Sensors and Actuators
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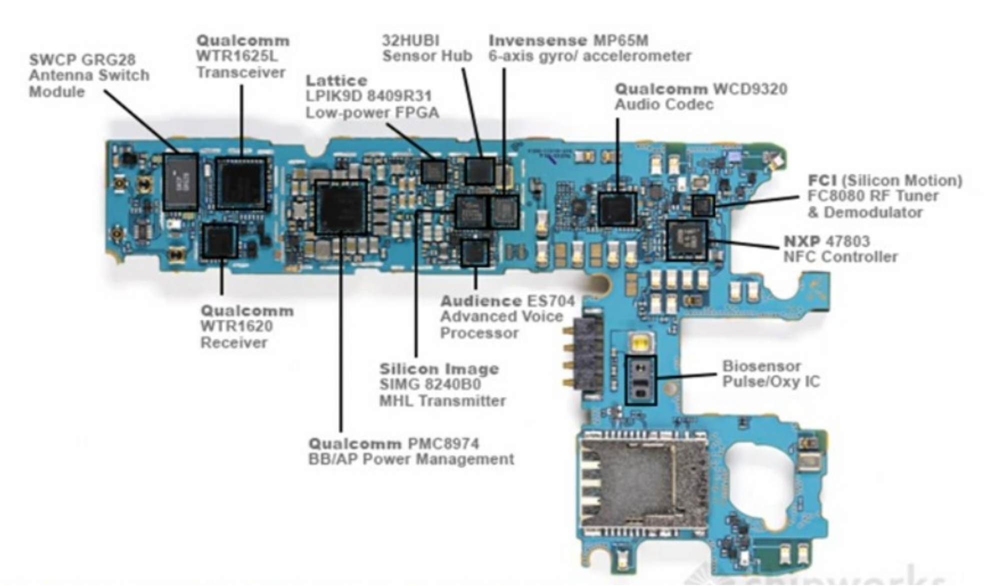
Lecture - 14
Overview of MEMS based sensors

When we talk about micro, there is a system called micro electromechanical systems which is also called MEMS based systems and lot of sensors that we will be discussing here or actuators that will be discussing here are based on MEMS based technology. MEMS are used in smart phones, tablets, camera, gaming devices and many other applications.

There is an antenna switch module, a transceiver module, a sensor module, a low power FPGA module, an accelerometer, an audio codec, a tuner and demodulator, a controller, an advanced voice processor, a transmitter, power management, biosensors, etc as shown in the diagram below.



Right now, there is a few nanometers technology for fabricating MOSFETs but when we talk about a sensor, it is a bit different than MOSFETs. However, this consists of all the things together and there are several companies which are working on this domain. Qualcomm is one of the companies which extensively uses the transceiver while the bio sensor is used from the pulse oxy IC where the other things are from different companies like InvenSense and this is what is there within the Samsung Galaxy S5. So, if we talk about S 10, it would have a more advanced version of these kind of sensors.

Types of transducers

- capacitor transducers
- piezoelectric transducer
- thermal transducer

$$C = \frac{KA\varepsilon_0}{D}$$

Where K is dielectric constant

A is the area

Is permittivity

D is diameter

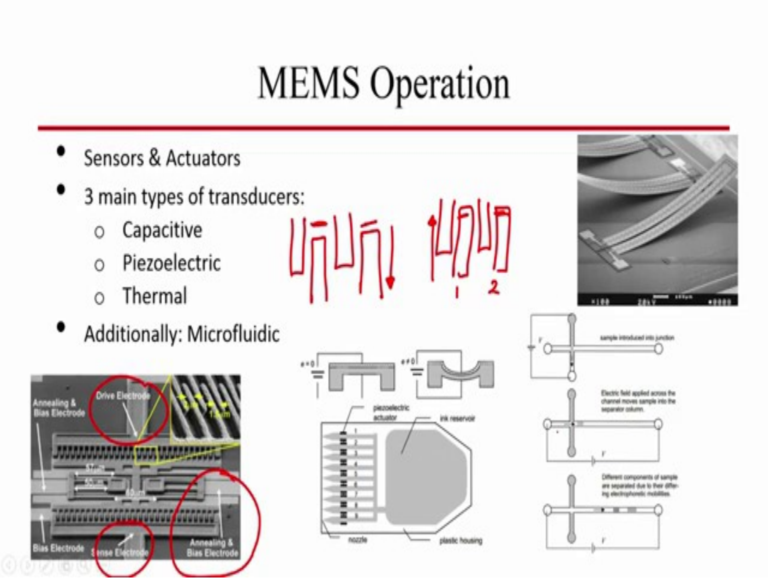
If we change the diameter, the capacitance would change. If we change the area, capacitance would change. If we change the material, dielectric constant will also change. That means that if we change the size of the cap of the fabrication, the capacitance would be affected. If we change the distance, capacitance would change. When we say size, it means either we can change the distance or the area depending on which we can change the capacitance.

