Fundamentals and Applications of Dielectric Ceramics
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Module No # 08
Lecture No # 39
Principle of Piezoelectric and Pyroelectric Materials

So welcome again to the new lecture of the course fundamentals and applications of dielectric ceramics. So let us just briefly recap what we are doing in the last class.

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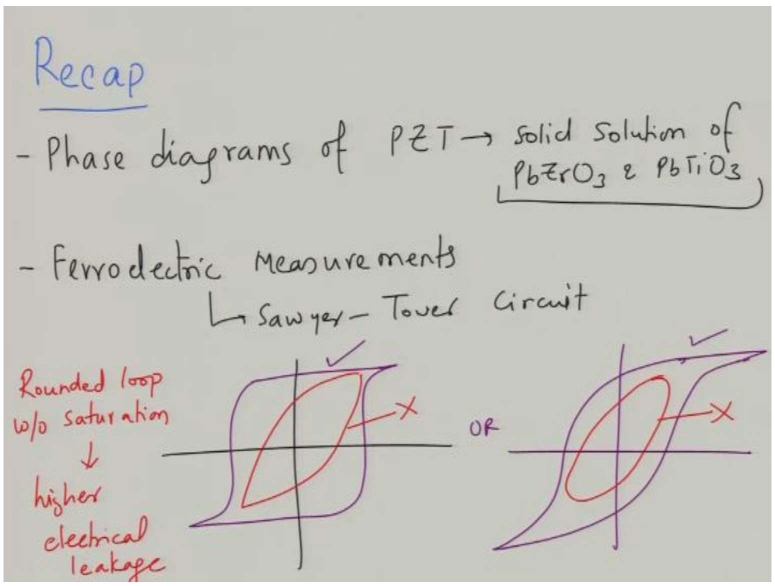

So in the last lecture we were talking about we finished our discussion on phase diagrams of PZT for example which shows which is a solid solution of a $PbZrO_3$ and $PbTiO_3$ both are peroxide structure compounds and they make a extended solid solution. And the important thing about this phase diagram is that it contains the morphotropic phase boundary at 47-53 or nearly 50-50 composition at which both rhombohedral and tetragonal phases co-exist as a result as a result of co-existence of two phases that dielectric constant is very high as well as the polarization is very high.

And this is the so near 50-50 composition are most useful composition of PZT. And this is by far the most successful piezoelectric for various application. And then we were looking at the details of ferroelectric measurements. How do we make ferroelectric measurement? We saw that the ferroelectric measurements are made using something called as Sawyer-Tower circuit and the important thing is to make these measurements is in such a manner that so such that you do not consider RT effects are as a real ferroelectric.

So a good ferroelectric loop would be something like shown. But if you have a ferroelectric loop like this for example so this is these are good ones these are good ones. But if you have something like this let us say then this is bad ferroelectric loop. If you have something like this, this is a bad ferroelectric loop. So when you get these bad ferroelectric loop then you must make measurement at different temperature to see what is the intrinsic contribution.

Because if you have a rounded loop generally so rounding basically you can say the rounded loops without saturation have higher electrical leakage which means sample is of poor quality it contains defects. It contains entity which give rise to high leakage as a result often one needs to low temperature measurements to distinguish between the ferroelectric contribution and the leakage contribution.

And even at low temperature there is a possibility that you may not get saturated loops. So you must be aware of what is good and what is bad? And do not report the bad loops as a ferroelectric loop. So now let us go to the details of this lecture. So here so we would like to so we have seen ferroelectric measurements.

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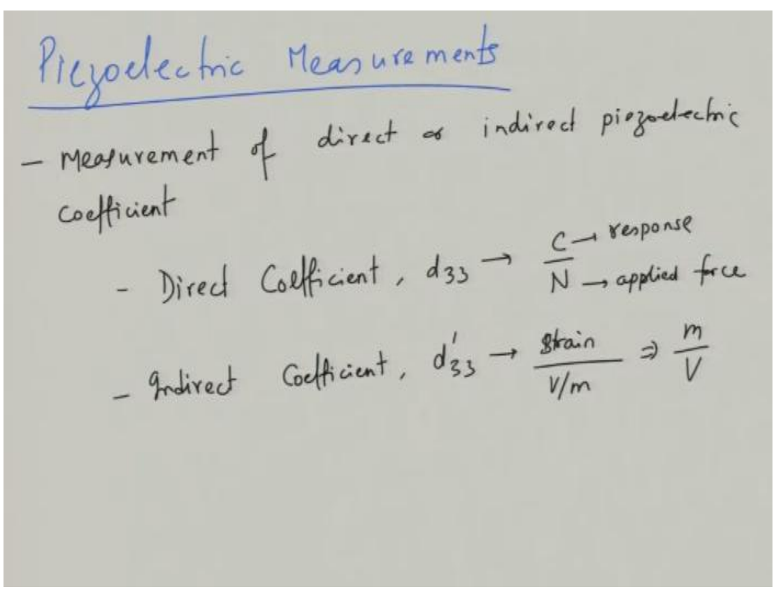

