Fabrication Techniques for MEMs-based Sensors: Clinical Perspective
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Lecture - 14
Micromachining: Fabrication of VOC Sensor and Cantilever

Hi, welcome to this particular module. And in this module, we will see nanostructures of sensing layers; particularly, metal oxide nanostructures and electronic module there can be attach to a sensor. In last module, what we have seen? We have seen if the use of bulk micromachining and bulk plus surface micromachining to form sensors that can be use to be take volatile organic compounds, right.

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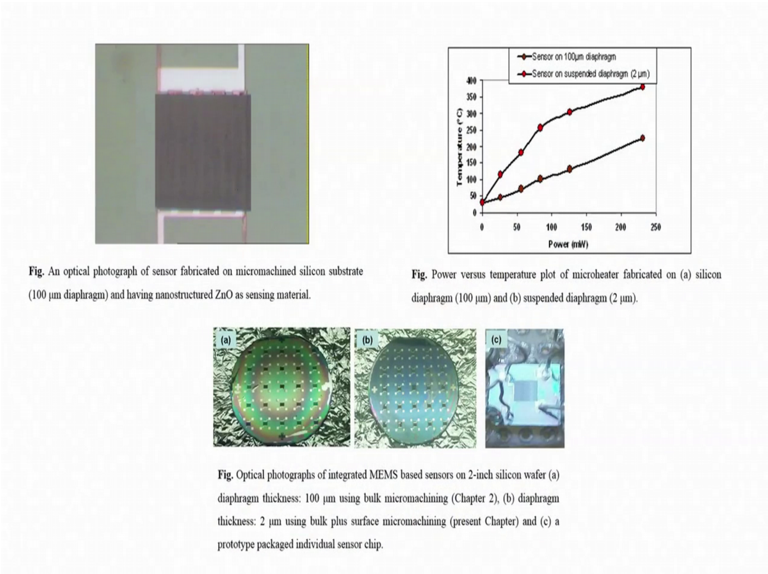

So, if you see the slide, what you see? This is bulk micromachining, this is bulk plus surface micromachining, this is a prototype that is packaged end user sensor chip. And you can see that using 100 micron diaphragm and using 2 micron diaphragm suspended diaphragm, there is a huge difference in terms of temperature for the same amount of power.

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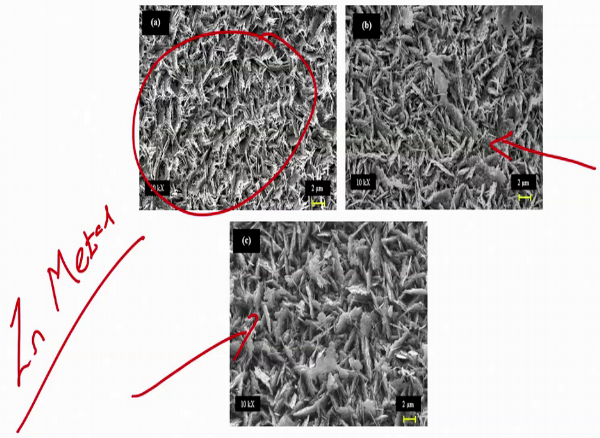

Fig. SEM image of (a) nanostructured ZnO film obtained after annealing Zn film at 500 °C for 2 h, (b) nanostructured ZnO film obtained after annealing Zn film at 500 °C for 4 h, (c) nanostructured ZnO film obtained after annealing Zn film at 500 °C for 6 h. The thickness of the Zn film for all samples is 500 nm.

Now, to form nanostructure of zinc oxide, you can deposit zinc metal; thin film of zinc metal and heat it in presence of oxygen add different temperature for certain amount of time right.

So, what re-found is; that if you deposit zinc metal and if you heat the metal at 500 degree centigrade for 2 hours, you get nanostructure of zinc film as shown here. But if we increase the time from 2 to 4 hours, this is what you get. And further increasing time to 6 hours, you get nanoflex along with the combination of nanowatts and this particular structure is better, because instead of using thin film we are using nanostructures and nanostructure using nanostructure will increase the surface to volume ratio. So, when surface to volume ratio is high is sensitivity of a sensor would be high.

So thus, using the nanostructure of a metal oxide material or metal oxide nanostructure we can improve the sensitivity of our sensor rather than using the thin film of zinc oxide or a metal oxide material.

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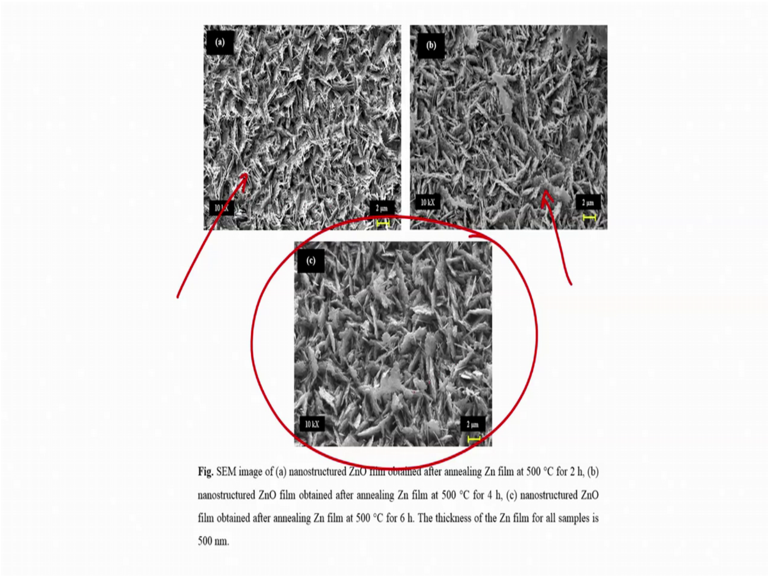

So, if you see the screen what you see here is a is a beautiful zinc oxide nanoflex and nanowires as a combination of both and this is at 10 k x; all three images and add a 10 k x these are all h c and images scanning electro-microscope, we will see the cartelization techniques in that we will understand what are the kind of microscopes. And as I said the zinc film should be extremely thin.

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In this case, we are using 0.5 microns; 0.5 microns or you can say 500 nanometers. So, 500 nanometer of a zinc thin film is used and then it is a annealed in a presence of oxygen at 500 degree centigrade for 2 hours, 4 hours and 6 hours.

So, this zinc film will sit on the sensor, this zinc film will sit here, right. So, this is zinc oxide nanostructure as a sensing layer on interdivision electors and everything is on 100 micron diaphragm, right, 100 micron diaphragm. So, you can use a copper oxide nanowires, you can use WO 3, you can use S n O 2, you can use N 2 O 3. You have variety of options to use and to see which one would be sensitive as well as selective for a particular VOC, right you see sensitivity we can improve what about selectivity: selectivity is a k is important aspect right because from a group of VOC that we have we have to selectively detect one particular VOC.

So, how can we detect particularly one VOC? So, there can be selectivity for this kind of individual sensor for different VOC is not so cool. So, what we are doing? We are doing here using temperature at a different temperature this sensor will show a sensitivity to particular VOC in higher better sensitivity particular VOC then they other VOCs, but single sensor cannot be selective and sensitive both.

So, to improve selectivity, we can use group of sensors and that group of sensors can work the sensor array and that array if we connect with artificial intelligence or ANN artificial neural network, then when we generate lot of data depending the amount of VOC is are; the combination VOC is that we are we are experimenting with and we train our network we train our neural network. Then a complete system can selectively tell what is the particular VOC of our interest in the group of the given VOCs and what is a concentration, right is a whole set of experiments. And that for people called as electronic nose.

