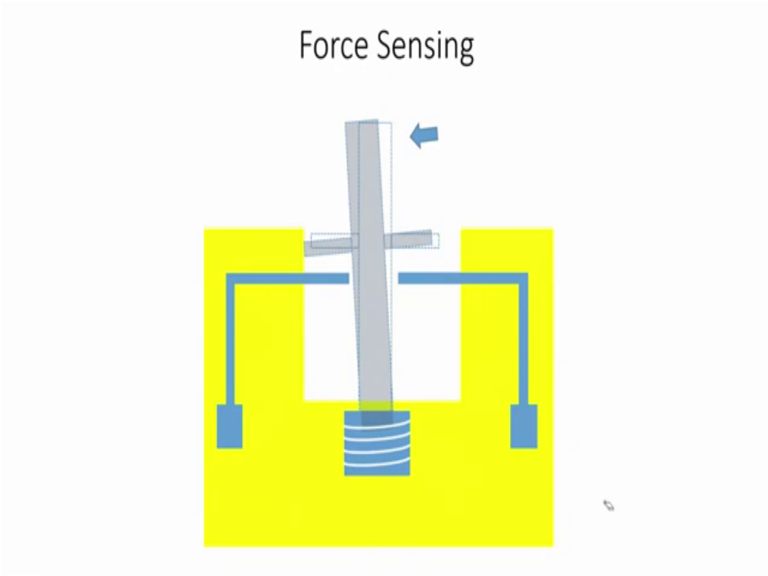

If the forcein this particular direction which is shown here, again you will see the change in the spacing between the electrodes, and you can see the change in the capacitance. But, but this is only one way, there can be capacitive force sensor, there can be piezoresistive force sensor, there can be cantilever, there can be strain gauges, there is a unlimited design of the for force sensing.

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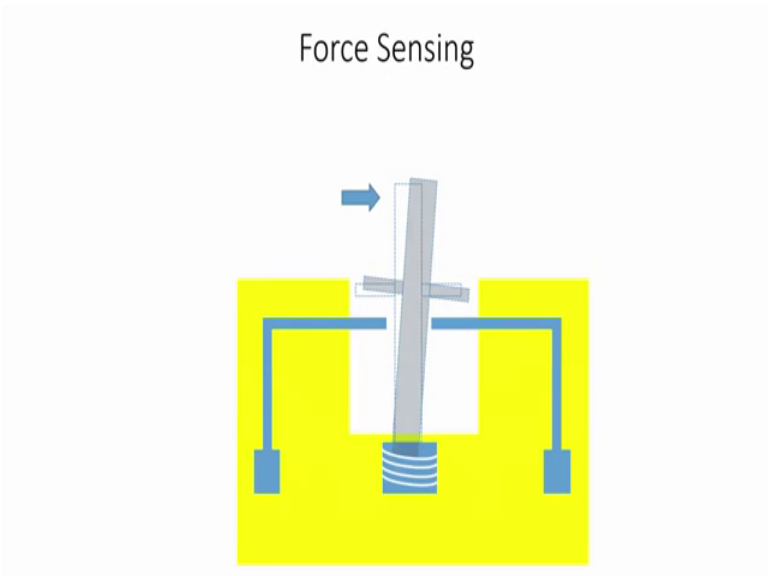

Now, when we talk about force sensing, again another design right.

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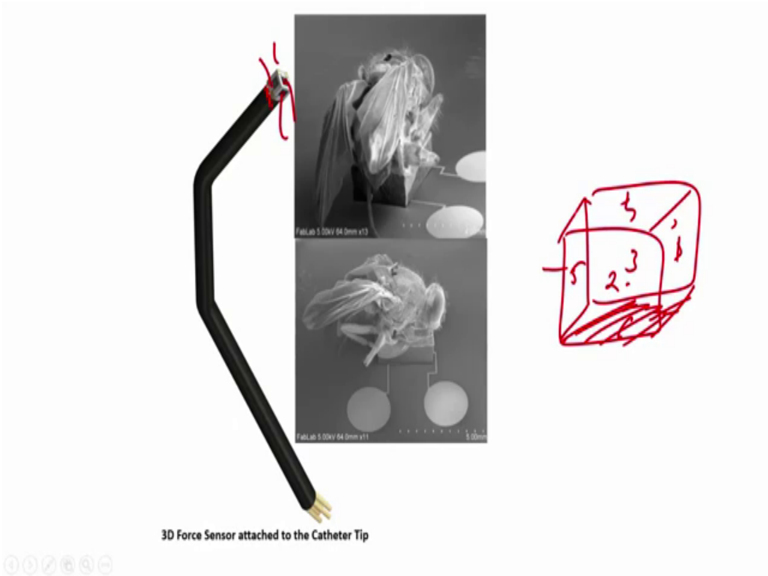

When we talk about force sensing, what kind of force sensor sorry what kind of force sensor we are we want to design. And here you can see a 3D force sensor attached to catheter tip, observe it carefully. Observe the section carefully, we will be talking about this section. So, what you see here, you see here a 3D MEMS based force sensor right. And on this 3D MEMS based force sensor, we have force sensor on five surfaces of cube.

