Fundamentals and Application of Dielectric Ceramics
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Module No # 08
Lecture No # 40
Application of Piezoelectric and Pyroelectric Materials

So welcome to the new lecture of this course fundamentals and application of dielectric ceramics this is probably going to be last lecture of this course. So we will focus on some more applications of these materials and then we will just summarize the course in this lecture.

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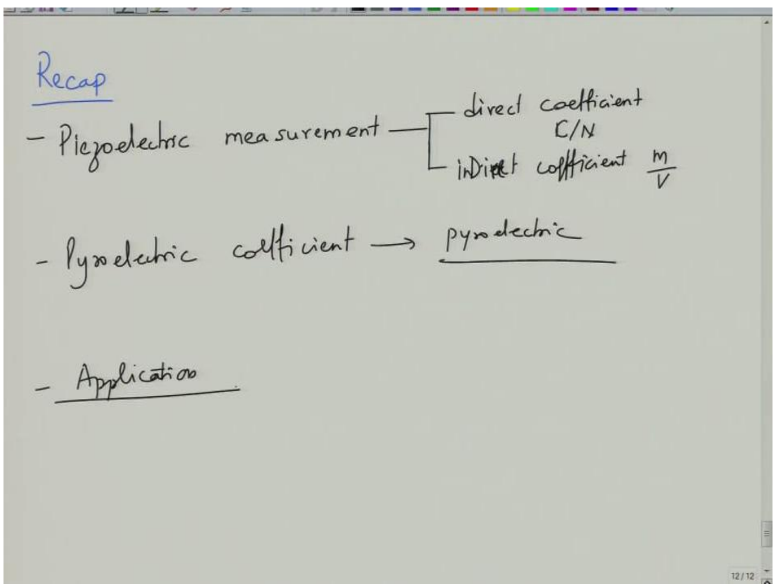

So let us just recap the previous lecture briefly in the previous lecture we learnt about the piezoelectric measurements what are different types of piezoelectric measurements which are basically aimed at measuring the direct coefficient which is basically you can say C/N or they are measuring at indirect coefficient that is m/V and then we looked at how do we measure the pyroelectric coefficients.

Pyroelectric coefficients they are generally measured using measurement of pyroelectric current and there are few methods in direct coefficients such as direct cantilever method or direct cantilever method direct load application method and the inter ferro methods laser method. So these are most common methods to measure the piezoelectric coefficients using and then we were looking at the applications.

And we looked at one application of piezoelectric material which is in case of which is basically about the running the gas lighter.

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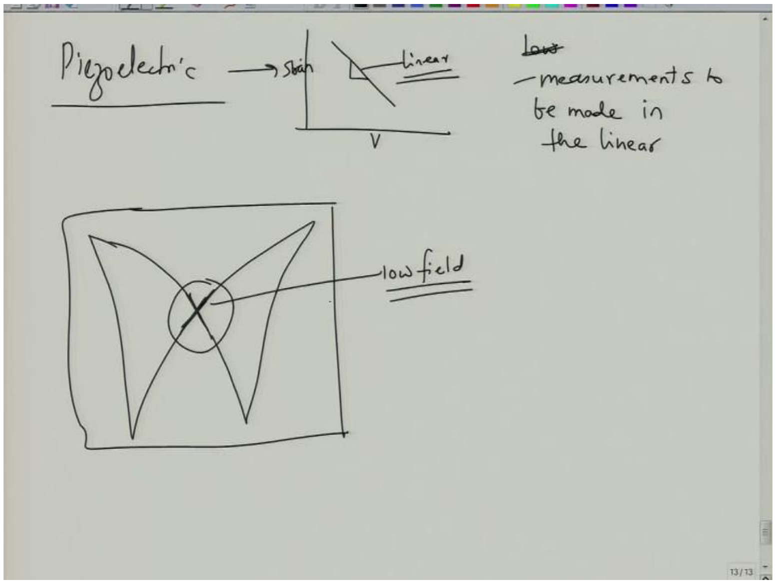

One thing which we forgot to mention is that when you make piezoelectric measurements you have to ensure that you are measuring the slope of basically the strain versus voltage or the charge versus the force. Basically the measurement should be made in the linear region so linear region requires that the measurement is made at smaller voltages or smaller forces otherwise the when if you go to non-linear region then the measurement may be wrong.