When you talk about nose has lot of sensors right and this sensors are connected through olfactory lob to you are brain and artificial neural network in the case it is a neural network right in the e nose this is electronic nose we have to use here. And coming back to here; what we understand is that we can use this sensor and we can designs several kind of sensors depending on using micro machining; right using micromachining.

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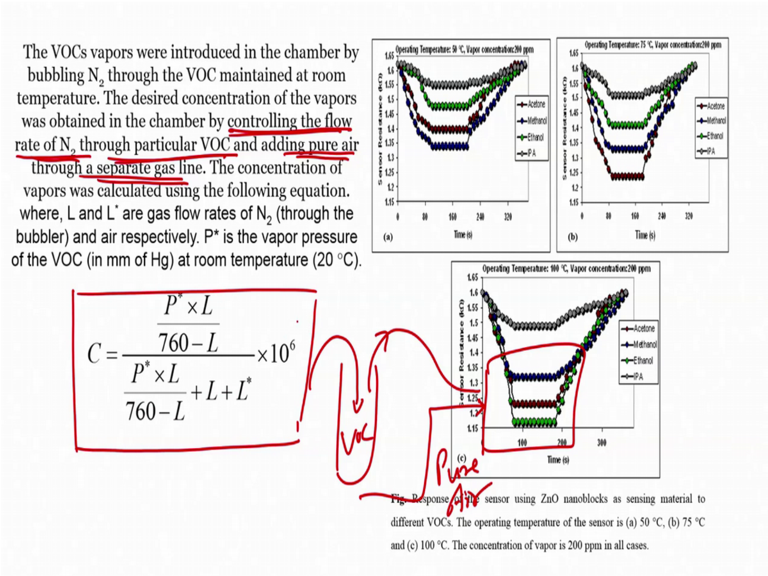

So, now if you see the nanostructures are here and how we can know the concentration of VOC, right. So, we need to take a chamber. So, let me first show you the chamber, I will just go to that particular slide and then we come back.

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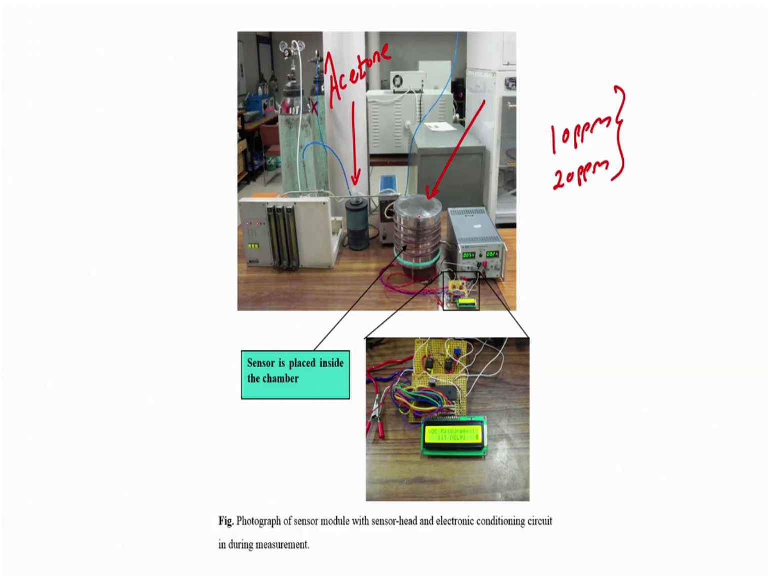

So, if you see this is the chamber in and sensor is placed inside the chamber. So, we are understanding; how to how to evaluate the performance of one single sensor. So, just understand this particular thing. So, we have a chamber and we have a bubbler here, we have a bubble here and the gas is passed through this bubbler and this gas will be inserted inside the chamber.

So, what is the concentration of? So, if you see here, we have bubbler right and in which we have our VOC of interest. So, we have acetone and this acetone the vapour of acetone is carried into the chamber right along with nitrogen. So, we will see how the concentration of this acetone can be determined in this particular chamber that is what we are interested in what is the concentration; is it 10 ppm, right, is it 20 ppm? How you know what is the concentration of the acetone in this particular chamber, there is what we are interested in to understand. And that is why to understand that we need to understand this particular formula which is right over here.

So, the VOC is were introduced. So, how can we get this data, how we variable to get this data, right? So, to get this data, the VOC vapors were introduced in the chamber by bubbling nitrogen through the VOC maintained at room temperature right: the VOC that was that we have seen through bubbler was maintained at room temperature, right. And the N 2 was passed through this VOC, right; nitrogen was pass through this VOC, the desired concentration of vapors was obtained in the chamber by controlling the flow rate of N 2 through particular VOC and adding pure air through a separate gas line, right we need to change the concentration.

So, what we you had done? We are introducing the vapors by controlling the flow of nitrogen through a particular VOC. So, assume that this is a VOC and we are introducing nitrogen and we are introducing this in a chamber along with that we are also introducing were also introducing pure air, right pure air, this is our VOC. The concentration of vapors was calculated using the following equation, right which is C equals to P star into L divided by 760 minus L whole division by P star into L by 760 minus L plus L plus L star into 10 to the power 6; 10 to the power 6.

Now you see here, in this case, L and L star are gas flow rates of N 2 through bubbler L and L star are the flow rate of gas of nitrogen; nitrogen through bubbler and air respectively while P star is a vapor pressure of VOC measure in millimeter of H g at room temperature, right. So, if you know we already know right what will be the vapor pressure of particular VOC for acetone it would be different for ethanol it would be different by every VOC the vapor pressure will be different at room temperature. So, we know this right now we also can know what is L l and L star are the gas flow rates of N 2 and air respectively. So, L is a gas flow rate of N 2 an L star is a gas flow rate of air.

So, using this equation you will know; what is the concentration of VOC that we are measuring, right? Now you see here the response of the sensor at different temperature we are measuring. Now at 50 degree centigrade; at 50 degree centigrade, you can see that the response to methanol right is higher compared to acetone ethanol and IPA while in case of at case of 75 degree centigrade the response to acetone it, sensors will more sensitivity to acetone.

And at 100 degree centigrade the sensor is showing higher sensitivity for ethanol, right, change in resistance change in resistance. Since the ethanol methanol acetone are all and IPA are all reducing gases are all reducing gases, the resistance of the sensor will decrease, if it is oxidizing gas, the resistance of sensor good increase for zinc oxide is a sensing layer.

So, you can clearly see that the resistance is decreasing for when we introduce acetone methanol ethanol IPA, but the change in the resistance is higher for different VOC at different temperature. That means, this the sensitivity is also depending for particular VOC is dependent on the operating temperature of the sensor then. And this particular all three cases, the concentration of VOC is 200 parts per million, 200 parts per million ok.

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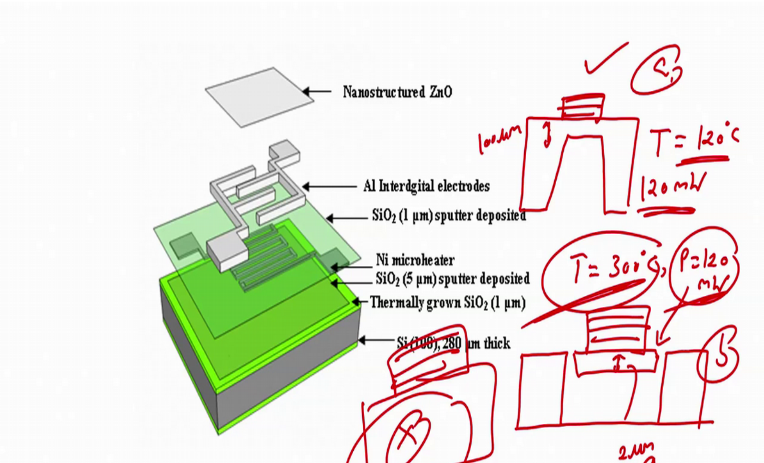

Fig. The blow-up diagram of VOC sensor fabricated on planar thermally isolated MEMS platform.

