Fabrication Techniques for Mems-based Sensors: Clinical Perspective
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Lecture - 21
Process Flow for Fabrication of ETM Phenotyping

Welcome to this module. And this is our last module for this particular lecture. In the last series of modules what we have seen, we have seen a chip that is integrated with a heater, over which there is an insulator, over which there are interdigitated electrodes on which there was piezoresistive sensors or sensing layers, on that there was an insulator, over which there was a gold pad.

Now, on this gold pad, we will be patterning SU 8 pillars. So, the role of this SU 8 pillars would be to transmit a force that will be applying to the tissue through the indenter right, but before we reach to that particular point, let us see how we can pattern the SU 8 pillar.

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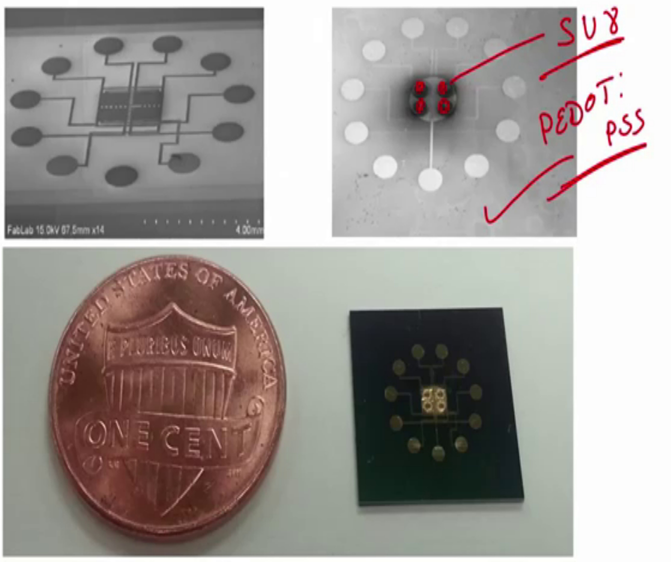

So, if you see the screen, what you see is that this particular chip, it has SU 8 pillars right, we have seen until gold pad. Now, how to create those pillars 1, 2, 3, 4 how to create these pillars, to create these pillars, we will be using a technique which you already know known as photolithography photolithography ok. And what I want is, this pillars, this pillars, as I will say SU 8, because this pillars are made up of SU 8 or pattern using SU 8, they are non-conducting. Why, because SU 8 is a polymer is a non-conductive polymer. Now, we will say how come polymer is conductive and non-conductive. Polymer can be conductive, for example, we have used PEDOT PSS PEDOT PSS, this is a conductive polymer, but SU 8 is a non-conductive polymer or an insulator.

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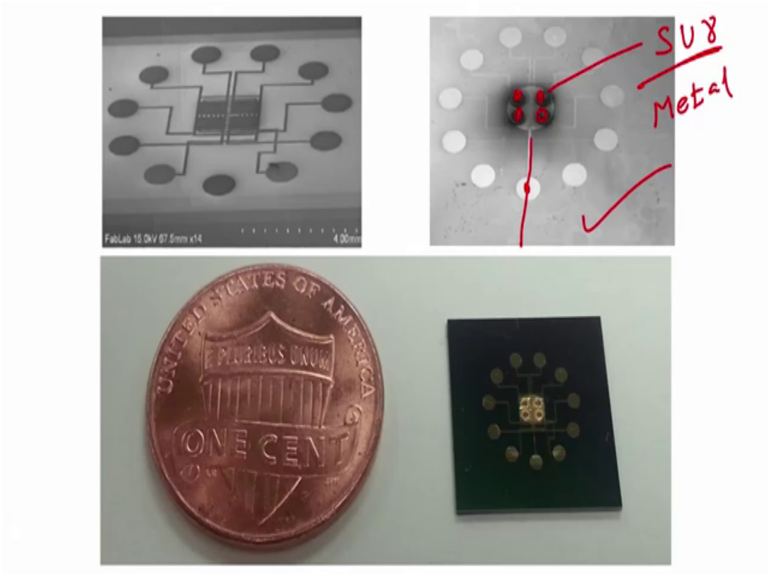

However, I want these pillars to be the part of the gold pad I want this four pillars to be part of the gold pad. So, when I apply a voltage between this, the current should flow from the pillars to the tissue, which is place on the pillars to the another electrode, we will see how that happens. So, to make SU 8 conductive what we can do, we can coat SU 8 pillars with the metal. We can coat SU 8 pillars with a metal.

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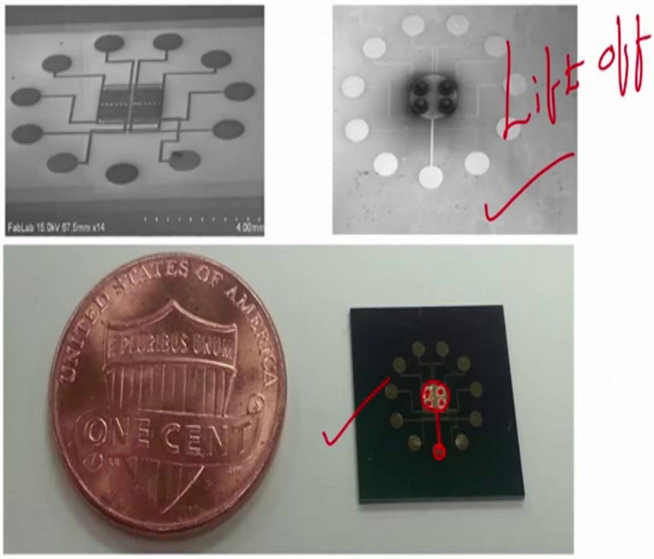

So, how to coat SU 8 pillars with metal, either you can use standard photolithography or you can use a technique called as lift off either use a standard photolithography or a technique called lift off all right. So, you see here in this particular chip, what you see is, there are gold pads, there is a there is a gold pad, and there are SU 8 pillars, which are coated with gold, you can see there is a gold over SU 8 pillar right. Same thing we want same thing we want at the end of our process flow.

