**Sensors and Actuators**
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# Lecture – 54
# Flexible MEMS for phenotyping tissue properties - II

Hi, welcome to this module. In the last model; what we have seen, we have seen how can we fabricate a piezoresistive sensor on a flexible substrate and that piezoresistive sensor was made out of a conducting polymer called PEDOT PSS.

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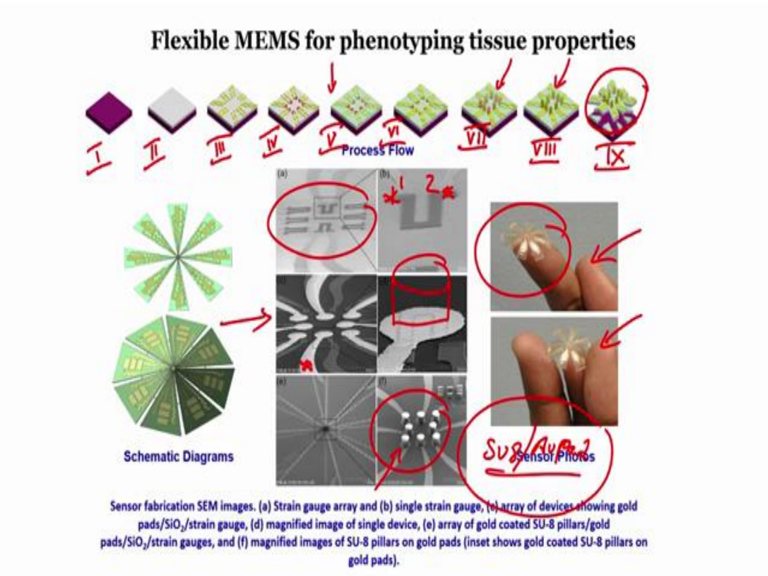


if we see the slide what we are seeing is, the step I where we take oxidized silicon substrate; step II where we have spin-coated PDMS, step III where we have the form of the pattern of chrome and gold, and step IV where we have formed the piezo resistor. these are an array of piezo resistors, 18 numbers; this is a single piezo resistor SEM image of that.

Now, what we will see how can we form this particular array of gold pads on this piezo resistor. Now, as know if if I deposit metal on semiconductor it will get short. that is we have to have insulating material.

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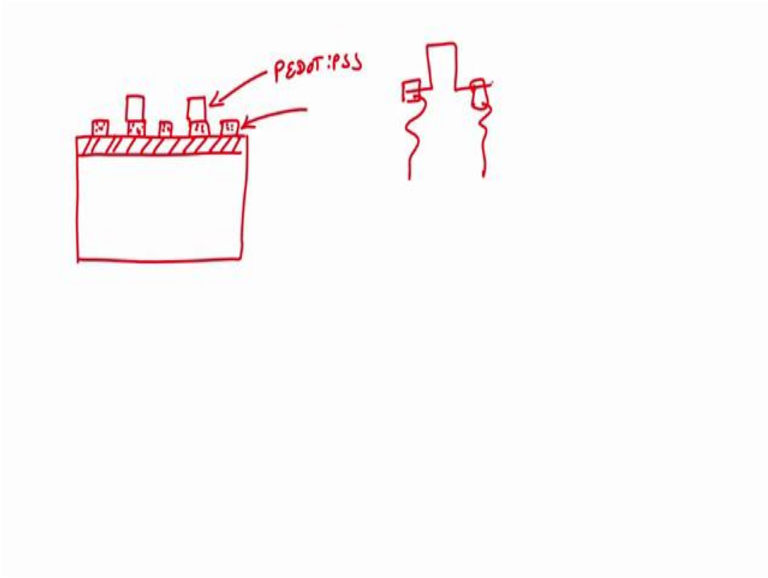


if I see the process flow, how it will look like; I have a substrate which we have seen in the last module, which has PDMS and on that PDMS interdigitated electrodes, on which there are piezoresistive sensors PEDOT PSS.

These are my let say interdigitated electrodes or can, not interdigitated electrode, these are actually the patterns or contact pads; because it is like this, it is like this and then on this, I have piezo resistor like this al.  it is a chrome gold pattern, I will say.