Now, comes our case where we were talking about a sensor on a diaphragm, sorry, right or a sensor on the suspended diaphragm, right you understand all the blocks are here, right. Now in both cases, what happens in both cases? We have seen that we have seen that the temperature. So, temperature here for 120 milliwatt of power was 120 degree centigrade, in this case, surface plus bulk micromachining temperature was 300 degree centigrade for 120 miniwatt of power, right.

This is the advantage that you will keep on reducing, if you have this suspended diaphragm which is about 1 micron or 2 micron in thickness, right. And you have this diaphragm where is 100 micron in thickness than compared to fabricating a sensor directly on silicon without creating a diaphragm, right. This is better because now we can reduce the power and achieve a temperature, but this is even better surface plus bulk because at a same power. We can even have a better temperature, but in both the cases; cases a and cases b compared to case x the mechanical strength is reduced compared to x a and b the mechanical strength of the sensor is low, right.

So, what can be an alternative techniques such that we can achieve a higher temperature at lower power and have mechanical stability like x, we can have a higher temperature at lower power and still have a mechanical stability as good as the starting silicon substrate. So, if you see; this is a schematic of that sensor, right. And it is a blow up diagram fabricated on a planar thermally isolated MEMs platform planar thermally isolated MEMs platform you can see here.

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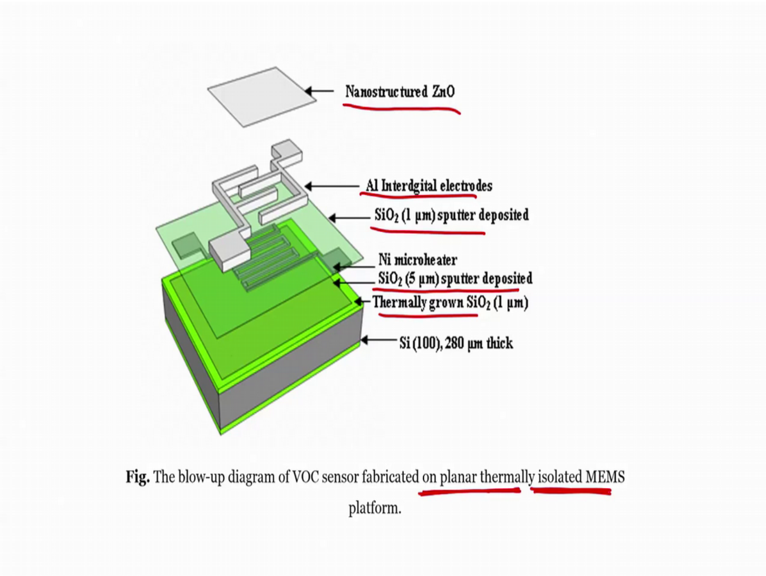

So, you have silicon and then you have thermally grown silicon dioxide. And then you have silicon dioxide sputter deposited followed by an insulator and the nickel micro heater an insulator interdigital electrodes and nanostructure zinc oxide, right.

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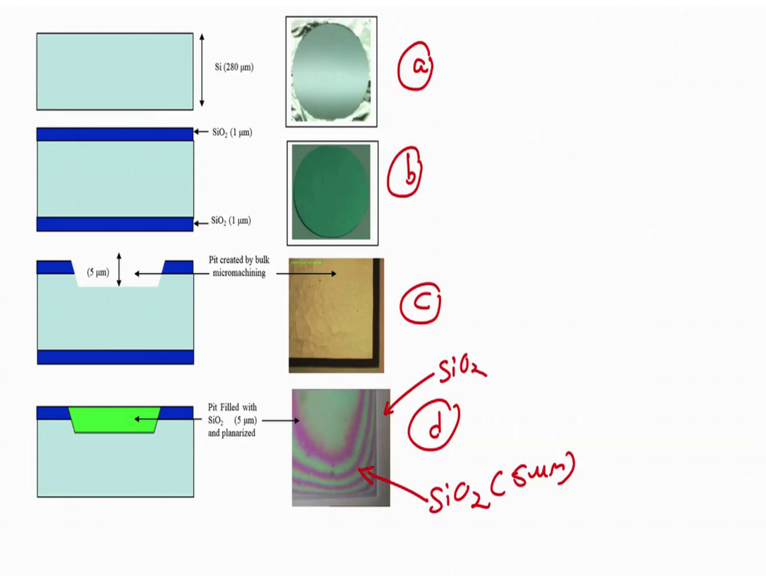

So, let us see what we are doing here?

Now, I will not draw individual steps in this particular case since we know since we know how photolithography is done, right. So, the first step is step number a; you take a silicon substrate, step number b you grow oxide. So, oxidize silicon, you can say SiO2 on both side, step number c is you create a pit. Now you know how to create a pit, we just took an example in the last module, right, you can create a pit by bulk micromachining. Then d you filled is pit with silicon dioxide last example, we have filled the pit with sacrificial layer of zinc oxide, here silicon dioxide is not sacrificial layer.

So, you have to fill the pit with silicon dioxide, you can do sputter deposition and then you planarized this pit. So, you can see here, you can this is also oxide, this also oxide, this is SiO2, but it is thick about 5 microns thick, all right. So, you create a pit, then fill the pit with silicon dioxide and planarize it.

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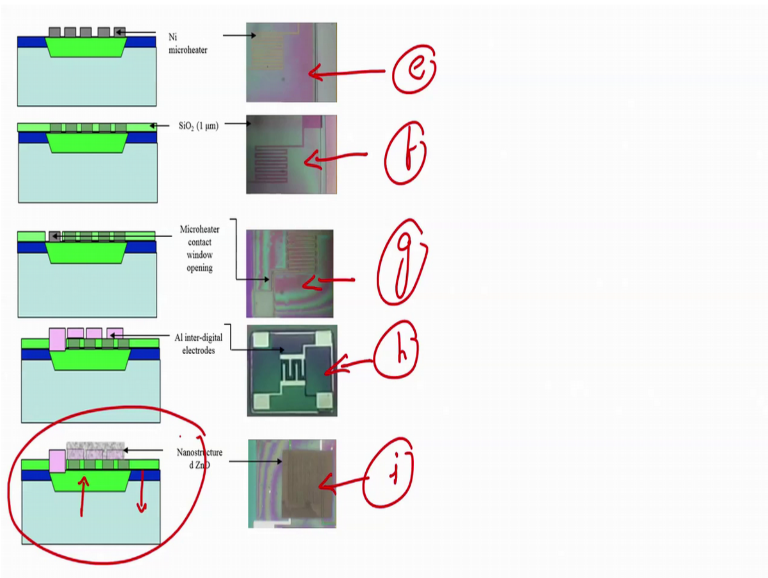

Once you planarize the pit, on that pit, you can now perform the same steps like depositing nickel and patterning nickel microheater depositing silicon dioxide and opening the contact, right. You can see here, if I go here; e, f, g, e is patterning is nickel microheater, f is depositing silicon dioxide on microheater, g is opening the contact opening the contact, right by etching silicon dioxide from the contact area of the microheater, h is too deposit aluminium as a metal for interdigited electrodes.