So basically you are looking at measurements to be made in the linear region so for example if you measure for a ferroelectric we measure generally a butterfly loop and this butterfly loop will have linear region somewhere here. So if you measure for example at very high field you may get now linear region so you have to ensure that you make measurements at low fields. So low fields measurements are required to make the measurements of indirect piezoelectric coefficient.

Similarly low force measurements will be required to make the measurements of direct piezoelectric coefficient so basically you are looking at the linear region measurements.

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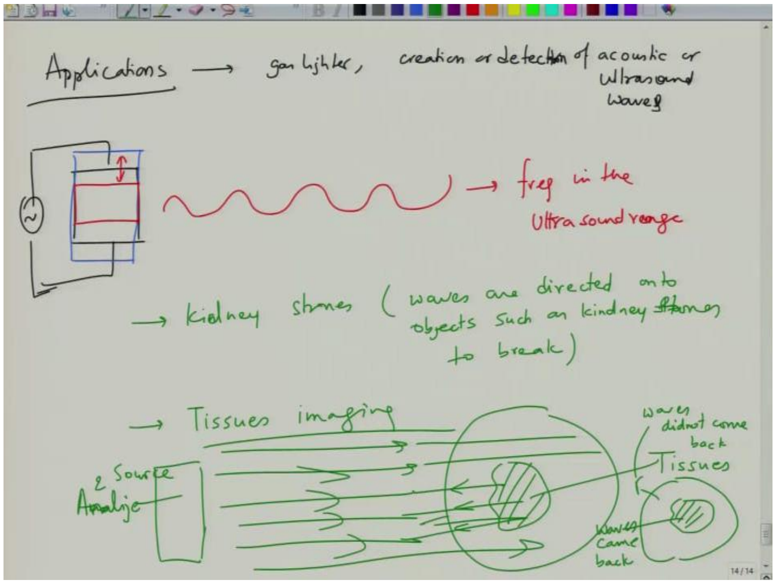

Now let us come back again to the application of piezoelectric, they are useful for gas lighter simple application. But they are most importantly useful for application such as creation or detection of acoustic wave acoustic or ultrasound waves. So for example let us say this is a piezoelectric if you apply field to it which means at some point it will become longer at other point it will become shorter.

So this size will change depending upon the signal sign of the signal so when this change that sign it creates what we called as these kind of waves and these waves have frequency in the ultrasound range. So what you can do is that you can use it for various methods for example nowadays we brake it we use it for braking things like kidney stones. These waves can be directed on the kidney stones to break them so basically waves are directed onto objects such as kidney stones to break them and once they break them in smaller pieces then they can come out through urine so this is something that is possible.

So another thing which ultrasound waves are useful for is for example tissue imaging so for example if you want to image the kidney if you want to image the internal body parts. So let us say some body parts here and you throw these ultrasonic waves so in the body let us say so let us say this is the tissue. It could be for example a baby it could be something else so wherever you have fluid you do not have tissues the waves will pass through.

But wherever you have tissues the part of the waves will be reverted back alright and the waves which are reverted back again analyzed using a analyzer here. So you have a source and analyzer here so by looking at the reversal of some of these waves you can construct a image you can see that which of the waves from which region is the waves are not come back and which from other regions the waves are come back and accordingly you can find you can construct a image.

Let us say image you will construct so from this region waves did come back so this is the region waves came back partially or completely and from this region waves did not come back. So this is how you can form the images by using image processing and this can lead to imaging of tissues babies and various internal organs in the body. So these are very important applications of piezoelectric materials both invasive as well as non invasive methods.

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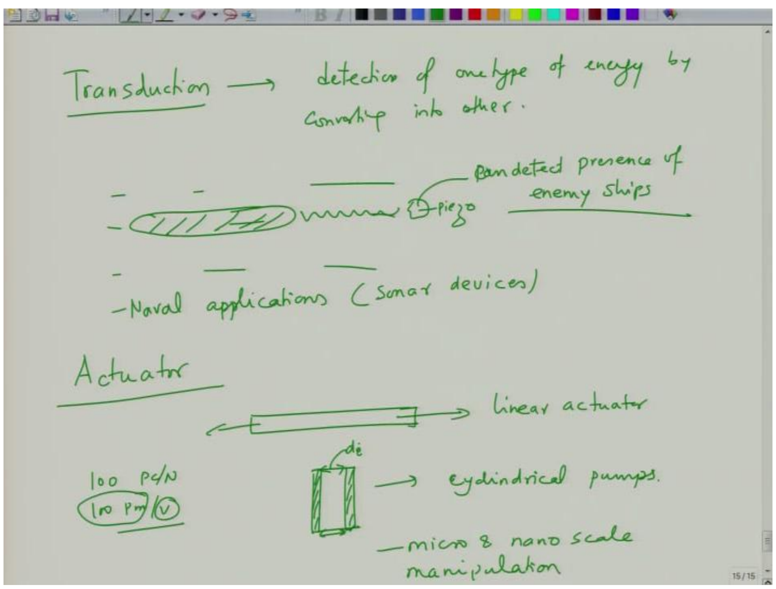

