Sensors and Actuators
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Lecture - 17

Hi, yesterday we have seen the example of inertial sensors and then example of how to create a diaphragm as well as where are the MEMS used.

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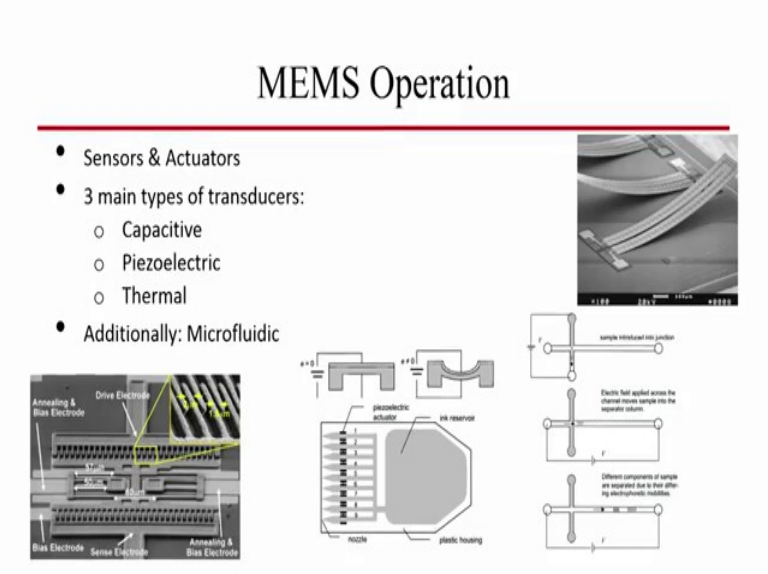

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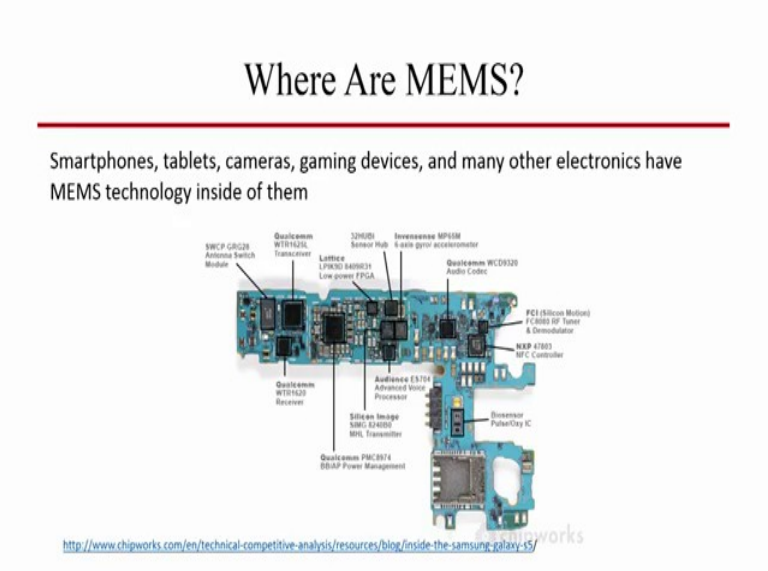

Now, today let us concentrate on a very important application of these miniaturized sensors and that is in the area of biomedical application.

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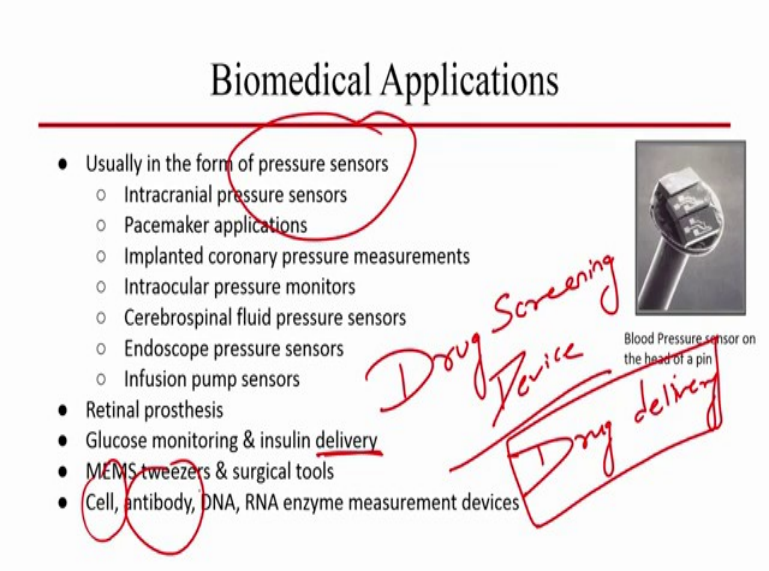