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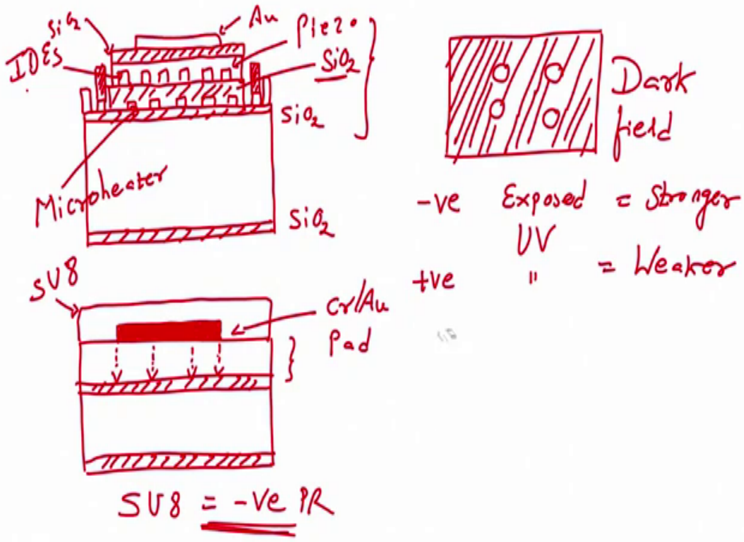

So, if I if I draw quickly, what we have until now is a oxidised silicon wafer, on which there is a micro heater right, on which there is an insulator on the insulator, now this is (Refer Time: 04:32) there are interdigitated electrodes right. And on this interdigitated electrodes, there is a sensing layer, which is our piezoresistive sensor. On this piezoresistive sensor, there is an insulator. On this insulator, there is a gold pad. So, let me draw gold pad like this hm. So, what is this, Si O 2, Si O 2, this is your micro heater, this is Si O 2, interdigitated electrodes, piezoresistive piezoresistive sensing layer, Si O 2, gold pad right. This is what we have seen.

Now, on this particular material, on this particular chip, what we have to do, we have to so, I will draw it here let me draw it here, that is easy. So, assume that assume that all the layers that we have drawn over here all the layers are there, and I am just drawing the gold pad I am just drawing gold pad. So, below this gold pad, this remaining layers are there, which layer, from silicon dioxide, piezoresistor, interdigitated electrodes in Si O 2, micro heater, and below it, there is an oxide. So, I will just draw it line here, below which there is an oxide ok, just to make it easier just to make it easier.

So, this particular schematic or part of the schematic represents all these five layers which is the silicon dioxide, and your piezoresistor, and your interdigitated electrodes, and your Si O 2, and your micro heater ok. Now, this is our gold pad, we know that right this is our gold pad. On this gold pad, I will spin coat I will spin coat SU 8, now spin coat in photoresist we will spin coat SU 8 ok. This is gold pad. Just to make it easier, I am just filling this block, so that it is easier to identify difference between your gold pad and SU 8 ok.

Now, SU 8 SU 8 is negative photoresist SU 8 is a negative photoresist. So, we all know, which kind of mask we have to use, so that we can save the area below which or save the area or we can save the SU 8 on the area that we want to have pillars for right, so which kind of mask we can use. If I use a bright field mask if I use a bright field mask, and the pillars are or the area that is dark field in the bright field mask, the area that are patterns. Will it work with the SU 8 or should I use the dark field mask, the light can penetrate only in the area, where I want to protect my SU 8, you get it. So, let us see this.

If I draw if I draw a mask, which has four pillars like this, and rest of the area is dark field rest of the area is dark field, is this mask a better mask, this is my dark field mask dark field. So, if I use dark field mask to form SU 8 pillar does not make sense, because

SU 8 is a negative photoresist SU 8 is the negative photoresist. So, if I use this mask, which is dark field, assume that this lines that we have drawn here, there is everything is dark ok. And only in the area, where you can see the circles, it is brighter.

Now, what is the characteristics of SU, SU 8 on negative photoresist, that the light or the area that is exposed the area which is exposed, will become stronger; the area which is not exposed with UV light, will become weaker, we know right. So, negative photoresist, the area which is exposed with UV, will become stronger will become stronger. And positive photoresist positive photoresist, the area which is exposed with UV, will become weaker will become weaker. So, we have to use dark field mask with SU 8 to from the pillars right. Now, so after spin coating SU 8, there is a data sheet that you need to follow, how to use SU 8 as a negative photoresist.

