Fabrication Techniques for Mems-based Sensors: Clinical Perspective
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Lecture - 22
Process Flow for Fabrication of Piezo Cantilever

Hello, this class is focused on understanding how we can design a Process Flow for Mems based Micro Sensors. And these sensors that will be learning in this particular class would be used to understand or diagnose cancer.

So, when you talk about cancer, we are focusing on tissue related cancer ok; cancer that occurs on in tissue. And to start with, we will talk about breast cancer. As we already know breast cancer is second largest cause, cancer related that the second largest cause of cancer related death in movement not only involved, but also in India. That is why, from clinical perspective, this is very important disease that one needs to understand and there are open ended problems that one is to find the solutions for.

So, when I say about open ended problems; that means, the problems that about the diagnosis, it is not that we do not have cure for cancer. The only thing that we are lacking is right time diagnosing of cancer. So, when we have a proper diagnosis, then we can go for a proper treatment. So, as an engineer our as an scientist how we can come up with an idea or novel sensors that can aid the clinicians or a path lab to diagnose cancer at early stage right; this is the focus.

So, when we talk about cancer and in the particular tissue related cancer, the tissue property changes as the cancer progresses. So, when I say about tissue, property changes what does that mean? If you have ever noticed a person suffering from a cancer, he will start developing or she will start developing lump right not every lump is cancer.

For example if it is, it can be know it can be just a benign lump, it may not be considered lump that I fibrous that develops and fibrous may not also always turn into cancer. Now, but the point is that whenever there is a lump, what we feel or what a patient feels is that that there is a stiffness right, there is a change in the stiffness.

So, in case of breast cancer, if there is a formation of lump that particular lump will have different stiffness compared to other area of the breast. So, one thing that we understand from this particular stiffness is that we can design a sensor that can be used to measure the stiffness of tissue. So, stiffness of the tissue or elasticity of the tissue can be one of the parameter to understand or to diagnose cancer at all the stage right.

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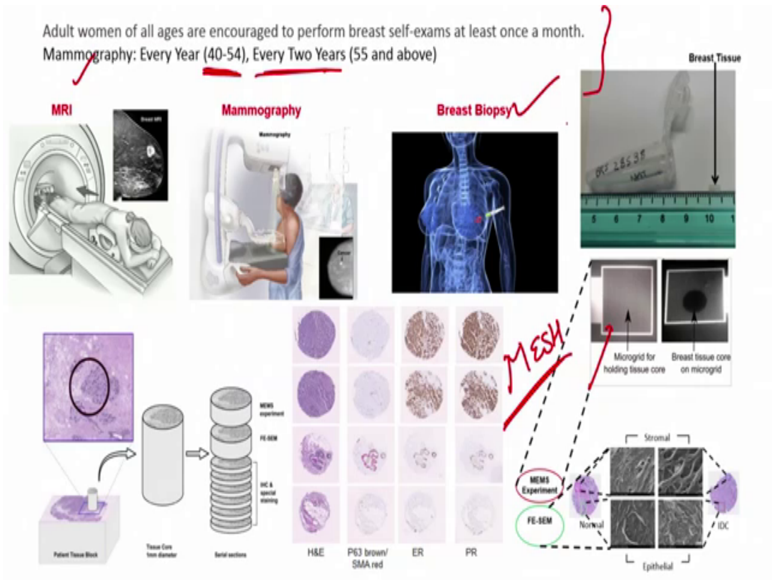

So, we will try to see how we can understand this particular tissue related cancer. To do that, if you see the slide, what we see is we are looking at the gold standard; gold standard in case of breast cancer is to go for MRI and mammography. And, if the MRI conforms the there is a suspicious region right, you can see here the suspicions region here; also, there is suspicious region than the creation would ask for the biopsy. Biopsies, you have to take the tissue out and then need to understand the tissue properties, alright.

So, in this case, once a issue is out, it is sent to the path lab where they look for different markers H and E, P 63 Estrogen Prostogene. There is also called marker called H E R right. And then, using this markers biomarkers right the final conclusion or final diagnosis would be a patient is having cancer or patient is not having cancer, right. In this particular case, in these particular techniques, there is one drawback and that is that there are very high number of false positive and false negative results.

So, how can we reduce this false positive and false negative result? That is our goal, alright. So, first thing that you learn in this particular topic is can we understand the stiffness of tissue right. So, you see that if the tissue is taken out right from the biopsy, when the tissue is taken out it is sliced into several parts. You can see here this is for immunohistochemistry and special staining this is for sem analysis.

And, this is we can use for our experiment which is our Mems experiment alright. And, when you look at the tissue, the morphology of the tissue is also different you can see the surface morphology of this tissue whether the stromal tissue whether this epithelial tissue right. If it is a cancerous tissue, the morphology would be different. Here, you can see if the normal tissue morphology is different right. So, from the morphology itself, we can see that there is some difference in the tissue properties right. So, how can we now measure the stiffness of tissue?

So, once the slice is out, the slice is kept on the micro grid. As you can see, here is micro grid is nothing but the mesh. If you see mosquito mesh at your home, similar to mosquito mesh, but is this extremely micron in dimension. That means, that the width and the spacing of this mesh. The lines are the width is about micron and the line spacing is also about few micron. So, this is a mesh and is micro grid on which we can place the breast tissue and we will see what kind of tool or a device can be used to measure the stiffness.

So, if you go if I go to the next slide, we will see what is the device. But, before I move to the next slide, let us see one more thing in this slide is that of women of all if this women of all ages are encouraged to perform breast self-exams at once at least once a month ok, once a month, every women is encouraged or if it is women are encouraged to perform breast self-exams while woman remain in the age of 40 to 54 age of 40 to 54 every year, they should go for mammography; while those who are 55 and above should go every 2 years once for mammography, alright.