So, very big umbrella when I say biomedical application, it can be anything from intracranial pressure to pacemakers, to cerebrospinal fluid, to endoscope pressures, to infusion pumps, retinal prosthesis, glucose monitor, it can be for drug screening, it can be for cell base antibody based devices. So, what are these sensors and how can we fabricate those sensors, what are the processes to design and fabricate the sensors there is what our idea is.

So, when you talk about in terms of pressure sensors if you know how to fabricate the pressure sensors then depending on the application, you can change the design whether it is intracranial or this pacemaker or the implanted coronary pressure measurements or it can be intraocular pressure monitors. It can be endoscope pressure sensors, it can be infusion sensors, retinal prosthesis as well as glucose monitoring and insulin delivery.

So, delivery systems are also very important how to deliver a drug across the thing and what we will be totally focusing on will be the drug screening tool, drug screening device. So, what is drug screening device, we will be focusing on that, because it is extremely important you can deliver the there is a drug screening and another device called drug delivery. So, both are different one is to screen which out of let us say three

given drugs, which drug you will give to a particular patient. Let us say there are two patients; patient 1 and patient 2, which one you will give drug 1 or drug 2 or drug 3.

So, right now unfortunately if drug 1 is given to a patient 1 and if the patient 1 is responding to that particular drug, the same drug when patient 2 comes with a similar kind of disease will be given to patient 2. And in this kind of a case, patient 2 may not respond to drug 1. So, a patient 2 may respond to drug 2 or drug 3, but we do not know, we do not know which drug to give to a patient coming to a hospital settings. So, now, what we are looking at is how can we design a drug screening device? Second one, when we talk about is a drug delivery device drug delivery is like, if you have seen mosquito bites, do you feel pain? You do not feel pain, when mosquito bites.

You know it is just like itchy, but not really painful so, but if you take a syringe and you get this injection at the clinics, you feel pain no it may be momentarily, but you still feel pain. So, how to design a micro needles for drug delivery such that it will just go inside the subcutaneous region, but will not touch the nerve which causes the pain. How can we mimic this biological system like; mosquito bite into an engineering technology and deliver the drug such that it is not painful; that means, do you have a array of micro needles and can you use that as a patch to deliver a drug? Can you deliver a drug across a period of time slowly.

This everything is possible when you understand sensors and actuators and its fabrication. So, we will see how to design a drug delivery a tool at some point of time now, let us understand that the pressure sensors when I talk about pressure sensors can be used for several applications which are listed here. And, as well as when we say about glucose monitoring, glucose monitoring is you may be knowing is that glucose monitoring device which has a which measures the blood glucose concentration.

Then there are MEMS based tweezers to used in biomedical applications, there are surgical tools which are in micron dimensions for example, a needle holder and to hold the tissue and to stitcher the tissue and to sew the stitcher is when you take two tissues and you want to sew it. You just stitch it is called stitchering. So, we you stitcher, the tissue you need a equipment or a tool which has a micro dimensions you know micrometer in dimensions at the tip, because stitchering is done at a very precise dimensions in very small dimensions, it should be done precisely, because you are now,

stitchering the heart tissues for example, if it is a heart surgery and then you are holding the heart tissues. So, there is a needle that you require.

So, can you design a MEMS based micro needles and stitchering systems there is another application we talk about cells. So, whether the cell from can we understand whether a person is suffering from cancer and if yes then what is the stage of cancer just by looking at the cells of the person for example, somebody has a melanoma, melanoma is skin disease or else skin cancer. So, if you take the cells from that particular region in melanoma and understand the impedance of those cells; so, if I measure the impedance of normal cells.

If I measure the impedance of cancerous cells, then the impedance at a certain frequency would be different. So, if I can if I understand what is that frequency on which I can see the, I can measure the delineation in the cancer cells over normal cells, I can use that particular frequency right and understand different cells at different stages and get the electrical parameter and correlate it with the gold standard.

