Sensors and Actuators
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Lecture - 15
Introduction to Cleanroom Equipments: Impedance Analyzer, LCR Meter, Micromanipulator

If we apply a force on the tissue, then the amount of force the piezoresistor will transmit depends on the elasticity of the tissue or the stiffness of the tissue. We are talking about micro sensors and microchips. So, the tissue itself is about 5 millimeter in thickness and we cannot just press it with our hands. So, we need to press it uniformly and the system that can be used for uniformly pressing this tissue with micro steps.

We can attach an indenter which looks like a pen to a system and that system is called manipulator. And when it can precisely manipulate this indenter onto the tissue force fully by applying a force, then this manipulation, step manipulation, in micron steps is called a micro manipulator. We are manipulating our indenter in micron dimensions or micron steps.

The applications are vast, and it is a costly equipment. One of the important problems is a drug screening problem. If you have a given drugs out of three drugs, which one you need to select for the given patient? Here we will be discussing about a process called impedance measurement.

The current techniques are based on colorimetric or optical way of detecting but how about we introduce one more morality and that is your electrical sensing? We want to see that for the three different wells indicated with interdigitated electrodes and those wells also have cells or tissues with ECM which is called Extra Cellular Matrix with Matrigel as extracellular matrix. It acts as an extracellular matrix.

We require ECM because the cancer or tumor cells are surrounded by ECM. To replicate the same in vivo situation on to the in vitro platform, we are using these wells with inter digitated electrodes. On the well, we are placing the cancer cells or spheroids along with Matrigel and we are loading three different drugs.

These tumors are from the same patient and we use the same quantity of gel, and when we load three different drugs. If a drug is effective, the cells would die and that dying is called lysing and that will cause change in conductivity. If that happens, we can measure this conductivity. We cannot just measure resistance because we are looking at a Matrigel which is complex itself in nature and you have the cancer cells. That is why we cannot just measure resistance; we have to go for the impedance. Sometimes we must load media because how will we load drugs? They are media.

There will be double error capacitance coming into picture when we are looking at the measuring of the electrical sensing. And this electrical sensing is why we must use impedance morality or impedance analyzer to measure the change in the impedance of each chip. If the drug is effective, conductivity increases and impedance decreases; if it is not effective, then the conductivity would not increase because our cells would not lie and the cells does not lie. Then that means that the impedance will remain intact.

So, we can see the change in the impedance and that correspondingly we can correlate with the efficacy of the drug which means the performance of the drug.

Impedance is the opposition that current faces when it flows through a circuit or component or any of the component in a sensor or any of the system. Resistance is also the opposition faced by electric current when you it passes through a conductor.

Based on resistance, we classify materials as conductors, insulators. Semiconductors, etcetera. We have also heard about superconductors. Conductors conduct electricity and they do not show much resistant to the flow of electric current. For example, materials such as gold, copper, aluminum are good conductors of electricity.

Similarly, we have insulators which oppose the flow of current such as rubber, ceramic and other things and there are semiconductors also like silicon that you must have heard of it at different parts of your education.

What essentially is the difference between impedance as well as resistance? The term impedance is used in case of AC circuits, that is, Alternating Current circuits and resistance is the term or concept that we use mainly for DC or Direct Current circuits.

Impedance has two terms in it, that is resistance as well as reactance. Impedance is something like resistance in a DC circuit. Resistance is nothing but the opposition that electricity or current faces when it passes through a circuit. When the electrons pass through a conductor or a ionic medium due to a potential difference, the potential difference is essential for the flow of electric current. So, this potential difference will create a flow of electrons and when these electrons pass through the medium, they will collide with ionic lattice and that causes resistance.

When the electrons pass through a ionic lattice, it has resistance. A capacitor is basically two plates that may be separated by a dielectric medium. So, when we apply a potential difference across it, the current starts flowing through it and the capacitor will charge itself. It accumulates the charge.

$Q=CV$

Where Q is the charge stored by the capacitor

C is the capacitance

V is the potential difference across the capacitor

The property of a capacitor is such that when the current flows through it, it will charge automatically, and it can store a maximum amount of charge corresponding into its capacitance and the potential difference applied across it. So, at a point it cannot store anymore charge and it will oppose or stop the current that flowing through it.

When the electricity flows through a capacitor, it will charge itself to a maximum level and the potential developed in the capacitor will get ideally equal to the potential applied across it and the current no longer starts flowing through it.