So, this is something that is required as an awareness is an awareness. We are not aware of diseases, we are not aware of things around us and that is why, there are large number of deaths. So, if you are learning this particular subject, also try to aware the people around you, your loved ones, your relatives, your friends and understand this kind of diseases. So, that more we understand, more we are aware; less number of deaths will happen around us, alright.

So, awareness is very important along with understanding engineering and creating new devices. But, if you are not aware, then we will reach to a stage that already cancer has been that particular or final stage that it is very difficult to cure the patient alright.

So, when I talk about awareness is just like what kind of programme. What kind of screening methods that are available in market that we can use to understand the wellness for our body right. Everything is working well within our body. The there are there are programs available to understand those things, that is what I mean by awareness.

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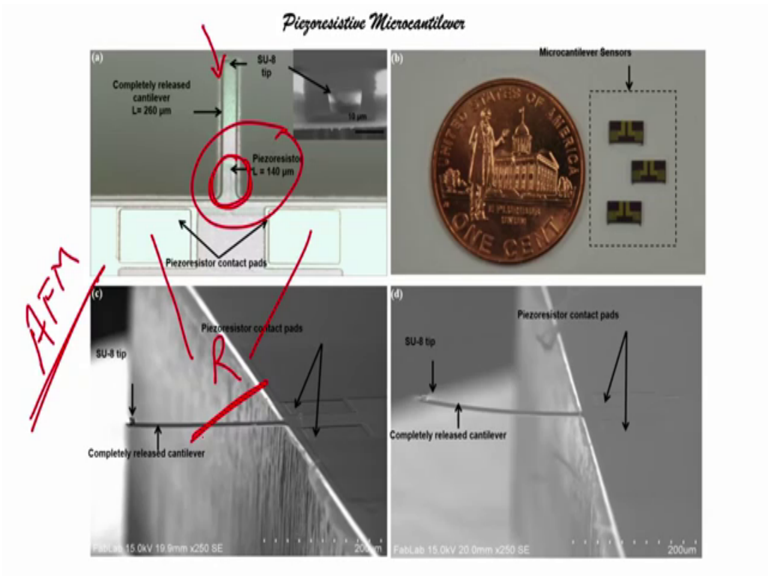

So, when we go to this particular slide, what we see is we see a Piezoresistive micro Cantilever Piezoresistive micro Cantilever. What is the role of Piezoresistive micro Cantilever? The Cantilever the role of a Cantilever is just to you know if you are using it in AFM, we are using it in AFM is called atomic force microscopy.

Then, it is role would be to let us know the surface roughness of the film if the Cantilever is integrated with the Piezoresistor, you can see here. If in a Cantilever is integrated with a Piezoresistor, then whenever there is a strain in the Cantilever, whenever Cantilever bends, there will be strain in the Cantilever and this strain will cause changing the Piezoresistive material.

So, the Piezo resistivity would change depending on how much force we are applying to the Cantilever and we can measure this by changing resistance. That means, if I measure the resistance across this 2 pad right, depending on the how much my Cantilever is bending, depending on how much my Cantilever is bending, there would be strain induced into the Piezoresistor and corresponding to this change is to this strain, I would see the change in the resistance, right.

So, the point is how we can create this Piezoresistive micro Cantilever and how we can use this, to understand the surface or the tissue properties surface of a tissue or the tissue properties right. So, as you see that this is the top view, this is the top view is an optical photograph, this is an sem image. These 2 are sem images and this is the chip is one single chip. At the end of this chip which you cannot see, there is a Cantilever. This is not visible with a mechanise so this fine alright.

So, what is there on the tip? When the tip of this Cantilever as you can see, there is an S U 8 material. This tip is made up of S U 8. You can see here S U 8 tip, right. So, what is SU 8? S U 8 is nothing but negative photoresist. S U 8 is the negative photoresist uh. We have seen photolithography and in photolithography, we have seen there are 2 types of photoresist.

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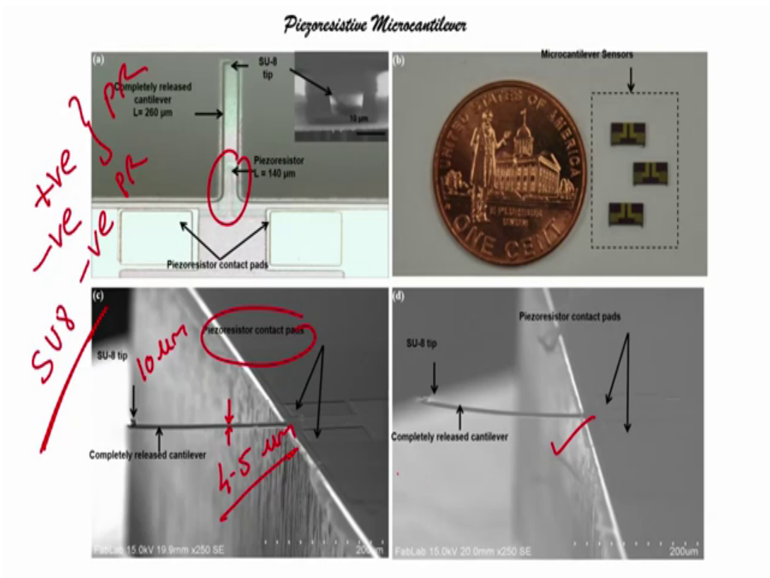

One is positive photoresist, second is negative photoresist. S U 8 falls under the category of negative photoresist, negative photoresist alright. There are several advantage of using a S U 8. And then, we will discuss later on right. Now, just focus that you see there is a tip, there is a Cantilever. This is this Cantilever is completely released. You can see that you know the best kind of the Cantilever is not anymore connected with the silicon wafer. This is a silicon wafer you can see all the lines right. So, this Cantilever is completely released.