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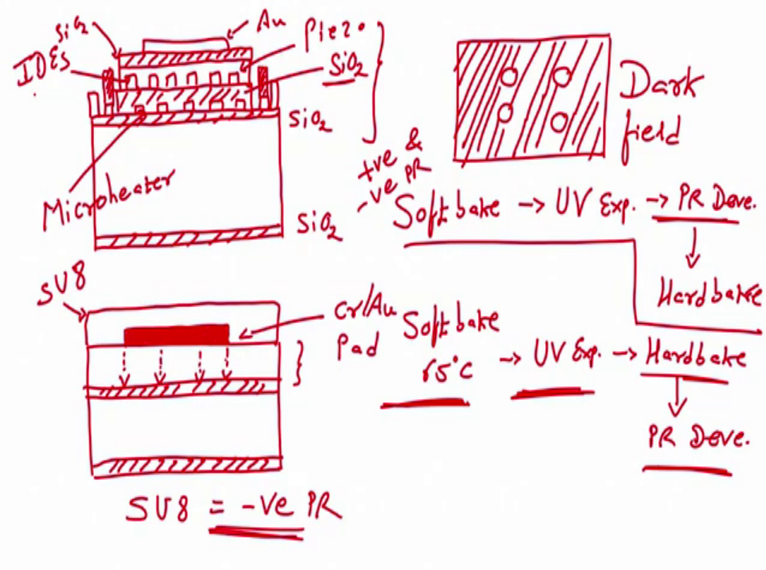

In case of positive and negative photoresist what we have this, we what we have learned until now is that the first step is after spin coating, you have to do a soft baking soft bake followed by UV exposure, so alignment mask alignment followed by UV exposure followed by PR developer PR develop followed by post bake or hard bake right hard bake hard bake and so on. This is what we have learned until now, for positive and negative photoresist right.

In case of SU 8, SU 8 is similar to negative for this photoresist, but the process step is little bit different. So, what is the process step, after SU 8 we coat the SU 8 on these chip, we first go for soft bake, which is done at 65 degree centigrade followed by followed by UV exposure followed by hard bake followed by photoresist developer. What I said after SU 8, which is our negative photoresist, soft bake a 65 degree, this temperature is given in the datasheet. For how much time you have to soft bake, is also given depending on the thickness of SU 8.

So, when you look at the datasheet of the SU 8, you will see the temperature, the thickness, the soft bake time, the hard bake time, and same strengths same strengths to for soft for negative and positive photoresist as well. So, when you look at the datasheet, you will know this numbers. But, the one thing that is different than positive negative photoresist compared to SU 8 is that here after soft baking at UV exposure, we are going for hard baking instead of photoresist developer, this one step you have to remember all right, so that is only different. Here you see there is a photoresist developing, and then hard bake. Here it is hard bake, and then photoresist developer.

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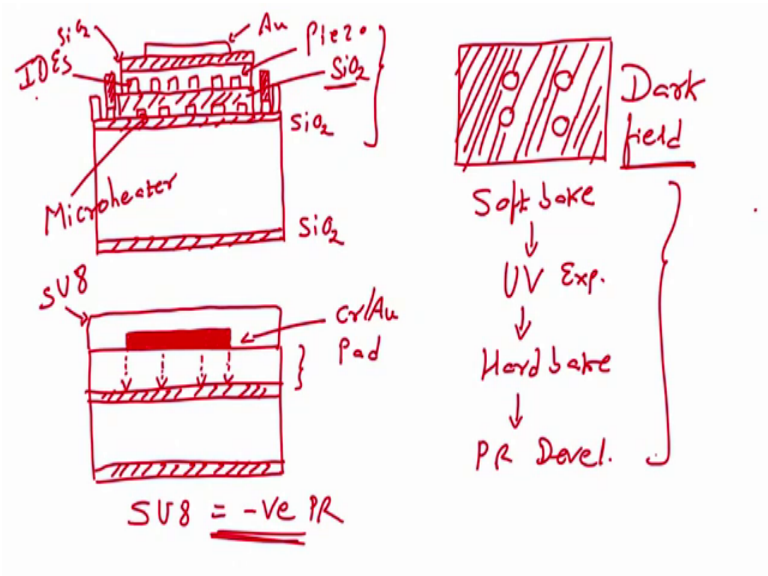

So, the thing is one thing that you guys have to remember, in case of SU 8, so I will use SU 8 with my dark field mask I will use SU 8 with my dark field mask. You are you now know my dark field. So, after the SU 8 what we will do, we will perform soft bake, we will go for soft bake, then we will go for UV exposure we go for UV exposure followed by followed by hard bake UV exposure followed by hard bake followed by PR developer. So, if I perform this step soft bake, then I use here UV exposure. When I say

UV exposure, it is understood that there is a mask, that we will load, and then we will align, and then followed by a UV exposure, next step would be hard bake, next one would be PR developer.