So, a device to study the change in this cellular property, electrical changes in the cellular properties as the disease is progressing. When we talk about disease, when we talk about cancer, it can be any cancer, it can be melanoma, it can be breast cancer, it can be prostate cancer, it can be lung cancer, it can be stomach cancer and several other types.

So, we can understand the cell that is what it is written cell antibody DNA. Now, what is this antibody thing. So, let us take an example that will make our life easier. Let us take an example of pressure sensor, then we will take an example of a cell based screening and we will see example of an antibody alright for measuring a very important you know bacteria which is E.Coli, we all have E.Coli in our body, but that is below 10 to the power 4 cfu per ml or below 10 to the power 5 cfu per ml anything above 10 to the power of 5 cfu per ml in the body E.Coli will cause a urinary tract infection. So, the people who has who suffers from urinary tract infection has bacteria around 10 raised to 5 cfu per ml and above alright.

So, why I am talking about bacteria, because I am talking about the antibodies base measurement system. So, let us see in the next slide.

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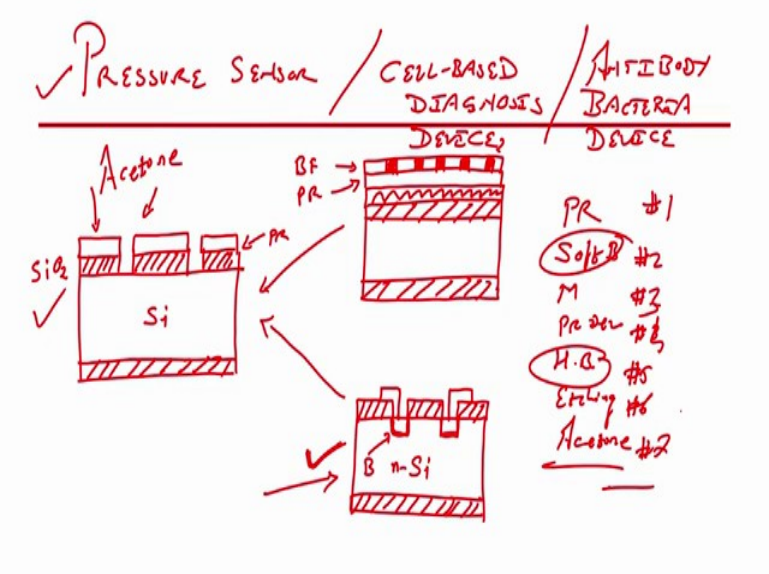

So, let us take an example of a pressure sensor, we will see three examples ok. First is pressure sensor, then we will take example of cell based diagnosis, then we will take example of antibody based, antibody based bacteria capturing bacteria capturing, antibody based bacteria capturing device, cell based diagnosis device and pressure sensor.

So, let us start with the first one that is our pressure sensor. How pressure sensor looks like? It is extremely simple take an oxidized silicon wafer. So, you have a silicon wafer, you grow oxide becomes oxidized silicon wafer. Now, two ways right two ways of designing a pressure sensor; one is you deposit a piezoresistive material on this oxidized silicon substrate.

This is my piezoresistive material alright, but second case I will not deposit piezoresistive, instead of that what I will create is I create a window. So, we will create a window when you say window how to create you all know very well now, that to you create a window in this particular silicon wafer like this. What is the process? Process is that on this silicon wafer I will spin coat photoresist, on that I will use a bright field mass.

So, photoresist after spin coating photoresist; soft bake, then a bright field mask, such that it covers the region or it protects the region that you do not want to etch right like this. Now, after this we will expose with UV, expose with UV what will happen after

exposure with UV. If I dip this wafer in positive photoresist developer or photoresist developer, then the unexposed region would be stronger and the exposed region would be weaker.

So, what would I have? I would have photoresist like this and then if I dip this wafer in buffer hydrofluoric acid then I will have this particular. So, after BHF what will I have? I will have let me just show it to you, so it becomes little bit easier. I have SiO 2 I have for the positive photoresist when I dip this wafer in BHF silicon dioxide from this region would get etched. When silicon dioxide gets etched, then I will dip this wafer in acetone, when I dip this wafer in acetone the photoresist will get etched and I will be able to get this pattern alright, this one we will get easy.