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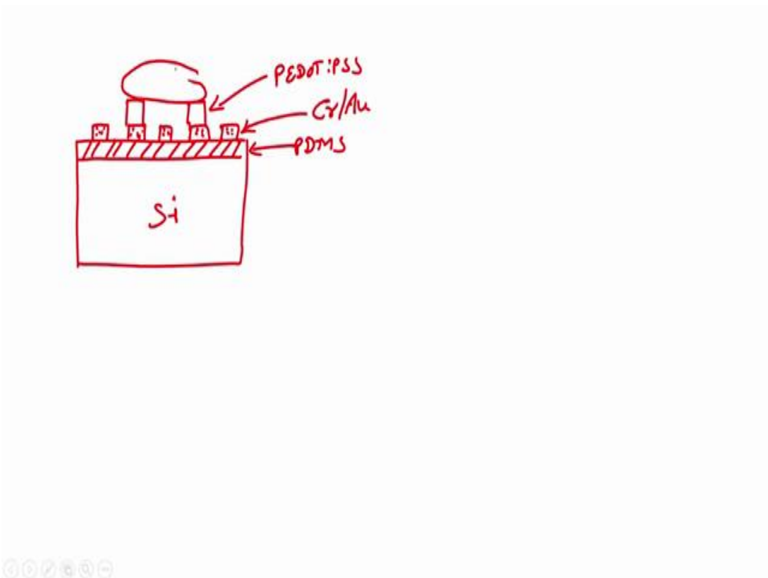

I will say chrome gold, this one would be PDMS and this is silicon. On this substrate what we want We want to have a contact pad which will sit over here al, which is gold contacted.

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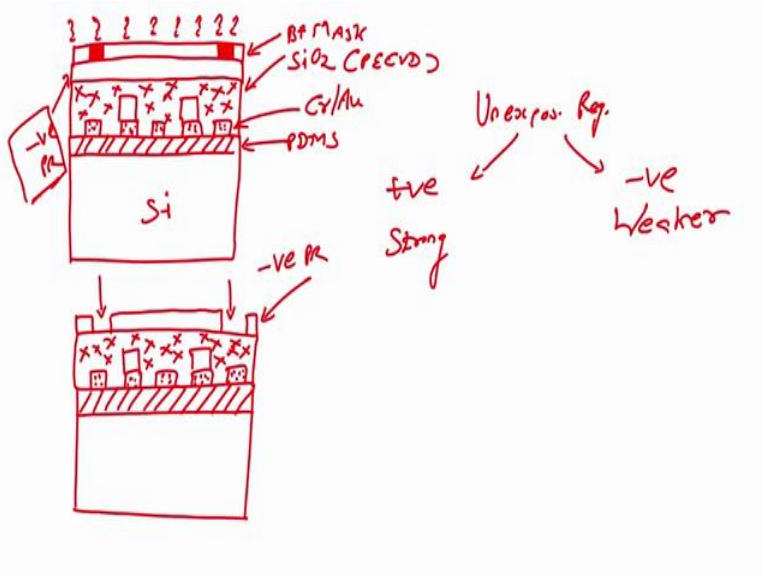

But if I deposit gold directly on this then it will get short; that is the next step would be, I will deposit insulating material and this insulating material the pattern would be this x cross ok, this is my insulating material. if I have this one, then what I will do is; I will spin coat photoresist resist and this time I will spin coat negative photoresist, then I will load the mask.

after spin coating negative photoresist, the next step would be soft bake. After soft bake, so this one would be a negative photoresist; then I have a mask, which is my b field mask and it will only open the contact area. This is my b field mask my photoresist is a negative photoresist ok, a photoresist is a negative photoresist b field mask.

After that as know we would expose the wafer with UV light; when exposing the wafer with u v light since are have used negative photoresist, the unexposed region would be weaker, and the exposed region would be stronger. what we will have, we will have a wafer with PDMS and interdigitated electrodes over which there is a piezoresistive sensor, on which there is insulating material which is my silicon dioxide. This silicon dioxide we can grow with the help of PECVD, this silicon dioxide PECVD; PECVD stands for Plasma Enhanced Chemical Vapour Deposition.

And then I will have my photoresist like this, this is my negative photoresist, al. As see here the photoresist from these two areas got etched, is not it when the photoresist gets etched, then I can remove my silicon dioxide below it. And the negative photoresist got etched from this area because we have used a b field mask and the unexposed region for negative photoresist will become weaker.

For positive photoresist, the unexposed region says unexposed region by talking about positive photoresist and negative photoresist, that unexposed region in positive photoresist would become stronger and the unexposed region in the positive photoresist sorry, the unexposed region in the negative photoresist will become weaker. What we have used We have used negative photoresist. the unexposed region is weaker.