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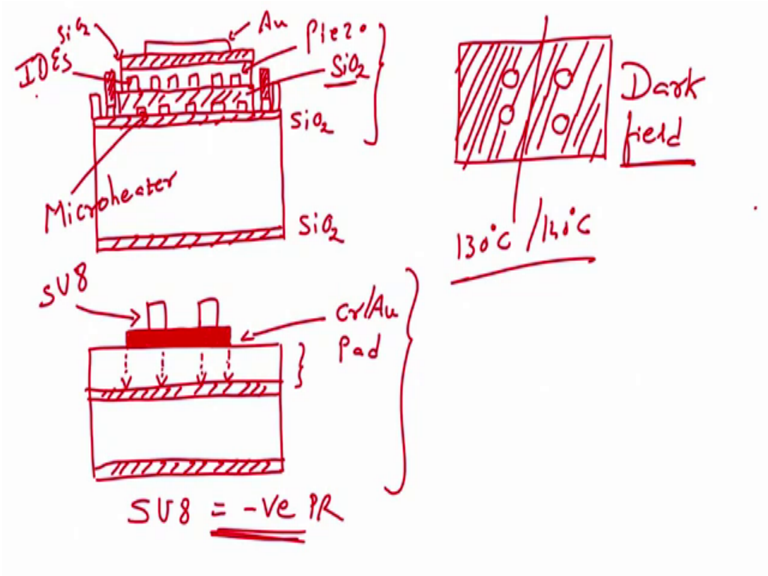

When we perform all these steps when you perform all these steps what we get, we get when you perform all these steps, we get you look at this particular diagram what we get is because two pillars on the backside, assuming the two pillars on the backside cross section, we get SU 8 in this particular fashion. Why, because we are taking a cross section of this right, so that is why we are representing only two pillars. Two pillars are on the backside of these pillars, you got it. So, this is just a negative photoresist.

After this, you have to go for annealing this particular chip at a higher temperature. So, let us say at 130 degree centigrade or 140 degree centigrade, we have to anneal the chip at higher temperature to make the SU 8 harder to make the SU 8 harder, you got it. So, this is how we pattern the SU 8 on the chrome gold pad; things to remember is SU 8 is a negative photoresist. And compared to the positive and negative photoresist, the only difference is that instead of going for PR developer after UV exposure, we have to go for hard bake followed by PR developer right.

So, after we learn this what we will learn now, how we can coat the SU 8 with metal how we can coat the SU 8 with metal right. So, we will see how we can coat the SU 8 with metal in the next module or actually let us finish in this module, because I want to teach you something in the next module. So, in this particular thing what we have done until now is, we have created SU 8 pillar. So, now let us see what is a step that we will do to make the SU 8 conductive all right.

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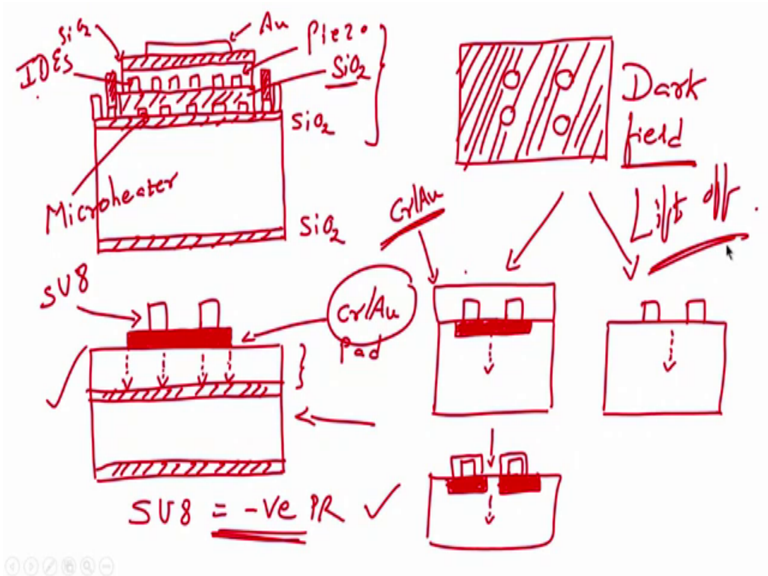

If you see the screen, what we have is SU 8 pillar in this particular fashion. Now, there are two ways two ways ok, one is one is I was drawing a chip, so that you it will becomes easier, just concentrate on these two figures right. And let us directly draw SU 8 pillars here, there are other layers below it other layers below it ok, we will start with SU 8 pillar. On this SU 8 pillar, I deposit chrome gold I deposit chrome gold right, and make it conductive and make it conductive.

But if I do this right, I have to perform a photolithography standard photolithography to pattern the chrome gold in a way that, it should only coat it should only coat SU 8 like this, correct. And remaining area, I do not want to coat it with any other metal. But if I deposit chrome gold, and if I perform standard photolithography, and I want to protect only in this area, then below this pillars what was that below this pillar, there is a gold pad right below this pillar, there is a gold pad, you are with me right. We are this is the exactly this figure this figure, and below this, there is another layers.

So, if you compare this one, what we have done is we have to we have to coat the SU 8 pillars without coating this particular area, otherwise everything will be shorted out everything will be short right. So, if I perform a standard photolithography, what will happen is the gold in this region will also get etched the gold in this region will also get etched.

So, what will happen is, it will look like this you see. In this case, it will look like this, but this is not what we want, we want a single gold pad below SU 8 pillars right. Because, see chrome gold we are depositing which is here, there is a chrome gold below it, which is like here like. And then, if I perform standard photolithography and I just want to coat the SU 8 pillars, then this region will get etched. So, in that case what I can do, I can perform soft not soft lithography, I can perform lift off technique what is call lift of technique.

