Introductory Neuroscience and Neuro-Instrumentation
Professor Hardik Pandya
Indian Institute of Science, Bengaluru
Lecture - 8
Applications of MEMS Fabrication Technologies

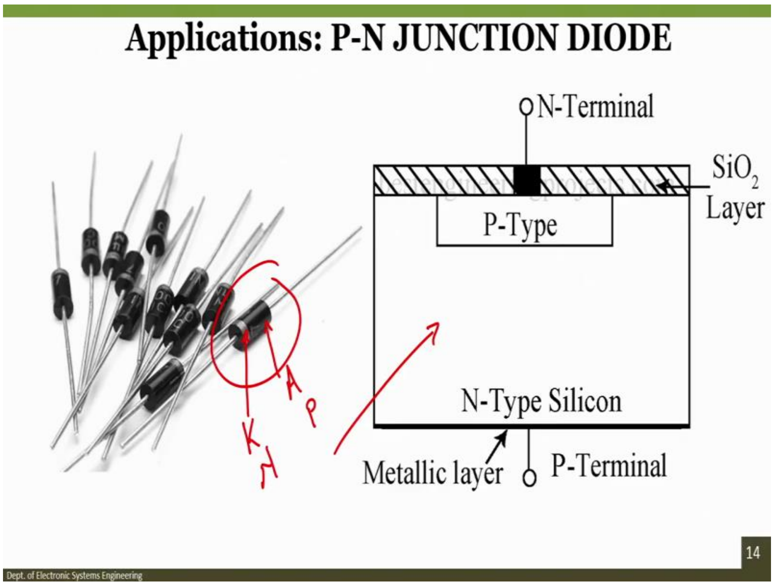
Hi. Welcome to this module. In the last two modules.

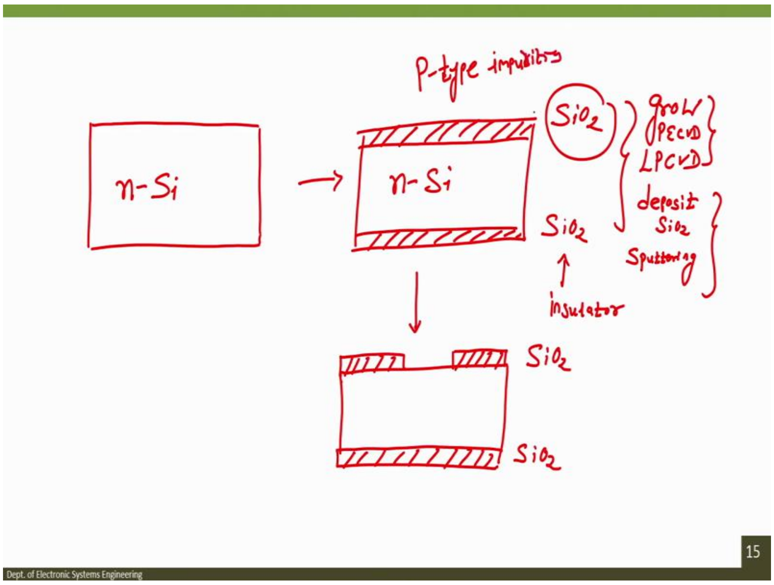
We have seen the introduction to a fab lab or at least the part or equipment or tool inside the fab lab. And then, we understood how the silicon can be manufactured from silicon dioxide, a quick process to understand that followed by the EEG-rated probes, where we can say that the leads or the electrodes, so there are wet electrodes and there are dry electrodes. And then we understood the anatomy of the brain.

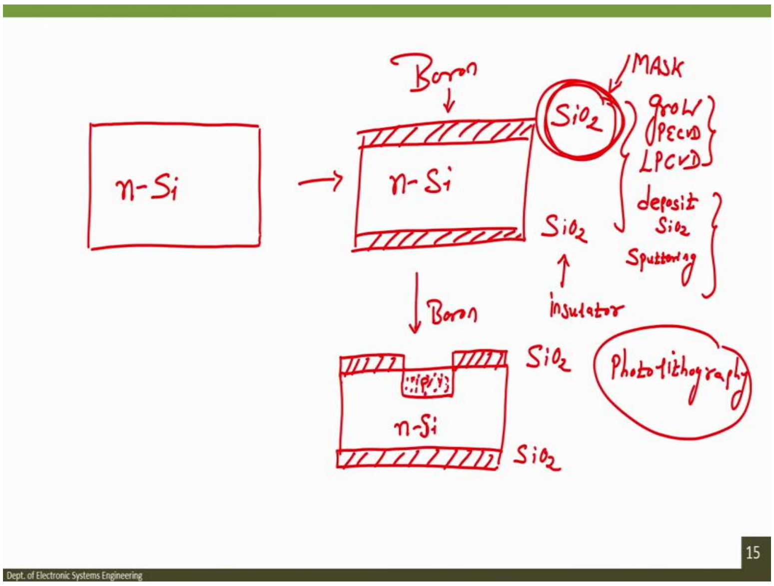
Now let us quickly see what kind of other devices including transistors, diodes we can fabricate if we know how to use the micro-fabrication process. And I will be teaching you a part on how to deposit a material that is on PVD techniques, a bit on CVD techniques which are chemically deposition, and a bit on lithography so to understand how can you create different electrodes using the micro-fabrication technique.

If you see the applications, the applications of micro-fabrication are many although our focus is on the EEG electrodes or the chips that are related to neuroscience. Let us also understand that what kind of other applications we can use, or we can think of if we know how to fabricate the devices.

(Refer Slide Time: 02:03)







If you see the slide, what you can see is a known structure which is your P-N junction diode. You know that when you take a diode, this is your anode, and this is your cathode. You can say K, you can say C, whatever you want. The anode will be P, cathode will be N. This is P-N junction. How to fabricate the P-N junction diode?

So you can see here, this is a cross-section of a P-N junction diode and a way to fabricate this particular structure, I will anyway teach you lithography but right now, let me just give you a quick example that you have silicon substrate. If somebody ask you, draw the cross-section of silicon wafer, you can draw a rectangle like this. The next step would be to grow silicon dioxide. I will explain you how to grow silicon dioxide, do not worry about it.