And pattern it and pattern it and I would be i would be to deposit nanostructure zinc oxide or to pattern nanostructure zinc zinc oxide using lift off technique right using lift off technique. So, what is the advantage; what is the advantage of doing it? Now you have silicon dioxide filled here, silicon dioxide is thermal insulator. It is a insulator to heat as well right that is why it is thermal insulator and of course, is a electrical insulator.

So, the loss the heat loss from the back side of the vapor is reduced, because now we have thermally grown we have thermal insulator filled in the pit on which the entire structure is fabricated which is our sensor, right.

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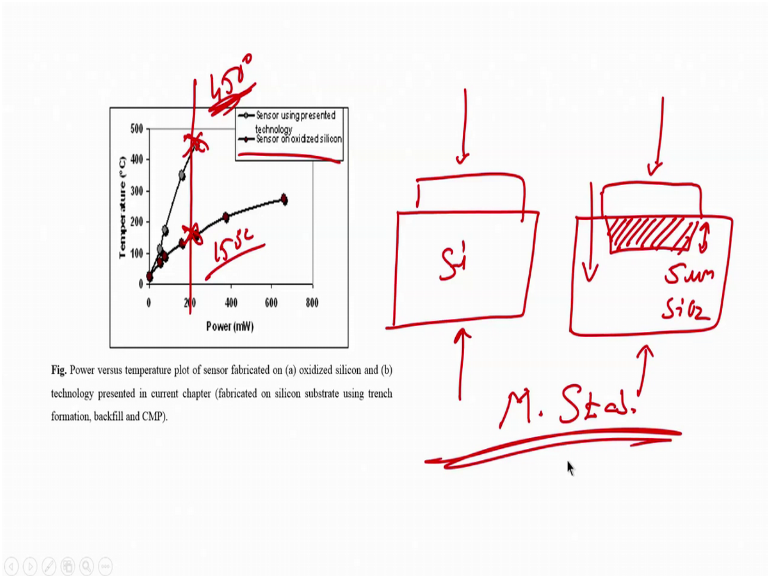

So, small changing because of this what we get is; and interesting data right sensor using the technology that is right over here creating the sensor on a filled pit with silicon dioxide which is a thermal insulator, right compared to sensor on oxidize silicon substrate. So, what we are doing is we have sensor on oxidize silicon substrate and we have sensor on a pit filled with silicon dioxide and you assume that there is the sensor block here, the sensor block here, what we found is that the mechanical stability. You see mechanical stability is still say right is still same, mechanical stability is still same, but the structure the sensor here what we are done we have five micron pit filled with SiO2.

By doing so, we are creating a thermal insulator and that is why the heat loss on the back side of the wafer will be reduce and thus the difference in the temperature that we get for the same amount of power is tremendous, you can see here if I say about 200 watts; 200 milliwatt. We are achieving 450 degree centigrade while for this particular substrate, we are around 150 degree centigrade, you see a difference of 200, 300 degree centigrade; 300 degree centigrade, right. If this is my 450 and this one is 150, I have a difference of 300 degree centigrade at a same power when I compared with the silicon substrate and sensor fabricated on silicon substrate and my mechanical strength is almost similar, right.

So, what changes we have done? Just a small change of creating a pit and filling with silicon dioxide, right; so, a small change in the structure can get you what you desire right. And this is how we have created our sensor, right. And we recall this sensor as sensor that is fabricated on a planar thermally isolated MEMs platform planar thermally isolated MEMs platform ok. Now, once you have this, you have to connect your sensor to the electronic module, is it not? You have to connect our sensor to the electronic module how can you connect sensor to electronic module.

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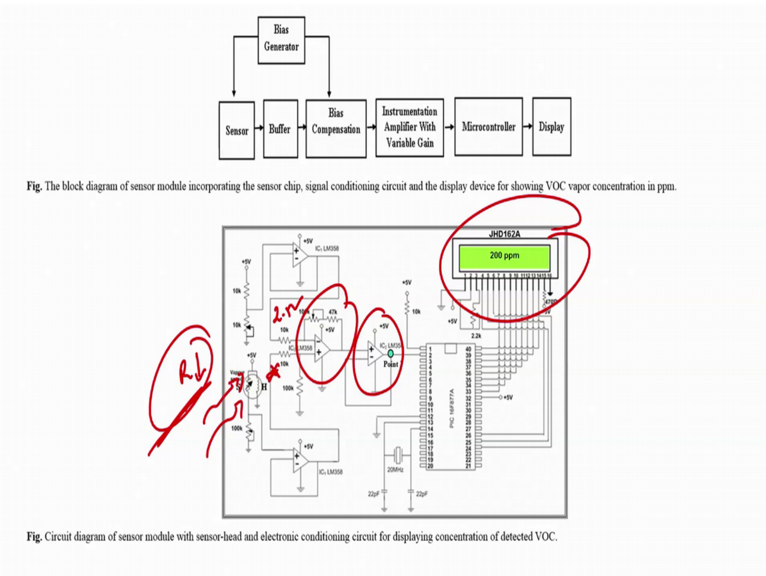

Fig. The block diagram of sensor module incorporating the sensor chip, signal conditioning circuit and the display device for showing VOC vapor concentration in ppm.

Fig. Circuit diagram of sensor module with sensor-head and electronic conditioning circuit for displaying concentration of detected VOC.

So, what should be the block diagram? So, block diagram of sensor module incorporating sensor chip signal conditioning circuit and the display device is shown here. So, you can see here there is a sensor, there is a bias generator for bias compensation, there is a buffer and to this after bias composition we connected to the instrument amplifier with variable gain which is for the connected to a microcontroller and finally, a display.

So, if you see this particular case is nothing, but a Wheatstone bridge, right and here you have a sensor with heater you have a sensor with heater, right. So, you have a buffer here buffer 1, buffer 2; the difference this is a differential amplifier is a differential amplifier and you can see here; what will happen. Let us say initially the sensor the resistance are at same value.

So, let us say this will be having 2.5 volts. This will also have 2.5 volts. So, the output should be close to 0, right if because there should be nothing if you are balance of these properly. Now when you change; you when the sensor senses of VOC when a sensor senses of VOC resistance would decrease; this reduced in resistance will cause the change in the potential divider here and the voltage that you obtain at this time would be different than this particular end right.

So, the difference in the voltage the difference in the voltage would be. So, initially of course, you have here 2.5 volts right 2.5 volts you have here 2.5 volts. So, the different should be 0, right different should be 0, but when the sensor senses the particular VOC this 2.5 volts will change. And whatever the new value is the difference of that value would be amplified by this differential amplifier along with the advantage here is that the noise will be also differentiated the noise will that there will be difference of noise as well.

So, we are taking care of the noise as well. And of course, if we use instrument amplifier that is a beauty that we can reduce the noise signal, then it is further connected to buffer which is connected to pin 2 of your peak of microcontroller, it is 16 f 8 7 7 8 and this controller is connected to your display just a small simple LCD display, GST 16 to a and what; and corresponding to the change in the sensor value that is change in resistance; this change in resistance we can show in terms of parts per million and in terms of vapor concentration right.

So, it is a tremendously easy electronic module to understand, right with a sensor ahead and electronic conditioning circuit. Again, if you have any confusion do ask any confusion in this do ask any confusion in the earlier lectures also please feel free to ask ok. So, how can we design this we can design a call of an; and we can take a call of an L N 3 5 h and then we can use all four op-amps in this one, you can see here right.

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Fig. Photograph of sensor module with sensor-head and electronic conditioning circuit in during measurement.

Now, if you see here, right like a discuss is the chamber is the electronic module, right. That is connected to your display and then you can measure the concentration of VOC right measure the concentration of VOC you can see here right. You can see here, it is we can control the gases right there is a needle valve to control the gas.