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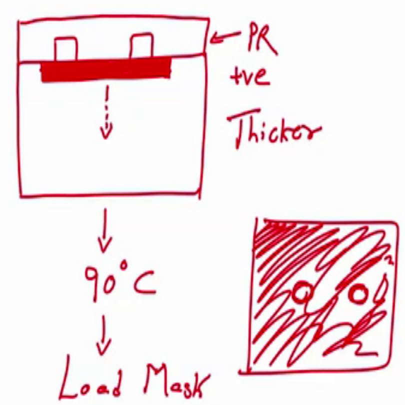

So, let us see how lift off technique can be done lift off technique. So, I am only drawing I am only drawing SU 8 pillar and gold pad right. And you guys have to assuming you guys have to assume that there are other layers below the gold pad there are other layers below the gold pad. So, let us see all right. So, this is the starting wafer, where these are this is your SU 8 pillar. In case of lift off, what we will do is, we will coat this SU 8 pillar in every area of the wafer with a photoresist. So, we will spin coat positive photoresist we will spin coat positive photoresist. This photoresist is thicker compared to our earlier positive photoresist. The idea of keeping this photoresist thicker is that here we want to use a lift off technique.

So, for lift off technique, we have to use a photoresist, which is thicker compared to normal lithography techniques or standard lithography techniques. So, once I spin coat photoresist, what is the next step? Next step is my next step is I will pre bake the wafer at 90 degree centigrade right, next step is I will load the mask I will load mask. And this time this time, I want to open only the area, which I want to make it conductive that means, the area which is surrounding SU 8 pillar.

So, what does it mean that I will have a mask that will be a dark filled mask, there will be a dark filled mask with only area the circular area, you can see here right that is bright field that is pattern. So, only the circle, through the circle only light can pass. Now, why this, why we are why we have to do this, so you see here.

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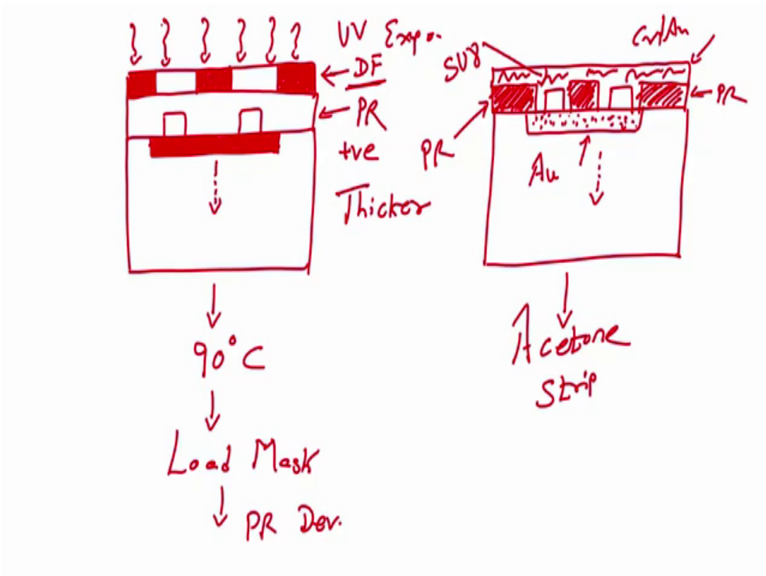

If I load the mask right, such that is I am loading the mask such that the photoresist is protected only in the area, which you can see right over here, which is dark red. And in this area, photoresist should not be there. So, I will have a mask, which looks like this, this can be my dark field mask dark field mask ok. Now, what I will do, I will go for soft lithography sorry after this after this, we will perform we will perform UV exposure or we go for UV exposure UV exposure all right. So, after UV exposure, what is the next step, next step is photoresist developer right.

So, when I will develop my photoresist after performing this step, what will I have, I will have SU 8 pillar right, and everywhere there will be photoresist. So, I am just drawing photoresist to save time in this fashion. This is gold pad, this dotted version is the gold pad, and this is SU 8 pillar right. So, this is my photoresist right, because we have used you we have used dark field mask the positive photoresist. So, area which is not exposed area which is not exposed, will be stronger area which is not exposed will be stronger. Now, you see here the, what is there, there are SU 8 pillar, there is a positive photoresist, and here is a gold pad, and below there are other layers.

So, the next step is I will deposit chrome gold on this particular chip. This is my chrome gold see this is chrome gold. Now, see the beauty of lift off, after depositing chrome gold, I will put this chip I will put this wafer in I will load this wafer or dip this wafer in acetone right, so I will leave I will dip this wafer in acetone. What will happen is acetone will lift off the photoresist acetone will strip the photoresist right. You know, acetone is photoresist striper; it will strip photoresist. When it strips photoresist, the metal on the photoresist, which also get stripped when acetone strips photoresist, the metal on the photoresist will also come off right.