Now, I will dope a piezoresistive material inside, I dope piezoresistive material inside. Now, do not understand, do not worry about like how it is connected the top view is something different than the cross sectional view. So, a top view you will have this something like this, if I take a cross sectional view it will just look like this, inside a dope doping inside the material.

So, this is a silicon and I am doping a piezoresistive material inside silicon right, maybe a boron, if I dope this entire silicon, I will dope boron and then I will take out the contact somewhere so that I can I can use it as a sensor. In this case I will perform again photolithography; that means, it that we will spin coat photoresist, then we will have your mask. In this case the mask would be like this and this area would be protected again, we have a bright field mask and positive photoresist. So, this one is my positive photoresist this is my bright field mask, then we will have a exposure right UV exposure after UV exposure.

So, you understand this thing please when we do photolithography the first step is photoresist coating, second step is soft bake, third step is mask, fourth step is photoresist developer, fifth step is hard bake, sixth step is etching the silicon dioxide or a material which you want to etch, seventh step is when you remove these or strip the photoresist by using by dipping the wafer in acetone.

So, if I say that we have photoresist and bright field mask that does not mean that we are skipping for soft bake or in this case when I said after you have photoresist, you when

you pattern the photoresist and photoresist developer. Then you dip this wafer in BHF that does not mean that we are skipping hard bake, that is there that is there.

So, this step is very important you to remember photoresist spin coating, soft bake, mask loading, and exposure photoresist developer, then hard bake, then itching and finally, stripping of the photoresist using acetone. So, this all the steps are there. So, just when I tell that let us see use photoresist coating and then we load the mask that does not mean that we are not using soft bake, we are using soft bake. So, after this when I have exposed the wafer with UV rays and then I am dipping this particular wafer in photoresist developer, what will I have? I will have my photoresist, which will look like this.

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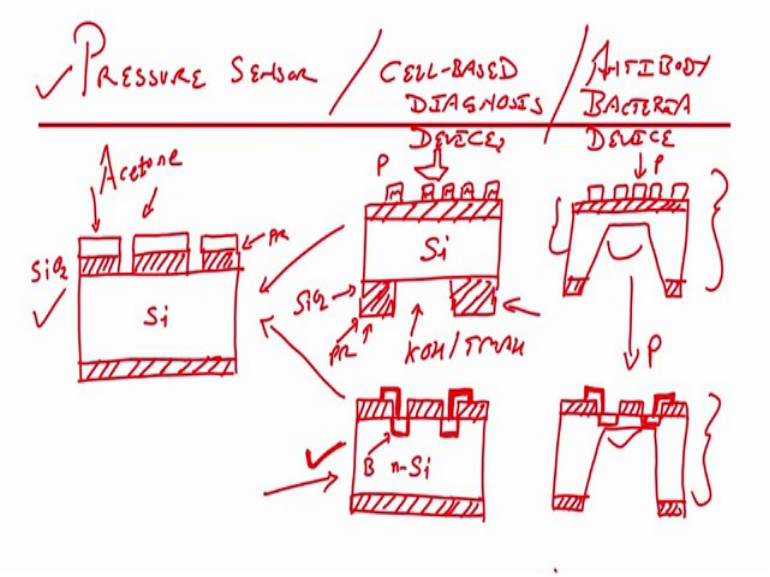

Now, I will perform hard bake and then I will dip this wafer in this pressure sensor or piezoresistive materials whatever piezoresistive material is that is etchant. When I did this before in piezoresistive materials etchant the photoresist will save the material below it and the area which is not protected by photoresist, the material which is not protected by photoresist what will I have? I will have this pattern. Finally, all of you know what is the next step, next step is dipping the wafer in acetone right, dipping the wafer in acetone. So, when we dip this wafer in acetone, what will happen? The photoresist will be stripped off, photoresist will be stripped off.

If photoresist gets stripped off, what we will have? We will have piezoresistive material like this correct. Now, this is another way of doing it like I said we are taking a contact from this piezoresistive material right, but in both the cases now, if we apply pressure if you apply a pressure like this and similarly on this, pressured pressure, then you will not find a great change in the piezoresistive material, because your silicon is a hard material and that is why what you have to do in both the cases? You have to create a diaphragm everybody knows how to create a diaphragm. If I use wet etching I will have this particular shape of the diaphragm, correct.