If you have a cube, how many surfaces of cube has 1, 2, 3, 4, 5 and 6 right. Six surface is attached to the catheter here. So, on five surface, we have force sensors right that is why we say 3D anyway. This is just a concept right, can it be actually implemented. So, first to implement something, once to design something, you should start somewhere.

So, this is force sensors that we developed earlier. And we try to measure the we try to calibrate it with the actual force sensor available or commercial force sensor available in market. And I will talk about the results in the following slides. But, the idea is that if you have force sensor on the catheter, can it be used for measuring the catheter contact force.

Now, here what you see is a housefly you can see a housefly right. A housefly is sitting on the sensor right. And the interest of making the housefly sit on the sensor was to measure the weight of (Refer Time: 10:48) housefly right.

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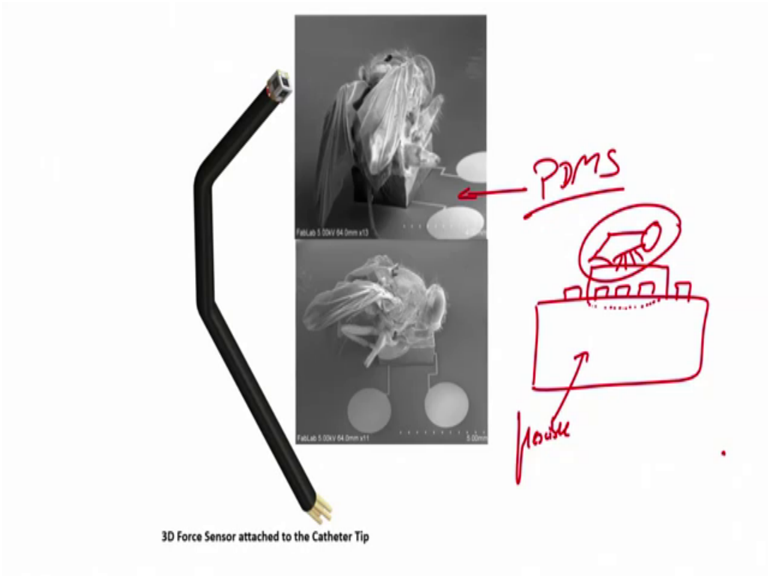

It is a strain gauge, it is a flexible material that we have used, again it is PDMS; PDMS right on which there is a strain gauge. And on the strain gauge, there is a cube. So, if I just draw a cross section, there is a strain gauge, and there is a cube right, you can only see one contact. If I draw a cross section, again you will sees see both contacts there is a matter. So, on this housefly is sitting.

And this is a flexible material, the substrate is flexible. So, if my sensor is sensitive enough, it should bend depending on the weight of a fly depending on the weight of a fly. So, anyway the this is this is just to understand the sensitivity of a sensor right, not actually we are interested in measuring weight of fly, we are interested to use the sensor for the for the atrial fibrillation.

So, and that the grams is about 40 grams, and the weight of a housefly is just few milligrams just few milligrams. This is a dead housefly, not alive. So, do not get confused with that particular thing the housefly is dead. And then we have stick this housefly on the sensor using a silver paste, otherwise the housefly will start flying you know, it is not a fact that I can ask sit on the sensor.

So, and the image that we have taken is using SEM imaging. So, SEM we will talk about SEM, we will talk about AFM, we will talk about TEM in the in the following classes. SEM is nothing but scanning electron microscope. TEM is transmission electron microscope. AFM is atomic force microscope. XRD is x-ray diffractogram.

So, what are these techniques, these are all catheterization techniques material catheterization techniques right. If you want to see micro sensor, which you cannot see with your microscope right. Can we go for a scanning electron microscope or you want to know what is the crystalline property of a film that you have deposited, whether it is amorphous, whether it is poly crystalline, whether it is crystalline. Then you have to go for TEM right sorry you have to go for XRD right x-ray diffractogram.

If you want to know the surface roughness right of the film, there once you deposit the film, what is the roughness of the film, you can use atomic force microscopy right. So, we will look at these catheterization techniques in this particular course. Right now, this one is a dead housefly that we have used silver paste to stick it on a flexible force sensor, and we took an SEM image right, along with the you taking a measurement, we have taken the SEM image. So, having said that let us move further.

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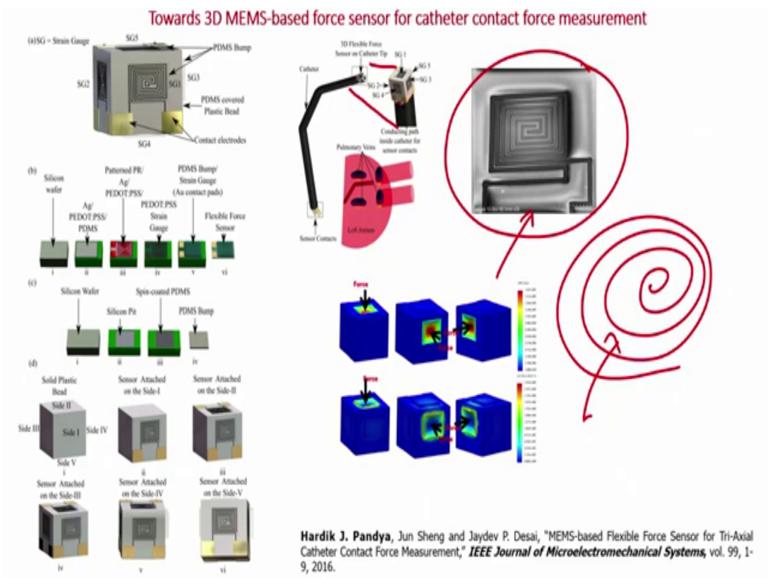

So, what is the idea, idea is to develop a catheter, connect a 3D flexible force sensor on the catheter tip, and there are five sensors as you can see here. And since, it is a strain gauge, we have named SG for strain engage, so SG1 to SG5. You can see when you magnify this particular portion right, and there is this connection through the strain gauges that comes through the catheter. As you can see the sensor contacts are right at the tip of the catheter another tip of the catheter or you can say end of the catheter.