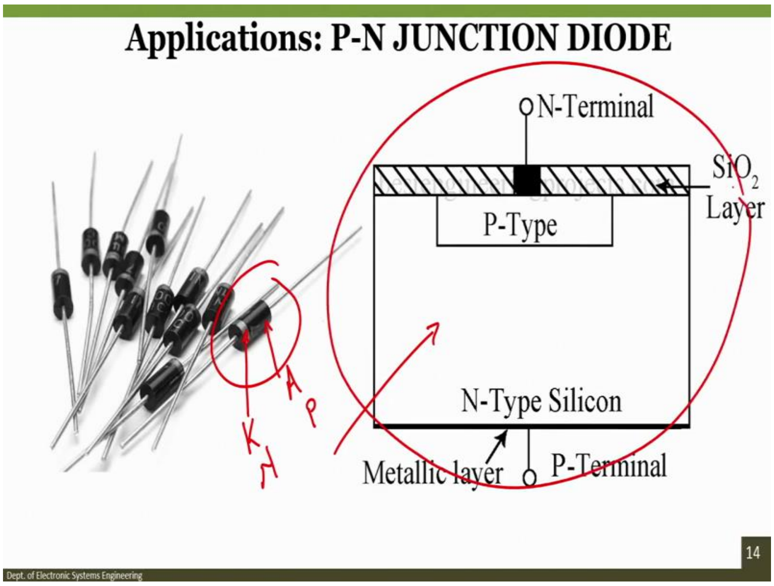
Silicon dioxide we have grown using a technique called LPCVD if you want to grow it. If you want to deposit SiO_2, then you can use sputtering. You can also go for, if you want to grow, you can also go for PECVD. PECVD is plasma-enhanced chemical vapor deposition. LPCVD stands for low-pressure chemical vapor deposition while if you want to, this is for the growth process, growing SiO_2. SiO_2 is silicon dioxide. And you know silicon dioxide is an insulating material, is insulator. Or silicon is semiconductor.

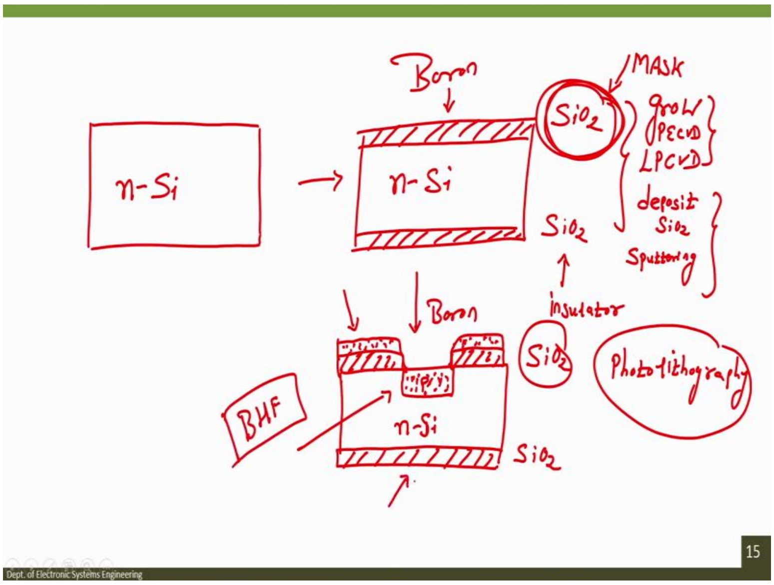
As a starting process the substrate is n-type silicon. That means a silicon wafer doped with pentavalent impurities. Now I want to create a P junction inside the n-side silicon wafer. For creating a P junction inside the n-type silicon wafer, we have to create a window. Why this window is required? Because if I doped P-type material, P-type impurities, what are P-type impurities?

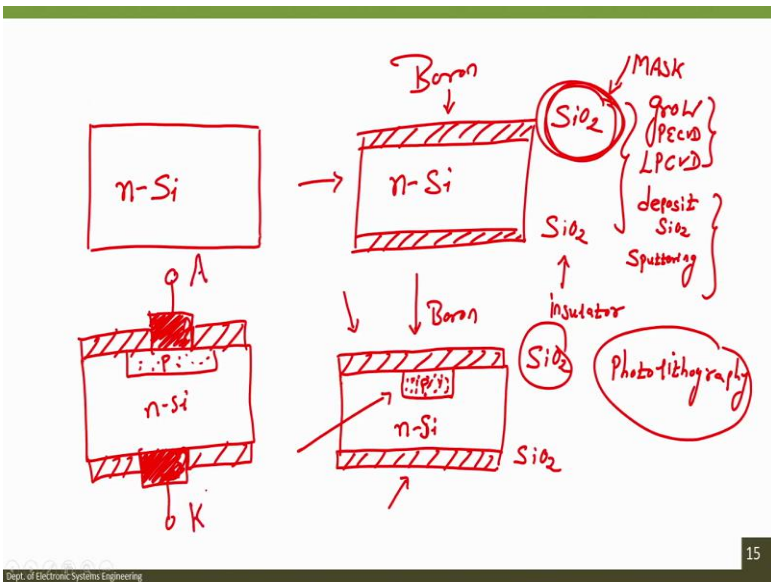
P-type impurity example will be boron. Say if you want to diffuse or dope boron inside silicon, boron cannot pass through silicon dioxide. This impurity cannot pass through silicon dioxide. Silicon dioxide works as a mask, it acts as a mask. Mask to prevent boron to pass through it. And that is why we must remove silicon dioxide using photolithography. We will see what photolithography is; do not worry about it right now.

I have created a window. Now after creating a window, we will dope boron. If I dope boron, it will create a layer inside the n-type silicon, n-type silicon. Let us pattern it like this. So it looks like dots. Now what we will do?