Now next we move on to how we would make piezoelectric measurements? Now piezoelectric measurements are basically based on measurement of direct or indirect piezoelectric coefficient. So direct so you can see that direct piezoelectric coefficient is and the most common of them is to d33 measure d33 ok. So d33 is nothing but you can say so direct piezoelectric coefficient is when you apply stress you measure the polarization.

So basically your measuring coulomb versus per neutron of force that is what is the direct coefficient. So basically the polarization is the response and force this is the applied force. So this what is the direct piezoelectric coefficient and indirect piezoelectric coefficient would be so let say indirect would be d33 prime let say it would be the when you apply electric field you are measuring that is strain. So that is basically you can say strain divided by V/m.

So basically what you are measuring is m/V. So how much is the change in the length that you have observe or change in height that you observe upon a application of a certain voltage. So this is what is the indirect co efficient and there are various methods which achieve this.

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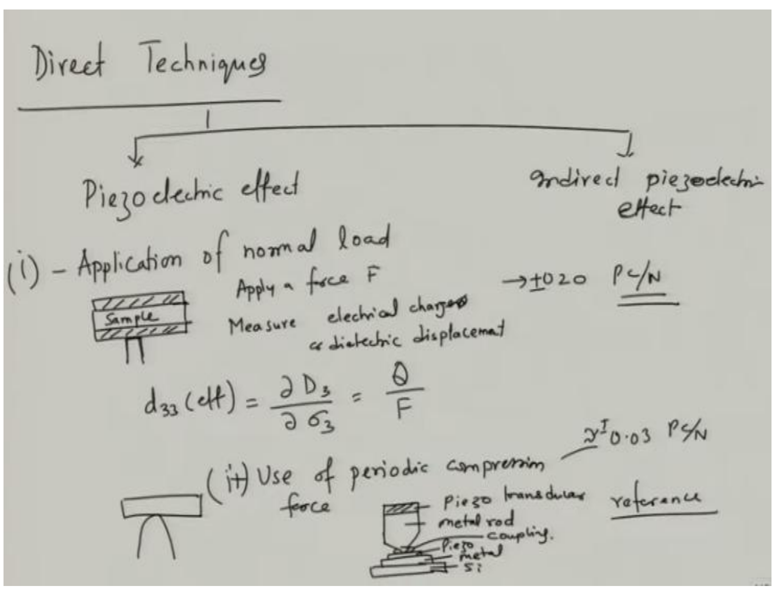

So in piezoelectric case there are direct techniques such as direct techniques also you can have two of them. So you can have piezoelectric effect and you can have indirect piezoelectric effect. So among these also we have lot of techniques. We have just the technique based on the application of normal load. So basically what you would do is that you have a sample which is so this is your sample.

Sample is sandwich in between two electrodes you will apply mechanical load and then you will measure the basically for the force. If apply a force ‘F’ and you basically measure the electrical charge or dielectric displacement as we say. So basically d33 effective in this case would be:

$$d_{33}(eff.) = \frac{\partial D_3}{\partial \sigma_3} = \frac{Q}{F}$$

This is very simple method but the problem here is the tips when you apply force using a tip that tip has to be in contact. And also how the so generally what happen is that in these sample that the tip is the so this is for example we do in the piezo force microscopy. Generally, the tip is not flat and tip tends to be so if you have a sample the tip tends to be like this.

So we there is a problem in calculating the effective area which is of contact and secondly the electric field distribution within the sample that is rather uncertain. So this is but this is easy technique to measure the piezoelectric effect. And the second method that is used is what we call as periodic compressional force use of so this is first so the second one would be use of periodic compressional force in this case what happens is that there is a piezoelectric transducer.

So this is a piezoelectric transducer which is in contact with the metallic rod. So this is the metal rod and this rod is then in contact with so on the bottom we have silicones we have substrate let say silicon on the silicon we have metal and then we have a piezoelectric so this is piezo and then in between we have what we have called as a coupling liquid. So using the piezoelectric the vibrations are transferred using from the top metal to the piezoelectric and that is how you measure the charge.