And we can have a better control if you have a mass flow controller mass; flow controller can be used to better control the gases we have here VOC right of our interest and we are inserting it. And the gases are right the cases of VOC is will come out right after the reaction the sensor has indicated heater. So, once the sensor saturates, let us say for a given VOC we heat it for certain times to get back to its base value right baseline resistance is obtained again once the griddings are once the measurement is done right.

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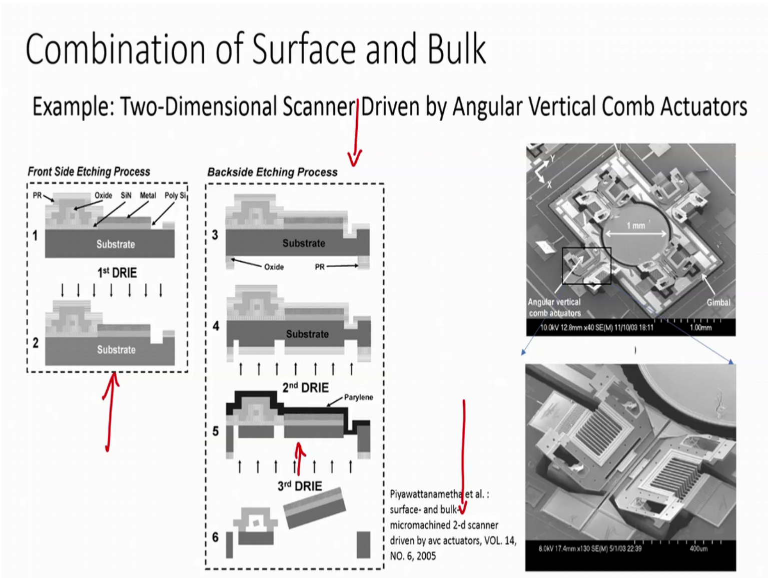

Now, let us take a example of another device and that is a two dimensional scanner driven by angular vertical comb actuators, right is a angular vertical comb actuator you can see here and here we are using the process called deep reactive and etching, right. So, this is this is a mirror and this mirror can be tilted with the help of this angular word actuators, right. So, there can be different techniques one technique can be you can have a thermally actuator that can work on the thermal property. That means, that if you change the thermal property at the temperature of that actuator it will start actuating which will cause the band in the micro mirror right.

So, one application and of course, when you have to create this as you can see here front side etching and then you are using back side etching and clearly we can see that not only surface micromachining, but a bulk micromachining is used right to finally, h out our; h out our comb actuators right the more about this you can find it in a micromachined the 2 d scanner driven by a VC actuators in a vapor by even Piyawattanametha et al ok.

So, the point here that I want to make is that you can use micromachining that is bulk plus surface micromachining to create several structures of our several structures of various devices.

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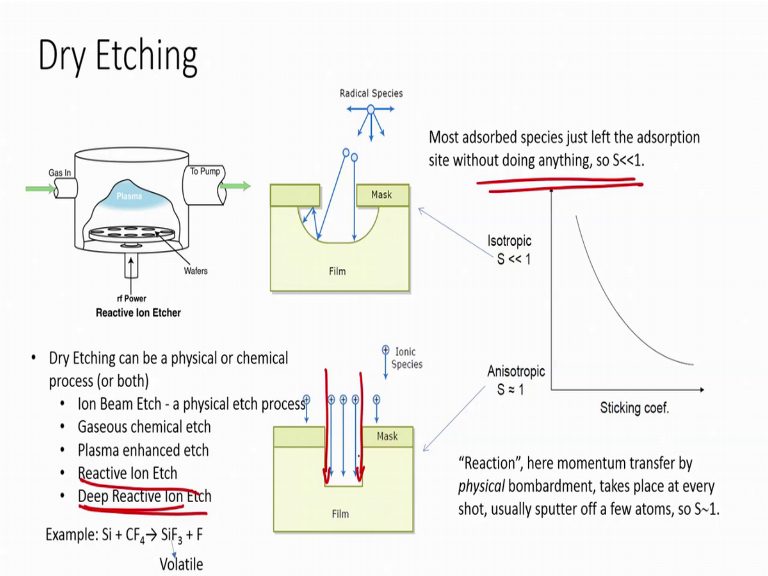

So, let us see now what exactly is a dry etching ok; what is a dry etching. So, you have to load your wafer inside a chamber there is a gas in, and there is a gas is there is a gas out like I said yesterday, d r i; it uses C 4 H 8, SF 6 as well as a helium and argon so to, and of course CF4. So, here you see that there is a RF power and is a reactive ion etcher the when you put the wafer it will be etched in a direction; so, most of the adsorbed species; left adsorption site without doing anything.

So, you have the isotropic where in case of the plasma etching you will have anisotropy which is s equals to 1 and the wall that you get is vertical compared to wet etching compare to wet etching this is how we get. So, I will show you an example that where you can use a d r i; we are just seen a micro actuator will see one more example where you can appreciate how does the DRI etch is the silicon. So, DRI can be physical or chemical process are both ion beam etch a physical process gaseous chemical etch plasma etch reactive ion etching and deep reactive ion etching. So, dry etching can be not DRI dry etching can be both chemical base and physical based and we are interested in understanding DRI in particular or r i.

So, here you can see the reaction here reaction is the what momentum transfer by physical bombardment takes place at every shot usually sputter of a few atoms and. So, s is approximately equal to one. So, it is it is etch physically and then gases are used to smooth the surface smooth the boundary.

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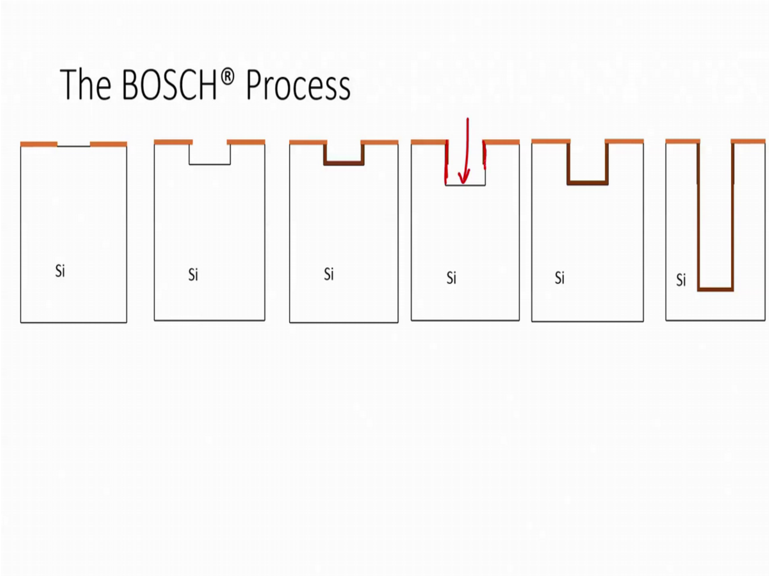

So, what we can see we can see this is a process which is used by Bosch and its S i is called Bosch process to adds the silicon. So, you keep on etching the surface. And then you keep on smoothening the wall keep on etching the surface and smoothing the wall. So, this is a video which will tell you how a DRI system can be used for etching a silicon wafer. Let us see the video and then we will the; continue our discussion.

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Welcome to the STS room, we can explain your quick a buffer, we have to operate the STS machine.

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So, buffer thing to do an once you have this, it is the check that to save the CDO is off or otherwise if the machine has any problem and cannot be operated. In case the take its down or like hidden, you can operate the machine normally. The first thing to do is like come next to the screen of the room to the small laptop unlock gain. Once you locked in you have to proceed to the gas chase next to the STS room.