Inductor is nothing but something like a coil. So, when the current flows through it, it will create a magnetic field, and this created magnetic field will create another back EMF. So, once the current flows through it or the current that is following through it increases, the magnetic field strengthens and one, at a moment the back EMF will be strong enough to oppose the potential difference of applied across it and the inductor will stop conducting current.

When charging happens, a capacitor will start resisting the flow of current through it and an inductor will oppose the current flowing through it once it starts creating a magnetic field. When alternating current flows through a capacitor, it will charge as well as discharge.

This resistance that is put forward by the capacitor or inductor is called as reactance. The reactance is time dependent and this reactance will put forward a phase change between the current and voltage flowing through the system.

The impedance is also referred to as complex impedance at times because it has two parts; the real part called as resistance and the imaginary part called as reactance. So, it is like a vector, but resistance just has a magnitude and no phase. Impedance analyzer is a testing device, electronic test device, that is used to measure impedance.

The unit of impedance is Ohms that is same as the unit of resistance and it will also have a phase angle that is presented in radiance or degrees. Impedance analyzer is an electronic test device that is used to measure the impedance across any electronic circuit or component, and it is very useful when it comes to sensors and actuators.

A new device was released by Xiaomi recently which is something like a weighing scale. It is named as Mi body composition scale. It is something like a weighing machine which can give your body mass, give a body mass index, the fat content in the body, the muscle composition in your body and so on. It looks something like a weighing machine that you have seen before, but it has about 2 or 4 electrodes; 4 SS, stainless steel, electrodes.

What it does is when you stand on this disk or a weighing scale, it will send a small electric current through your body which will measure the impedance across your body. We know that our body will have water in it and most of this water is stored either in muscles or as blood. As the muscle content in a body increases, the water present in the body also increases. Based on this, since water decreases impedance, the device will be able to tell us the percentage of muscle in our body, the percentage of fat in the body, based on this impedance measurement as well as a lot of machine learning algorithms they have developed and using process data that they are obtaining related to impedance.

Now come to a cellular level; we know that a cell will have cell wall as well as cytoplasm. Cytoplasm has ionic solutions inside it. So, what happens is if we pass current through a cell, it will provide some resistance and because there is an ionic solution inside, it will conduct electricity at the same time. It will provide some small amount of resistance. At the same time, the cell membrane will act something like a dielectric which will have properties like a capacitor.

For a small amount of current through a cell, it will have both capacitive as well as resistive effect and hence, if we measure the impedance across the cell, we will be able to know the properties of the cell. So, if the cell ages or some other properties of the cell change, something like for a bacterium or any other cell, we will be able to predict the cell properties. So, impedance can be used as an extra modality to understand the properties of a cell or a tissue.

Another application is you must have heard of gas sensors. A lot of different types of gas sensors are available. One of them is metal oxide gas detectors or sensors are there. This will give you the quantitative data of how much gas is present in the atmosphere. So, it can be alcohol detection or any other gas like acetone or any other poisonous gas or something like that.

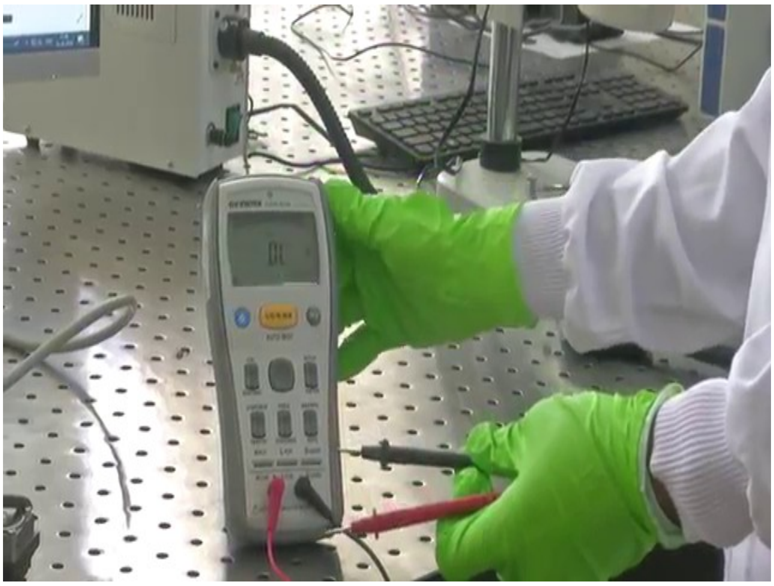
There will be a ceramic substrate on which an electrode will be fabricated. So, over this electrode, we will be coating a metal oxide specific to a specific gas. Once this metal oxide is coated, if that gas is present in the atmosphere, then what the metal oxide does is it will either absorb or adsorb these gas molecules and some small reaction happens on the metal oxide surface. So, measuring the impedance across these electrodes; since the property of metal oxide deposit or again it changes, we will be able to say the concentration of the gas in the atmosphere. So, this impedance measurement is a very good modality that can be used for different application.