(Refer Slide Time: 06:44)







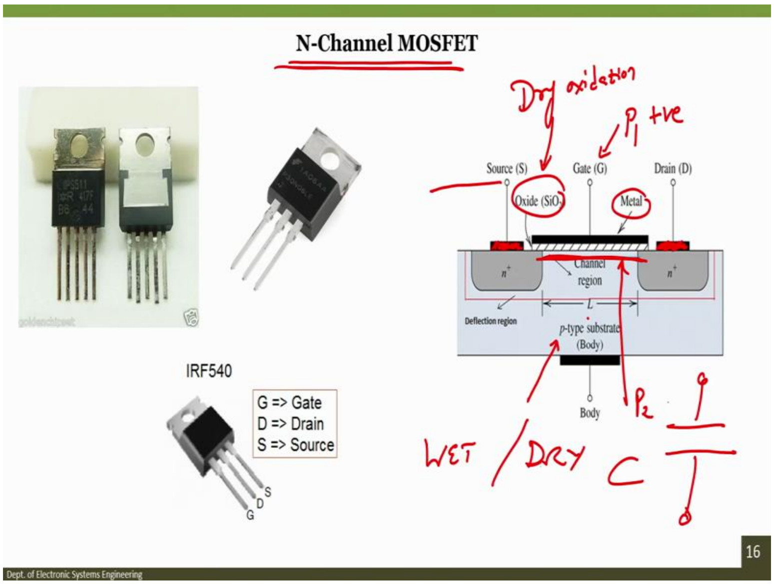
If you see the schematic here, what you can see? That you must then remove this silicon dioxide. Because when you dope boron, what will happen? It will be like this. Boron will also be here like this. But we do not want boron on the surface. We only want boron in the window area, this area what we have shown. So we have to, and this boron at the surface will become boron oxide or boron dioxide.

So, this boron oxide and silicon dioxide we have to etch it. This silicon dioxide and boron oxide at the layer, at the surface of the silicon we must remove it. Removing this etching. So we will use buffer hydrofluoric acid, BHF. If I dip this wafer in BHF, what will happen? This boron oxide and silicon dioxide will get etched. The impurities that are doped inside silicon will be boron, outside will be boron oxide.

The next step would be I will grow a silicon dioxide like this and then I will create a window. I will create a window to take out the context, so like this, and from the backside like this. P, n-silicon, metal to take out the contact. Here also I will have metal deposited and pattern to take out the context. This is your anode, and this is your cathode. This is your anode and cathode.

So the point that I am making is if you know the fabrication then you can create a, you can design a P-N junction diode. Similarly, you can also design several other devices. So let us see another device.

(Refer Slide Time: 09:21)



I will not go into detail about this device and how to fabricate it. The fabrication will be a separate module. So if you see this particular device, what we see here? We have a N-channel MOSFET. What is MOSFET? Metal oxide semiconductor field-effect transistor.

Now, we have P-type silicon substrate. And we are doping n plus, that means we are doping pentavalent impurities inside the silicon wafer by creating windows like I have shown earlier. We will take this as a separate class, where I will be showing you how to design a process flow for creating a MOSFET.

However, just here you focus that you can dope n plus type of impurities inside a P-type substrate and then you have a metal connection which is this black line here, black shadow boxes, these black boxes and you have a source and drain. Similarly, you have a thin silicon dioxide. This silicon dioxide is generally grown by dry oxidation process.

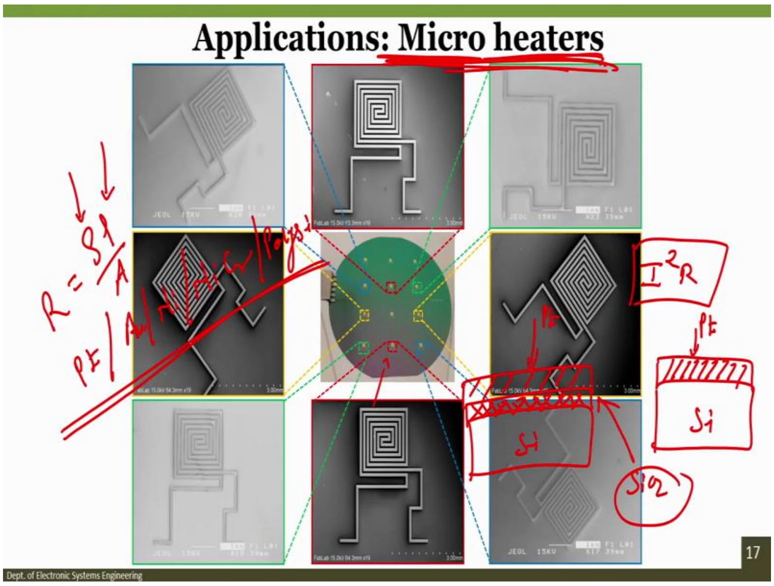
In oxidation process, there are two processes. One is wet oxidation and another one is dry oxidation. There are advantages and disadvantages with wet and dry. Dry oxidation generally gives excellent quality of silicon dioxide film. And we will use, or generally, silicon dioxide is grown using dry oxidation technique.

Over that, we have a gate and that again, there is a metal. So this gate is one metal end, let us say P1. This channel, when you apply a negative with respect to source, gate is the negative with respect to source, what will happen? Gate is positive with respect to source, what will happen? The n-type impurities will form a channel. When gate is positive with respect to source, n-type impurities are attracted towards the channel.

And that is why this will become another plate, you can say plate 1, plate 2, and there is a oxide between two plates. So if there is two, if there are two plates separated by a dielectric or air, it becomes a capacitor. So this forms a capacitor gate oxide and the N-channel that is created because of the gate being positive with respect to the source.

So the point that I am making is we can fabricate N-channel MOSFET, we can fabricate P-channel MOSFET. We can fabricate CMOS all using the micro-fabrication techniques.

(Refer Slide Time: 12:23)



Now let us see another application of the micro-fabrication technique. Another application is in heaters. And when we say heater, we are talking about microheater. Now, what is heater? If you have a resistor and if you heat the resistor by applying a power, then your heat will I square R, which is your joules heating.

Now, what will be the resistance of the coil? The resistance of the coil can be measured by rho l by A, where rho is the resistivity of the material, l will be length of the pattern and A will be the area. So here, if I know the thickness, if I know the length, I can calculate the resistance of the heater. How to fabricate this microheater?

So we can see here, in the center, there is a silicon wafer. And in the silicon wafer, there are 12 microheaters. See here, 1, 2, 3, 4, and you have three rows or three columns and four rows. So you have 12 microheaters fabricated on a 2-in silicon wafer. So if I have 4-in silicon wafer, if I reduce the distance between two patterns, I can make, I can fabricate large number of micro heaters on the single substrate. So how to fabricate this microheater? Is very simple. I will teach you in one of the class.