And then the idea is that the signals that are generating at the PVI, wherever there is a misfire, the catheter can be placed there, and you can start ablating. When it ablates, it should measure the force of the catheter during the ablation right.

Now, if you see here what we have used, we have used a coil. A coil as a strain gauge right, we also did a measurement. And if you want to see in detail, please go through this particular work of mine is MEMS-based Flexible Force Sensor for atrial fibrilation for Tri-Axial Catheter Contact Force Measurement, it is published in I triple E Journal of Microelectromechanical systems. And you will be able to see in detail, how we have perform the analysis. The idea today is to show it to you how you can design this particular force sensor, and then you can always change the design, and the at the you know pattern to fabricate a better sensor than what we have fabricated in this particular work.

Now, if you see this, this is a rectangular kind of coil. If I asked you that instead of rectangular coil, if I use a circular coil, which I have drawn here, which one would be more sensitive. Then you have to understand what kind of mathematical equations you have to see, and you have to go through it to understand the gauge factor. Gauge factor of this particular design would be hair or this particular design would be hair. When you understand, then you will then you will know which kind of design you should use for particular application.

Now, I hope that you all know what is gauge factor right. Gauge factor is nothing but strain by stress. So, strain by strain delta r by r by delta l by l. And the gauge factor for metal is poor compared to gauge factor of semiconductor. So, you need to understand that when you are fabricating a sensor, you need to understand which material you are using, and what will be the effect on the gauge factor using that particular material.

Now, when you apply so, this is the simulation like I always say that no fabrication should be done until you perform a simulation. This is a COMSOL Multiphysics. Using COMSOL Multiphysics, we have perform the simulation. And we applied force in different directions, just a normal force to understand what is the effect of applying force on the sensor, how much sensor will bend right, how much sensor will bend. And this is very important, because we need to understand that if the sensor breaks, then it will not give a correct result. So, we need to understand what is the limit that a sensor can take the force, and that is why the simulation becomes very important.

Now, if you see the this force sensor what you see here, you see that there is a there are five strain gauges right. Then on each strain gauge, there is a PDMS bump. Why we are using PDMS bump, because if I have a strain gauge let us say like here right. And if I want to apply pressure right, I do not know whether it will be here or it will be here or it will be here right. If I use a bump right, and if I have if I apply a pressure right, then it will kind of transmit to all the area kind of uniform transmission of the force can happen. So, PDMS bomb can be used for transmitting the force onto the strain gauge.

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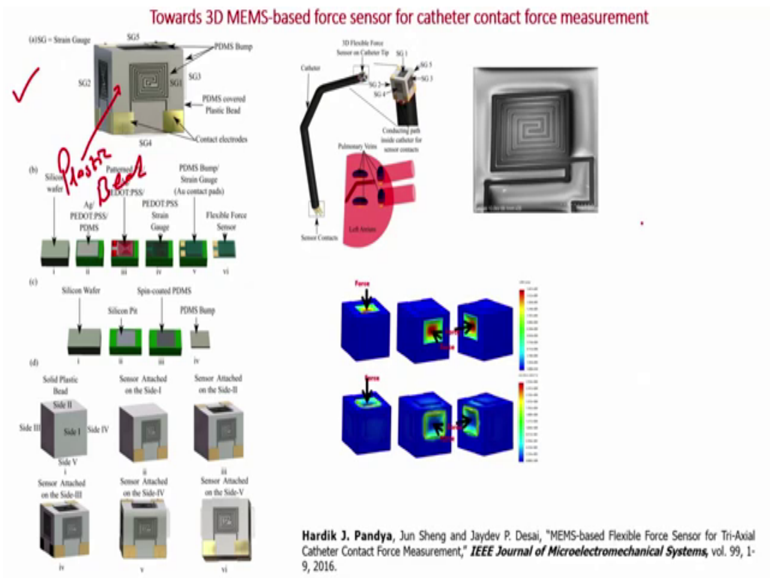

Now, we have contact electrodes, and we have PDMS covered plastic bead right. So, this is the PDMS covered by plastic bead or plastic bead on which there is a PDMS the substrate. The substrate here that you can see is nothing but a plastic bead plastic bead. So, see this is again a the preliminary works. So, preliminary work, we are using a plastic bead to understand, can we have a 3D MEMS based force sensor. But, but like I said can it be actually used in the atrial fibrillation, no. Why, because the force sensor is sitting at the tip of the catheter.