Similarly piezoelectric also used for transduction is basically you can say detection of one type of energy by converting into other. So for example let us say you have this sea and within sea you have these kind of torpedoes or you know objects. So these are all let say enemy torpedo if you have piezoelectric somewhere here this is a small piezo these have sudden since they make mechanical vibrations they lead to acoustic waves.

These waves can be deducted by piezo’s can deduct presence of for example enemy ships because of by look at the vibrations in the sea. So the sea creatures will have different frequencies of vibrations as compared to the these moving things like ships and torpedoes and any other objects inside the sea. So they can be used to deduct for example there is a lot of naval applications used naval applications which are called as sonar devices.

They use these piezoelectrics for deduction of these waves similarly they can also be used actuators. Actuators could be let us say you have a piezoelectric rod it can be applied voltage in such a fashion so that this you have this linear transduction linear actuations you can have linear actuation you can have cylindrical actuation. So you have a cylinder let us say of a certain thickness and let us say you wanted to change this diameter d_i.

So by applying the voltage you can change the length as well as diameter of this so this would be cylindrical actuator. So wherever you want change in dimensions either in lateral directions or in circular directions or whatever directions you can use these piezoelectrics because they work at very small voltages and the good thing about them is they can be used for actuation at micro at nano scale.

Because you can control the movement of these at those scales by applying very small voltages because you can see that you know the most of the piezoelectric have this piezoelectric coefficients. For example let us say 100 pC/N or 100 pm/V for a 1 volt of voltage applied you can have a displacement of 100 pm which is nothing but 0.1 nm.

So basically you can make nano manipulators micro manipulators scanner devices we can say these micro and nano scale manipulation that is eas that is easily achieved using a piezoelectric material. For example atomic force microscope uses piezoelectric for manipulation so these are certain applications of piezoelectric materials.

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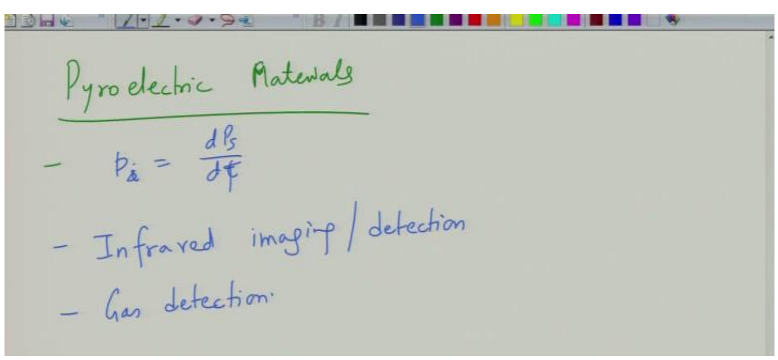

Now let us get back to what we look at for let us look at the application of pyroelectric materials. Pyroelectric materials as we saw earlier they are based on basically:

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

change in polarization as a function of temperature. Now piezoelectric pyroelectric materials can be used for a variety of applications for example they can use they can be used for infrared imaging slash detection. They can also be used for gas detection and so on and so forth so let us see an application of pyroelectric.

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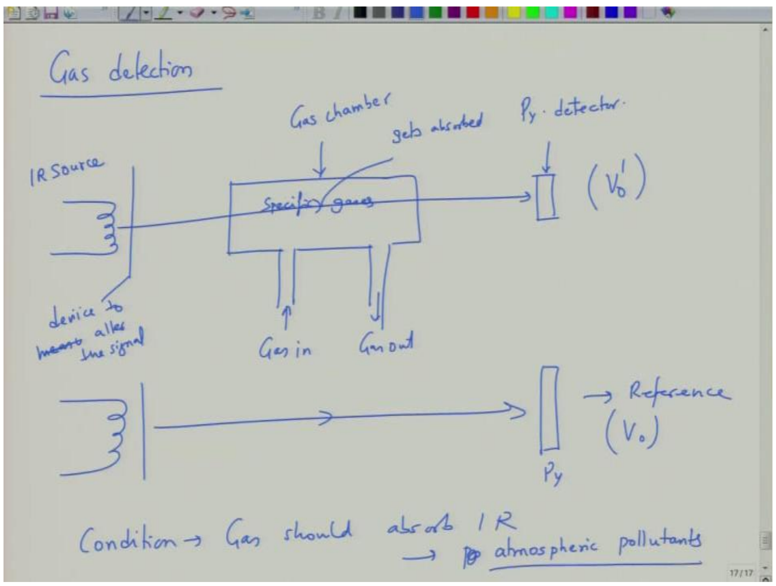