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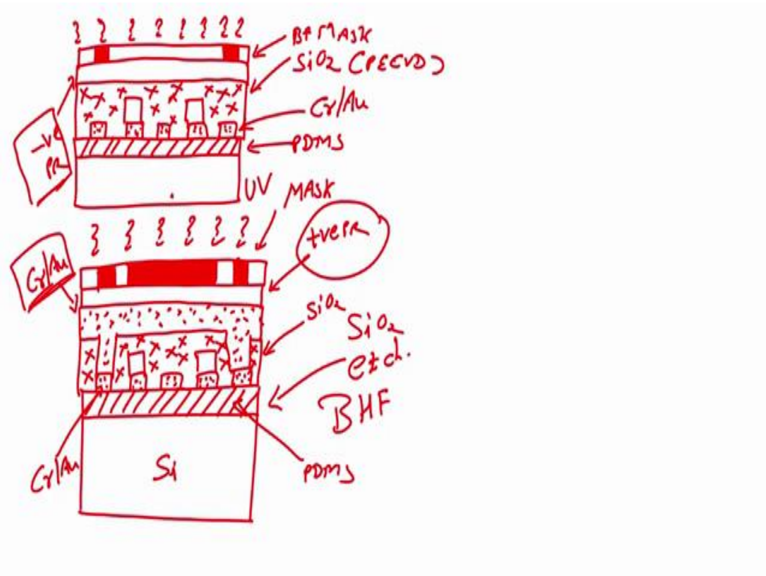


The next step would be I will dip this way of, I will perform hard bake and after hard bake, I will dip this wafer in silicon dioxide etchant. What is my silicon dioxide etchant is buffer hydrofluoric acid or BHF. When I did this wafer in BHF what will I have, I will have this pattern ok; because the silicon dioxide will get etched, this x pattern is for silicon dioxide, this is my chrome gold, this is silicon, and this one is PDMS, can have oxidized silicon, silicon (Refer Slide Time: 07:42) al.

The next step is, the next step is that I have to deposit chrome gold on silicon dioxide; but before that, we have to remove the photoresist, or we have to strip up the photoresist. after this next step would be. when exposing the wafer and we develop the photoresist, have to perform hard bake ok. After hard bake has to dip the wafer in silicon dioxide etchant, when silicon dioxide gets etched the next step would be, will dip this wafer in acetone. When dipping this wafer in acetone what will happen; will have r photoresist stripped off from the wafer.

The next step is, that deposit chrome gold, again deposit metal, chrome gold; and chrome gold is shown by dot pattern will perform we will use the same pattern ok. Now the next step would be I will spin coat this one. let me remove this particular or let me make a short space. it becomes easy. the next step would be after I have deposited chrome gold using my PVD method, Physical Vapor Deposition; the next step is I will spin coat positive photoresist al.

Then performs soft bake, then I will load a mask; and the mask will be such that, it will have a pattern like this and like this and this. what is having, I am saving my gold from the contact pads; which can see here in the pattern, which is my mask ok, this is my mask. And I am saving or not allowing the photoresist to get exposed to this region; since I want to protect my gold below this region and this region will form the gold pad.

after this I will expose the wafer with UV light; then perform photoresist developer. Now what the, then perform photoresist developing. photoresist will get developed from the area which is exposed, the unexposed region would be stronger; Because this time we have to use the positive photoresist, correct. what we will have, we will now have a photoresist, which will be protected in this region, in this region, in this region. This is my positive photo resistive correct.

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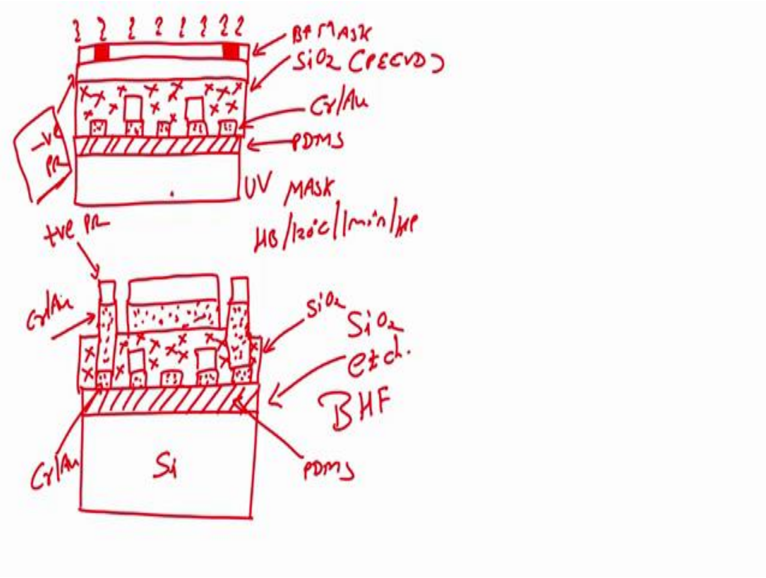


The next step is I will dip this wafer in the gold etchant, then rinse it then I will dip.  after this of course; there is a hard bake, 120 degrees 1 minute per plate followed by dipping the wafer in the gold etchant, then rinsing the wafer, then leaving the wafer in chrome etchant, rinsing the wafer.

And when do that what will have;  will have this pattern where the chrome gold got etched which, in the area which was not protected by the photoresist, this is chrome gold. The next step is, I will dip this wafer in acetone; when I dip this wafer in acetone what will happen, the photoresist will be stripped off.