How to perform diaphragm, you will protect the area which you want to etch which you do not want to etch and remaining area you will be exposing to the BHF, because this is silicon dioxide. This is your photoresist how to pattern this photoresist everybody knows you spin coat a photoresist in this under the backside of the silicon wafer, then you soft bake it then mask, then you expose it mask would be such that the photoresist in this particular pattern that you have seen here and here will be protected and remaining area it will get developed.

After developing what you will have? You have this pattern and then you have a hard bake after that if I dip the wafer in silicon in silicon dioxide etchant which is your BHF what will I have? I will have this pattern right and then I will dip this wafer in silicon etchant, which is potassium hydroxide or T MAH to get this particular structure. Same thing goes for here. Now, because of this diaphragm, if I apply a pressure the diaphragm will bend, this will bend this will bend and, because of bending there is a change in the piezoresistivity and there is change in the resistance.

This is how the pressure sensor will work and depending on the application which is either it is intracranial or pacemaker or coronary pressure or intraocular pressure or the cerebrospinal fluid pressure sensors or endoscope pressure sensors or infusion pump pressure sensors you need to change the design you need to change the design, but the process would remain same when we are using a photolithography technique cool. Now, let us see the second one which is our cell based screening device quickly. It is very easy. Everything is extremely easy, if you know photolithography. Photolithography is the heart of micro engineering devices. So, understand photolithography your life will become easier. So, let us see screening device based on cells.

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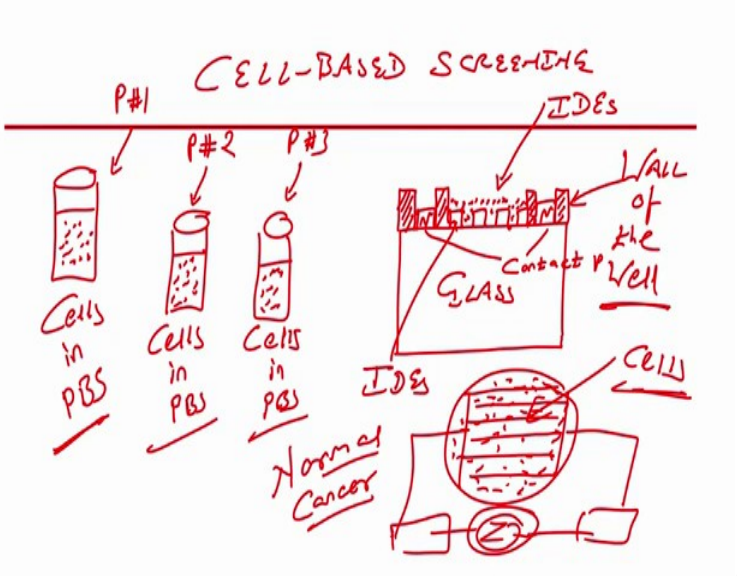

So, let us see here, if you see the skin cell based screening tool screening. So, what we want? We want that if I have a cells from a person, in a tube. So, this is patient 1; I want to know and let the same, I will take cell from patient 2, I will take cells from patient 3. These are cells; cells from patient 1, cells from patient 2, cells for patient 3.

So, now, what we want to know which patient is suffering from cancer or is out of out of three any patient is suffering from cancer. If there is a question if there is the question right, what kind of device you want to design. So, the easiest way of understanding is if I have sensors that can measure the impedance of the cells, then everything is easy, because the impedance of normal cells would be different than impedance of cancer cells.

So, how do device will look like; I will show it to you here, if you see the screen you have a glass, on which you have interdigitated electrodes, which looks like this and then you have a well, these are well. So, this is the wall of the well, wall of the well. These are interdigitated electrodes. This is glass, these are my contact pads contact pads.

Now, why I have created this well? What is the reason, because if I load the cells with so, cells are floating right in let us say phospho buffer silane, you can write down PBS in Google and you will understand what is PBS. So, cells are in PBS this is a liquid solution. So, if I load the cells here with liquid right, if I do not have the well what will happen the cells would not stay there is not it.