So let us say first let us see we look at the gas detection or so let us say we have IR source this is let us say IR source and this IR source is basically you can have a device to alter the signal. You can measure the intention the intensity or you can create a continuous signal or you can have a pulse signal and so on and so forth. So basically IR source followed by something to change it is and then let us say we have a chamber in which we have so let us say this is gas chamber.

So here we have gas in and we have gas out and then we have let say here so we have the pyroelectric detector and basically what happens here is you have a particular gas let us say specific gases which observe a specific kind of radiation. So here we are talking about IR source and we have what you do is that you first create IR source directly to a piezoelectric.

So this becomes sure reference there is nothing in between the IR goes directly using whatever chopper etc., you have directly to the detector. So similar kind of IR goes to detector pyroelectric detector which is used as reference and then you look at you basically pass this IR through the specific gas and this specific gas will lead to some sort of absorption or whatever and then IR is detected IR is nothing but it will cause heating.

So it will cause heating to the pyroelectric as well as it will change in the polarization and when it brings change in the polarization basically you will change the voltage. So you are looking at the change in the voltage by the radiation which is passing through the gas and this depending upon the presence of gas how much gas is present how much the radiation is absorbed. You will have different changes in the voltage and that is how you can calibrate the system with respect to the reference you can measure the concentration of gas.

So when you fire the radiation so when the first time in the radiation goes from here it does not go through anything but when the radiation goes from here it gets absorbed. So obviously you have to have a gas which is which basically absorbs IR radiation if you have a gas which does not absorb IR radiation then it is not very useful so if condition is gas should absorb IR so certain kind of gases can be absorbed.

So correspondingly you will have a voltage with respect to reference and then you will have V_0' which is different from the reference depending upon absorption and correspondingly you can measure the you can calculate the so this is basically used for pollutant kind of gases which absorb IR like higher absorbing gases are things like CO_2 and so on and so forth which are pollutants not every gas absorbs IR. So you cannot use it for every kind of gas but it is useful for atmospheric pollutants and then let us look at another application which is in the which is basically the infrared.

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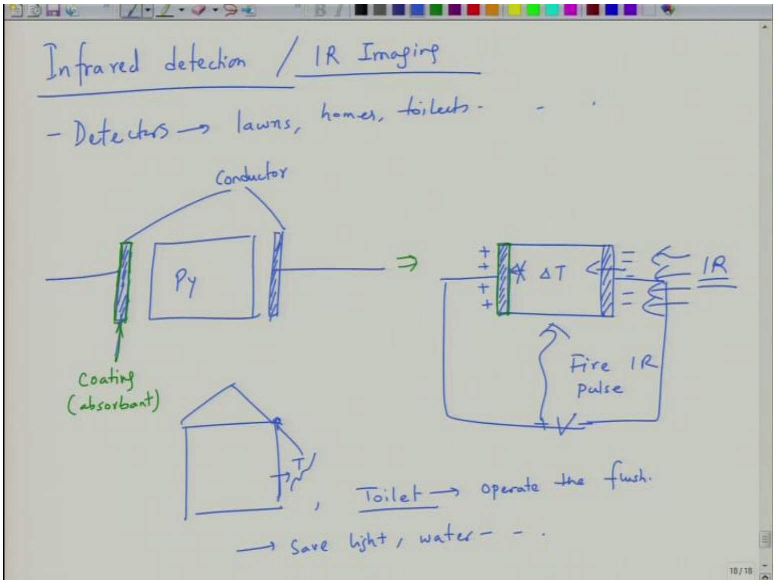

So another application which is used for you which these materials are useful for are infrared detection and they are basically the detectors which are present in things like so these detectors are found in lawns, homes, toilets, variety of places. So basically what you have here is you have a pyroelectric which is so you have two metal pieces these are let us say conductors this is a pyroelectric and this conductor is coated.

