Sensors and Actuators

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Lecture – 3
Sensor Part 3

Hi, welcome to this particular module. Last module we have discussed few of the Sensors and their application, but as I have promised you, that I will teach you each sensor fabrication in detail in the few of the modules, as a part of this particular course. Right now, our focus is on understanding what kind of sensors are available and what are the application of those sensors.

And we will be focusing on medical domain. So, that you can understand that how understanding basics about micro fabrication and technology and sensor design technology can help you to fabricate several sensors and actuators for medical domain. The same sensors and actuators can be used for other applications as well. We will be discussing those applications in detail including different physical vapor deposition techniques, chemical vapor deposition techniques, lithography techniques to fabricate those devices alright.

So, if you recall yesterday, what we discussed was micro heaters. And then we discussed why we had to fabricate a micro heater? How we can fabricate micro heater? And how you can have the resistance values?

Now, if you assume that, this two are metal, metal lines and if I am not connecting two metal lines, what will, and these are the contact pads alright. So, these are the contact pads, this one and this one alright and this is the these are metal lines. So, if I measure the resistance or impedance, what will be resistance or impedance, it would be; it would be infinite.

Because there is no connection, it would be infinite. Now if I place anything on this particular two electrodes, I will see the change in the impedance values, depending on the material that I have placed on this particular electrode, is not it. So, the point that I am making here is that, this interdigitated electrode can be used to measure the impedance of different materials.

Now, if I load cells on this particular interdigitated electrode, then I can measure the impedance of a cell. So, if I take a cell from a normal person and if I take a cell from a deceased person, let us say we talk about the cancer. So, cell from the person suffering from a cancer, then are the cells changing their electrical properties. If you want to measure the cells from a normal person and cells from the person suffering from cancer, you will see that the impedance values are different; that means, the electrical properties are different.

How we can measure impedance with the help of the interdigitated electrodes. Now what is the situation within our body. What I mean by situation is what is the temperature inside the body around 37 degree centigrade correct, how much amount of CO_2 is there around 5 percent. How much humidity around 95 percent average.

So, the point is that at 37 degree the cells would be alive, we can keep the cells alive at 37 degree centigrade. To now, where I am taking this lecture the temperature is about 20 degree centigrade, I want, when I take the cells from a normal person and I take a cell from a cancerous person I want their cells to be alive. And to keep the cells alive, we require 37 degree centigrade. To reach 37 degree centigrade, we have to heat the cells or heat the device from 20 degree to 37 degree; you got it. How can we heat with the help of a micro heater?

So, now if you have a micro heater and if you have an interdigitated electrode over the micro heater. Now interdigitated electrodes are made up of metal, heater is made up of metal if I place two metals together what will happen, it will be short circuit it will be short. So, I cannot place one metal on the top of another metal what I can do is, I can have an insulating layer in between. I can place one insulator in between the two metals.

Now, there is no short; there is no short, correct. So, the point here is that if I have a heater and I have a insulator which can be my silicon dioxide, which can be my silicon nitride and over that if I place interdigitated electrodes, then I can heat my device with the heater and I can measure my impedance with the help of interdigitated electrodes, when I place any sample on the interdigitated electrodes, you got it. That is what we have seen yesterday, how to fabricate the heater and how to fabricate an interdigitated electrode with a sandwich layer in between. When I say fabricate you have to just, we have just seen the device. We will see the process flow in detail and the recipe also for that.

So, that was the second sensor. The third sensor that we have, we were talking about is a force sensor. What can be a force sensor? It can be a piezoelectric sensor; it can be a piezoresistive sensor. Piezoelectric is when you apply a pressure there is change in the voltage. So, the mechanical you know parameter is changed to an electrical parameter or vice versa.