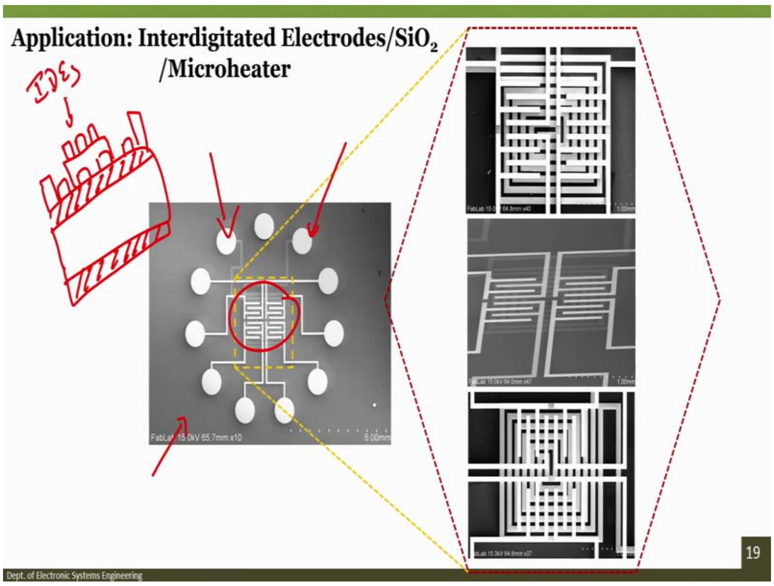
So another application of the micro-fabrication or lithography technique is to fabricate microheaters. The metal for the microheaters can be platinum, can be gold, can be nickel, nichrome, polysilicon, and so on so forth.

So this can be several metals that one can use depending on the availability. You need to deposit the metal on the silicon wafer and if you deposit a metal on a silicon wafer? What will happen? Let us say this is a metal and this is a silicon wafer. Let us say this is platinum. What will happen? This will not form a right way of fabricating or this is not a right step for fabricating microheater. Why? Because metal and semiconductor will be shorting, shorting.

So you have to create insulating layer between semiconductor and a metal. So what we can do? You can take silicon wafer; you can grow silicon dioxide. Over silicon dioxide, you can deposit platinum. So this will be your silicon dioxide. Over silicon dioxide, you can deposit platinum.

Now this will not short because silicon dioxide is insulating material. That is why you can see here; the color of the wafer is greenish depending on how we had taken the photograph. But mostly it is green and somewhere here you can see purplish color. This is because of the silicon dioxide deposited on the silicon wafer. Again, like I said, we will see in detail how can we fabricate the microheaters on the silicon substrate.

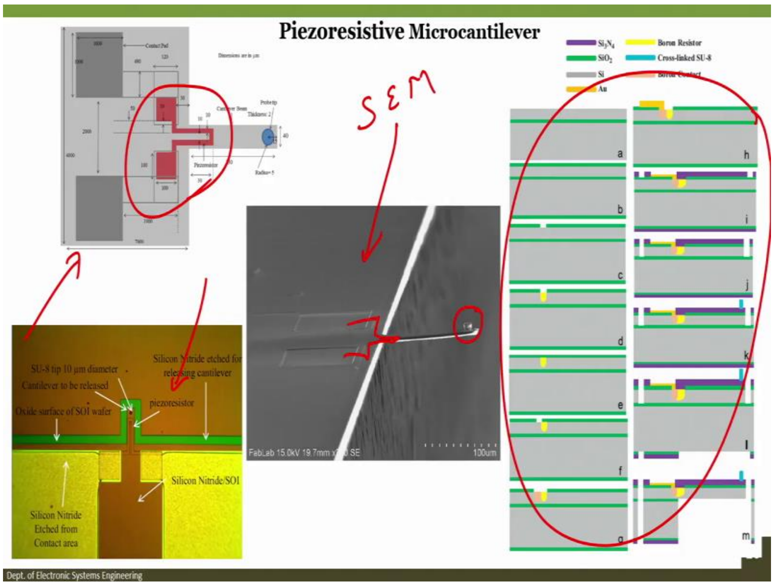
(Refer Slide Time: 16:10)



Now, let me take another example. So now if you want to have two layers on the same wafer, that means you want to have microheater on the silicon substrate, on the oxidized silicon substrate, like I said, we cannot have a microheater directly on silicon, it will short. And then over that what we want? We want insulating layer like this and on the insulating layer, we want to have interdigitated electrodes.

So you can see here, there are four interdigitated electrodes. So how can we create this? This is also possible by using lithography technique. So these are interdigitated electrodes. If you see the, from the bottom this is silicon wafer, then you have a microheater. The pairs of the microheater are here, then over that, you have insulating material. Over that, you have your interdigitated electrodes. We will see how we can fabricate this as well.

(Refer Slide Time: 17:13)



Let us take another example. We can also fabricate a piezoresistive microcantilever. What is micro cantilever? Now let us see, if you see a swimming pool and the diving board of the swimming pool, if some diver dives from the diving board, what will happen? This will vibrate. This vibration, so it is holding at one end, it is open at another end. And that is why it will vibrate.

If you take a ruler and if you hold it on one side like I am holding on this one like this and you press it here, that will be vibrating. So this becomes a cantilever. So microcantilever is a cantilever fabricated at a micron scale. So can we fabricate the microcantilever? Yes. And can we make it piezoresistive?