Now, there is a Piezoresistor embedded within the Cantilever, you can see here right, embedded within the Cantilever and the thickness of this Cantilever. The thickness of this Cantilever is about 4 to 5 microns, the thickness of S U 8 is around 10 microns, 10 microns ok.

Now, you can see here this Cantilever is also completely released. But, there is a bend in the Cantilever; you can see this bend right. So, why this bending occurs? What is a why this Cantilever is bent? And the Cantilever that you can see on the left side is not bent. It is straight. That is the first question.

Second question, how we can embed the Piezoresistor, alright. Two things we right now understand that there is a Piezoresistive Cantilever. One is a straight Cantilever, second is a bent Cantilever. And this role of Cantilever would be to understand the tissue properties to understand the elasticity of the tissue ok. We will see how.

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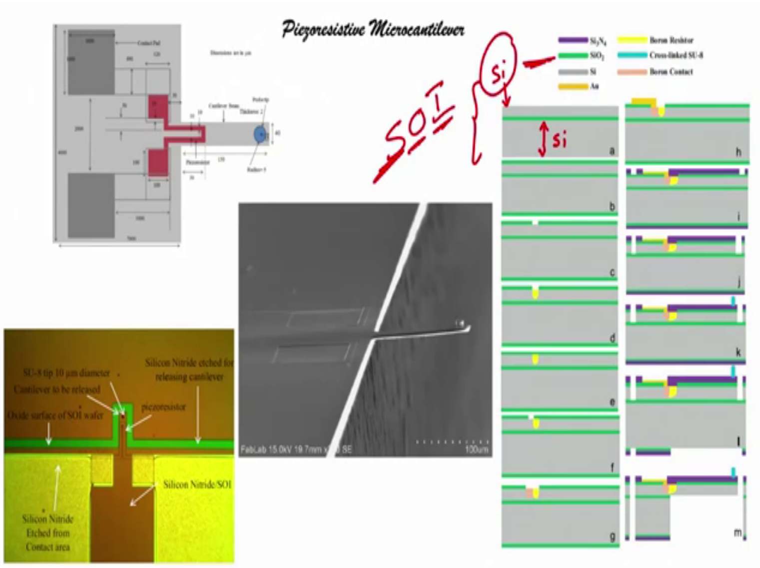

So now, on the screen, what you see is a Piezoresistive micro Cantilever schematic diagram where the tip probe tip the thickness is written radius is written right. Cantilever beam is there is a Piezoresistor is dimensions are given right. And then there is a contact pad. This is the contact pad through which you will measure the resistance ok. This is a Piezoresistive Cantilever, another Piezoresistive Cantilever. Now, you can see it is completely released. It is completely released and there is a Peizo resistor embedded onto the Cantilever.

Now, how can we embed or how can we integrate the Piezoresistive material or Piezoresistive sensor in the Cantilever beam alright? So, to do that, we will start with the wafer that is called SOI. SOI it is silicon on insulator. So, what does that mean? You see, this is silicon right. This is silicon, this green thin green line is what silicon dioxide and on the top of this green line, we again have silicon right. So, this looks like this top silicon is there is on the oxide material that is silicon on insulator silicon on insulator is SiO2 silicon is the Si.

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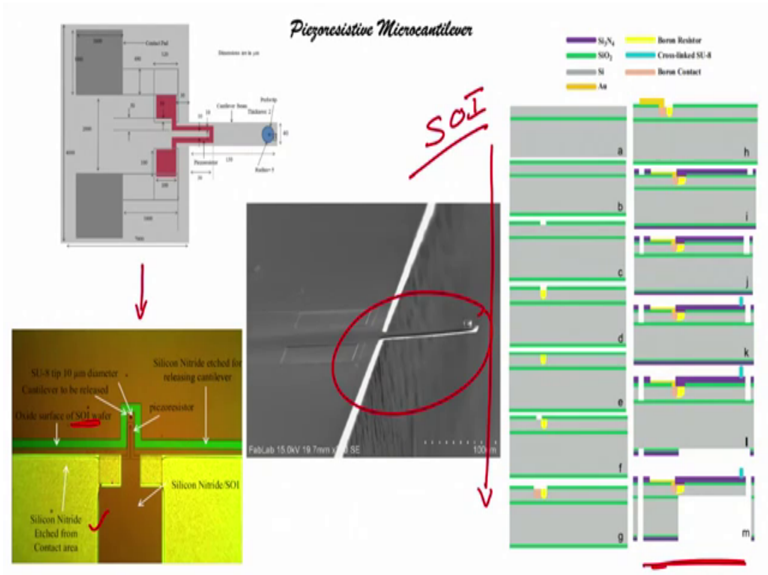

So, we can see that this silicon on oxide or as we can on insulator right. This is our starting substrate right and there are several process flow. There are there are several steps, there is a process flow. There is a step to reach to this particular Piezoresistive Cantilever. What are the steps? What are the steps? Let us see on the on the before we go to the next slide, let us see this particular diagram which is on the left bottom. You can see that there is a SOI tip Cantilever to be released, you can see this is not released right.

Now, it is you can see the oxide, you can see oxide surface of SOI wafer right. Then, there is a silicon nitride and then there is a silicon nitride on SOI. In this particular area, silicon nitride is etched silicon nitride etch for using Cantilever right. This everything is written over here and there is a role of silicon nitride in this particular Piezoresistive Cantilever right. The silicon nitride role is to compensate the stress due to the silicon oxide film. The role of silicon nitride is to compensate the stress that is obtained due to silicon dioxide film.