Now this uses the coupling liquid to ensure that the charges which are generated our over the uniform area and the force distribution is small and then you also compare this to the reference. So you use the reference sample to make measurement. So that you compare the charge generate in the normal sample with respect to the reference sample. So this is a good method but it is not very easy to make because you can see that use of liquid and stuff like that which make it complicated.

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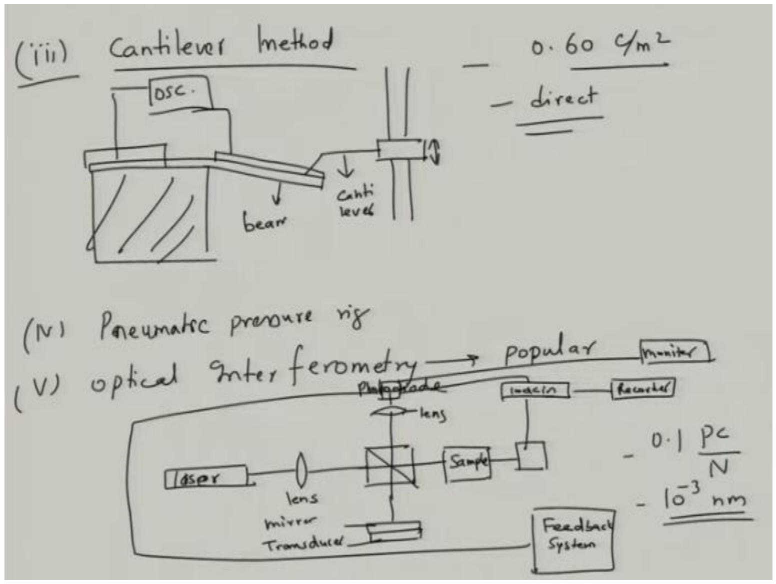

And thus this is the second method and the third method among this is called as cantilever method this is the most common method. So in the cantilever method you have a cantilever which is pushed against a pointed let say is a cantilever which is moved up around and this cantilever pushes the. So this is sort of a strain beam kind of you can say kind of a cantilever.

This is let say the cantilever and this is the beam on which your sample is quoted let say and then this is connected to your what you can say and a lower some where here and then this is connected to a oscilloscope. And you measure the basically the displacement of the by using by moving this cantilever up and down you measure the displace displacement. So this is very easy method but again the problem is the strain produced may not be uniform and there could be a problem with different kinds of samples.

So you have to use a silicon cantilever on which you have to quote the film. So when you quote the film is the certain quality but when you make a real sample, the real sample quality may be different as compared to what is quoted on the beam. Those are the issue that may be there. There are other methods which are also there is a pneumatic pressure rig measurement and there is also what we call as optical interferometry.

So optical intro interferometry is a popular method nowadays for measuring the piezoelectric coefficient what happens in this case is in optical interfere in case of optical interferometry is you have a laser and this laser goes to the lenses and then it goes through a beam splitter let say this is beam splitter and then this laser falls in a sample and then using the beam, beam splitter the laser also goes through the lens to a photo diode.

So here we have a photodiode so this is lens this is also lens and then this photodiode is connected to what we call as a to a feedback system. And then this laser through a beam splitter is connected to a reference mirror. And so we have a mirror and then here we have a transducer. And when the laser falls on the sample under the load it generates the signal. This signal goes to lock in amplifier, so we have lock in here.

And this lock in is connected to some recording device and then this photodiode takes signal from lock in and then this goes to the monitor or oscilloscope or what ever it can be. So basically you are measuring the oscillation of the surface of the sample using a laser beam here and you were comparing that with a reference sample and that is how you make the measurement of.

This is the technique which is used in nowadays in a few commercial samples especially for thin film measurement because direct measurements are not easy to make on thin film samples they are more suitable for bulk sample or thick samples. Whereas for thin films very thin film the optical interferometry method is more popular.