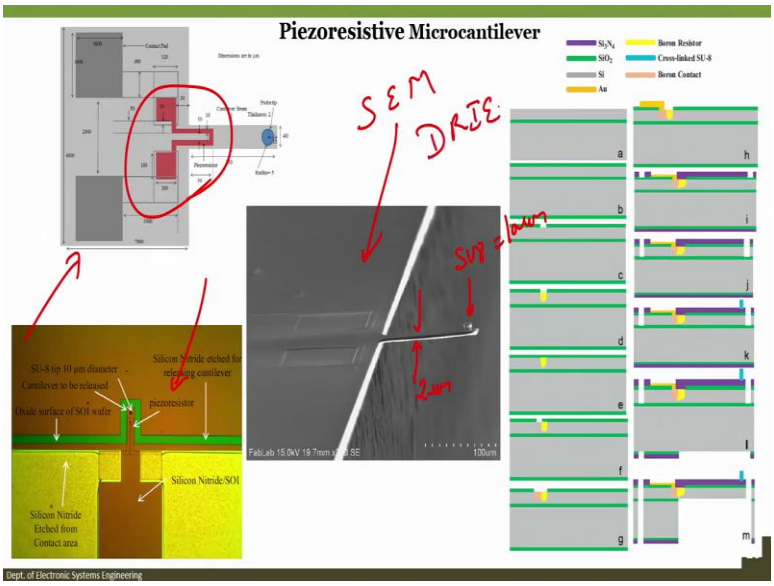
Now I have brought a word called piezoresistive. What is piezoresistive? Piezoresistive is a property of the material that when you apply a pressure, there is change in resistance. Whilst you also know what is piezoelectric.

Piezoelectric is again a property of material. When you apply a pressure, there is change in the voltage. Piezoresistive, change in resistance; piezoelectric, change in voltage, electric. So pressure to electric, pressure to resistance; piezoresistive, piezoelectric. Remember this thing very well.

Now, if you want to create a piezoresistive or piezo resistor inside a silicon wafer, we must dope n-type polysilicon with p-type boron material in a certain fashion to form a resistor. We will investigate that at some point of time. Right now, what you can see on the slide is a piezo resistor, a schematic is shown on the left side if you see this one.

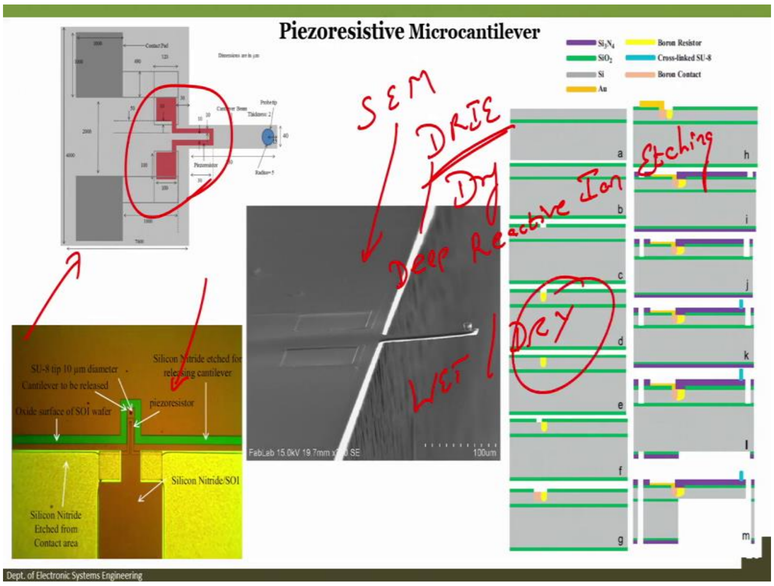
This is the optical photograph. These are the processed flow to fabricate a piezo resistor and this is a SEM image, scanning electron microscope. Scanning electron microscope image of a microcantilever fabricated using micro-fabrication process. And here this is a SU8 tip. There is a piezo resistor which is this guy right here, which we cannot see here, and this is connected like this. So it is diffused inside this thin silicon layer.

(Refer Slide Time: 19:41)



What is a thickness of this piezo resistor? So the thickness of this cantilever, thickness of the cantilever is 2 micrometer. What is the thickness of SU8, this is a tip, SU8 is about 10 micrometers. Now SU8 is very light compared to silicon, that is why it is not bending. And, of course, we have taken care of the stress effects by using silicon nitride. We will discuss it separately. And this is created using a technique called DRIE.

(Refer Slide Time: 20:15)

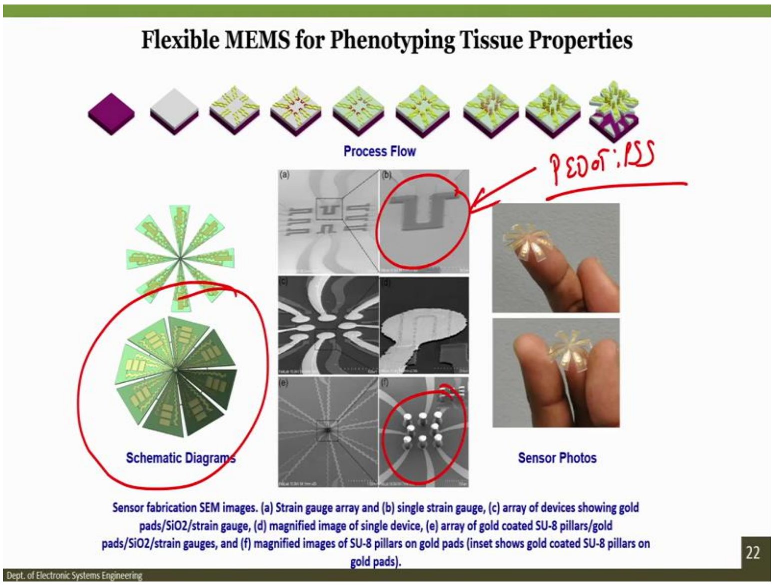


So the etching if you see, let me just delete this one. If you see except this guy, it is like a board hanging. You see, there is a trench here, is it? So this etching is done with the help of deep reactive ion etching technique.

Deep reactive ion etching is a dry etching technique. Etching are two types, so wet etching, and dry etching. So deep reactive ion etching, D stands for deep, R stands for reactive, I stand for ion, E stands for etching. Deep reactive ion etching. This is a dry etching technique.

So the silicon has been etched using deep reactive ion etching technique. So the point is that we can fabricate piezoresistive microcantilever. We can fabricate microheater, we can fabricate transistor, which is a MOSFET, we can create a diode. Now let us see what else we can create.