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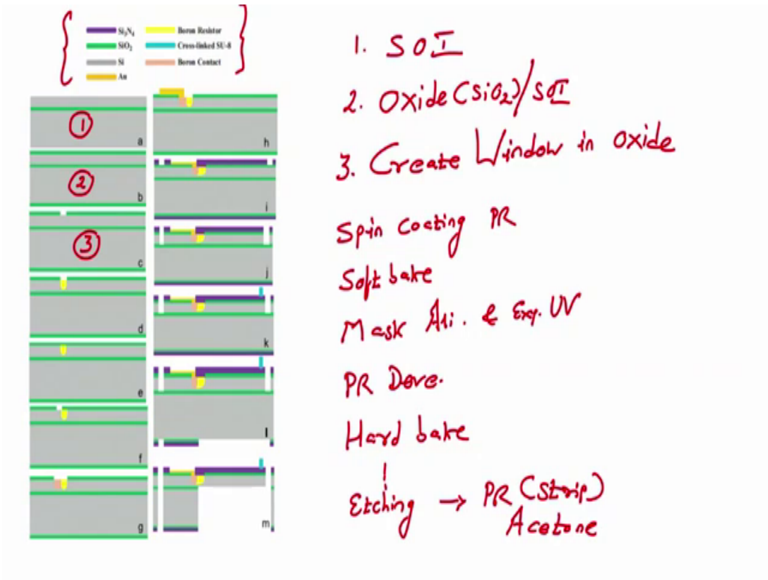

So, how does it work? How does this work? Now, this is our first step we took SOI wafer. Second step, second step is we are growing silicon dioxide right. See here, there are some colours given. So, we can understand what each colour represents. The first one that is purple in colour show silicon nitride. Next one which is green in colour so silicon dioxide next one which is green colour is called silicone. Next one is gold is allowed gold in colour. Then, you know is Boron resistor blue is cross link S U 8 and orange kind of stuff is Boron contact, ok.

So, our second step is second step is to grow oxide on SOI. First step is SOI. Sorry, second step is oxide; that is our SiO2 on SOI right. Third step, third step third step is to create a window create window in oxide right top layer oxide you can see here. The window is created. How this is created? Using photolithography we all know what are steps in photolithography.

First is spin coating, spin coating of what photoresist second step is soft bake. Third step mask alignment and exposure UV exposure right. Next step, next step photoresist developer. Next step next step would be hard bake hard bake right? And next step would be you etch whatever the material perform etching of the unwanted material. And then finally, you strip photoresist stripping of photoresist is done using acetone right. This is the steps for photolithography.

We already know using these steps. Using these steps, what we have done? We have created a window in silicon dioxide window in silicon dioxide. So, once the window is created in silicon dioxide, what is the next step? Next step is you diffuse.

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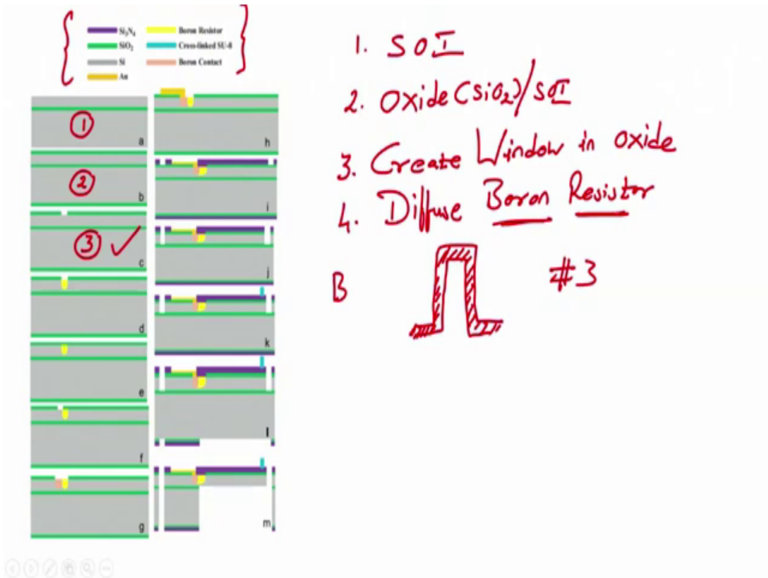

Diffuse Boron resistor right. You diffuse Boron resistor; that means, the step that you have created step you created. If you see the top surface, top surface looks like this. This is the top surface which 1 point number 3 here this one.

Next is, we are diffusing Boron because, only this area oxide is not there right. You can see here only in this area where I am drawing the pattern, the oxide is not there. The remaining area there is an oxide. So, we are diffusing Boron in this particular area. That is why, we say Boron resistor Boron resistor. That is how we have shown by yellow colour right. Next step, what is the next step? Next step is we grow silicon dioxide.

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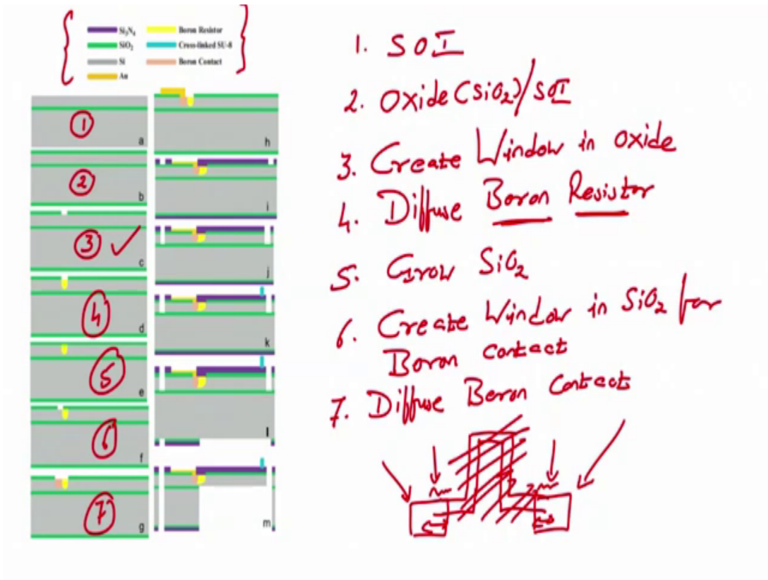

We grow silicon dioxide on this particular resistor and next step would be create window in silicon dioxide for Boron contact. For Boron contact, you can see right after this after growth. So, this is our 4 step right, we have created a window. Then, we have created an oxide and now we have created a window for the Boron contact.