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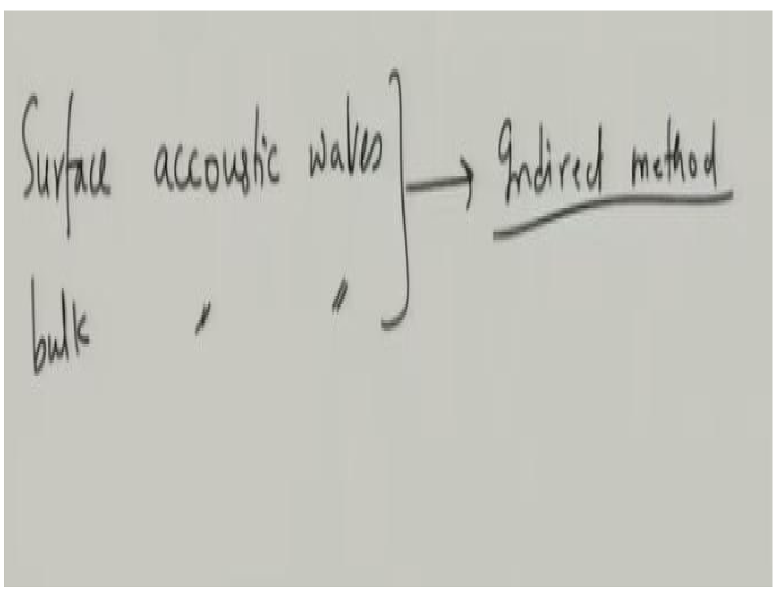

So these are certain methods for making measurements of a direct type and so and then we can have measurements related to surface acoustic waves or bulk acoustic waves these are typically the indirect methods. So they are basically coupling of acoustic wave so respective the sample which are used to measure the piezo response. So in case of single beam in case of optical interferometry the resolution can be quite high.

So we can measure up to about 0.1 pC/N. So this is fairly high resolution and the displacement that can be measured of the order of 10^{-3} nm range of displacement. So very accurate method if you on the other hand if you look for cantilever method, cantilever method can measure up to about 0.6 C/m^2 resolution. It has pretty high sensitivity 0.6 C/m^2 is pretty high sensitivity.

And you can convert this into $\mu C/cm^2$ and that that tell you that this is quite sensitive method and it is also direct. So it is very useful method. And then if you look at the application normal load this has a load accuracy. This has a accuracy about $\pm$ 20 pC/N.

And the periodic force the periodic compression is about 0.03 pC/N accuracy pretty accurate but little difficult measurement to make because of the use of the liquid and things like that. So among direct methods the popular methods are a application of normal load and cantilever method and the optical interferometry method. Whereas among the indirect method surface acoustic waves or bulk acoustic wave type of methods are more important basically based on resonance and so and so forth.

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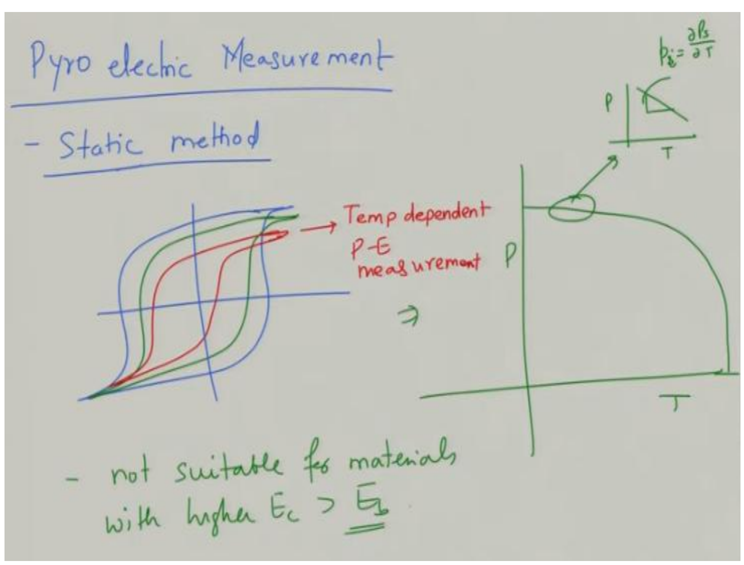

Now let us look at the pyroelectric measurements. So in case of pyroelectric measurements what we are measuring here is basically there are again two methods one is the first method is called as static method. In the static method what you are doing is that the measuring the hysteresis loop is the function of temperatures.

So let say you measure the hysteresis loop at one temperature then you measure the hysteresis loop at the another temperature and so on and so forth. So basically, you make temperature dependent P-E measurements and then from this you can plot what is the this can lead to what is the plot of polarization as the function of temperature.