While in case of piezoresistor when you apply a pressure or force there is a change in the resistance. Now, if I talk about the strain gauge, strain gauge when I apply a pressure there is change in the resistance, because of the strain on the sensor. Now we should also know, when you talk about any strain gauge, you should talk about gauge factor or gauge factor the accent would be different it will be gauge factor. And what exactly gauge factor is? Gauge factor is a ratio of a stress/strain = $(\Delta r/r)/(\Delta l/l)$

That means that when I apply a pressure on a piezoresistor, then the resistance of the piezoresistor would change and because of piezoresistor let us say this is a piezoresistor embedded, let us say this is a piezoresistor and the register is embedded onto this material. So, when I apply a pressure this will change, this will bend like this. So, bending will cause the change in length delta l, l delta l and there is because it is bends there is a stress and if there is a resistor inside, there is a change in the resistance values.

So, now we have delta r, because we had an original resistor and there is a change in resistance value, and we have delta l in there was original length and there is a change in length. So, delta r by r divided by delta l by l will give you the gauge factor. How you will use this value? Because depending on the gauge factor of gauge factor value is higher the sensitivity is better. So, if you compare a metal and if you compare a semiconductor, the semiconductor gauge factors are generally better than the metal gauge factors.

So, we took an example of arrhythmia. And I was talking about the beating of heart and then I gave you an example that there is a catheter which you can you know place inside the body and not you of course. It is a surgeon will place inside the body and the heart will be that particular region which is misfiring the signal will be burnt and that burning would be with the help of RF. So, RF ablation and when you press it you should know, what is the force at the tip of the catheter.

And if the force is less recurrence is higher, if a force is more than the other parts of the tissue heart tissue will get burned in both the cases is not good for us. We require an optimized force value and to get that optimized first value, we need to design a force sensor. So, we will see how to design a force sensor for that particular application, cool alright. The next sensor that we discussed was the cantilever, piezoresistive cantilever and we saw that how a piezoresistive cantilever can be used to measure the change in the mechanical properties of tissue.

Now, the same cantilever can also be used to see the change in the mechanical properties of cells. How these cells from a normal to cancer the mechanical properties changes? What I mean by mechanical property elasticity of the cell would change, a cell which is cancerous would have different elasticity compared to cell which is normal. If that is the case from the cells can we diagnosed that a person is suffering from cancer, but group of cells together makes a tissue.

If you work on tissue and if you press the tissue, what will happen you may have a property that from the onset of the disease to it is disease progression, how the mechanical properties of tissue are changing. And that you can convert to an elasticity value alright. So, you can use a piezoresistor and assuming that this is a tissue you can apply a force the tissue depending on the elasticity of the tissue or stiffness of the tissue, that the sensor will bend. This bending will cause change in resistance because there is, we have diffused a piezoresistor inside the cantilever and that change in resistance will help us to understand what the elasticity of the tissue is.

Of course, this change in the resistance with applying or the tissue before that you have to calibrate it with the commercial force sensor. And you also want to know the what is the change in the tissue in the stress of the cantilever by using some hard material you can press it, it will bend, and you will know the calibration protocols, alright.

Now if you say that a cell or a tissue is changing it is property, what property elasticity, why because there is a calcification and different biological terms let us not go into that biology. But we know that the tissue elasticity is changing. Now when the tissue elasticity is changing, if I go for a scanning electron microscopy you have, I have written yesterday you have seen some images interdigitated electrodes or the heater that were SEM images. So, if I do field electron or field emission, Field Emission in Scanning Electron Microscopy which is FESEM, then I can understand the structure of the tissue.

So, if I take a normal tissue and if I take a cancerous tissue and if I see the structure of the tissue or with the help of FESEM, what I will have or a topography of the tissue, if I see what I will have, I see that there is a change in the roughness of the tissue. A cancerous tissue is rough compared to the normal tissue or normal tissue is much smoother compared to cancerous tissue.

So, when the tissue is rough or tissue is smooth, what will happen? The resistance would change. A resistance of a smooth material would be different than the resistance of a rough material. The resistance would change as per the tissue property and what I told you the cancerous tissue, normal tissues are different than the cancerous tissues in terms of the surface roughness.

Can we use this property and understand the change in the tissue property so; that means that if the roughness is different, resistance is different; that means I can see the change in the resistance of the tissue as cancer progresses. Now you have to keep the tissue alive. To keep the tissue alive or do not out the tissue to get dry, there is in a different way you have to load that tissue with some saline solution like PBS Phosphate Buffered Saline alright.