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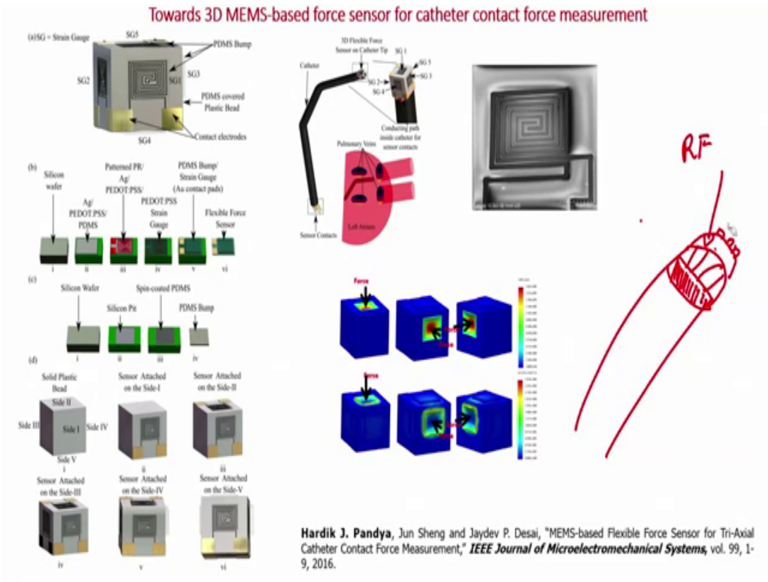

But, if you want to perform the experiment, then if you have seen right the tip of the catheter that we have designed right now right like this, and let us say like this right like this. So, the this tip will be used for applying RF radiofrequency right for ablating the tissue. So, if I have a force sensor sitting on the tip, which I have shown here like this, it is very difficult, it is very difficult.

And the burning of the tissue that the heat that is generated, we may cause the force sensor may cause damage to the force sensor. So, we cannot have force sensors at the tip of the catheter as shown here right. However, the idea was to understand what is the how the force sensor is performing at to evaluate the performance of the force sensor.

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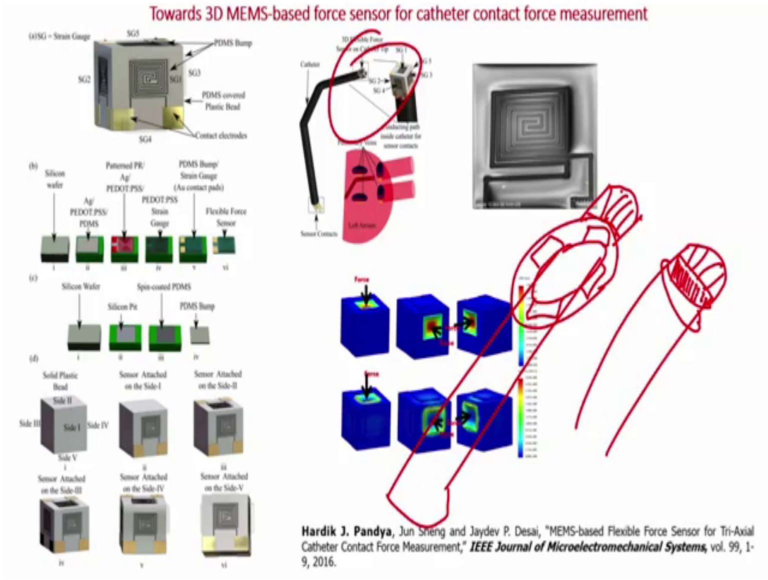

But if I want to have a force sensor what I will do is, I will perform I will make a sleeve along this catheter, and we will make force sensors. What I am saying is, I will make a sleeve like this, and along the sleeve I will have my force sensors, and here the catheter will sit, so it will go something like here like this right. My drawing my drawing may not be so cool, so do not worry about it, I hope you understand. If you understand, just look at me, I will just show it to you what I mean.

Yeah. So, this is a catheter this is a catheter. And what I want is to create a sleeve that can sit on the catheter like this. Now, this sleeve itself, the sleeve itself, so it is just like a rubber band. If you have seen a rubber band that we put on the hair right, how the hair is tight with this rubber band. You assume the similar kind of thing or you can see about a wrist band right, friendship band, wrist band right. So, wrist band you put on the hand right. Same way this band that is connect that there is having the sensor can be it is a sleeve that you can put on the catheter.

So, now when you perform the experiment, if there is a force acting here, here, here or normal force or shear force, you can easily measure it right that is what I mean by creating a sleeve instead of putting the sensor in the tip of the catheter that is not. Because, tip should be used for applying RF ablation RF frequency or cryo whatever you want to use for ablating the tissue.

But, the force sensor should be on the sleeve or it should be inside the catheter like what a tacticath tacticath or and thermocool catheter comes with, so that is a bug in there is a fiber optics optical sensor, there is a spring mechanical sensors. And of course, you we have we have discuss about it yesterday or in the last lecture, but that itself has few limitations. And we have to overcome those limitations by designing this particular sensor however. So, my point is the you can developed a sleeve on which you can have the sensors area of sensors, and that you can insert on the catheter either inside or outside.

So, if you come back to the screen what we see here what we see here is the fabrication process these two. So, first fabrication is from silicon wafer to a flexible force sensor, second is from silicon wafer to PDMS bump right. And then we are taking a plastic bead here, and then attaching sensor on each side of the plastic bead right. See we are taking a plastic bead and attaching sensor on each side of the plastic bead, so that makes our sensor ready for measurement. So, now the question lies how you can design this flexible force sensor right, how you can design this flexible force sensor. So, let us see in the next slide, how can we design this flexible force sensor.