So you will have a plot something like this, for a second order phase transition and then for a the change in polarization let say if you zoom this section then you can so this is P versus T from this determine what is P:

$$p_i = \frac{dP_s}{dT}$$

the slope can give you from the linear region the change in the pyroelectric coefficient. But the problem is that it is in this case it is not suitable for the material of higher coercive field.

So which is which could be higher than their breakdown field. So if the if the coercive field is very high specially more in the breakdown field then it is not then it is leads to conduct conducting samples and sort of a very useful measurement. Another measurement this is called as dynamic method.

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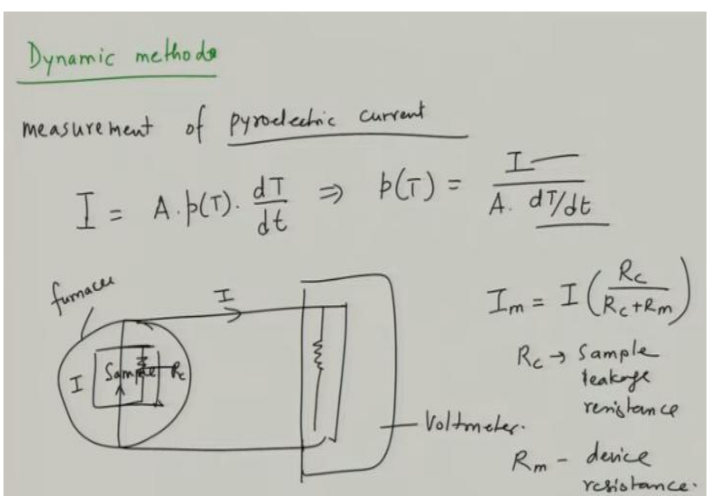

This dynamic method is basically measurement of you can say the pyroelectric current. So when you have this spontaneous varying spontaneous polarization as a function of temperature this varying spontaneous polarization causes the change in the current which is the pyroelectric current in the measurement of this current basically. So what you have here is this this current is basically you can say into so if you look at this is the pyroelectric coefficient this is temperature and you have to multiply by the times, where q = I.T.

From this you can measure what is the pyroelectric coefficient which is I/A the area of sample multiplied by the change in temperature as the function of time. So the measuring current as a function of changing in temperature with respect to time and basically this is the ways simple circuit what you have here is you have a sample here which is let say the sample.

Sample will have certain resistance and as a result you have certain current passing through the sample this is basically it is kept in a oven which is or a furnace with the controlled scam rate and then you have a basically you can say on this side you have voltmeter and you measure the current which is flowing in this direction. So taking through a voltmeter to measure the current.

And so if you have a circuit like this let say the resistance of the circuit sample is let say R_c and then resistance of the measuring circuit is R_m then we can say I_m will be:

$$I_m = I\left(\frac{R_c}{R_c + R_m}\right)$$

Where R_c is the sample leakage resistance basically and R_m is the device resistance. So you can see that what you are interested in measuring.

So this is a simple measurement of pyroelectric current is the simple way of measuring the pyroelectric coefficients. And there of course there are other method such as laser intensity modulation method and so and so forth which you can get into details. Now what we would like to do that is we have discussed the ferroelectric the physics of ferroelectric materials, the pyroelectric materials, the piezoelectric materials, the mathematical expression, the phase transitions the kind of crystal structure they have.

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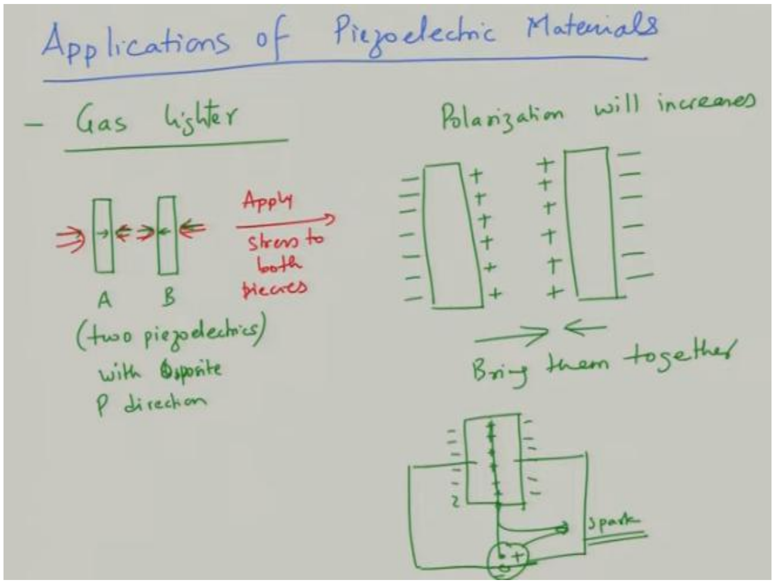

So about the now let us look at certain application of these materials so you can say first we will look at the application of piezoelectric materials. So let see some of the piezoelectric materials the applications. So the first application let us consider that is of gas lighter which is very simple application just to light the gas by generating the pyroelectric current in the circuit.