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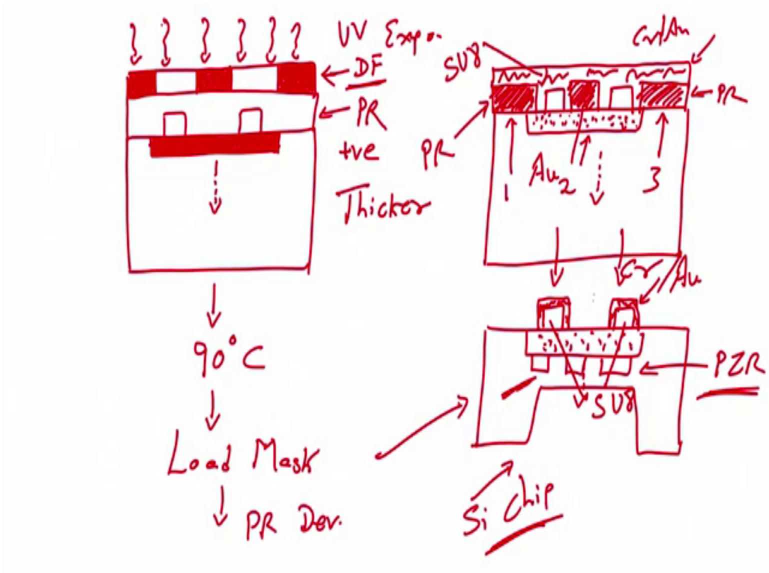

And what we will see is a wafer a wafer with a gold pad, SU 8 pillar, and SU 8 pillar coated with coated with chrome gold. Why, because see photoresist from this area, from this area, will be and from this area right this three, 1, 2, 3 all three area will be stripped off, and the metal on the photoresist will be lift off. So, we lift off the metal on the photoresist, and thus we get SU 8 pillars, you can see right over here SU 8 pillars. And on SU 8 pillars, there is a chrome gold or a metal right. This is how we perform lift off.

Here there is no tension of performing the whole steps for standard lithography that is you spin coat, then you load the mask, then you spin coat, then soft bake, then load the mask, then developer, develop the photoresist, then you go for a hard bake, and then perform chrome gold etchant right and then finally go for photoresist stripping off. Here the idea is that you spin coat photoresist, you pattern the photoresist, and you deposit chrome gold, and you dip the wafer in acetone. So, the life becomes extremely easy, because acetone is a striper, it will lift off the metal on it, and thus we directly get SU 8 pillars that are coated with metal right.

So, if I do this kind of stuff what will I have, I will have a chip that is ready with SU 8 pillars, there are conductive, because there is a metal coated on the SU 8. Now, one thing that we have to remember in this particular application, if you remember the lithography and the physical wafer deposition in particular thermal evaporation or E-beam if you use thermal evaporation or E-beam, what will happen, there is a there is a cons of E-beam there is a drawback or limitations of E-beam or thermal evaporation. What is that there is a it cannot or it has a pure step coverage.

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So, if this is my SU 8 pillar and if I am depositing a metal right if I am depositing a metal, it will not cover this area or maybe it not cover this area. This is my gold pad right this is my gold pad; this is my SU 8 pillar. And if I am depositing metal, it may not cover this area because of the poor step coverage poor step coverage in the case of in the case of thermal evaporation or E-beam evaporation.

So, but if I tilt this wafer right if I have wafer like this, if I tilt the wafer, what will happen, it will deposit on this particular area right you see this particular area will also get coated along with the tip. So, now if I tilt the wafer, I will have one side coating of SU 8 pillar. This is gold pad, so this becomes conductive the path is conductive path from tip to the gold pad.

If I use like this, there are chances that the step here the steps here would not be covered. So, SU 8 pillars if there are four SU 8 pillars, they may not get covered uniformly. And that is why, the idea is that we should at least have a conductive layer from the tip to the pad, and that we can do by just tilting the wafer in one of the direction either in this direction or that direction, you can use 50 45 degree. If this is if you consider this one as a flat, just put angle and at the angle, you can cover at least one side of the SU 8 pillar.

So, if you see the chip how chip will look like that the chip will look like the one shown in figure over here right. And this chip has what, this chip consist of now it consist of a electrode gold electrode with SU 8 pillars that are conductive, this is a gold electrode, correct. And what it has, it is also integrated with micro heater, it is also integrated with piezoresistive material right. So, in that case what we will do, we will see how this chip can be used to understand the properties of tissue.

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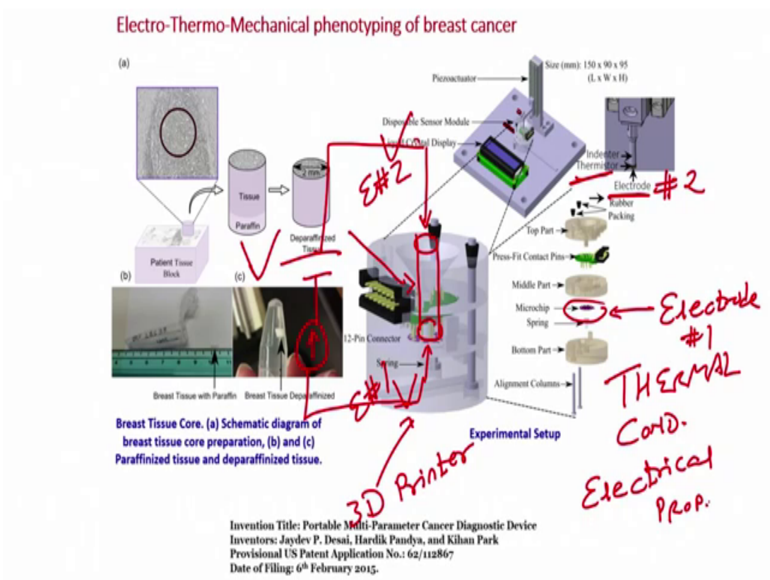

So, since this chip has heater, if I use a 3D printer case as shown here 3D printer 3D printer if I use a 3D printer to create a case, which is shown right over here. And if I am using a chip, which is integrated with a heater, you can see this funnel right. If I place the tissue in this funnel, this tissue like this, this tissue will be placed or (Refer Time: 32:51) touching the chip centre of the chip.