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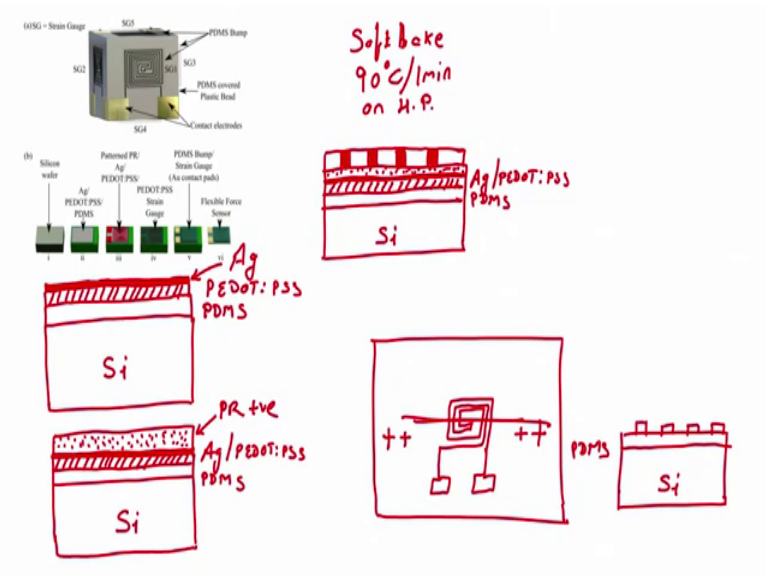

So, what is the first step, first step is to take a silicon wafer, we will draw little bit smaller, so that we can use entire screen judiciously, we take a silicon wafer. On this silicon wafer, we pour PDMS ok. On this PDMS, we have PEDOT PSS on which there is a thin layer of silver. This thin layer of silver along with PEDOT PSS, we will form our strain gauge. So, this is our PEDOT PSS.

What is PEDOT PSS, PEDOT PSS is a conducting polymer is a conducting polymer, this is our silver right. So, what we have, we have silicon, we have PDMS, we have PEDOT PSS over which there is a thin layer of silver. Now, on this particular wafer on this wafer as you can see here, what was that silicon, PDMS, silver on PEDOT PSS. We have we have to pattern this right; we have to pattern to form a strain gauge. So, what we should have, we will spin coat photo resist we will spin coat photoresist right.

After spin coating photoresist, what is the next step, next step is to soft bake soft bake right. Soft bake is done it 90 degree centigrade for 1 minute on hot plate right. Now, after that what is the next step, we all know right now we all know how to perform photolithography, it is very easy right silicon, what is next one, PDMS, then we have silver PEDOT PSS. On that what we have, we have photoresist. On photoresist, what is the next step, we have to load the mask load the mask and align the mask right; load the mask, and align the mask.

So, if I load the mask, what kind of mask I have a bright field mask correct, I have a bright field mask. Because, I want to form a strain gauge, so the pattern on the mask should be like this you see 5 inch mask, because our wafer is 4 inch, we have 5 inch mask. The pattern on this there should be alignment mark, I will talk about alignment mark some time, what is the importance of alignment mark.

When we talk about the we have already talked I think in the section of photolithography right, so there is a alignment mark. And here we will have our strain gauge. So, in this case, our strain gauge was something like this right something like this. So, if I do a cross section, if I take a cross section of this, what will I see, I will see substrate right with strain gauge, and this is my silicon, and that is PDMS, correct. This is how I should look at the this is how the cross section will look like correct.

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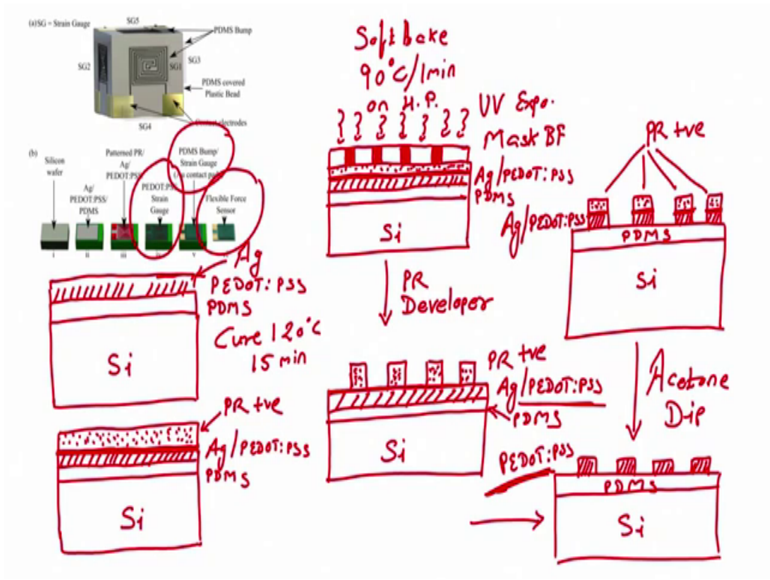

Now, now after loading mask, so that mask was bright field, we can see clearly right bright field mask. After loading mask, what is the next step, next step is UV exposure right in next step is UV exposure. So, UV exposure cool next step. Next step would be photoresist developer right, you have dip the wafer in photoresist developer. So, when you dip the wafer in photoresist developer, what you get, you have PDMS, then you have PEDOT PSS right on which you have photoresist right.