So let say what does this require for this lighter so what does this require you need you need two piezoelectric pieces. So let say A and B these are two piezoelectric samples we take it in such a manner so that their polarizations are reversed. So let say one is this polarization another is this polarization so two pieces with opposite P direction.

So we need to take these two samples let say in this sample you have up in another sample you have down and then when you apply the stress so then you apply the stress to them. So let say you apply stress to this stress let say in this fashion. So then you say you apply stress to both pieces. So when you apply stress to both pieces so you will develop the polarization. So let say one of the samples has the charges like these and so another sample will have charges like.

When you apply stresses the polarization will increase. So you can say polarization will increase and what will polarization increase means? Polarization increase in that you have increase in the surface charge density. So your surface charge density increases and then what you do is that you bring them together. So now you can say sorry bring them together how do you bring them together?

You bring them together because the same charges will come together so basically when you same when you bring the same charges together like this. Then these charges let say here this will generate a spark when the when they are press together they will generate a charge and this will basically lead to you so you will have a circuit connected and this and let say this is the circuit which is the positive charge from here you will flow the negative charge.

So this is the negative charge and hence this will generate the spark. So this will across the gap when the charges is combine together it will generate the so this is where we will have the spark generation when you bring them together. So basically you take two pieces of opposite polarization applies stress create more polarization bring the same charge faces the same sign of bring the opposite faces together.

So that the positive-positive faces are front of each other or negative-negative faces in in front of each other. So positive charges will flow to one direction negative charges are taken through the outer circuit. So the positive negative will meet with each other they will create a what we call as a spark. So this is what this gas lighter going to work like.

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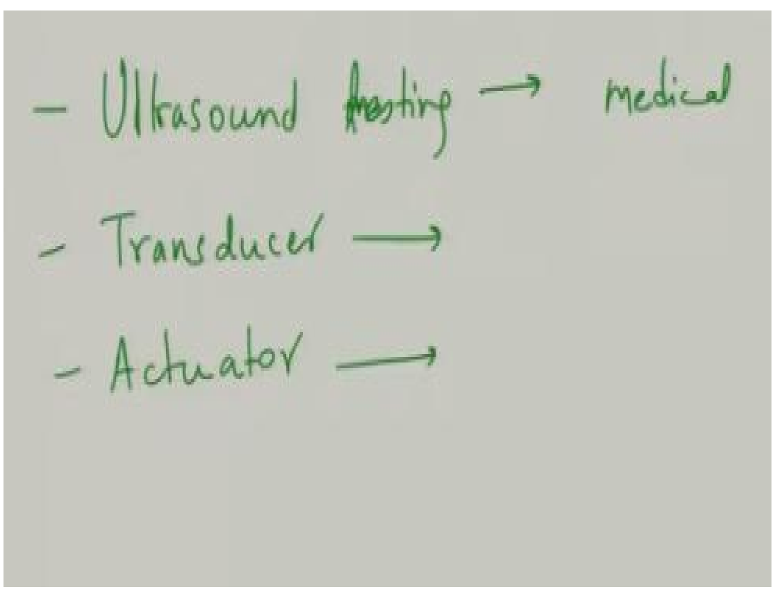

Now there are another application as well piezoelectric is very useful materials. It is used for other application such as you know if you know the ultrasound measurements. Ultrasound testing it works as a transducer it works as a actuator. And so the ultrasound testing basically on the principle of generation of detection of ultrasound waves which are generated using to piezoelectric. So they are very useful for medical applications.

Transducers are the once where you create a transduction. Transduction means create a linear motion. So wherever you want to create a linear motion you can create use a piezoelectric actuation means you provide actuation and then you can again set some motion related device you can create a actuating device. So we will look at some of the application in the next class. So what we have discussed in this class is basically the principles of measurements of piezoelectric and pyroelectric measurements in very brief manner and now we are going to and then we looked at the application of piezoelectric. We will continue on the application of piezoelectric and pyroelectric as well as ferroelectric in the next lecture.