Now, I have indenter you can see here, I have a indenter, and there is a thermistor on the indenter. So, if I heat the tissue from the bottom, I can measure the temperature of the tissue at the top right. So, I have a temperature T 2 here, temperature T 1 here. If I know the difference between T 1 and T 2, I can measure thermal conductivity thermal conductivity of tissue right one thing.

Now, we know that there is a electrode, which electrode, electrode that consist of a gold pad along with SU 8 pillars, which are conductive. So, we say this electrode number 1 electrode which is a consist of a gold pad and SU 8 pillars, which are conductive. If you see the indenter, that we will press it, right we have to press the tissue. You see the indenter here, indenter has another electrode indenter has another electrode let us give this electrode as number 2 name as number 2. So, we have electrode 1 on chip, electrode 2 on the indenter.

Now, if I apply if I apply voltage between this electrode and the top electrode; that means, electrode 2 and electrode 1, what will happen, correspond corresponds to the resistance of tissue corresponding to the resistance of tissue the current flowing through the tissue would be different right. See I am applying voltage across this terminal, so I will apply a voltage across tissue in this particular fashion.

Corresponding to the resistance of the tissue, I will be able to see change in current right. So, now I can measure the electrical property of tissue electrical properties of tissue. Next, next we know that the sensor or the chip consist of piezoresistive sensing materials right consist of piezoresistive sensing materials.

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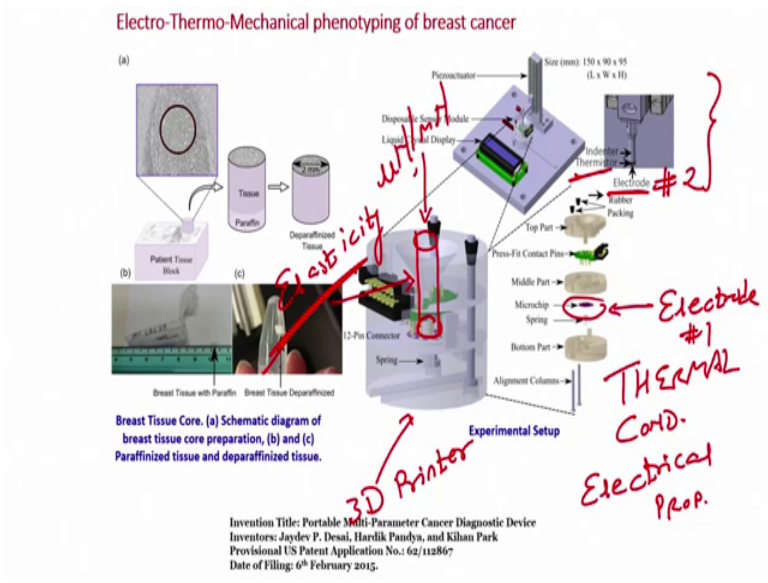

So, if I have indenter and if I press the tissue, then the piezoresistor on the chip will have or will experience certain amount of force depending on my indentation, how much I am indenting the tissue. And that force transmitted from the indenter to the chip depends on the elasticity of the tissue is not it elasticity of the tissue.

Again, there is a indenter, we are indenting the tissue with some micro Newton to milli Newton of force. How much force will be transmitted on the chip, depends on the elasticity of the tissue. Now, the amount of force that transmitted on the chip can be measured, if the if the chip is integrated with some sensor. And our chip is already integrated with the piezoresistive sensor, but there is a catch here. Until now, what we have seen if you see this slide, we have seen that we have everything below SU 8 pillar like interdigitated electrodes, sensing layer, and micro heater everything.

But, if I let say if I draw a piezoresistive sensor, this is the piezoresistive material PZR piezoresistor. If I apply force if I apply force, what will happen, this sensing layer should feel some force that force how much force it feels, depend on the elasticity of the tissue. But, this piezoresistive sensor will not be sensitive, because we are using silicon chip, and silicone is hard material. So, there will be no strain piezoresistor, there the there will no you know sensitive piezoresistive will be extremely extremely small.

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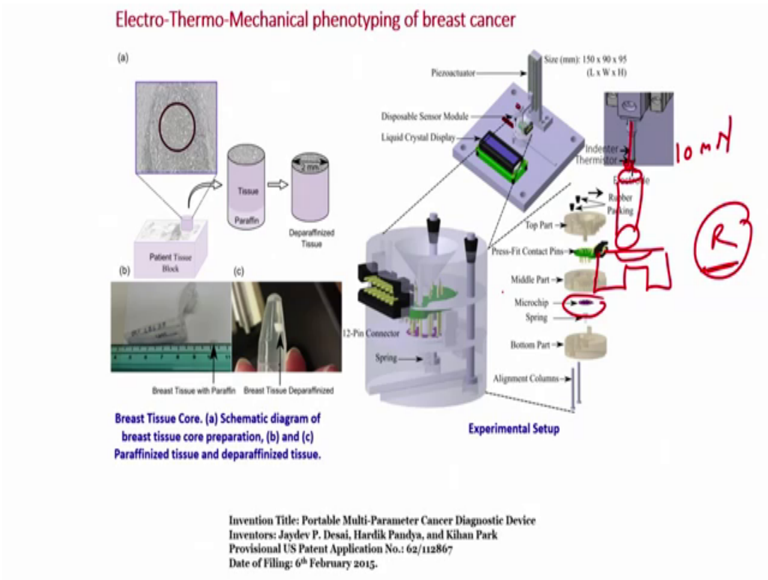