And you want to measure the resistance, but now since you have added the saline you cannot directly go and look at the resistance values, you have to go for an impedance value, what I mean by that.

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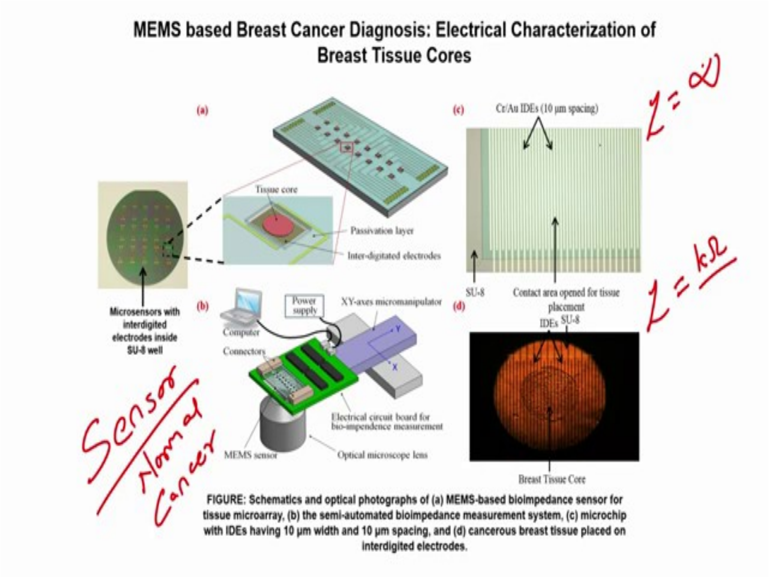

MEMS based Breast Cancer Diagnosis: Electrical Characterization of Breast Tissue Cores

FIGURE: Schematics and optical photographs of (a) MEMS-based bioimpedance sensor for tissue microarray, (b) the semi-automated bioimpedance measurement system, (c) microchip with IDEs having 10 μm width and 10 μm spacing, and (d) cancerous breast tissue placed on interdigited electrodes.

So, if you see the screen, these are the interdigitated electrodes here and what will be the impedance of this? Impedance of this would be infinite or extremely high, why? Because there is nothing on this interdigitated electrodes and only there are metal lines not connecting with each other. You see here there are metal lines not connecting with each other; these are lines which are not connecting with each other, correct.

Now, on this if I place a tissue, place a tissue which is this particular image, you can see the tissue here, placed on the interdigitated electrodes, what will happen there will be change in the impedance value the z would change. The z of this and the z of this, this z would be some kilo ohms or mega ohms this will be close to infinite, understood. Now you can design this kind of interdigitated electrodes, which are also called sensors.

Because it will sense the change in the impedance, impedance of what impedance of normal tissues and cancerous tissues. So, the impedance change of the normal tissues and the cancerous tissues can be measured with the help of interdigitated electrodes. What I say impedance? Impedance is an electrical parameter. So, we are measuring the electrical characterization of breast tissues with the help of an interdigitated electrodes.

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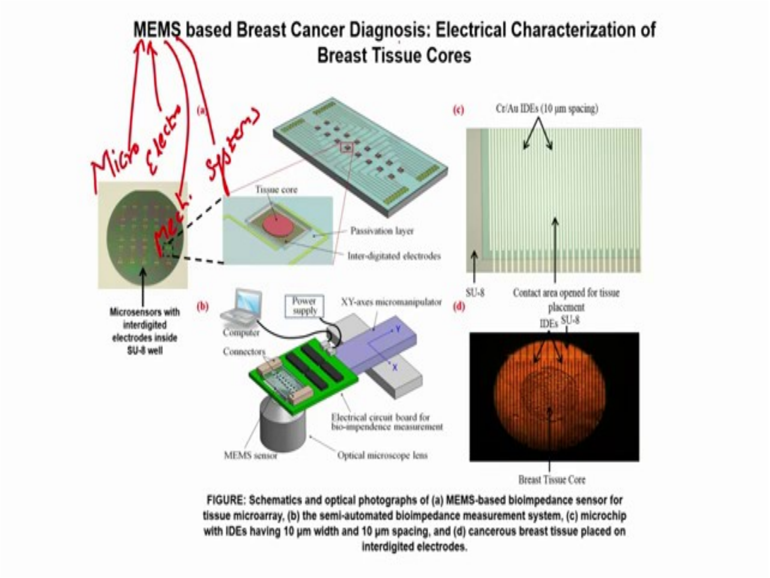