Piezoresistive components are components where when we apply a pressure or a force, there is a change in resistance. In case of piezoelectric, when you apply a pressure, there will be change the output will be in terms of few volts. In piezoelectric, if we give the electrical signal, there will be change in the force.

That is a piezoelectric material where thermal is when we apply a thermal energy, it will change the shape. For example, there are SMAs which are smart actuators and finally, there is a microfluidic platform.

When you have an in sample introduced junction and the electric field is applied across a channel, it moves the sample into a separate column. Different components of samples are prepared due to different electrophoretic mobilities.

There are thermo actuated micro cantilevers, that means when we apply heat, it will actuate, and it will start bending. We also have the drives where you have a sensing electrode, an annealing and bias electrode and an electrode. There are these finger electrodes, the finger electrodes are there and when we apply voltage, the distance between the fingers reduces.



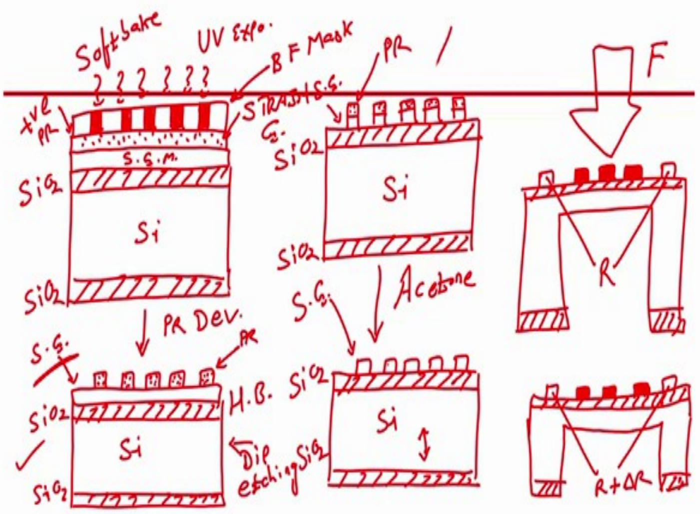
MEMS Operation

- Sensors & Actuators
- 3 main types of transducers:
  - Capacitive
  - Piezoelectric
  - Thermal
- Additionally: Microfluidic

We are moving the fingers as drawn in the diagram above. That will, that depend on how we apply the external energy. This is fabricated using micromachining. If I have a diaphragm and if I apply a pressure, then there is change in the resistance.

If we take a silicon wafer and we grow oxide which is thermal oxide, which is silicon dioxide, we have a strain gauge. There are the contact pads of strain gauge and there is an oxide layer.

Silicon is hard material. If we apply pressure, it will not bend. Hence, we must create a diaphragm. We will use step micromachining.



We have strain gauge on an oxidized silicon wafer, contact pads, and contact pads the strain gauge. When we apply a force along ‘F’ in the above diagram, it should bend but since silicon is a hard substance, it doesn’t bend. Therefore, we need to make a diaphragm. Because of the strain, there is there will be change in resistance. If we measure the resistance, R, then $R+\Delta R$ will either exist or not depending on the compressive stress. So currently, if we apply a stress, there will be minimum bending as it is made of silicon. There is a bending that is caused because of the applied application of a voltage and because it is a piezoelectric actuator, applying a voltage will show change in pressure. As pressure changes, it will bend but this bending is only possible when we have our micro machined sensor based on MEMS based technology.

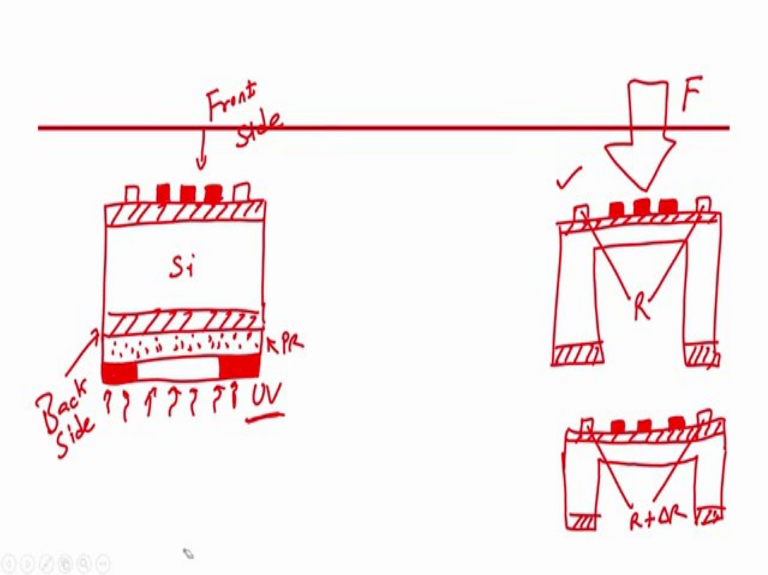
For fabricating the strain gauge, we take oxidized silicon wafer. Take oxide silicon wafer and then coat a material that is used for our strain gauge. Next step is we will spin coat positive photoresist. Next step would be soft bake. Next step would be loading a mask; mask would be bright field mask. The region of the photo resist which is not exposed will get stronger.