So, how to improve the sensitivity, we can improve the sensitivity, if I create a diaphragm if I create a diaphragm in this case, when I apply force when I apply a force right to the tissue with the help of indenter, I will be looking at the change in the elasticity at the change in the elasticity of tissue based on how much force is transmitted onto the chip that is integrated with my piezoresistive sensor that means, that if this is the indenter, if I indent this on the tissue right. And if I know that there is let say 10 milli Newton of force that I am applying on the top. How much force is there on the chip, depends on my resistance of the sensor. This when I apply force, this will bend, this bending will cost change in resistance, and this resistance corresponds to the elasticity of tissue, got it.

Now, what we can do, we can measure the electrical, mechanical, and thermal property of tissue that is what we have written here electro-thermo-mechanical phenotyping of breast cancer because, the tissue that we can try is a breast cancer tissue that does not stop you to use any other tissue. You see you can use any tissue related cancer, and you can try with this chip to see whether the tissue has as the cancer progresses or as the disease progresses are the parameters or property of tissue different, is the mechanical property of tissue different that is elasticity is different or is the resistance is different or thermal conductivity is different. So, this is not limited to just breast cancer, it can be used for oral cancer, can be used for liver, can be used for any tissue related cancer, you got it.

So, this kind of chip we can use to understand the electrical, thermal, and mechanical property of tissue. And now, we know that after looking at several modules, we are able to understand what is the process flow for developing a biochip, that can be used for measuring the ETM properties of tissue right. So, just to help you out, how it should look like. So, what is the next step, now this everything is using the piezo actuator this and that.

But, can we design a device that is small like a pen, and it has everything, how can you squeeze it down right. How what I hold the device on my palm, and I can just put the tissue and so when I am saying it should be hold it on the palm does not mean it can be always hold it on the palm, that I mean is that what I mean is that the size of the device should be very small portable right.

See once you understand that the tissue properties we can measure, now let us try to understand how we can reduce the cost. Not everything is important in micro engineering or MEMs devices or devices for clinical research that the cost should be down, one thing is a performance, sensitivity, accuracy, resolution, and then everything is figured out now can we bring the cost down. This is our research approach should be right.

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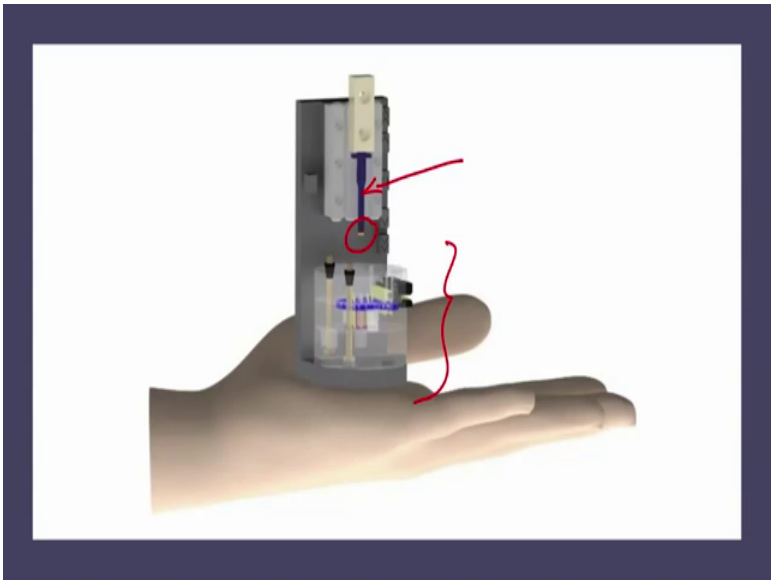

So, you see the slide, this is the how it should look like. This is what I think that ok, can we bring it to a palm size device. This is the indenter; you can see very clearly, this one is the indenter. And this indenter you can see here, it is comes you know attach with the gold pad, it has an electrode, and then this is the 3D printed device on which there is a chip, and it is a palm size device handled small device.

Now, this particular application does not require this device to be handled. The idea of showing you this schematic is only to make sure that the device that we are designing should be small enough for portability point of view. Now always like I said, it is not always that we have to go for it, but is better to have a smaller device. You see we have a phone, which was really longer right cell phone you are bringing down bringing down bringing down, so you are making a small chips, we are we are making things down easy, easy accessibility, easy portability, and better operation right.

So, this end of this particular module and what we saw in this whole lecture, which is divided into several modules is that we learn a process flow to create a chip that is integrated with three different sensors, and the idea is to understand the ETM properties that is electrical, thermal, and mechanical properties of tissue.

And the bigger idea is that we with this particular modalities, there is electrical, thermal, and mechanical modalities along with MRI and mammography right, can we help can we aid the clinician or a path lab to take a decision right can we help or aid the clinician or path lab to take a decision to reduce false positive and false negative signals in case of cancer that is our bigger goal all right.

So, we will continue in the next lecture, and we will look at other kind of application of the sensor, and how the sensors can be used to solve a very important problem in clinical perspective or from the clinical perspective.

Till then you take care, I will see you in next lecture. Bye.