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The first you think to check in the gas rooml the gas chase is like the CDO box the CDO box is responsible of neutralizing the exhaust gases from the STS.

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So, by burning them is likes them harmless nothing that we have to check is the both the lights are green and the temperature it is within parameter as well as the labels of the overall nitrogen and have chosen. Once we check that everything its under working conditions.

So, we will check if the operating gases are closed.

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As you can see the gases are in which side of the room. we are going to be using the force the phrase before gases the C 4 F 8. So, we have to check it, it is in use the SF 6, the oxygen and the helium. If once you right period here not is that any of the taxes, they are nothing use please contact the supervisor of staff to turn them on have. Once you are inside the room take advantage to check before any weird noises all like punishments. If everything is in place, you can proceed with the operation operating the machine.

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And back in the STS room.

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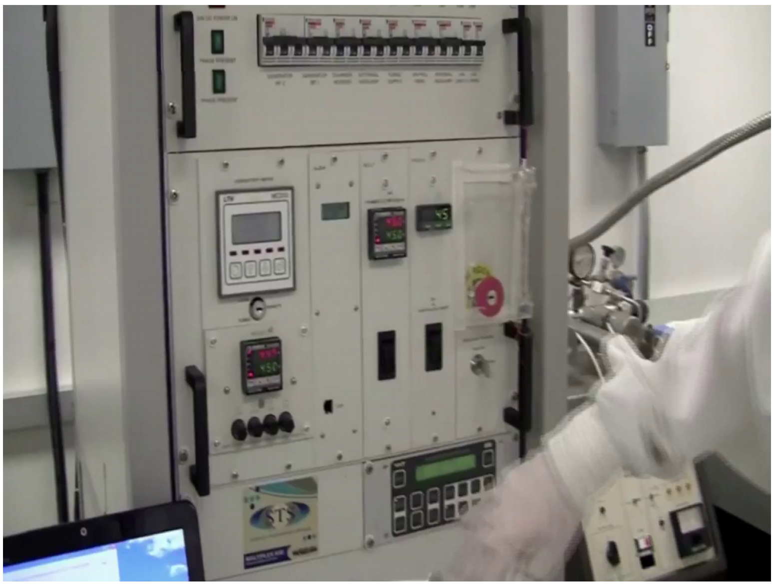

The first thing that we will do is check the STS tower and then we will record the conductivity of the overall, and the temperatures on the on the STS FCU 500 like free and one. So, record the values. And once we have recorded the values from the tower, we will go to the computer to record the other different values that we have to record.

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The once have you need are going to be the high vacuum pressure the couplum pressure and 4 line pressure and the low lot pressure. So, you have any problem finding any of the values in the strange, you only have to go in top of them to see; what are the values.

Once you recorded the parameters the first thing the do you have to those to change the operator mode in the software of the STS in order to where we go to edit operator mode and we change from monitor to the parameter. So, far as change and then we log in the password. So, for pattern choice and we change, now through the robin mouth where we can operate the machine.

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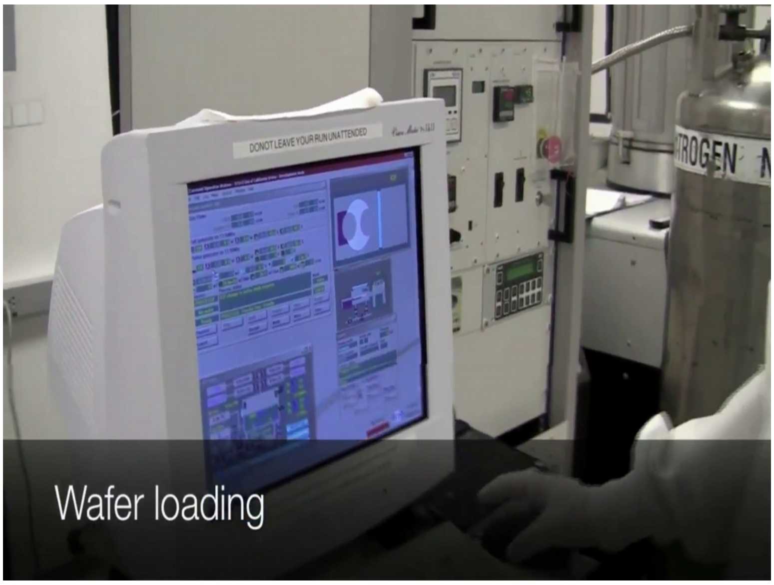

And now the first thing to do is to know the desired wafer to the non log chamber, it is that going to the transfer window and pressing when.

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And once we press, then we have to wait for the role of chamber to which a atmospheric pressure. I have once the transfer chamber is on the atmospheric pressure we can choose we open it. Now, we will charge the desire wafer into the chamber, assume, we say like usually the wafers have the flat and closing characters we have a small line.

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It is the line the flag with the line on the desired spars, once we have the wafer properly loads to close the lower chamber and we go to the transfer window and you press it, now the lower chamber. It is going to and the running conditions and it can also scan to see one of the wafer place, I have once the server has not where large, we will know the desired one you know a case, we have a wafer in the slot number one.

So, just have to press light. And now the machine it is pressuring to load the wafer into the chamber once the wafer is load into the chamber.

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We have a flash light, change the machine to check that the wafer has been load properly sure; we have to turn on the light and check through the window the wafers prescribe properly and the clamps inside the machine are holding it in place.

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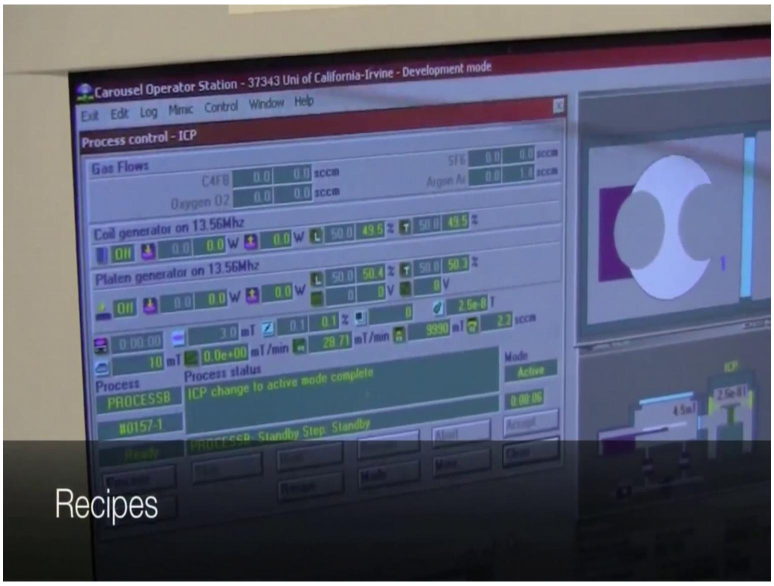

Once the wafer is known that into the chamber, we have to proceed by selecting the process of Google use.