So, what happens to photoresist, photoresist will get developed in this particular fashion right. Why, why it will develop in this particular fashion, because the area which is not exposed right area which is not exposed, will become stronger right area, which is not exposed. You see these blocks red blocks that is the area, which is not exposed right. The area below this will not get exposed, because the UV cannot pass through this blocks, so the area which is not exposed. In case of positive photoresist, we will get stronger right. So, we will have this kind of structure.

What is the next step, next step would be to next step would be to etch the silver and PEDOT PSS, so we etch silver and PEDOT PSS. When we etch silver, PEDOT PSS what you will get, you will get photoresist, this, this, this, and this. This is what photoresist positive right. This one would be silver on PEDOT PSS. This would be PDMS, and the this would be silicon, correct. After etching, PEDOT PSS and silver.

What is the next step? Next step would be acetone dip. Why have to dip the wafer in acetone, you have to dip the wafer in acetone, so that you can strip of the photoresist right, you can strip of the photoresist. So, you have silicon, you have PDMS right, on that you have PEDOT PSS. When you can now strip of the silver also. After you strip of the photoresist, the silver that was there, you can strip it off. We do not require silver, silver is just used to it will help in patterning the PEDOT PSS.

So, what you get, you have strain gauge pattern of PEDOT PSS on PDMS, and PDMS is on silicon. So, of course, when you when you pour PDMS after pouring PDMS, you have to cure PDMS do not forget it. Pouring PDMS, you have to cure PDMS that is a 125 degree or 120 degree for 15 minutes depends on the datasheet manufacturer protocol right. So, this is what we get.

But, (Refer Time: 35:57) about the contact, contact should be this is this is conducting polymer, this is conducting polymer. We want contacts, which are metal right we want contact, which are metal. So, we have reached we have reached this particular stage, where we have PEDOTs PSS strain gauge formed on PDMS. But, next stage would be to PEDOT PDMS bumps strain gauge and Au contact pads, both things we had to get. First is Au contact pad, and that then next would be the next would be the PDMS bump right PDMS bump. So, let me let me have one more slide, so that we can see we can see from here, once we this with this particular stage right, how can we form gold contact pads contact pads of gold.

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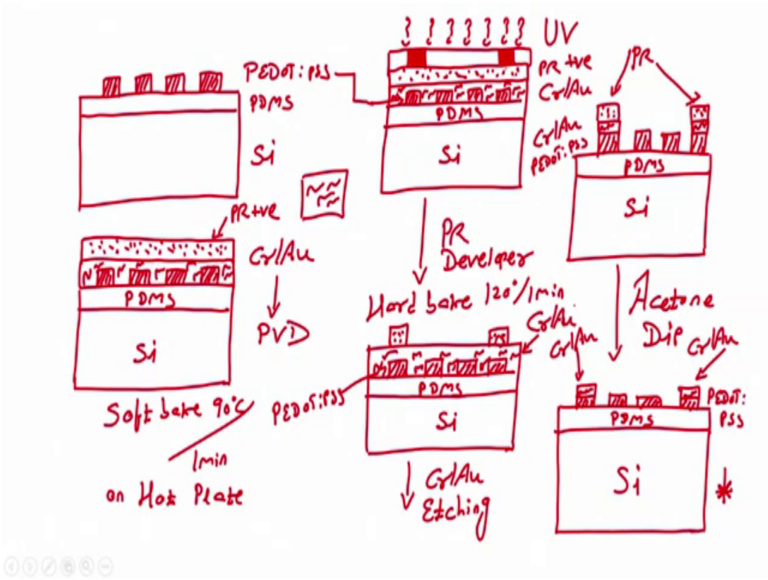

So, for that what we will do, we will have PDMS with PEDOT PSS strain gauge right sorry PEDOT PSS, PDMS, silicon. Now, what we want, we want gold pads on this particular contacts of the strain gauge right gold pads on the contact gold pads for the contact of the strain gauge. So, we have PDMS, we have silicon, and we have a strain gauge. On this, we will deposit chrome gold all right.

So, let us talk chrome gold with some different pattern chrome gold ok. Chrome gold is shown like this design. How we can deposit chrome gold, we can deposit chrome gold with the help of physical wafer deposition, we can use EB mythography. We can use EB mythography to deposit chrome and gold. Why we need chrome, chrome is required for better addition of gold right chrome is required for better addition of gold, so gold will stick well.

Now, after this what is the next step, next step would be we all know right what is the next step, next step would be to spin coat photoresist spin coat photoresist right. So, we have spin coated positive photoresist. After spin coating photoresist, next step would be pre bake pre baker or soft bake right soft bake at 90 degree for 1 minute on hot plate right.

Next step, next step is our favorite step. What is the next step, next step would be to use masks right, and expose the wafer, use masks and expose the wafer. Exposing the wafer with what, exposing wafer with UV light right. What are we doing now, we have chrome gold, we have PDMS, we have PEDOT PSS. And on that, we have positive photoresist.