Next step would be diffuse Boron contact. So, if you see how it will look like, there was a resistor right. Now, only this area is open ok. You can see I am deliberately drawing something, what you can see? There is oxide here. Everywhere except this area, you see this area that goes in, right.

So, if I diffuse Boron contact, this Boron contact with Boron resistor only in this particular area, fine. Only in this particular area; that is, we will have a contact with a resistor. Through the Boron contact, you will have contact to the resistor use through the Boron contact right and the Boron concentration for the contact region is higher compared to the Boron concentration of the resistor. That is because we need to finally, get a gold contact on the Boron contact to form the ohmic contact right. On this, we will have ohmic contact. We will see.

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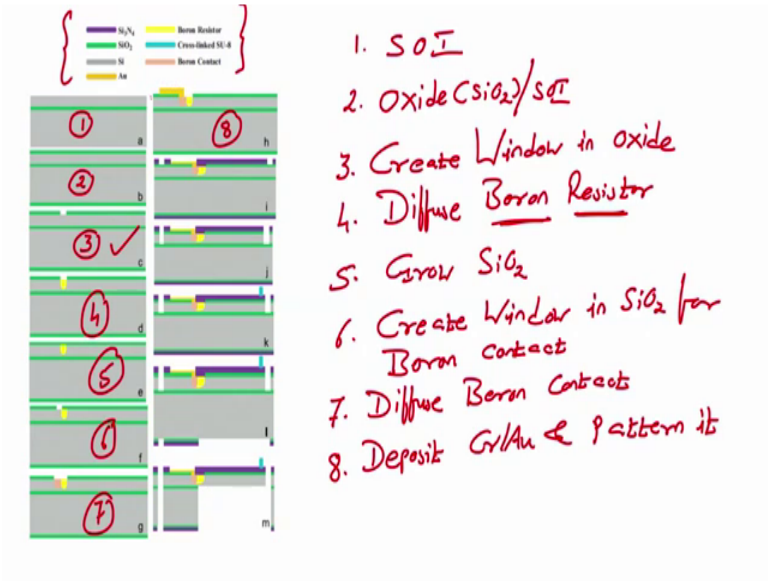

Next step would be, next step is you deposit next step is deposit chrome gold and pattern it um. So, here what we are getting? We are getting a long contact pad out. So, where are we? We see here this contact pads.

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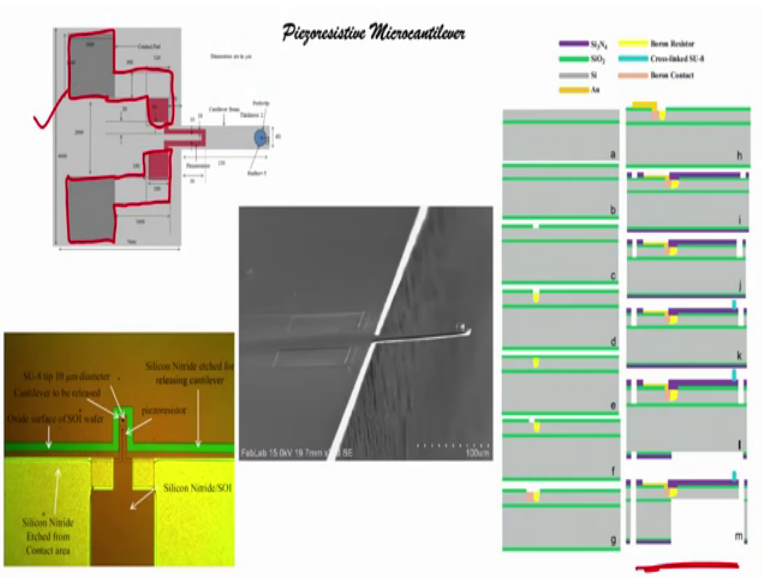

So, if you see, I am drawing here. It goes all the way here, come back here, here. And then, this particular box same way in this area because, here goes here goes here comes here, and then like this right. So, this particular the one that I have done with red is the one that we are right now on which is point number 8.

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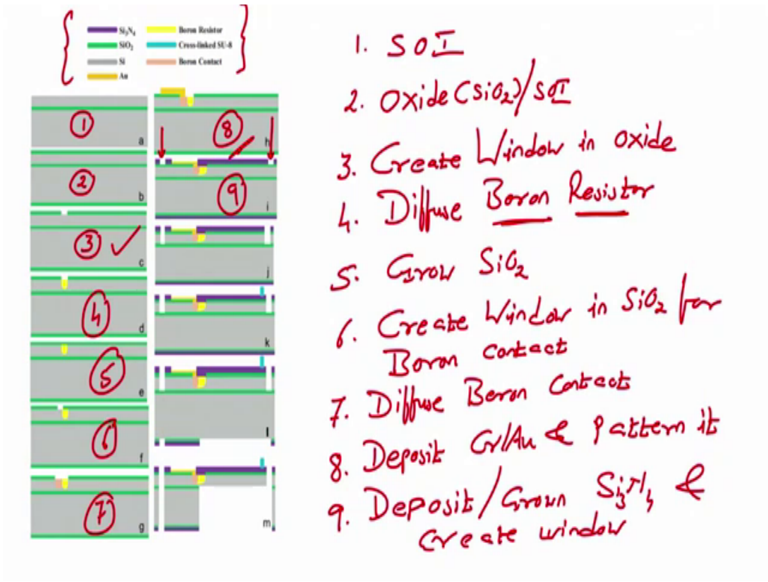