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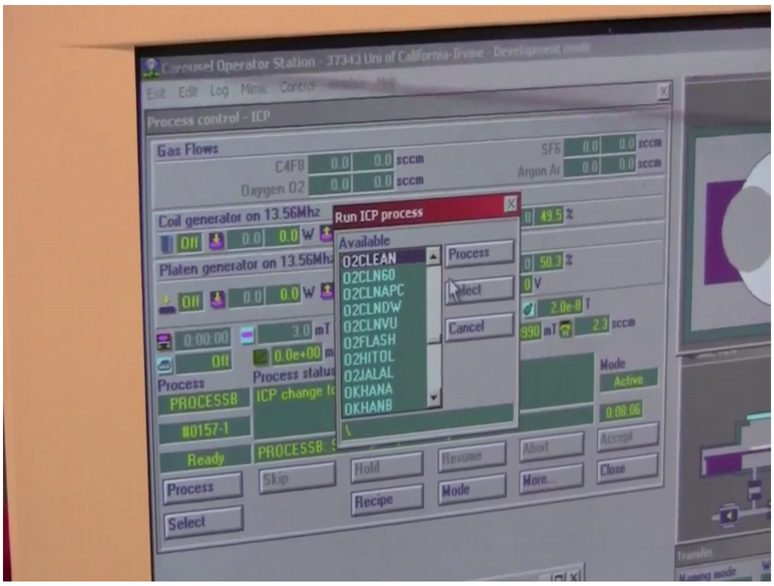

We have previous under processes process b, process i and how to clean in this page, we are going to use the how to clean you press select bumpers process. otherwise, we will go to straight ahead into processing the wafer please press select and where the machine is selecting the process in compress the recipe.

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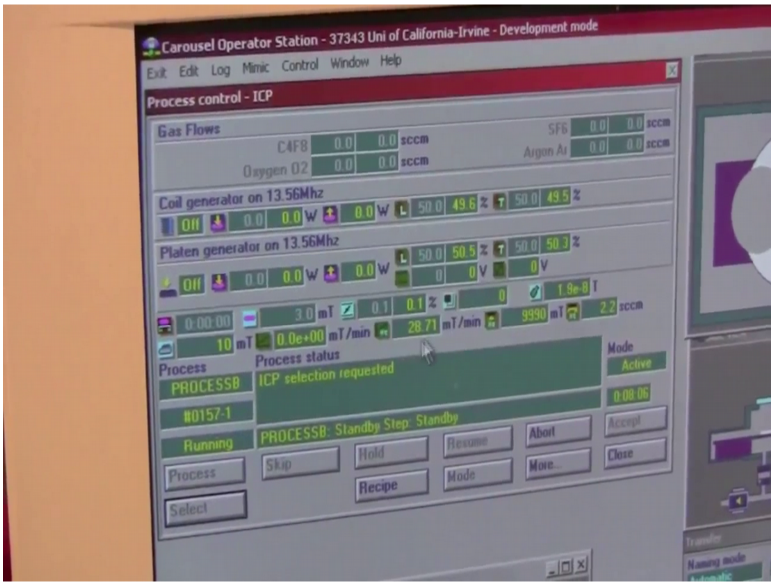

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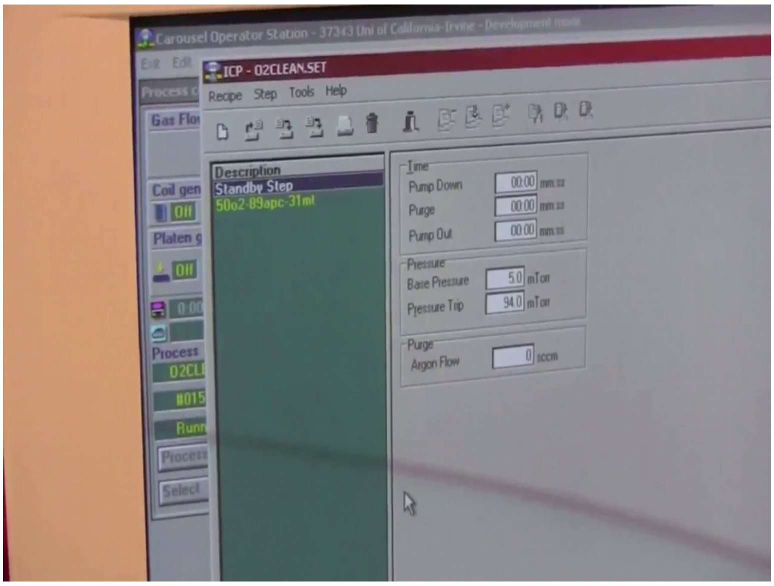

To modify the values of the recipe and in our case in the second manual because its online examples we are going to use a only like few minutes of a how to clean and also I am going to show you; how to perform general makeup test you should be the like from we have the program of whether it to check that rational a major like a scalum coming from the wafer. In order to relax you press enable one touch anything else and just say for the recipe once to set the recipe and the recipe has been select it you only need to press process as we can see.

Now, the gases our stabilizing as we can see here we have the wafer inside the chamber and also we have light pure blue that is just change it to Ajantha from you see that change of column in process, just added from the process starts to have to record the remaining values in the lock they are the four gas fluxes. So, C 4 F 8 SF 6 and the oxygen the now a case the how to clean, how to flags of may have appliers of chain, we also we have to record, the power generate to power that express here and the platen edge who have the recall the power generation. So, fascination and H and now a case on you on a have 4 H we also have to because the NPC and the process pressure and we were the helium nickel press the helium leakage.

And if we have any problem finding any of the parameters with an only leave the curser and top of the window. And we allowed in the mutual power challenge you we have this what is what is your display once the process controlly finish, you have say that the wafer cover changes from brown to green once that is really nothing to use just you know the wafer, it is very easy you go through the transform window on fascinating life and will see have the wafer, it is going to be go turn into the lower chamber.

Once the wafer is in the lower chamber when I seeing to use to press, then we can till the chamber is into the atmospheric pressure. Now the lower chamber is back into atmospheric pressure. So, we open it we graph the wafer are the just process wafer box wafer box kept it in a safe place and next thing into those where caresoual chamber into standby pressure is it that by clicking transform window. And because processing anything else and nobody is after last we will go through the edit menu again go to operator mode compress monitor to operate in to standby. Once we if the latch then, I think to do is to log out from the laptop.

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So, that is it for like the operation of the STS, if we have any doubts. Please contacts staff, but we can also check the SOP for the STS and also the complementary videos that explain more into tell you just or the operating procedure

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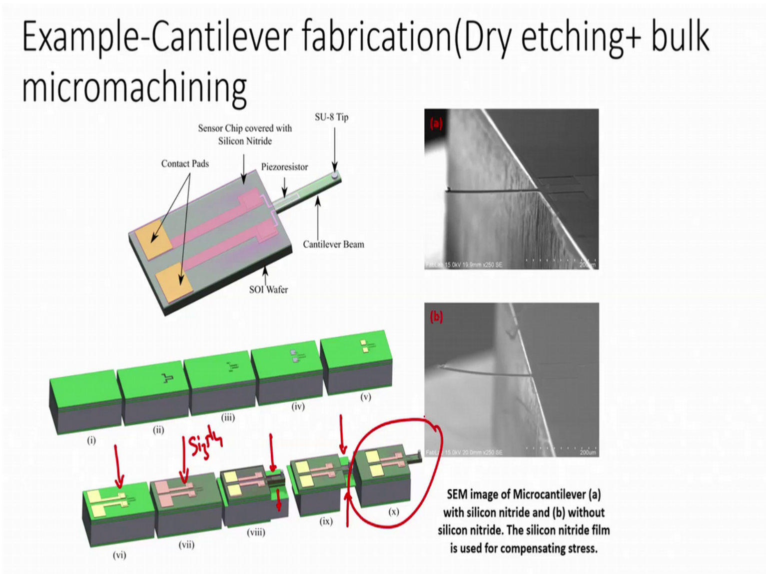

Now, are you guys no right that how DRI system can be used, but like I said, I will show you an example where you can appreciate the advantage of DRI. So, here you can see what we have done we have used DRI to H cantilever to fabricate a microcantilever and you can see the smooth wall that is created with the help of DRI, right if you take an example of wet etching you will not be able to release the cantilever in this particular fashion through bulk micromachining is very difficult very difficult.