Next step would be UV exposure, next step would be photo resist developer. If we dip this wafer in photo resist developer solution, we would have oxidized silicon wafer with the material for strain gauge and on that, we would have photo resist protected where it was unexposed. Next step would be, we perform hard bake and then dip this wafer in etchant for the strain gauge material. If we dip the wafer in the etching solution that will etch the material for the strain gauge, we would have this pattern. Wherever there was photo resist, the material below the photo resist got saved, it did not get etched.

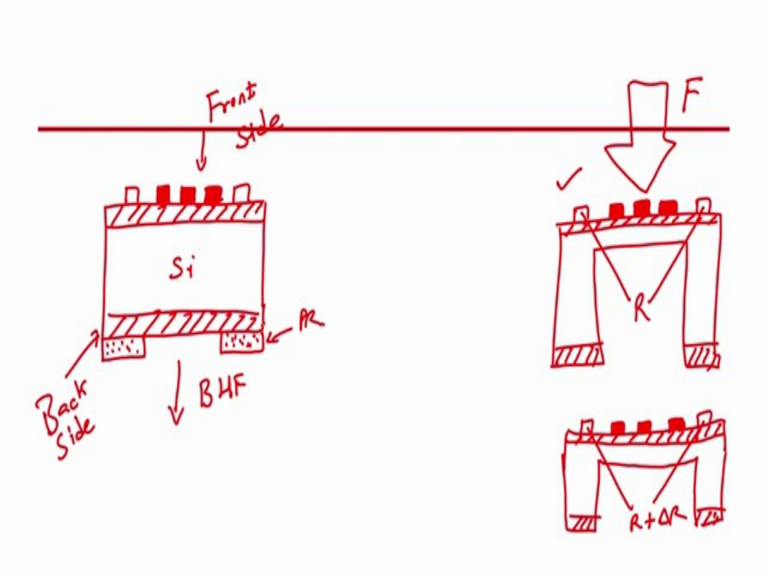
Next step would be that we dip this wafer in acetone. So, if we dip this wafer in acetone, the photo resist will be stripped off and we would have the oxidized silicon wafer with a strain gauge.

To recap, you have oxidized silicon wafer, you have your strain gauge material, you deposit using one of the techniques either PVD or CVD; PVD is physical vapor deposition, CVD is chemical vapor deposition. On that you spin coat positive photo resist on. After that you have to do soft bake, which is a 90 degree, right, 1 minute hot plate followed by a bright field mask and then you expose it with UV. The area which is not exposed will get stronger when you develop the wafer in a photo resist developer. So, you can see this particular pattern. After that you have to dip this way or you to perform a hard bake at 120 degree centigrade 1 minute hot plate and then you have to dip this wafer in etching solution for strain gauge. Then we strip off the photoresist. Now we will form the diaphragm form using micromachining technique.

First, silicon dioxide etching using BHF and second one is etching silicon. If it is wet etching, it is using KOH or TMAH or if is dry etching, then we will use the SF_6 right and CF_8 where we will use the DRIE, CF_x, NSF_6 for DRIE to etch silicon as shown in the below diagram.