Ninth step: 9 step as you can see, we have 9 step would be we have deposited or grown silicon nitride. You can see here ninth step deposited a grown silicon nitride and create window and create a window you can see here, right. We are we have grown silicon nitride and created a window step number 9. Now, what next step would be? You etch; you etch silicon dioxide and the silicon all right. So, 10 step. So, I am just rubbing it down, rubbing it down. The first 4 5 steps so what is my tenth step?

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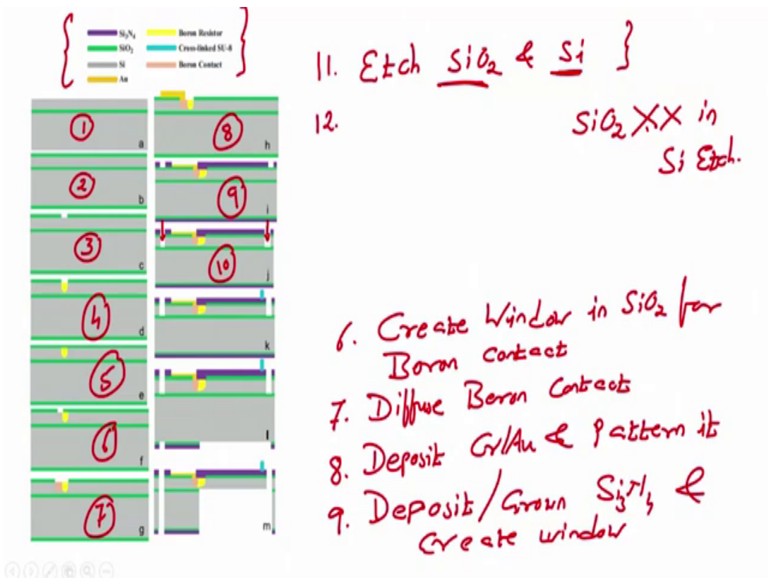

Tenth step is: etch can you see no let me go down; you can see clearly.

Is it better? Ok. Etch; etch silicon dioxide and silicone right. Now, the question is, when should I stop etching silicon dioxide and silicon? Now, you see below silicon dioxide and silicone. So, first we have to etch silicon dioxide. Then, you will see silicon below it, when you have silicon you against the silicon dioxide below it.

But, when you dip the wafer in silicon, you do not worry. When it can be stopped because, silicon dioxide will act as a mask or etch stopping mask for silicon, because you see silicon dioxide will not be affected, will not be affected in silicon etchant ok. So, that is the next which is the etching of silicon dioxide and silicon. What is the next step?

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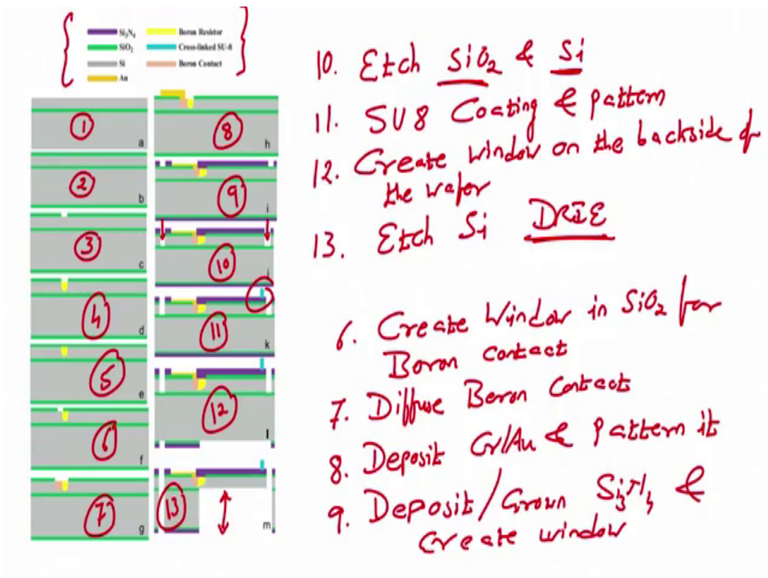

Next step is S U 8 deposition or S S U 8 coating. We cannot deposit coating and patterning for forming tip, right; S U 8 spin coating and patterning to form the tip right. Next step, I think this is number 10: 10 11 12, next step. What is next step? Create window, window on the backside of the wafer where we have created window. We see here, we have created a window where we want to etch silicon completely and release our Cantilever, right.

We have created a window where we want to etch our silicon completely and create a Cantilever which silicon the silicone which is the base silicon not the silicon which is grown on insulator, because silicon which is grown on insulator will help to form the

Cantilever alright. So, create a window on the backside of the wafer ok. Fine, we have created. Now what? So, to create this, you have to understand that we when we create it, we have to do silicon nitride followed by silicon dioxide. We have to etch silicon nitride followed by etching silicon dioxide.

Last step, last step in this particular case would be to etch silicon to etch silicon right. We can use we can use DRIE to etch the silicone DRIE is here deep reactive ion etching deep reactive ion etching ok. So, this step number 13, step number 13.