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So, we said MEMS based, MEMS stands for micro this stands for Micro Electromechanical Systems, micro electromechanical systems MEMS. MEMS based best cancer diagnosis. Now this is tissue-based diagnosis. So, it is a biopsy-based tissues will discuss this thing. When we discuss this device in detail how to fabricate it, because that is a part of this particular course, you should be expert in understanding the process flow and the recipe and the fabrication of different sensors alright.

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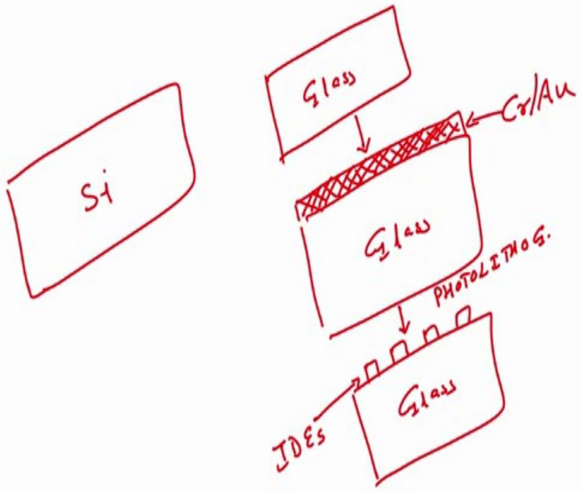

So, if I want what is this, if I draw a cross section of this, this is nothing, but you have this silicon wafer and on silicon wafer, let us say you have silicon wafer and you have a glass as a substrate alright. This is silicon this is glass. What I want to have? I want to have interdigitated electrodes on the substrate, silicon and glass are substrate. So, if this is a glass then I can deposit a metal, this is chrome gold alright. This is glass then you deposit a metal and then you perform photolithography, then you perform photolithography to pattern this chrome gold to form interdigitated electrodes.

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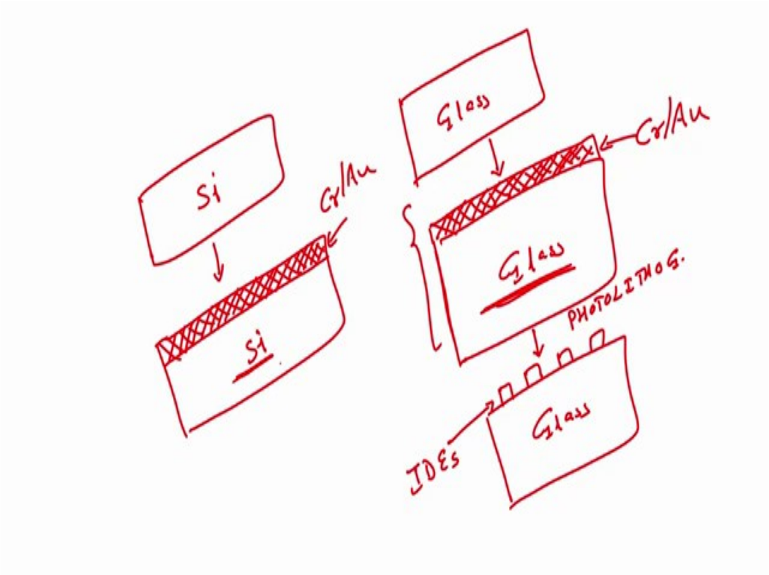

In case of silicon, let me draw little bit smaller schematic, silicon. Can I deposit a metal directly on silicon? This is my chrome gold on silicon wafer. My question is, in case of glass, I could directly deposit chrome gold on glass and pattern it to form interdigitated electrodes. In case of silicon, can I do the same thing? I cannot, why because glass is an insulator while silicon is a semiconductor.