So, and is not that the wet etching is not good compared to and dry etching is better it is I am not I am not claiming that what I am claiming is that dry etching plus bulk micromachining in the case of fabricating devices such as the microcantilever is a right approach to fabricates, right.

So, here we have fabricated a Piezo resistive microcantilever and what it consists of it consists of a piezoresistor as you can see here clearly it as an SU-8 tip, it has the cantilever beam contact pads which have we can see here right and what is the fabrication process. So, this is us SOI wafer is a silicon on oxide, right silicon on insulator wafer and we are growing a oxide. Then we are creating a window then we are diffusing piezoresistor we are opening the contact we are creating a contact of gold which is contact pads right it is all way from here to here contact pads. And after the contact pads are created right; what we are doing we are creating when depositing a layer of silicon nitride the point of depositing silicon nitride is to compensate the stress that is that happens in the wafer because of silicon dioxide.

So, there is a compressive stress that is that comes into play because of silicon dioxide and the compensate that compressive stress we have to use silicon nitride. So, if you do not use silicon nitride you can see here that without silicon nitride the cantilever is meant because of the stress induced by silicon dioxide. So, once you have your piezoresistor, you deposits silicon nitride silicon nitride right. And after that you will create your etch; you etch your wafer from the top, you can see here right to create the structure. And then from the back side you start etching until you reach until you reach this oxide layer. Finally, you have to break this wafer break this chip from the entire wafer and you can obtain a single microcantilever, right.

So, very easy now I hope that you can understand the process flow of how to fabricate a piezo resistive microcantilever right again the piezoresistor is formed by defusing boron into a polysilicon right or single crystal silicon. So, we can diffuse boron and that is how we can create a piezoresistor.

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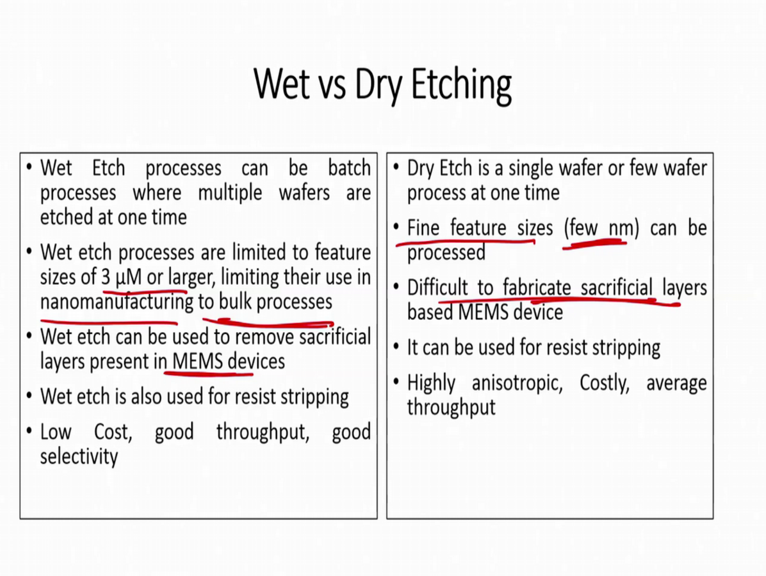

So, let us now see wet versus dry etching right wet etching versus dry etching. So, and we will compare both wet etching versus dry etching and see. So, wet etching process can be batch process for multiple wafers are etch at one time right you can you can place in a beaker right multiple multiple wafers and you can etch at one time if the chemical is there, it will etch all the wafers at one time, right. But in the case of in the case of dry etching most of the time single wafer or few wafer are process that one time.

So, that is the difference second is wet etch process are limited to feature size of three micron or larger limiting their use in nano-manufacturing to bulk process, right. So, that is the disadvantage by in case of dry etching fine feature size few nanometer can be processed right. However, wet etching can be used to remove sacrificial layer present in MEMs devices, but dry etching cannot dry etching cannot be used to remove sacrificial layer. So, that is the advantage of wet etching right same way wet etch is also used for resist stripping right while dry etching can also be used for resistive both can be used for stripping out the photo resist.

Finally wet etching is low cost high throughput high selectivity right while the dry etching is highly anisotropic, but costly and average throughput, right high highly anisotropic costly, but average throughput. So, that is a comparison between your wet etching and dry etching, right.

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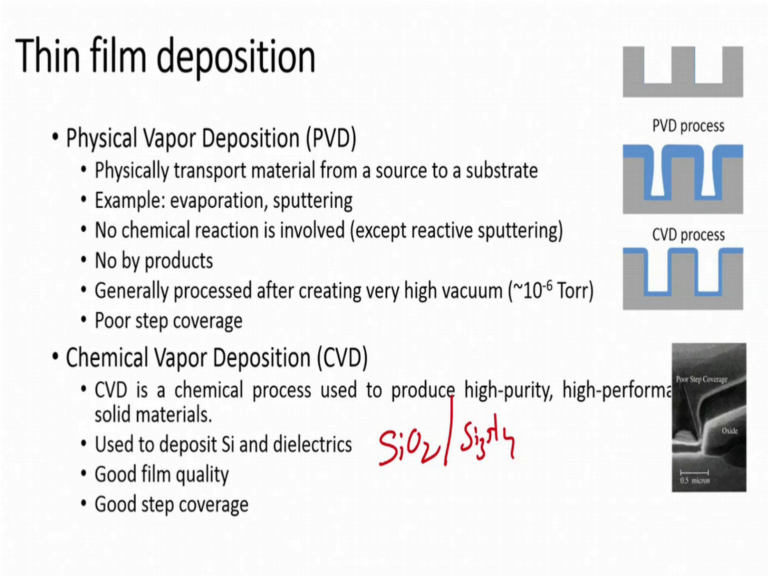

Now, see further want to go and understand how the thin film is deposited. So, thin film is deposited using two techniques one technique is physical vapor deposition that we already discuss right. Another technique is chemical vapor deposition.

So, in the next module of this particular series, we will be looking at chemical vapor deposition techniques ok. So, physical vapor deposition we have already seen that physically transport material from a source to substrate example is evaporations sputtering any evaporation we has in thermal evaporation and EB evaporation. The other advantage of physical vapor deposition is there is no chemical reaction involved, no byproducts. Generally process after creating very high vacuum about 10 to the power minus 6, but the disadvantages poor step coverage right the step coverage is not.

So, cool in case of PVD, but when you take the case when you case of CVD, right you can see here very clearly poor step coverage when you use PVD, but if you take CVD; CVD you have a good step coverage, you have a good film quality right. It is used to deposit silicon and dielectrics like silicon oxide silicon dioxide or silicon nitride right and CVD is a process used to produce high purity high performance solid materials, right guys.

So, what have what are the kinds of chemical vapor depositions what are the kind of chemical vapor depositions. We will see in the next module in this module what we have seen we have seen use of a novel technology or a use of a different idea to fabricate a microsensor, right with a higher mechanical stability while obtaining the temperature at we lower power then we have also seen an example quick example of an actuators which is driven which is driving a micrometer. And then we have seen a example of a cantilever where you can fabricate using bulk micromachining, and then we have seen dry etching versus wet etching its advantages disadvantages. Finally, what we are looking at is PVD versus CVD and we have seen is advantage disadvantages, right.

In the next module, what I want to show it to you is that kind of chemical vapor depositions, right, we will talk about few chemical vapor depositions and that will be the end of this particular lecture and then you will see some other techniques in the next lecture. So, for this module just go through it, whatever I have taught and I will see you in the next module. Till then you take care, have fun. Bye.