Similarly, there will be pH sensors and other sensors that can be made using the same concept.

Similarly, when comes to actuators, the motors and the other devices we use have coils in it. So, we can measure the impedance across it. So, when we are going for manufacturing of consistent leasing motors with the same torque and speed, it’s always useful to measure the impedance to know the properties of the motor and whether they are consistent or not.

Below is an image of an LCR meter by GW Instek which is a Taiwanese company and is the LCR 8100 series.

Below is an image of an impedance analyzer by GW Instek which is a Taiwanese company.



Whatever instrument or sensor that we are going to test, we call it device under test or DUI. A DUI will be connected across the probes of an impedance analyzer or an LCR meter and we will measure the impedance across it.

Let’s look at the impedance analyzer now. The last two digits of the series show the frequency range of a impedance analyzer.

The key specifications of an impedance analyzer are its frequency range over which we can measure the impedance because the impedance is a function of reactance as well as resistance and reactance depends upon frequency of the test signal. As the as we sweep through the frequency ranges, we will have different values of absolute impedance.

One of the key specifications of the impedance analyzer is its frequency range. Second important thing is the accuracy of the impedance value or the absolute impedance that we can measure with it. The third parameter is the range of impedance values that we can measure with it. It can vary from 0 to a few mega ohms and similarly, the fourth key specification is the phase value across your phase angle accuracy. These are the four parameters or the four key specifications of an impedance analyzer; the frequency range, the impedance range or the value, the impedance values that we can measure and the accuracy of the absolute impedance which consists of both resist, resistance as well as reactance values and the phase angle.

we are using these precise instruments which are very costly because we can measure the impedance very accurately even to the range of ohms.

We can see written letters written C L X B Z Y etcetera. So, these are the different modes we can select and for the measurement. So, C is for capacitance, L for inductance, X for reactance, B for the magnetic intensity, Z for the impedance and Y for the admittance. So, these are the different modes or measurement modes that we have in the impedance analyzer.

We can see that the potential difference that will be applied across that sample and the frequency. There are 4 probes for measurements. There are two end effectors across which the measurement of impedance is done across electrodes.

These kinds of instruments using four probes are called four probe measurement or four probes sensing, etcetera. It is also called as Kelvin sensing. What is the difference between a four-probe sensing and the two probes sensing? You can see here in the LCR meter there are only two probes like an ammeter or a voltmeter. We know that when we are going to measure the impedance of an instrument or a sensor that we have fabricated using a four or using two of these probes, we will be contacting it to the surface. So then, we will start flowing a small amount of current through it or applying a potential difference across it and based on the V by I value, we will be measuring the absolute impedance.

To get the phase or the proper impedance with phase, we will be doing phase sensitive V by I ratio to get the impedance. In this case, when we go for the lower assistance or lower impedance measurement, what happens is due to the contact resistance between the probe tips as well as the device under test, DUT, there will be a variation in impedance that we wanted to measure and there will be a loss of accuracy.

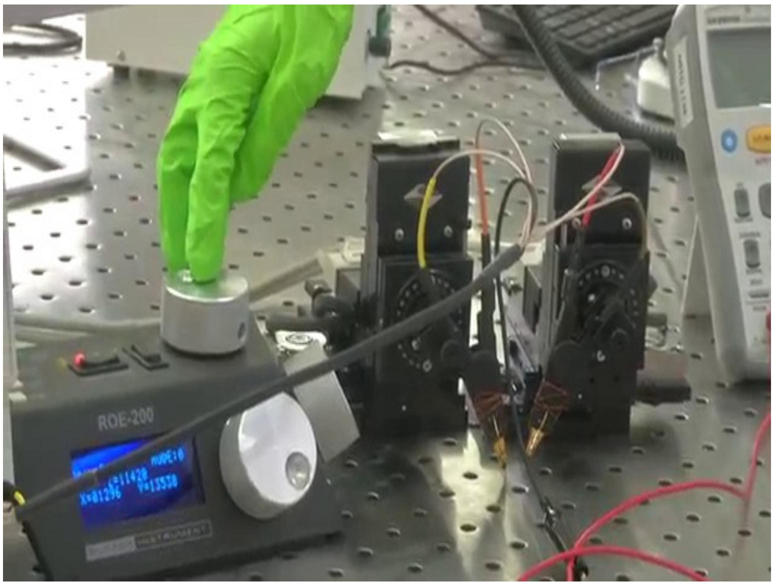
A four-probe instrument does something different. Out of these four probes, a pair will be called as force cables or force probes and the other will be called sensing probes. What force probe does is it will pass a current through the system or the DUT and which will cause a potential difference to be developed. When this happens, the potential difference that is applied will be dropped across the DUT as well as due to the contact resistance.