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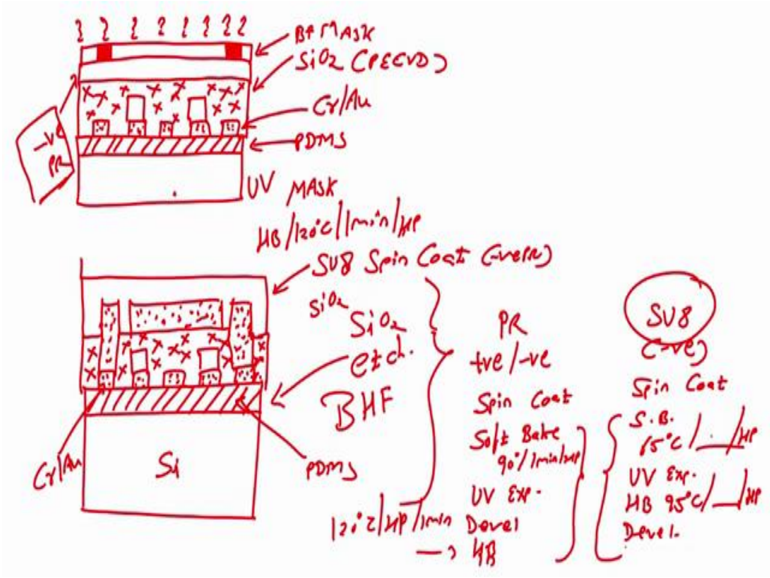


When photoresist gets stripped off, my wafer that I have a pattern like this looks similar to my pattern number VI and this particular platform, what we had done We had a substrate with PDMS and PEDOT PSS a strain gauge on which we have insulating material which is step number V, and then we have performed of photolithography and remove the contact; then we are deposited chrome gold and we have patterned to form the gold pads.

What is the next step is to form SU 8 pillars; the next step is to form SU 8 pillars. on this what will I do I will now spin coat al, I will now rather spin coat, we will grow now ok. For our step is to have SU 8, SU 8. what we will do, we will spin coat; we will spin coat SU 8 because SU 8 is a polymer and it will act as a negative photoresist. I will spin coat SU 8 on to this particular substrate, which we substrate this substrate, this one al.

when I spin coat SU 8 on the substrate; SU 8 is the negative photoresist. What I want; that there should be an SU 8 pillar on each of this gold pad like can see here. I want to protect SU 8 on the gold pad, SU 8 is a pillar al; I will tell we are making these pillars ok, I will tell . when we coat SU 8 using spin coater, the next step would be to protect SU 8 only in the center. I will load, I will, of course, perform the soft bake in SU 8 know; again I am telling here, please pay attention photo resist positive and negative SU 8. SU 8 acts as a negative photoresist; what is the difference, we spin coat, spin coat this also spin coat

Next step soft bake 90 degrees 1-minute hot plate; soft bake these are done at 65 degrees, for time on the hot plate, this time depends on the thickness of SU 8 al. Then there is a UV exposure, then developer, and then hard bake; hard bake is done at 120-degree centigrade on a hotplate for 1 minute . In this case, 65-degree soft bake, then UV exposure, then hard bake, again the temperature is 95-degree centigrade, time depends on the thickness of SU 8 on the hotplate, then we will form developing.

see this is the difference, soft bake, UV exposure, developer and then hard bake; here soft bake, UV exposure, hard break and developer there is a difference. that have to remember when we talk about SU 8. SU 8 x is a negative photoresist; that means, the unexposed region will be weaker and the exposed region would be stronger. Exposed to what Exposed to UV light, exposed to UV light.

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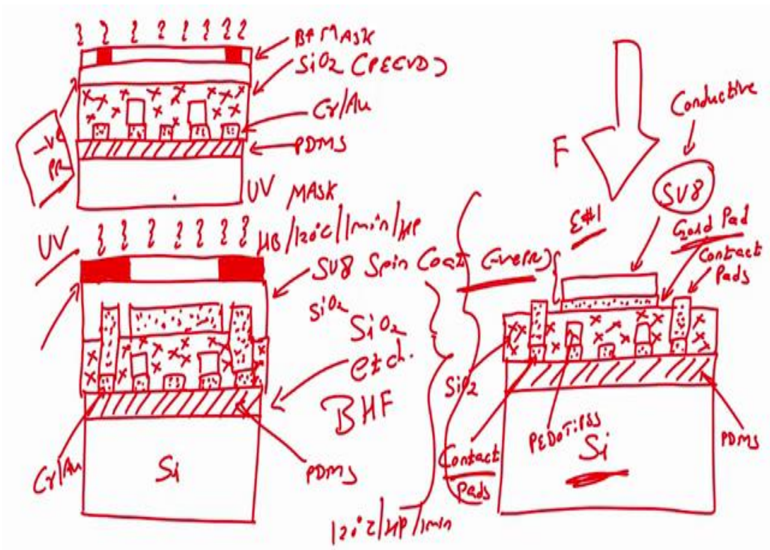


now we will have a mask, we know that SU 8 x is a negative photoresist and we want to protect SU 8 in the center. what we will do We will use a b field mask and by using the b-field mask what we are doing; we are protecting the layer of SU 8 which we do not want to get develop in the SU 8 developer.