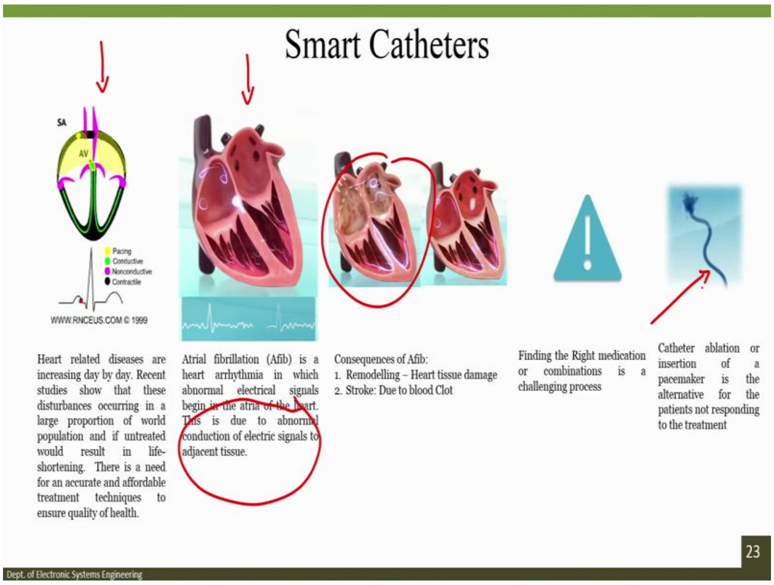
(Refer Slide Time: 21:22)



We can also create a flexible sensor, flexible microsensor. And flexible microsensor has a strain gauge, we can see here, a strain gauge. This strain gauge is fabricated using PEDOT: PSS. PEDOT: PSS is a polymer which is piezoresistive in nature.

And then over that polymer, there are some insulating material, over there are gold pads, on that there is a SU8 pillar. You do not have to worry about it right now. You just understand that if you know fabrication, you can also create flexible sensors as shown here in this slide.

(Refer Slide Time: 22:05)



Now let us see how, where else we can use our fabrication understanding for. You see, EEG, you must understand this term, ECG, EMG, EEG, ECoG. ECG, electrocardiogram; EMG, electromyogram. Electrocardiogram for heart; Myogram for muscles; then EEG, electroencephalogram, scalp, the brain signals from the scalp; electrocardiography, ECoG, from the brain when you open the skull, place the chip on the brain, ECoG.

Now, let us understand ECG. And what ECG shows? It shows the functioning of our heart. Generally, hearts pumps evenly, 65 to 70 beats per minute. If a person is running, exercising, the heart rate would increase. But let us say take example, let me take my example. If I am right now giving, recording this lecture, my heartbeat should not increase more than 75, 80. Because there is no reason for the heartbeat to increase.

But if suddenly it starts increasing without any reason, it is called arrhythmia. And arrhythmia is a heart disease. Same way, in one case, heart starts beating or pumping unevenly. This uneven beating is because of the misfiring of signals. And this case is called atrial fibrillation. So how to cure this heart disease?

So if you see the slide, what it shows is that the first schematic you can see here, it shows that the heart, of course, we know heart-related disease are increasing day by day because of lot of issues, our lifestyle, food eating habits, the comfort that we get compared to the earlier times and less of physical exercise. So heart-related diseases are increasing.

A recent study shows that this was occurring in large population of the world and if untreated, it would result in life-shortening, that we know. Now let us focus on this schematic. It shows you can see the atrium and the ventricles. Now, what it shows that atrial fibrillation is a heart arrhythmia in which abnormal electrical signals begin in the atria of the heart. This is due to abnormal conduction of the electrical signals to the adjacent tissues.

So what happens if there is a case remodeling of heart tissues, remodeling, that means heart tissue will get damaged. You can see it is uneven beating. You can see uneven beating. Second is due to blood clot, there may be possibility of clot. What is, how it is cured? First are right medications. But in some cases, right medications do not work and that is why the treatment is with catheter ablation.

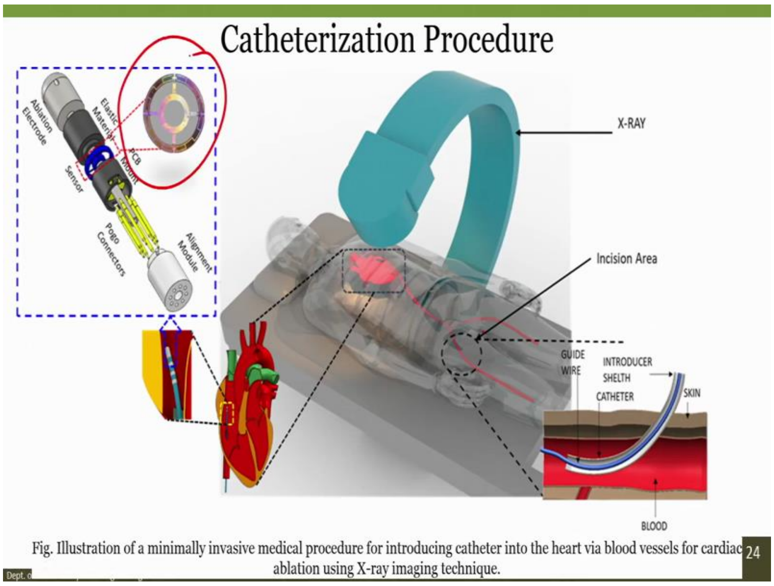
Catheter is a tube-like you can see here and this tube is inserted from the groin area all the way to your heart and once it reaches the heart, we can let us say this is the heart and it reaches the heart, then you have to ablate the heart. What is ablation? Ablation is heating. Heating is ablation.

Now what kind of ablation are there? There is the cryoablation, there is RF ablation. RF frequency to heat the heart is called RF ablation technique. Cryo is to use the liquid nitrogen. So it will freeze the tissue. Both will create in ablation. Both will create in a burning of the tissue. So if the tissue is burned, it is destroyed, it will stop conducting, as simple as that.

Now if I want to apply RF frequency, that means I must touch the tissue. Touching of the tissue, that means if I touch, if I apply more force, then the remaining area would be ablated or the larger area other than what I decide or what is required to ablate would be ablated. If the pressure or force is less, then the area which needs to be ablated will not get ablated completely.