On positive photoresist, we have to load a mask. And mask should be such that it will just protect chrome and gold on the contact pad of the strain gauge, and remaining area we do not need chrome gold right. So, your mask will be look like the one that I have drawn on screen correct. So, after loading the mask and aligning the mask, what we will do, we will perform UV exposure UV exposure UV UV exposure.

Next step, photoresist developer right. When we develop photoresist what we will have, we will have photoresist will have photoresist protected only on these two area right. This is our chrome gold, correct. Why we have only these two area, because we are using positive photoresist and the area, which is not exposed get stronger.

What is the next step, this is our chrome gold. Next step would be to etch chrome gold right to etch chrome gold. So, the area which is protected by photoresist will not get etch, remaining area will get etch. So, when we perform chrome gold etching, what we will get, we will get strain gauge, chrome gold, photoresist, correct. We will have this photoresist, then we will have chrome gold, then we have strain gauge, then we have PDMS, and we have silicon.

Next step is easiest step right easiest acetone dip, dip the wafer in acetone. Acetone is a stripper to your photoresist. When you dip the wafer in acetone what you will have, you will have wafer which I am showing it to you right here you got it. This is what we will have.

Now, next step would be next step would be to strip of to strip of PDMS from silicon the strip of PDMS from silicon. So, in the strip of PDMS from silicon, you will get this right, you will have PDMS with strain gauge. And on the contact with the strain gauge, you have chrome gold. So, what we will have, we will have this particular structure, not this particular structure is just bump is not there bump is not there.

So, alternatively alternatively what I said if you do not want to remove PDMS right now, if you do not want to remove PDMS right now, then you can remove it later. And keep PDMS on silicon alternatively, you can puts you do not have to strip of or you do not have to fill of the PDMS from silicon after this stage, you keep this stage as it is ok, we say star we say star.

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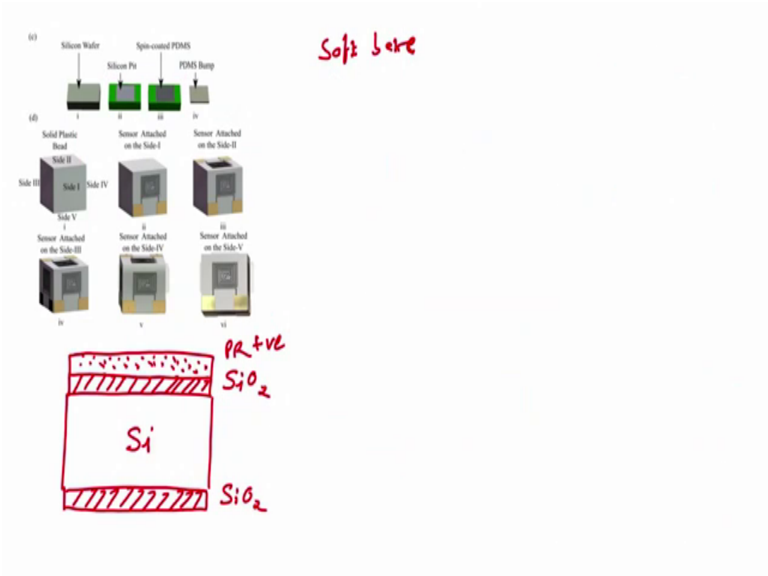

Now, what you have to do, you have to create a PDMS bump right we need PDMS bump. Now, creating PDMS bump, you take silicon wafer take a silicon wafer, grow oxide, you have silicon wafer, you have grown oxide. Oxide is grown using LPCVD or dead oxidation or die oxidation. You can also sputter oxide right, but we will grow oxide oxidize silicon wafer. Next step would be next step would be to create a pit. So, to create a pit, we have to perform photolithography. So, I will first spin coat positive photoresist, now you will know right what I am doing, so it is very easy positive photoresist.

Next one would be soft bake of course, wherever we are I am not adding hard bake every time like for example, after this developing PR developer right, we in before the chrome etchant, we had to perform hard bake we know it. After PR developer, this will look like this. After that, we had to perform hard bake at 120 degree for 1 minute on hot plate we know it right. So, I am assuming that now you guys know, when to perform soft bake, when to perform hard bake. So, after photoresist coating, we will perform soft bake by by loading this wafer on a hot plate and the temperature should be 90 degree for about 1 minute.

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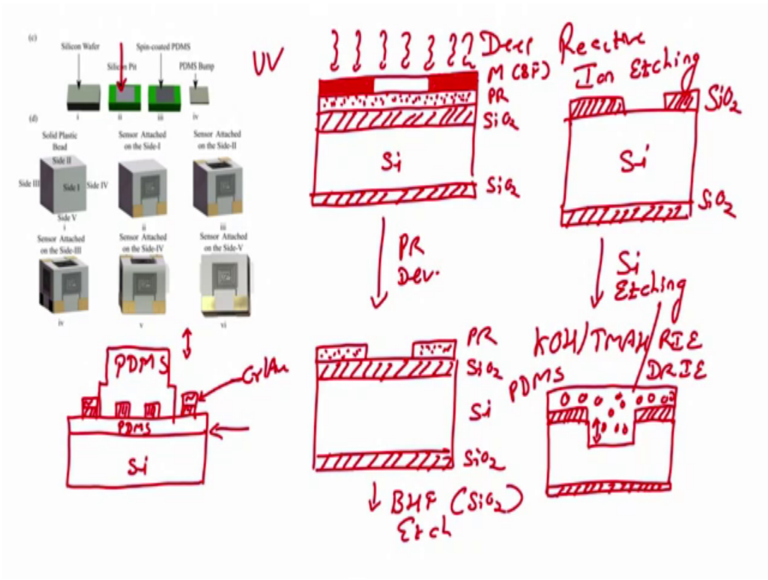