So, now, the well will hold it is like a container with interdigitated electrodes, these are called interdigitated electrodes. If I see the top view it looks like this, these are interdigitated electrodes. Now, what you have to do you have to load the you have to load the cells on this.

So, you have a well in which you have lot of cells like this right and these are my contact pads. So, I can measure impedance of this well with cells, impedance of this well with cells, using this interdigitated electrodes. So, the idea is if I load normal cells, normal versus cancer cells, then I am able to or the question should be would I able to measure would I able to see the difference in the impedance value and the answer is yes, designing such sensors will help you to measure the impedance and the impedance of the normal cells would be different than cancerous cells.

So, what you have to design an interdigitated electrodes. Can you design that? Everyone can design by this time, everyone should be able to design. How? You take a glass substrate on this you deposit a metal, let us see quickly, if you see the screen I will just show it to you and you all will agree that yes its very simple to design such a sensor. And, then we can definitely think over how to fabricate it, because it is just a single mass process to fabricate interdigitated electrodes. So, let us see just give me few seconds. So, I can just clean this screen.

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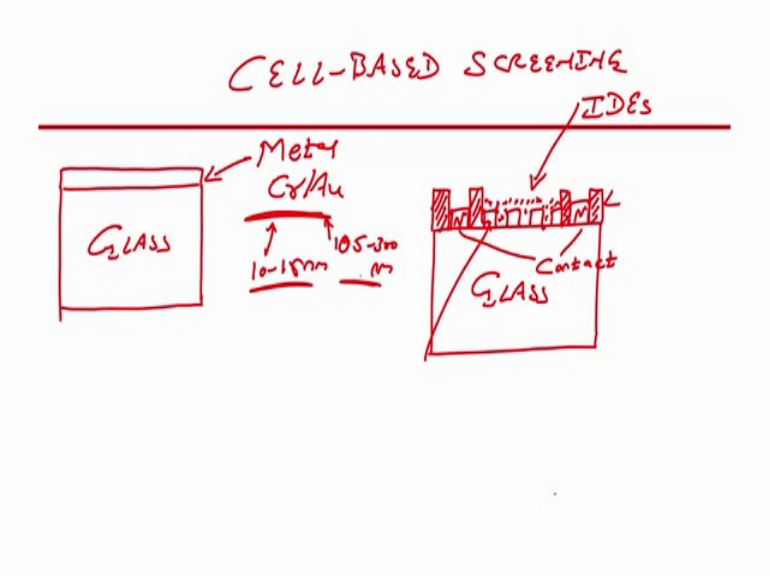

So, now, what is our step you take a glass if you have a glass you need not to worry about growing silicon dioxide, because the glass itself is silicon dioxide. So, glass is your substrate on this glass, what you will do? You will deposit a metal, metal for interdigitated electrode metal. Let us say it is a platinum or it is chrome gold right, I always use a word chrome gold not only gold, because chrome thin layer of chrome will help to for a help thin layer of chrome will help in improving the addition of gold to the substrate if you directly deposit gold the addition of the gold to the substrate is poor and that is why we use a thin layer of chrome over which we deposit a thick layer of gold.

When I say thin and thick it does not really change in terms of like few nanometers to microns or few nanometers to millimeter, it is not like that it is like few nanometers like 10 to 15 nanometers for 195 to 300 nanometers, 100 to 300 nanometers gold. So, I am just saying thin layer of chrome over which thick layer of gold does not mean that it is really thick, it is still thin, but compared to chrome it is thicker, that is what I mean. So, thin layer of chrome which is 15, 10 to 15 nanometer over which you can deposit a gold.