So, what we have seen is after following 13 step: we are able to release our micro Cantilever and another thing that we have observed is we are using Boron as Piezoresistive material. And the silicon that is on insulator is our poly silicon or it can be single crystal silicon. The point is that you can also grow silicon on insulator and perform and perform the experiment and evaluate it is performance by or with the Cantilever that you can make a using silicon on insulator which is single crystal silicone, ok.

So, Piezoresistor is formed by diffusing Boron into the poly silicon material or single crystal silicone material. And, this will result in a creation of a Cantilever or let us say, this my hand is a Cantilever, creation of Cantilever with a tip, with a tip right.

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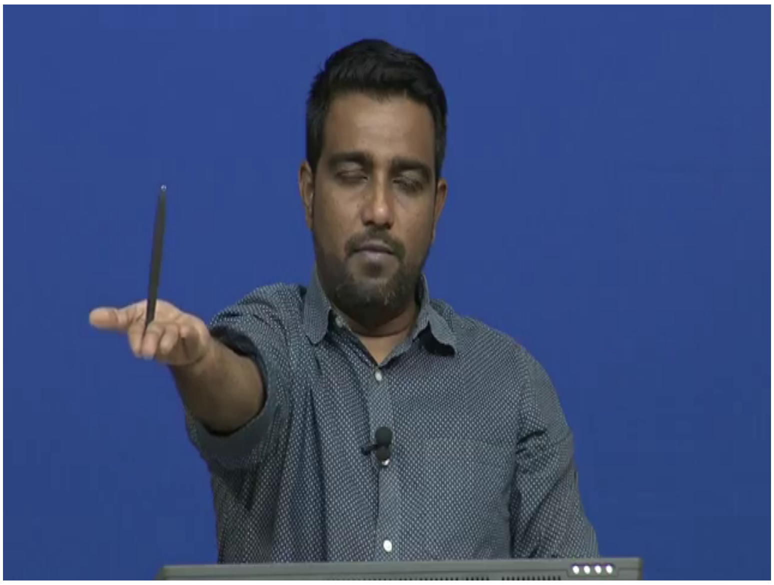

So, if I now use the Cantilever in this particular fashion right and I press the Cantilever on a surface, what will happen? The tip will touch first. This is tip SU 8. When a tip touches, my Cantilever will move depending on how hard the surface is right, how hard my; the surface is. This is my surface, this is my Cantilever. I am holding my Cantilever in this particular fashion; so S U 8 tip that was on the top. Now, it is at bottom right and now I am pressing the Cantilever against the surface and depending on the surface, my Cantilever will bend, my Cantilever will bend right.

So, this is the phenomenon. Now, when it bends, there is a Piezoresistor embedded in the Cantilever. When the Piezoresistor is embedded within the Cantilever, what will happen? The there will be change in resistance based on how much is the bending of the Cantilever because, base in the bending on the Cantilever, there will be a strain that is induced in the Piezoresistor that will cause change in resistance.

So, what we understand that, now from here, if I instead of having the surface, I will have a surface which is again hard surface or which if I place the tissue. So, if I have a place a tissue on the surface, what will happen now?

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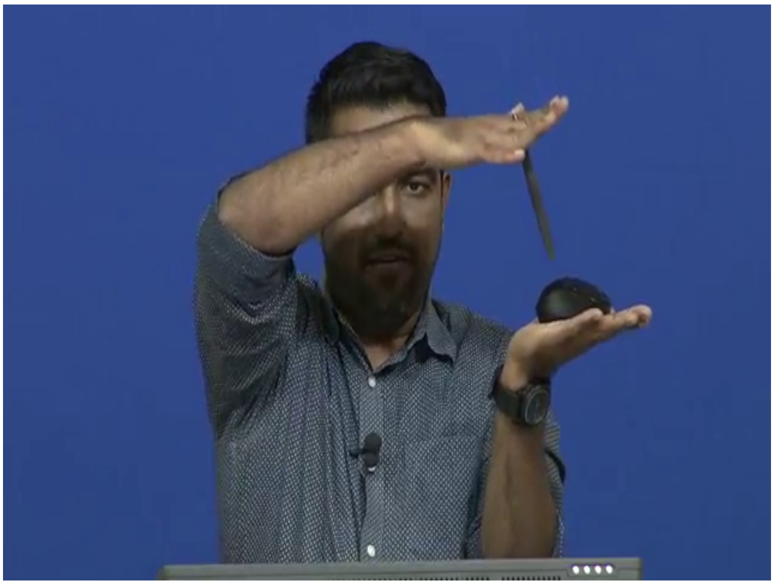

Now, if I press the Cantilever depending on the stiffness of tissue, my Cantilever will bend right. So, these are change in resistance will correspond to the stiff tissue, stiffness right. This is how we can measure the stiffness of the tissue. So, if you see here, the next slide, what we have done?

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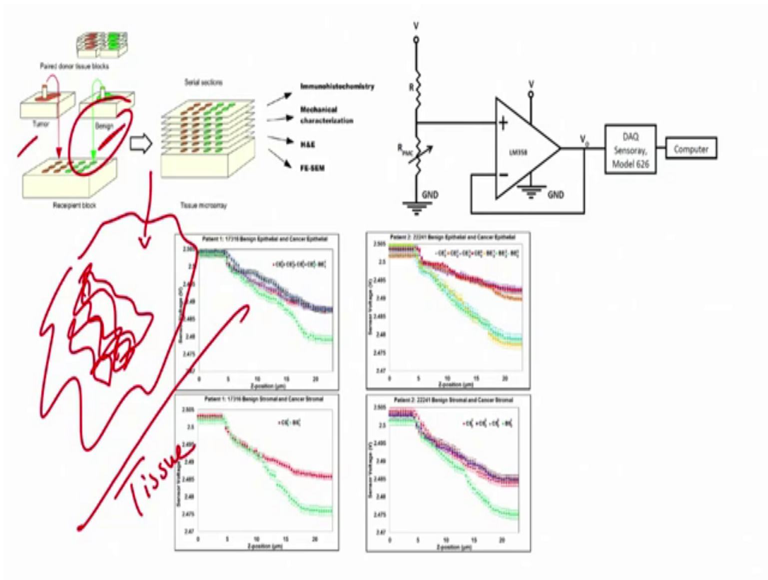

We have got the slice of the tissue right. The slice from the benign region, slice from the tumour region. So, just understand this if the cancer is somewhere here in this area and this is the tissue. This whole thing is a tissue cancer is in this area. So, this area is cancerous. This area is not called normal is not called normal is called benign, alright. So, it is not clear cancer, but it is benign, ok.