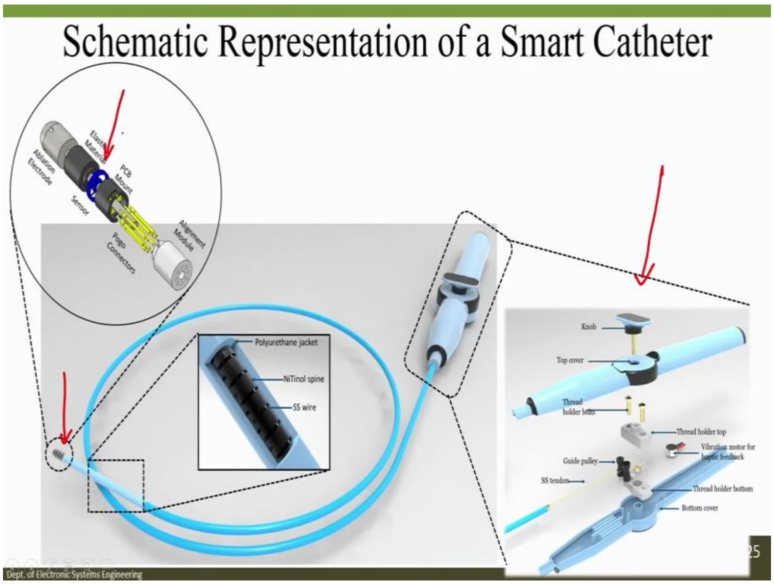
So in both the cases, what we are seeing is we require optimum force to understand whether the ablation is correct or not. That means at the tip of this tube what you require? You require a force sensor. And this force sensor we can fabricate if we know the micro-fabrication process. So that is a point.

(Refer Slide Time: 27:32)



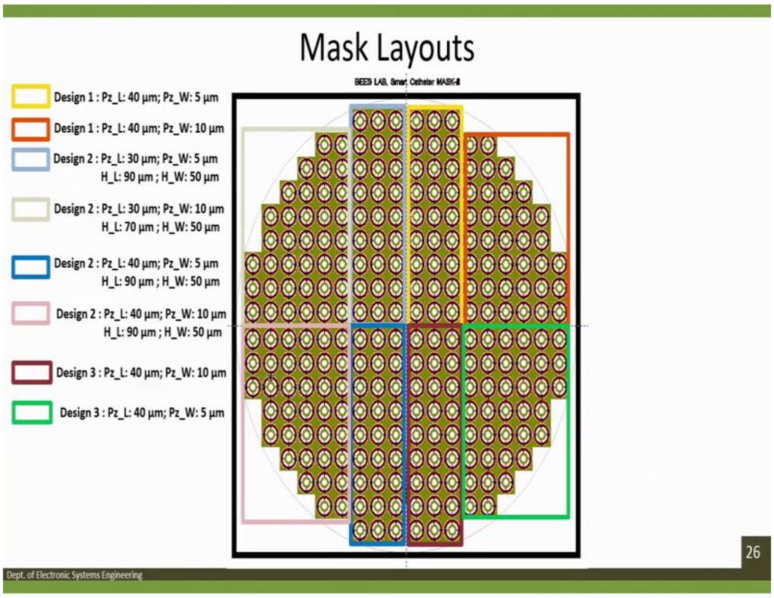
Now, if you see, this a catheterization process. And here you can see like I said that the catheter is inserted through the guidewire from the groin area here and it is, it reaches to the heart chambers and then the procedure is performed. And the importance of whatever we have discussed is all the way here, which is the tip of the catheter. So what is that?

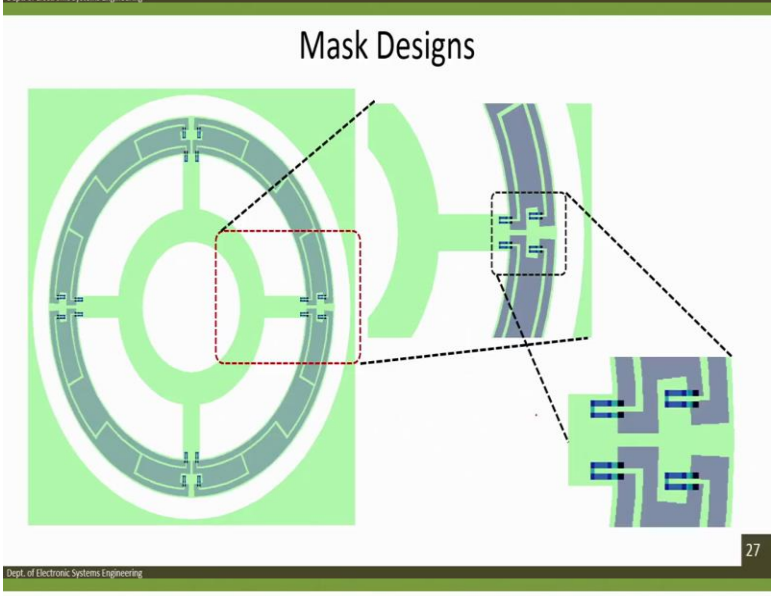
(Refer Slide Time: 28:00)

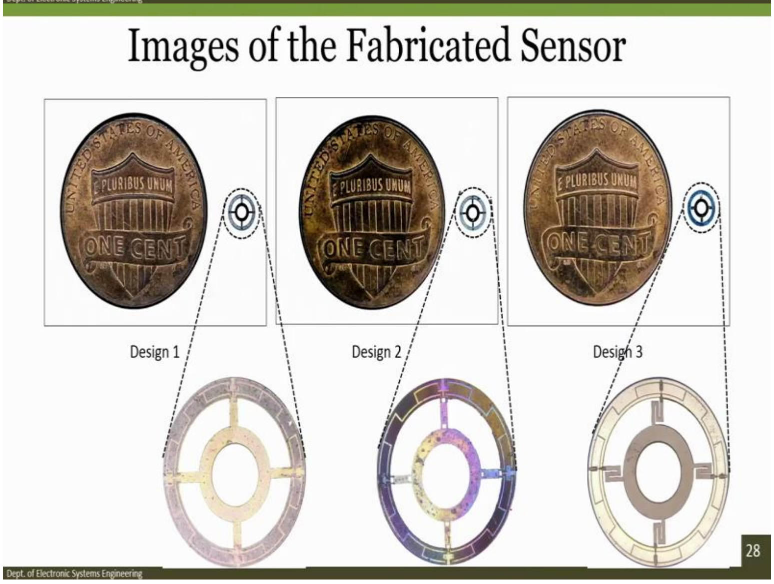


You see this is the maneuvering mechanism. You can maneuver the catheter; you can move the catheter with the help of the maneuvering mechanism. Now when you maneuver the catheter, this tube will go all the way inside the heart, and this is the tip where you apply the RF frequency to ablate. Within this tip, there is a sensor which will measure the force from the heart tissue.