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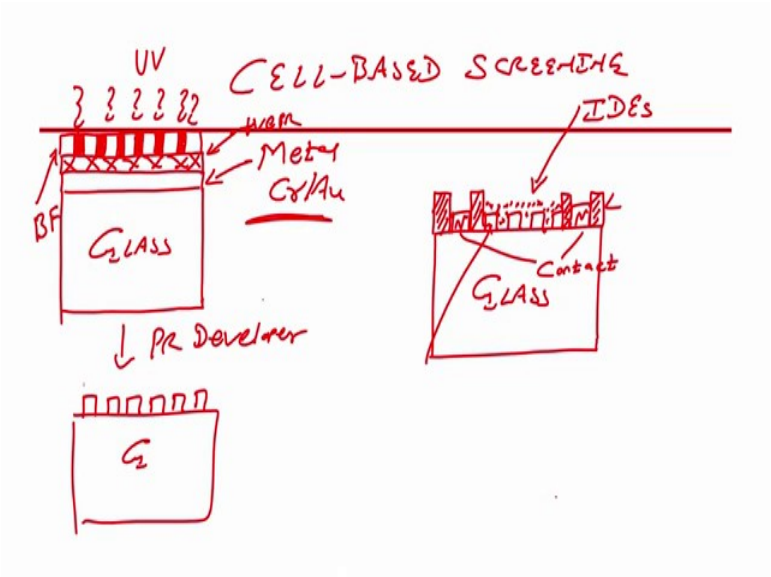

After that the next step would be you will spin coat photoresist, you will spin coat photoresist, positive photoresist, next step soft bake, next step bright field mask. How bright filed mask will look like in the way I want to make the interdigitated electrodes right so easy here, for let me just write it correctly so it becomes easier; 1 2 3 4 and the contact pads. So, this is my contact pad and this is first, second one, third one, fourth one

and fifth one are my interdigitated electrodes, this again sixth one is my contact pad what is this?

This is my bright field mask bright field mask, next step is exposure with what exposure with UV next step is you will dip this wafer in photoresist developer, next step is you when you do that what you will have you have a glass and then you have your metal and on that you have your photoresist. This is glass, this is metal, this is photoresist protected in the area, which was not exposed, not exposed, because this is positive photoresist.

You have bright field mask either which is not exposed will become harder, it will be protected. After that if I dip this wafer in the metal etchant right after that there is a hard bake like I said earlier please, remember all the steps photoresist developer, then hard bake, after hard bake I will dip this wafer in metal etchant. When I dip this metal etchant what you will have you will have right this is your interdigitated electrodes.

So, on that interdigitated electrodes, what you will have? You will have so, what you understand is we will, we got an interdigitated electrodes and on that interdigitated electrodes we will now, design the well. So, for designing the well what is the material that we can use. So, on the under ids or interdigitated electrodes what was there? There was a photoresist. So, you dip the wafer in acetone that you already know.

So, I am just skipping the step, but finally, you have interdigitated electrodes and now, we have to create a well. So, what will be the material for designing the well? The material for designing the well would be SU 8. An SU 8 works as a negative photoresist.

So, in the next class next module, we will see how to design this well for the interdigitated electrode such that whenever we load the cells with PBS, we will be able to see change in impedance that is your electrical impedance based sensor for screening the cells or for understanding the whether there is a cancer or where there is a normal only two things. That is why I say screening normal or cancer, not stage of cancer, that is something else. The normal ones is cancer cells, can you delineate using impedance measurement.

So, you now you have you will be designing a sensor that can measure this change. So, we will continue this in the next module and then we will see the sensor that are based on antibody based antibody that uses antibody to capture the bacteria. It is very-very

important problem bacterial infection, and then antibiotic resistant or you know the parameter. That means, that if somebody has a bacterial resistance, if you give the antibiotic to the patient, antibiotic is a drug like it is a medicine. When you give the medicine to the patient the patient will not respond, because the bacteria the antibiotic which are meant to kill the bacteria.

This bacteria are resistant to that antibiotics; that means, then the bacteria will start growing and bacteria's and cells they are enemies; that means, bacteria will kill the cells. Our body is finally, made up of cells, cells comes together forms a tissue, you have learnt these things in biology. So, but if there is a bacteria will eat these cells. So, bacteria infection very-very dangerous what is the treatment antibiotics, but if the bacteria is resistance we have to quickly understand that this antibiotic may not be useful.

So, how can you use antibody to capture such bacteria and if there is a capture, if we are able to capture the bacteria how would you know that the bacteria's are captured? That is using electrical impedance again and I will just show it to you how if you have if you have one sensor how can you use for multiple applications. So, we will see in the next module like I said and till then you just go through this lecture once again. Any doubts, you please ask me in the forum, you can also ask me in the live sessions. We have this time I think two or three live sessions. So, you have multiple chance to ask me questions relevant to this particular course. And, I will see you next module till then you take care.

Bye.