how does it happens, because SU 8 would is a negative photoresist; if SU 8 this negative photoresist then the area which is not exposed, will be weaker correct, the area which is not exposed will be weaker. if I use this mask will it work, will it work, it will not work; because we are removing SU 8 from this site, which is not what we want, we want pillars here. our mask should be having a pattern like this correct, the area which is not exposed will be weaker because SU 8 works similar to the negative photoresist.

Now, if I use this mask and if I expose UV, the photoresist to UV light what will happen; if I develop this wafer, I will have, silicon wafer, PDMS, interdigitated electrodes, strain gauge. Then the insulating layer is our S I o 2 and this is also our metal contact pad. And now when I say interdigitated electrodes, it does not mean like it is interdigitated, it is actually the contact electrodes. Let us say, it is a contact electrode al; on this what have is, have a gold pad here. have a gold pad here and on this now have SU 8 which is exposed to UV light and this is the mask.

if we use this pattern, then we will have SU 8 on the gold pad. SU 8 will stay here, this is my gold pad, these are contact pads, then silicon dioxide, contact pads again, this one would be PDMS, this is my silicon. what we have here is; the one which is similar to this one. But and what is the role of this, what is the role of this SU 8 pillar Now we understand that, if I apply a force to this area, then SU 8 pillar will act as a force transducing mechanism. the force will be applied to these strain gauge through SU 8.

Another point is, I want this SU 8 pillar to be conductive because see here if I have a gold pad below it and with the SU 8 pillar becomes conductive, if it becomes conductive, then this together SU 8 pillar and gold pad will act as electrode 1. I will tell what is the role of electrode 1 if the SU 8 is conductive SU 8 along with gold pad will become electrode 1, al

The second role of SU 8 is, when I apply a force, then this force will reach the strain gauge which is my piezo resistor, which is this one piezo resistor PEDOT PSS through SU 8 pillar, through SU 8 pillar ok. Now how it will bend We will see how this will bend and when to apply force because of this silicon substrate here. if I apply for silicon will not bend and that is I do not want silicon. I will remove silicon at some point of time, but until here I hope that all of the understanding,

Next step, what is the next step Now we have to make SU 8 conductive and for that, if remember I have taught a process called lift-off technique. let us use our lift-off technique and coat this SU 8 with a metal. that SU 8 and the gold pad below SU 8 will become electrode 1 ok.

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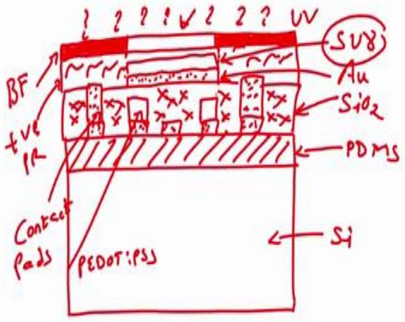


let us see here on the slide. have this particular thing. I will draw it, here again, it becomes easier and we will start from there. again I am repeating please focus here, have silicon substrate, have PDMS on silicon substrate al. This is r PDMS, this one is r silicon, then we have in, we have contact pads or contact electrodes. Then we have here PEDOT PSS strain gauge, then we have insulating material which is by silicon dioxide, al.

this one is silicon dioxide, this one is PEDOT PSS, this one would be contact pads al, and then I have here gold pad on which I have SU 8 pillar, this is SU 8, this is gold al Then what I want, I want SU 8 to be conductive. we will use the liftoff technique, coat the SU 8 material; and in liftoff technique what we will do, we will coat everything with photoresist and this will be our positive photoresist ok. let me use this design for positive photoresist and this is a positive photoresist.

Now, after this we will open a window only in this region and this region will save the photoresist ok. what we will do, we will after positive photoresist, we will perform soft bake; after soft bake, we will load the mask and load mask such that, we will protect the positive photoresist in this area.

And the center area which is having SU 8 we will not protect photoresist. this photoresist, see the area is a little bit bigger than the SU 8 area ok; the opening, the window opening is slightly wider than the SU 8 area. This is r mask; which kind of mask, b field mask al.

Next time know,  have to expose the wafer with UV light, UV light. After that have to develop the wafer,  have to unload the mask to develop the wafer; when to develop the wafer what will happen since there is a positive photoresist, the area which is not exposed will become stronger.