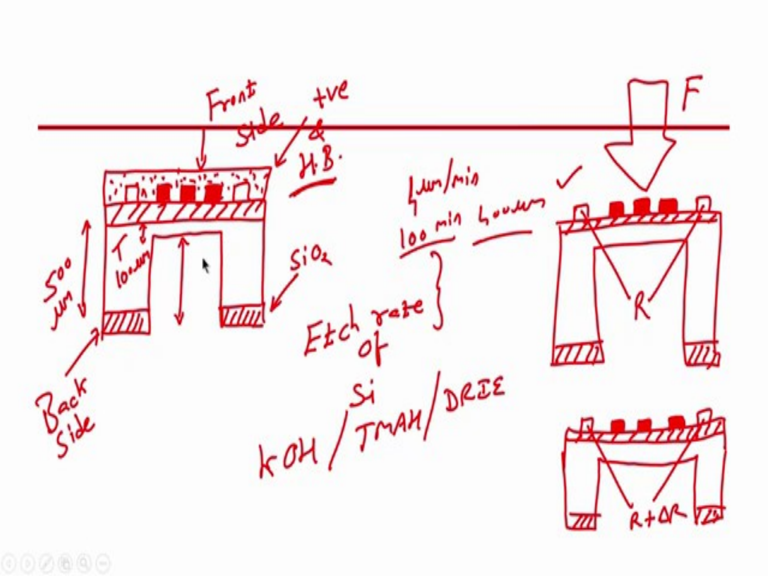


We can also use the gold contact to take out the final contact pairs. We will spin coat photo resist on front, and we also spin coat photo resist on the back. We would do a front to back lithography; that means that we need to know where we want to etch on the back side. We must perform front to back lithography, front to back alignment and perform lithography. After we have spin coat the photo resist, we will perform the soft bake. After loading the mask, after photo resist coating, soft bake, loading the mask, we will expose this wafer with UV. The unexposed region will be stronger, and the exposed region would be weaker when we dip this wafer in the in the photo resist developer. The diagram is shown below.



Next step is hard bake. After hard bake, the next step would be we dip this wafer in BHF because BHF is the etchant for silicon dioxide. We would have silicon dioxide getting etched from the area which was not protected by photo resist. Next step is we strip off this photo resist by dipping the wafer in acetone.

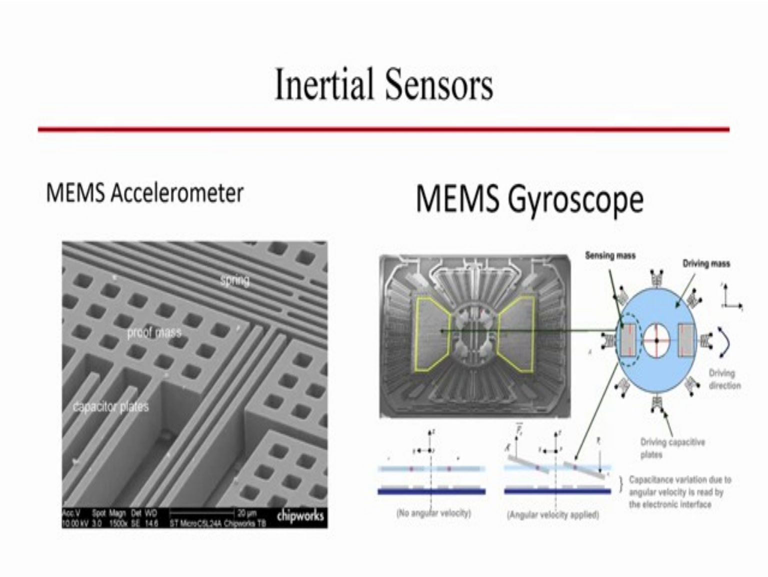
We spin coat positive photo resist in front and hard bake it directly. This will protect the front side. We either dip this wafer in KOH or TMAH for wet etching. We use DRIE which is dry etching. Either we use wet etching or dry etching to etch silicon wafer. When I etch silicon wafer, if it is dry etch, then we have diaphragm as shown in the diagram below. In wet etching, the angle that we create is 54.7-degree whereas in dry etching, we do not have to have the angle.



We have to know the etch rate and the temperature for etching because etch rate will also depend on temperature. Our silicon thickness is 500 microns; assuming that we are using a 4-inch diameter silicon wafer and then we are etching silicon which is about 400-micron. So, remaining is your 100 microns, the thickness of the diaphragm is 100 micrometers. That means, for our etching 400 micrometer, if our etch rate is 4 micrometer per minute, how many minutes do we require?

So, 4 inches and you have to etch 400 micrometers. So, we will require 100 minutes to etch 400 micrometers. So, we dip this wafer for 100 minutes in the solution if we know the etching rate is 4 micrometer per minute. Next step is to dip it in acetone. After dipping the wafer in acetone, we would have a strain gauge on the diaphragm.

There are other sensors which are called Inertial Sensors and in that, we are looking at MEMS accelerometer and MEMS gyroscope. Gyroscope can measure the angular velocity that we have applied and accelerometer can also understand what the acceleration is in our things in which we can have springs, capacitors, proof masses and same thing goes for your sensing mass and driving mass in case of the gyroscope. A diagram of each, a gyroscope and an accelerometer are shown below.


Inertial Sensors

MEMS Accelerometer

MEMS Gyroscope

Capacitance variation due to angular velocity is read by the electronic interface