When you slice the tissue, you can go for IHC you can go for mechanical characterisation; that means, understand the stiffness you can go for h and e image and you can go for FESEM or field emission scanning electron microscopy. FESEM is field emission scanning electron microscopy alright. This is a simple electronic module that we can use where your Piezoresistive micro Cantilever is given by p mc. It is connected in a voltage divider fashion which you can see right over here and correspond.

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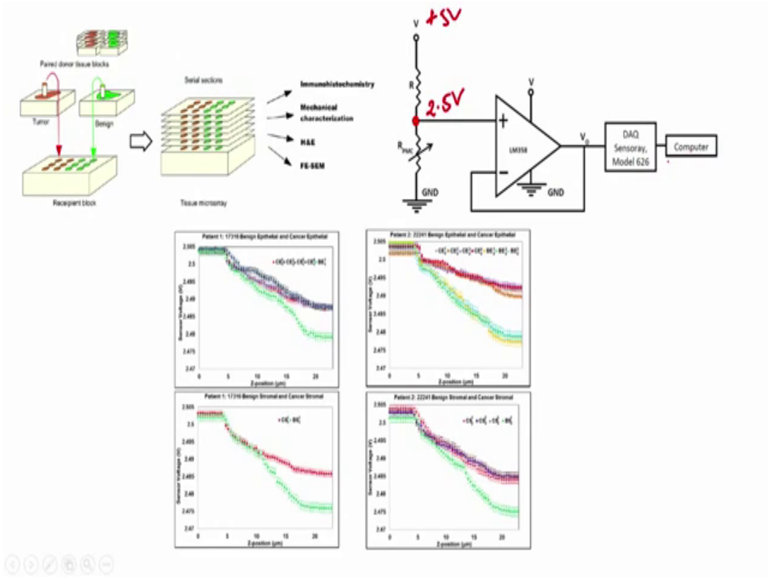

So, if your voltage is plus 5 voltage, my output here would be 2.5 volts. That 2.5 volts I am applying to nm 3 5 8 followed by sensory that final resistor will display on my system right. This is just one method there can be multiple methods to use similar condition circuit along with the sensor

The disadvantage here is that, already we are known to 2.5 volts. So, our range of change is extremely small. If I do not have this, and if I have a stone bridge, I will have a probable better signal condition circuit. But, that is not idea which kind of circuit you can use you can always use a better circuit. The idea here is that, if I now have a Piezoresistor micro Cantilever and if I press it against the tissue, how can I see the change in the resistance or change in the voltage right.

So, you can see here. Initially, it is close to 2.5 volts when both the resistors are balanced; that means, whatever the resistance of the Piezoresistive micro Cantilever is that same resistor I will use it here. The value of the resistor would be same and then, initially what I will have because of the potential divider? I will have a voltage of 2.5 volts.

As I go on pressing, my Cantilever you can see here 0 5 10 15 20 microns. When I press my Cantilever, I would be able to see the change in voltage because, it will be change in resistance and that change in voltage will depend on what kind of tissue I am using, right. There is a benign epithelial and cancer epithelial you can clearly see that benign epithelial has a different range compared to the cancer epithelial same way if I consider a stromal region. So, cancer can occur in a epithelial region cancer can occur in stromal region. If I understand stromal region, then you can very clearly see that benign stromal and cancer stromal there is again a difference.

Same way, if I take about second patient, you can again see that the cancer is different in benign cancer is different than benign right. So, from here, I can understand that this change in resistance can show me whether the tissue is cancerous or not, because the cancerous tissue would so different change in voltage compared to the normal tissue or benign tissue, right.

So, what we have learn until now is, we can develop a Piezoresistives micro Cantilever to understand or study the mechanical property of tissue. Now, the question is if I can study mechanical property of tissue, can I study electrical property of tissue and if I can study electrical property of tissue, can I study other modalities like thermal property of tissue right.

So, because I can understand the stiffness of the tissue, then understand the change in resistance of the tissue. Then, I can also if I change resistance of the tissue I know, then I can understand the thermal conductivity of the tissue. So, we are going towards measuring the electrical mechanical and thermal property of tissue, but this the first step where we understanding the mechanical property of tissue right. The next step would be how we can measure the electrical property of tissue.

So, that thing where we will look at the electrical property of the tissue; we will see in the next module of the same lecture and then, the equation is also that that if I can measure mechanical, if I can measure electrical, can I measure mechanical and electrical. Together, you see there, there is a never ending quest because, now if I can do mechanical and electrical can I also do thermal; that means, mechanical electrical and thermal together right.

So, if once I have a chip which has a mechanical, electrical, thermal, what will I do and how can I operate this chip? How can I use this chip to diagnose cancer right? So, that we will see across this particular lecture series; so just go through this particular module. This is a short module where we will understand how we can design a process flow for Piezoresistive micro Cantilever. And this Piezoresistive micro Cantilever can be used to understand or to delineate between the benign and cancer; also to delineate between epithelial and stromal region, right.

So till then, you take care. I will see you in a next module. Bye.