At the contacts, there will be voltage drop as well as across the device. That contact resistance would cause a huge voltage drop in some cases, especially when we are measuring devices with very low impedance. That error will increase, and the measurement will be invalid. What we have here is a four probe and in case of four probe what happens is the current or the potential is applied across the forcing probes.

The voltage drop will occur across the DUT and using the different sense probes, we will be measuring the actual potential drop across the DUT. We will be avoiding the contact resistance of the contact loss in the sensing. Whatever value we get will be free of contact resistance and whatever impedance measurement we can get out of this will be perfectly accurate.

The first step we need to do after switching on the device is, we need to calibrate it. There a calibration button. There will be another screen coming up which shows OC trim as well as SC trim and measure. OC trim means Open Circuit trim and SC trim means Short Circuit trim. What OC trim does is it will check whether the instrument is truly open. If the two probes are not in contact, it means that the circuit is open. OC trim checks whether the circuit is open and calibrates the device according to that.

We must press this F1 button corresponding to OC trim to calibrate it based on open circuit. When we press the F1 button, that is OC trim, it asks for frequency range. We will test it for all frequencies or F5 button. After this, we are going to test for the SC trim or the short circuit trim. We need to ensure that the probe tips are in contact as we press the F2 button. We will give for all frequencies. After this, we can observe that both are done, and we can go back to measurement. There is an extra probe for ground connection. This is to ground the instrument to the reference for the protection.



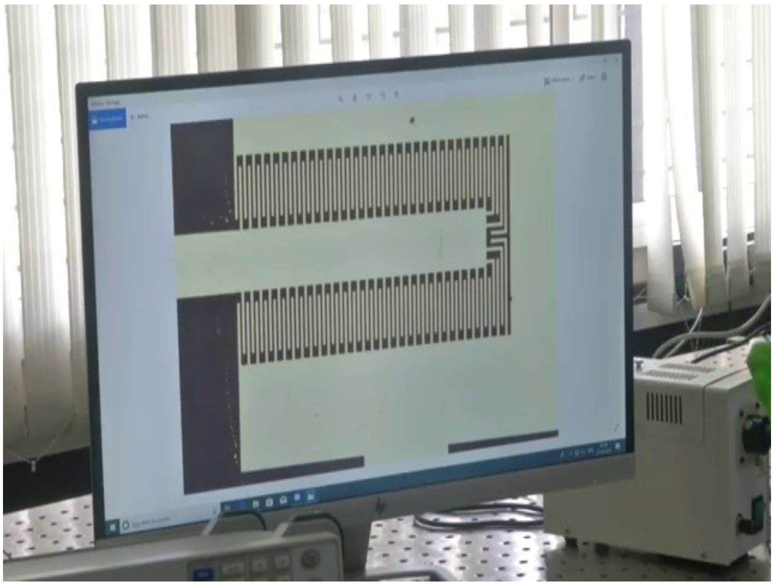
The micromanipulators are on the right, the two black boxes which are connected to the probes. The silver knobs are the controls to the micromanipulators and you can move them in the X, Y and Z planes, we have the devices relative position with respect to X, Y and Z planes.

We can change between the two since there are two of them. We can individually control each of them as well in all the 3 planes.

We will connect the impedance analyzer to the PC and check the measurements and plots. We have an LED here which will show us which micro manipulator we have connected to the instrument. If it shows the yellow one, it is the micro manipulator on the left and if I press this button, that is used to switch between the micro manipulator, the red led glows and it’s connected to the right one.

We can connect it to four micromanipulators using this controlling unit. When we rotate the knobs, the micromanipulators move. Depending on the speed of the rotation of the knob, the speed of the micromanipulator is also controlled.

A magnified version of the sensor is shown below.



If we cover the electrodes with fluid, it will cover the electrodes and we can measure the impedance of the fluid. we need to test a fluid on this chip or the electrode. Since this is a plane, we cannot hold a fluid. We have fabricated PDMS wells over this inter digital electrode so, that we can pour some fluid onto it.