Now, after this, what we will do, we will take the wafer, and we will load the mask silicon dioxide, silicon silicon dioxide right, positive photoresist. We have to protect silicon dioxide all the area except this area, because you want to etch silicon, you have to create a pit, you can see here right, we have we have to create a pit. After mask, so now we know what are the things SiO 2 right layer SiO 2. And we have here photoresist, we have a mask right, which is bright field. After that, next step would be UV exposure UV exposure.

After UV exposure, there is a photoresist developer. Photoresist developing step what we will have, we will have oxidize silicon wafer with photoresist protected in this particular area right, because we are using positive photoresist, so area which is not exposed, we will got we will get stronger, correct.

Now, what is the next step, next step is you dip this wafer in BHF. BHF is SiO 2 etchant SiO 2 etchant right. When you have that, then you have wafer, which looks like right. So, you have etched silicon dioxide from the center of the wafer.

Now, what is the next step, next step is silicon etching. Now, silicon etching can be done either using wet etching or dry etching right. Wet etching we know potassium hydroxide or TMAH, while dry etching is RIE reactive and etching or deep reactive ion etching. Reactive reactive ion etching or deep reactive ion etching deep reactive ion etching.

When you do that, silicon dioxide at as a mask during silicon etchant, you will get the pit you will get the pit.

Now, on this pit on this silicon pit, if I pour PDMS on this silicon pit, if I pour PDMS and cure it, so let us draw PDMS in this particular fashion. In this silicon pit what I have done, I have pour PDMS and cure it and cure it. So, when I pour PDMS and cure it, how it should look like, it will look like a bump.

And the height of this bump depends on the depth of the pit right, the height of this bump depends on the pit. So, this is PDMS bump right. This PDMS bump if I stick it on this silicon, if I stick on this particular bump, so let me draw it correctly, it becomes perfect right PDMS bump I am sticking on it. Now, after that what I will do is I will fill of this PDMS, I will fill of this PDMS.

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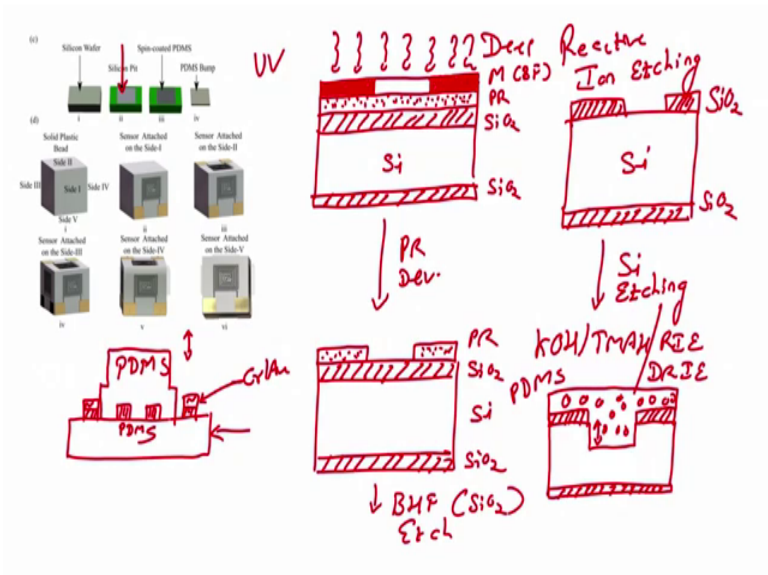

So, what will I have, PDMS with strain gauge with chrome and gold contact pads and a bump and a bump right. So, if you see this particular stage, you will see here PDMS bump on strain gauge with gold contact pads, you are pilling of PDMS, and you are getting a flexible force sensor with PDMS bump, you got it flexible force sensor with PDMS bump. This is how it is done.

So, even it looks very simple, and it is really simple. You had to perform photolithography process right to get to the level, where we can get a flexible force sensor using PDMS. So, when we have a flexible force sensor with PDMS bump right, flexible sensor is fabricated on PDMS, and we have a bump of PDMS on flexible force sensor, then you have complete sensor realized.

Now, you will attach this sensor to the plastic bead by the cube right that we have discussed on all five sides. And once you attach it to all five sides of a cube, next step is to catheterize that sensor. The catheterizing of or catheterization of this sensor or calibration of this sensor and using the sensor on gelatin by pressing it on gelatin or in the presence of water what kind of data we get, we will see in the next module.

Till then what you have to see, again just go through the this particular class first module, which is your atrial fibrillation, go through videos once again, understand the technique, understand how catheters can be used. And then you look at this particular module, and see how we can fabricate a flexible force sensor. So, in the next module, we will see how can you use this force sensor, and what kind of data you can obtain to understand the performance of the force sensor all right. Till then you guys take care, and I will see you in the next module. Bye.