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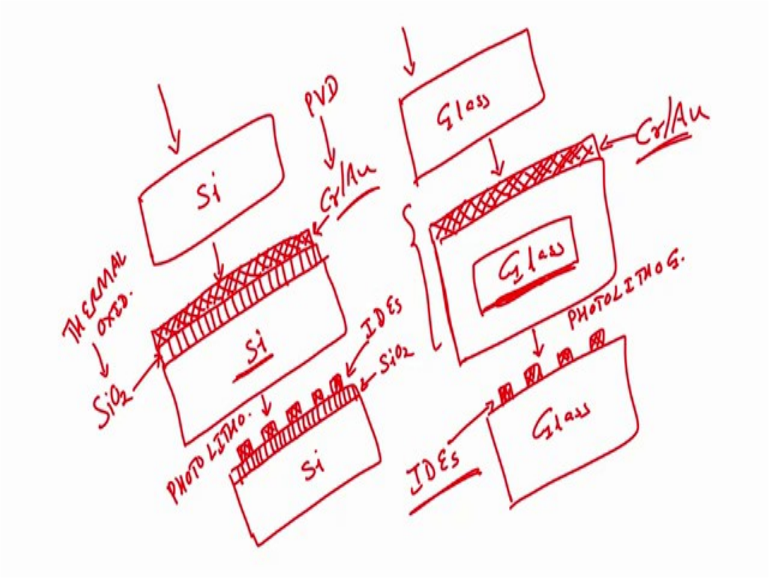

So, what should I do, for if I want to make the device on silicon wafer, I have to first grow silicon dioxide. This is SiO 2 what is SiO 2? SiO 2 is your glass. On this SiO 2, I can deposit a metal and I can do a lithography. I can perform a photolithography, alright. So, this is my interdigitated electrodes, this is my silicon dioxide, and this is silicon wafer you got it.

Now, do not worry about how the photolithography is performed, that I will teach you. Now just understand that, if I can if I want to use silicon as a substrate, I want to use glass as a substrate. What is the difference glass being an insulating material? I can directly deposit a metal and perform photolithography to fabricate inter digitated electrodes. In case of silicon, since silicon is a semiconductor, I need to a make an insulating layer or deposit or grow an insulating layer, over which I will deposit metal.

And then I will perform a photolithography to form interdigitated electrodes. This metal is grown using a technique called physical vapor deposition. Silicon dioxide is grown using thermal oxidation, alright. Now what is silicon dioxide? Silicon dioxide is nothing, but glass. So, this is how you can fabricate interdigitated electrodes. We will discuss the process flow later on, in the few models from now.

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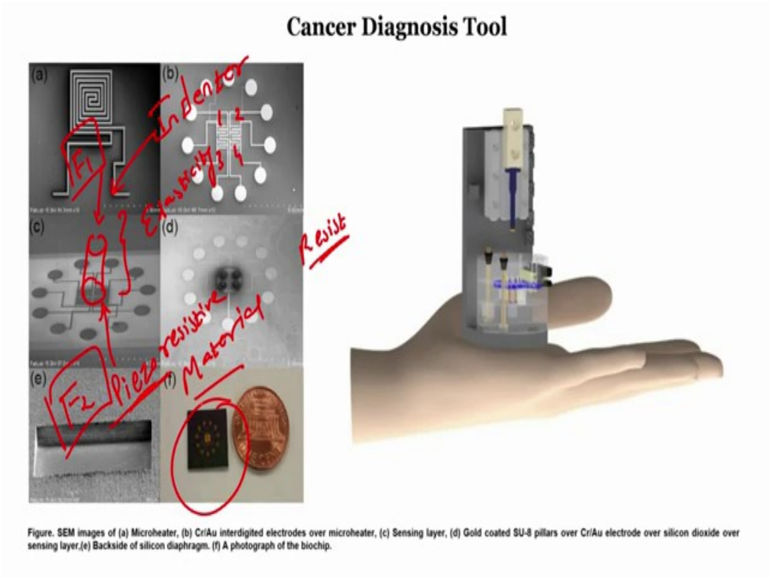

Cancer Diagnosis Tool

Figure. SEM images of (a) Microheater, (b) Cr/Au interdigited electrodes over microheater, (c) Sensing layer, (d) Gold coated SU-8 pillars over Cr/Au electrode over silicon dioxide over sensing layer,(e) Backside of silicon diaphragm. (f) A photograph of the biochip.