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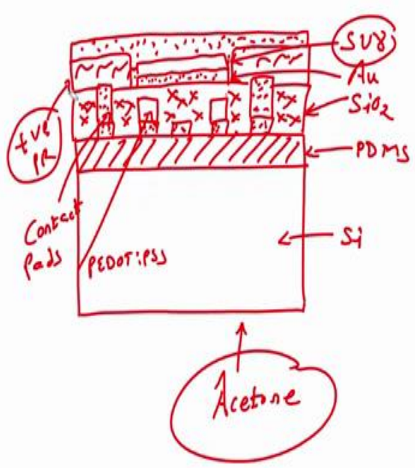


The area which is not exposed will become stronger; the area which is exposed will become weaker. Now,  can see that we have positive photoresist, we have positive photoresist and here we have open the window; there is a window that we have open correct. Now what we will do know, we will deposit gold or a metal everywhere, chrome gold, asr chrome gold everywhere and then the next step is we will dip this wafer in acetone.

If I dip this wafer in acetone, what will happen; acetone will strip off the photoresist, because this is the positive photoresist stripper. When it strips the photoresist, it will lift off the metal above it. And the metal where it is directly deposited on SU 8 pillar will remain intact; that means, that when I did this wafer in acetone what will happen, my photoresist will get etched from everywhere like this.

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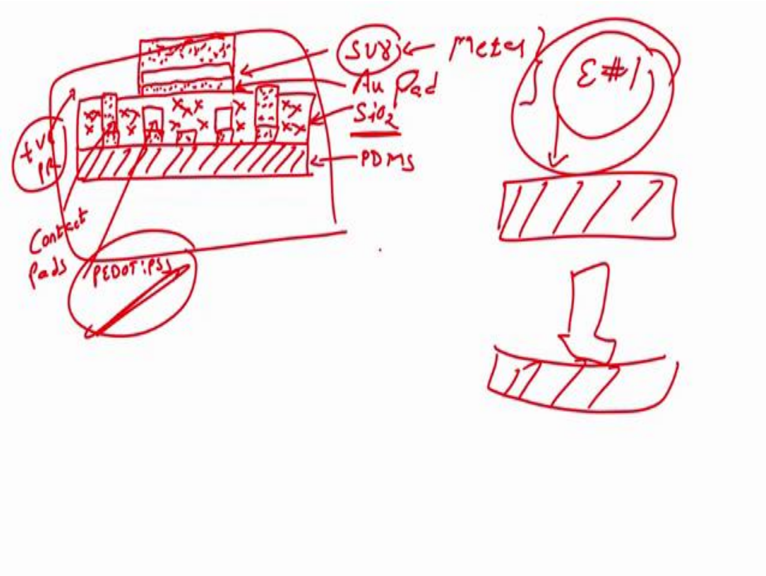


And I will have my metal coated on the SU 8 pillar, my metal will get a coat on SU 8 pillar. Now, see have a gold pair at the bottom over that there had SU 8 and now SU 8 is coated with metal; that means, SU 8 and gold pad together will become electrode 1, got it. now, what we have, we have a strain gauge made up of PEDOT PSS, we have an electrode which is made up of gold pad and SU 8 which is coated with metal that is SU 8 becomes conductive, and next step would sorry would be to strip off the PDMS. if I strip off the PDMS from the silicon substrate what will happen, this will happen.

now what I have, I have a flexible sensor on which there are PEDOT PSS integrated piezoresistive materials or piezoresistive sensors, and I have electrode 1 which is formed with the help of SU 8 which is conducting on a gold pad. And the strain gauge which is made up of PEDOT PSS is separated by an insulating material which is silicon dioxide from the electrodes. electrode and PEDOT PSS are separated by silicon dioxide in between. there is no shorting al. When performing this, then see we have after VI, we have now coated we had deposit we have spin-coated SU 8 and pattern SU 8 pillars; then with liftoff technique, we have coated gold, which is VIII and finally, we have stripped off the PDMS from a silicon substrate.

it will become a flexible sensor as shown in this schematic al; in the sensor photos, if see, this is the flexible sensor, here as well as here. If you see this particular photo, then you will understand that there are three contact pads; three contact pads Two contacts here, one and two, two contact for this and one contact for r SU 8 pillar, like this line one contact for this.