Now that we have connected the microchip to the manipulator, we will be loading a sample solution into the chip and we will show you the measurement on the PC screen as well as the impedance analyzer. After connecting the microchip, we take a micropipette and pipette 50 micro litre of salt solution to show as a test specimen and load it onto one of the wells.

The software is called LCR. You will be seeing some connecting errors. It is because we have to select the communication port that is being connected from the impedance analyzer.

We must give the COM Port to which the impedance analyzer is connected. In this case, it's COM Port number 5. We connect and exit. Now the impedance analyzer is connected and no error will be shown. We now select plot mode. Here, you can see different options and the values that we can enter. We can control all the features of the impedance analyzer using this software.

You can see the term level or the voltage that we are going to apply across the test sample. Here it is 10 millivolts. We can change it but usually for biological samples as well as testing, we use it as 10 millivolts. Next you see a drop down having many options. It is to select whether you want to record capacitance, inductance, reactance or impedance and even DC resistance.

We are going to select impedance here. Also, we can select a second item to be plotted together. So, when we select the impedance as one of the parameters, the other parameter we have is the phase angle.

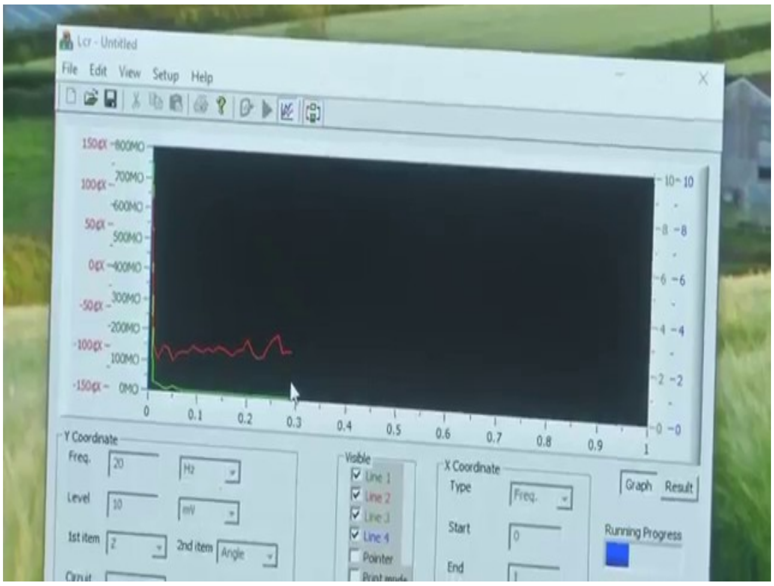
We have another option, speed of measurement; so, it is slow, medium, fast and maximum. depending upon the speed, the accuracy will also change. You can see that lines are visible; Line 1, Line 2, Line 3 and Line 4 which are of different colors.

Different colors mean we can plot four different color lines; if we select all of this together, we can untick them if we need. If we are just measuring impedance, we can plot the sweep four times. If we are plotting both impedance as well as phase angle, then we can plot it twice because we are using two lines each time.

We can see the plot in the impedance analyzer is impedance or phase versus frequency or the voltage. The lecture shows sweep across frequency although we can do a voltage sweep as well. Since we are using GW Instek 8105, we can go from 0 Hertz to 5 Mega Hertz.

We select 0 ohm as the lower frequency and type in 1 and select Mega Hertz from the dropdown as the higher frequency. We can select Hertz, kilo Hertz or mega Hertz. This means that we are going to have a frequency sweep and measure across 0 to 1 megahertz. We can know the number of points across which we should do the measurement and save it. Since we have the option to export this data as excel, if we give 100 points, we can save 100 values between 0 Hertz to 1 mega Hertz.

We will be connecting the measurement chip to the impedance analyzer. Now that we have connected the microchip to the impedance analyzer, we are going to start drawing the graph. There is a draw button which must be pressed.



In the above graph, the red line shows the phase and the green one shows the impedance value. At the same time, we can see the change in the value on the impedance analyzer. Now that we have got the plot, we can draw again. So, that we can take the measurement over or also we can export this file to excel.

It will have the data, all the data, that we have recorded as of now; it will have the frequency, the impedance value and the angle. This is how we use an impedance analyzer for the measurement of impedance and for the testing and calibration of the different sensors and components that we will be fabricating.

The LCR meter will have lesser accuracy than that of the impedance analyzer and it also does not have too much frequency sweep as we saw in the impedance analyzer. We can change between the different modes as, L, DCR, C, R etcetera. If we are connecting these probes across the measurement or the DUT, we will be able to measure the data and we will be able to see this real time on the device. This is how we measure using the LCR meter.