Now, you have seen a heater and interdigitated electrodes. You have seen this fabrication. Now on this interdigitated electrode, if I add a piezoresistive material, and if I place a tissue on this and if I apply a force f one. This piezo resistor material is nothing, but these are the sensors now, because how many sensors 1 2 3 and 4 there are four interdigitated electrodes.

So, I have four piezo resistors, on which I have placed a tissue and applying a known force. So, the piezoresistor will change the resistance based on the force that we have applied, but the amount of force that we applied and amount of force reaching the piezoresistor depends on the elasticity of the tissue, is not it. The force I am applying f 1 and the force at piezoresistor measures or it will reach the piezoresistor will depend on the elasticity or the stiffness of the material placed between the sensor and the indenter.

Indenter is where you apply the force, this is where you can say it is an indenter, alright. So, now, what will happen from this we can measure the elasticity of the tissue. I will teach you this is very interesting biochip. I will teach you in detail. now just understand quickly, now when I want to apply a force the piezoresistor will change the piezo resistivity only when it will it is able to measure the change in the force.

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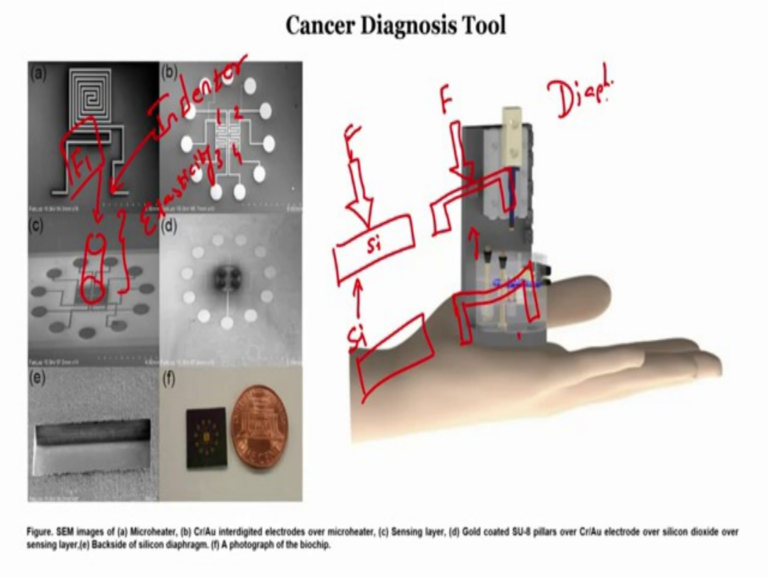

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Figure. SEM images of (a) Microheater, (b) Cr/Au interdigited electrodes over microheater, (c) Sensing layer, (d) Gold coated SU-8 pillars over Cr/Au electrode over silicon dioxide over sensing layer,(e) Backside of silicon diaphragm. (f) A photograph of the biochip.

So, suppose I have a silicon wafer and I have a silicon wafer with a diaphragm, like this. If I apply a force here and I apply a force here which one will bend, this is not going to bend because silicon is solid material hard material this will bend. So, here what I will see, what I what we are expecting is? It will bend like this; in this case nothing will happen.