(Refer Slide Time: 28:26)

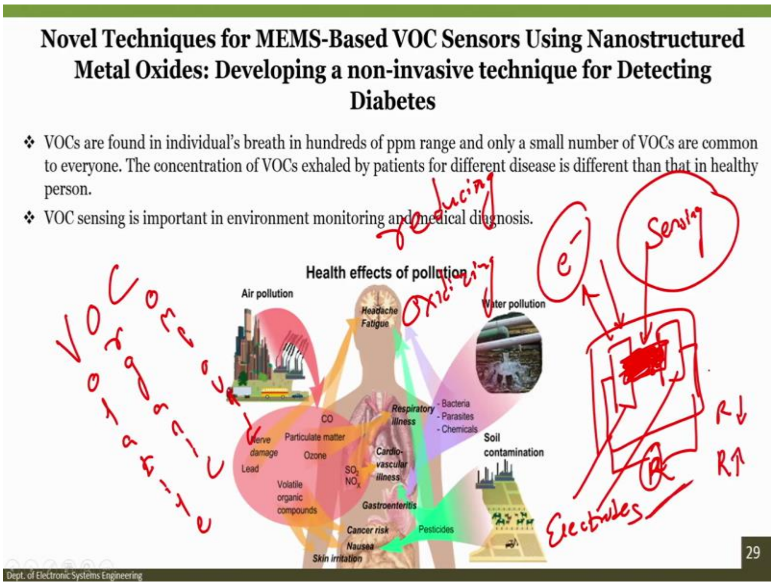






So, there are mask layout and then how we can fabricate the sensor, all details are there. Let us not work, do not worry about those details as of now. When we, when the time comes, I will explain you how to fabricate these sensors.

(Refer Slide Time: 28:40)



Now let us understand another area of fabrication and that is on the gas sensor side. So gas sensor is a sensor. Let us say you have electrode, and you have a sensing material over these electrodes. So here you can measure resistance.

This is a sensing material. These are two contact electrodes. And what you are measuring? You are measuring resistance. The resistance of the sensor would change depending on the sensing layer that use. Sensing layer would change the resistance depending on the whether the gas has oxidation property or a reduction property.

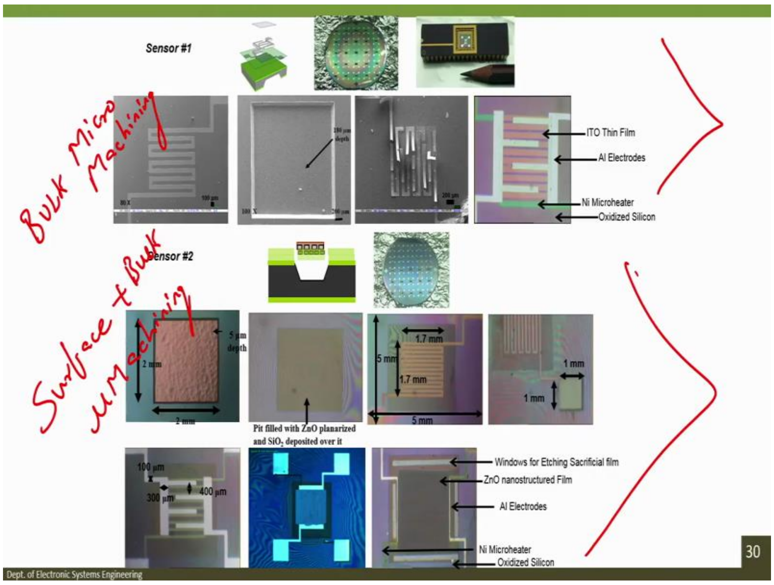
Now, what is oxidation and reduction? If the reduction, if the VOC or a gas, so what is VOC? VOC is volatile organic compound, volatile organic compound. So volatile organic compound are compounds that are volatile in nature at room temperature. For example, ethanol, methanol, acetone, propanol, isopropyl alcohol, kerosene, petrol, diesel, these are all VOCs. While some gases that we need to address, so gases are SO2, NO2, CO2, CO, these are all gases. So, VOCs and gases.

Now if the VOCs or gases are reduction, having reduction property or reducing, are reducing of nature, that means that when there is a, when the VOC comes in contact with the sensing layer, extra electron is created if it is reducing VOC, it is reducing. And if it is oxidizing

VOC, oxidizing gas, or VOC, then the electron will be taken away from the sensing layer. So reducing gas, electron is donated. If oxidizing gas, electron is taken away.

So, if the electron is donated, the conductivity would increase, and resistance would decrease. If the electron is taken away, conductivity would decrease, and resistance would increase. This change in resistance we can measure with the help of this sensor.

(Refer Slide Time: 31:35)



Now the applications are many, we will discuss if the time permits. Right now, you just see that we have fabricated sensor using two technique, one is called bulk micromachining, bulk micromachining. Second is called surface plus bulk micromachining. Bulk micromachining and surface plus bulk micromachining. Now, these are processed to create or fabricate the sensor.

Let us go to the next topic. So, before we go to the next topic, let me finish the module here and let me start the next module because it is related to understanding the layers within the cortical column. So, we will take as a separate module. Let us finish this module right over here.

I hope that you understand that the understanding or learning the fabrication would help you to design several sensors and it can be used for several applications, it can be used as a gas sensor, it can be used as a microheater, it can be used for transistors, it can be used for the four sensing for RF ablation, and many other platforms. It can be used for flexible sensor.

So in the next module, what we will look at, we will look at how to create a microneedle that you can place inside the cortical column and understand the signals generating from the cortical column. So it is related to a brain and that is why we will be discussing that particular topic in the next module. Till then you take care. Bye.