Another thing will observe.  it is 1, 2 and 3; this way if you see here, this is 1, this is 2, and this is 3; 1, 2 and 3. Another thing that needs to observe is, that the lines are not straight; these are wavy lines like this,  see it is a wavy line, is not it.  it is a wavy line not straight Because if I have a straight line, if I the since the material is flexible then there would be a lot of stress in the film and film will get cracked, to avoid crack we have designed the contact pads and the connecting lines in this particular fashion.

 all the things that we have discussing, it is in the center of this particular sensor al.  we have 8 piezo resistors and we have 8 electrodes; electrodes mean, SU 8 which is conducting over a gold pad. This is our one electrode, the same way there are 8 electrodes; as can see in this particular figure.  the center like what we were saying  has all the sensors  including r 8 piezo resistor and r 8 electrodes,

Now, let us see how can we use this flexible sensor for understanding the or it can in another term technical term is phenotyping tissue properties. Phenotyping, we will do two types of phenotyping; one is the electrical understanding of electrical signals and the mechanical properties

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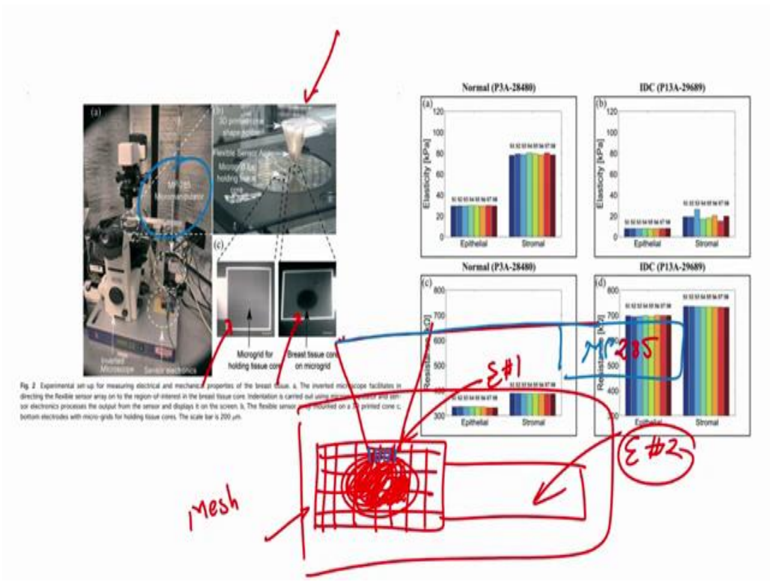

let us see how can we use this. Now see here, this electrode that we have fabricated, the flexible one, which is this one is connected. there are 8 of those, like this 8 of those that, this is the sensor; this is connected to a cone, see here to a cone.

the tip is on this site, all this 8 that see SU 8 pillars would be on the bottom side and there is a cone-like this al and the sensor is connected these are all the connecting wires that can see on this particular figure. And now this is pressing something al, and what is the something; something is, there are contact pads on the glass. What does it mean to have this structure on the glass, al

What is This is a Mesh structure, m e s h. if you see this one, these are microgrid or mesh for holding tissue core. if I load tissue on this, if I load tissue on this like this, this is the figure correct. How to create this Simple it is a one-step photolithography technique; how to create this, this is on the glass slide ok, like this on the glass slide, there is a mesh. How can we create this

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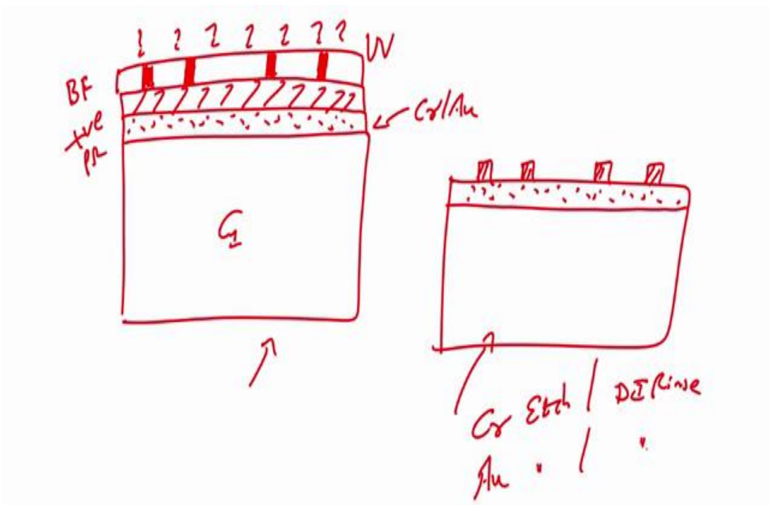


Simple, see take a glass slide glass; then on that, coat metal, which is r chrome gold, then spin coat photoresist, positive photoresist, then use the mask, b field mask, something like I am just showing a representative diagram al, b field mask.

Then expose the wafer with UV light, UV light we expose the wafer; after exposing wafer develop this glass wafer. When developing the glass wafer; what will have, will have r chrome gold and r photoresist protected in the area, which was not exposed since it is a positive photoresist. Then dip this wafer in chrome etchant followed by DI rinse, then gold etchant followed by DI rinse.