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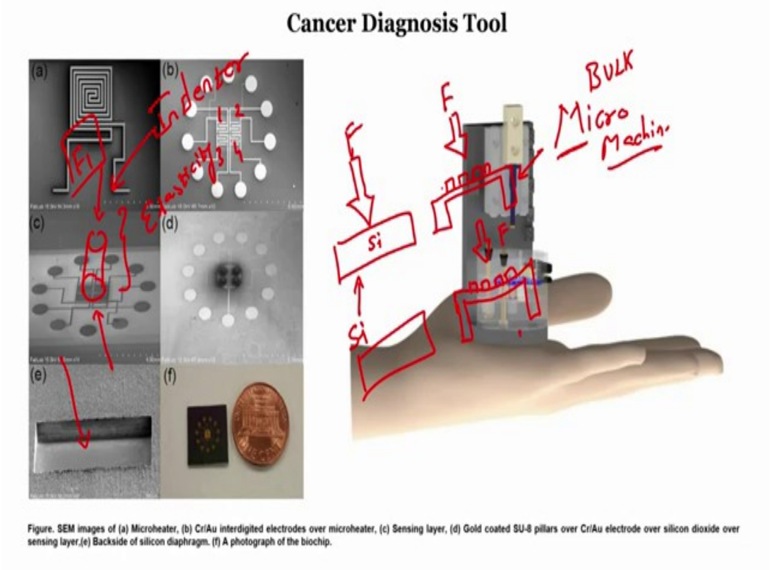

Cancer Diagnosis Tool

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So, we need to create this diaphragm. We have to etch the silicon wafer to create the diaphragm. How to etch the silicon wafer? There are there is a technique called micro machining, machining all of you have learnt in the workshop. We machine the different metals. At micro level when you perform machining is called micro machining, alright.

Now, the bulk of the silicon is machined is taken out, here you can see bulk of the silicon material is taken out. That is why this process is called bulk micromachining alright. So, this is how the silicon will bend, then if I have a piezoresistor on the silicon wafer. If I have a piezoresistor on this silicon wafer, then what do you see here? There is a bending of the piezoresistor.

This bending will cause change in the resistance. So, the stress in the piezoresistor will cause change in resistance. So, to help increase the sensitivity of the piezoresistive material, we are performing a bulk micromachining technique, by which we are etching the silicon wafer from the backside and this is what you can see over here, alright. This is the backside of this particular wafer, this one, on the backside there is a pit. So, it is becoming a diaphragm. So, we will see how to create this bulk micromachining, and this is also a sensor chip that can be used to understand the change in the mechanical and thermal properties.

How thermal properties? So, now, you have a heater on the chip. You have a heater and you have a piezoresistive material. You have a heater insulator, you have a heater, insulator, interdigitated electrodes on which you have a piezoresistive material. Now if I have a tissue, let us assume that this is the chip and I place a tissue on the chip. So, let me place a tissue, let us say this is the tissue, alright. I, what is there in my chip, my chip has a heater I heat this tissue and I have an indenter something that presses the tissue like this,

If this indenter has a thermistor what it has thermistor at the tip, what is the chip having? Chip is having a heater. So, I am heating the bottom of the tissue and I am measuring the top temperature of the tissue the bottom temperature I know, top temperature I am measuring with the help of indenter, because indenter has a thermistor. So, I will get t 1 which is a temperature that I am heating at the bottom of the tissue and t 2 which is a temperature at the top of the tissue.

Now, depending on the tissue properties or depending on the stage this property would change. What I mean by stage? Stage 0 stage 1 stage 2 stage 3 stage 4, these are different stages in breast cancer. So, the thermal conductivity of the tissue can be measured with progression of the disease. Any tissue related cancer we can measure the thermal conductivity of that particular tissue using this particular sensor. Which is our micro heater to measure the thermal conductivity with an indenter with the thermistor and then we have a piezoresistor.

So, now if you again consider this as a chip, this as a tissue and there is a piezoresistor, I have a indenter which will apply a known force on the tissue and how much amount of piezo resistance is changing depends on how much force is actually translated through the tissue and that depends on the tissue elasticity, you got it. So, now, we are measuring the we can measure elasticity of the tissue we can also measure the thermal conductivity of the tissue. That is a sensor that we are talking about. It is not ending; we have many more to discuss.

And let us see one more sensor or let us do like this. Let us stop here and let us meet in the next module. Because it will be too much for you to digest at one time ah. It is a good to eat food in small proportions. So, I will meet you in the next module talking about few more sensors. And there we will see what a microfluidic sensor is and how can you use it for rapid drug screening. Very interesting like I said once you understand how to fabricate a sensor, how to fabricate an actuator you will be able to find enormous applications of this particular devices alright.

So, till then you take care, I will see you in the next class, bye.