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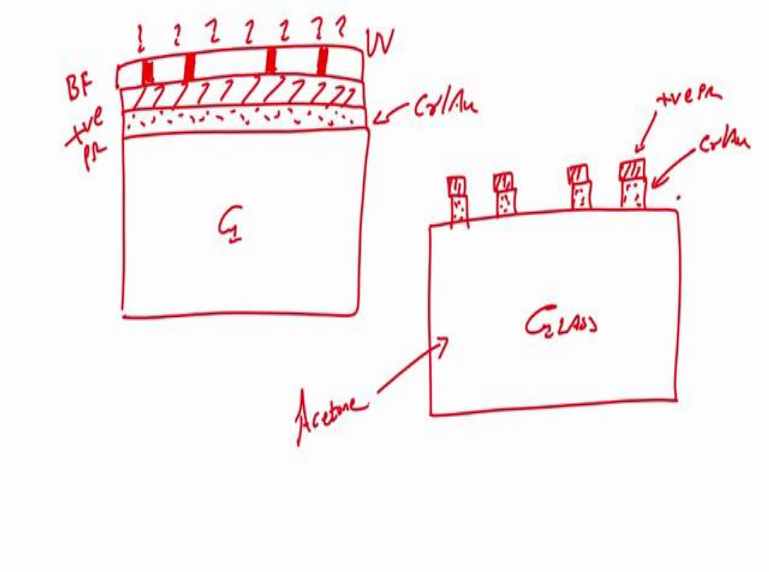


When doing that what will happen When to perform that particular process, then have chrome gold etched from the area which was not protected by positive photoresist, and the area which was protected by the photoresist will be saved or protected. Next step, know. after developing, of course, there is a hard bake, then have to do chrome gold, have to remember the photolithography steps ok. Now if I did this wafer in acetone what will happen If I did this wafer in acetone, then photoresist will strip off and I will get the pattern and this pattern is this pattern ok, this much is easy.

Now, understand that when I am pressing my there is a cone, which is connected to a micromanipulator as can see here; and these on this cone there are 8 pillars, 8 pillars are there. if I select a different color like this, there are 8 pillars pressing this tissue al; and this is the breast tissue core on the microgrid. What will happen when I press this tissue with the help of the micromanipulator, see here MP 285 micromanipulator.

this cone is connected to a glass slide, this glass slide is connected to the micromanipulator, micromanipulator 285, MP 285 ok. when indent it, what will happen; when indent it depending on the elasticity of the tissue, the sensor will bend and this bending of the sensor is this sensor.  it is a flexible sensor though.  if I just use one rectangle to represent the sensor.

When I apply a force, the rectangle will bend like this, since it is a PDMS material, this is a PDMS material. When it bends on applying a force what will happen; there is a change in resistance because of the piezo resistor, which is r PEDOT PSS. And now if I apply a voltage, this is a conducting material, this is will be an electrode 2; electrode 1 already knows, this is r electrode 1 correct. Electrode 1 is r SU 8 material with r AU pad and electrode 2 will be the bottom electrode on which are loading the tissue.

Now, when I apply a voltage between electrode 2, which is the bottom electrode and electrode 1, which is r SU 8 pillars with r gold p[ad; what will happen, depending on the resistance of the tissue, the current will change .  if I apply a voltage between electrode 1 and electrode 2; the current will flow depending on the resistance of the tissue.

 now we can measure the elasticity by pressing the tissue and we can also measure the resistance of the tissue; this is the advantage of simultaneous measurement of electromechanical mechanical properties of tissue.

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And can see here in this data that for a normal and for the IDC which is Invasive Ductal Carcinoma, the elasticity for the normal is higher compared to invasive ductal carcinoma and the resistance of the normal is lower compared to invasive ductal carcinoma. We can also learn about ethical epithelial and stromal regions, the same way for IDC and normal.

Here can see there is an inverted microscope and an inverted microscope is used so that can see that issue where when it is placed on the microgrid ok. this is the last slide of this particular module. In the next class, we will see how can we design one step, which can al which can not only do electrical and mechanical. But, also do or we can also perform the thermal properties, thermal characteristics or also sense the thermal characteristics; that means, that it will measure the stiffness or elasticity, it will measure resistance, and it will measure the thermal conductivity all three things.

Here it is electrical and mechanical; there will be electrical, mechanical and thermal. And we will see and that will design on the silicon chip again for understanding three properties of tissue which are electrical, mechanical and thermal. We will use a few; know videos to explain to what is breast cancer and what exactly, what are the types of breast cancer, and how it is different.

Same way when talking about prostate cancer, it is also different ; same way when talking about the brain tissue is different, liver tissue is different, stomach tissue is different; can we use electrical mechanical and thermal modalities in addition to the existing biomarkers for better diagnosis of a disease; that is our idea, this is a biosensor or cancer sensors al. I will see the next class with the more interesting fabrication of a biochip, which can do three properties simultaneously.

Till then take care, bye.