So this is basically a coating which is absorbent coating so and you connect them together then they so now what you do is that you put them altogether. So when you put altogether bring them together so far so when you bring them together it becomes like this. This is pyroelectric on one side we have this metal just shade it here.

On this side we have another metal which is coated using a absorbent coating alright and now what you do is that you send a fire a IR pulse when you fire an IR pulse what will you do. It will increase the temperature of the pyroelectric and what will happen is that you when you fire the IR beam on the pyroelectric the transmitting conductor on this side which is dot coated allows the radiation to get in.

But the other conductor which is coated by absorbing medium it does not allow to leave it as a result you will have heating because you will have built up. So on this side you have transmittance but on this side you do not have transmittance so as a result you have built up of heat and this will increase the temperature of the pyroelectric. So when you have temperature of the pyroelectric you will develop some sort of charges you will have let us say depending upon the pyroelectric coefficient value of this thing and you will have a voltage that is generated across the circuit.

So if you want to do it more and more you can just keep firing IR pulse from this side. It could be continuous it could be pulse depending upon the application and that is how you can use IR as a detector. So for example if you have a lawn let us say you have a house here you have put IR detector here this is the front door somebody passes by.

When somebody passes by the temperature of this person will create a so basically when human body is hot it creates a IR and this IR is detected by this detector and because of change in the pyroelectric the polarization it will turn the lights on and off. So basically it can be used as a light saving devices similarly in case of toilets it can be in toilets it can be used to operate the flush.

Because when a person stands in front of the toilet the IR is absorbed by the detector and when the person leaves then the temperature drops the IR stops as a result the feedbacks circuit will detect the presence of IR and at absence of IR when the person leaves no IR is present temperature will drop then it will release the water so this can again be used for make making the water saving.

So basically this can be used to make save light, water etc., so basically emotion detectors and so on and so forth. So there are the applications similarly based on the change in the similar application we used for IR imaging. So when you go for example in the night so there are different objects at different temperatures. For example in human body itself we have different objects at different temperature and you can image this using IR camera so we will show you one image which can be used to measure this kind of thing.

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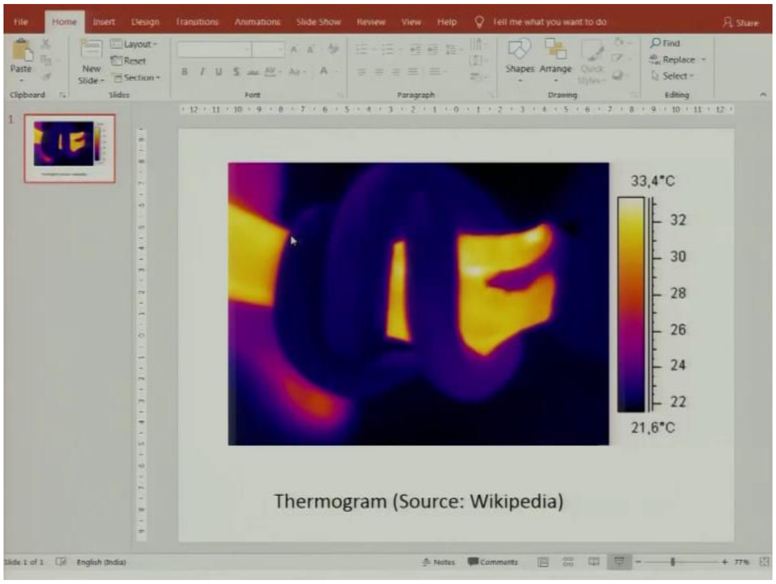

So let us say this is a image which we have obtain from Wikipedia so what you have here is it is a thermogram basically it is a image which shows changes in the local changes in the temperature. What you have you have a human hand on which there is a snake that is wound. Snakes as we know are cold blooded animals humans are warm blooded animals so you can see the temperature the human hand is at about 30-32^0C.

And the snake which is dark blue is about 22^0C so you can see this is very clearly so you can see a different color. So this goes from 22 - 32^0C you can see that all the colors there is a huge color variation which shows you that at a resolution of about 1 to 2 degree you can monitor the changes in the and this is what basically is also used for night vision cameras when you go do a imaging in the night.

These kind of materials can be used to create night vision imaging which is basically but based on temperature changes in the ambient basically thermal imaging as we call it so these are certain uses of pyroelectric material.

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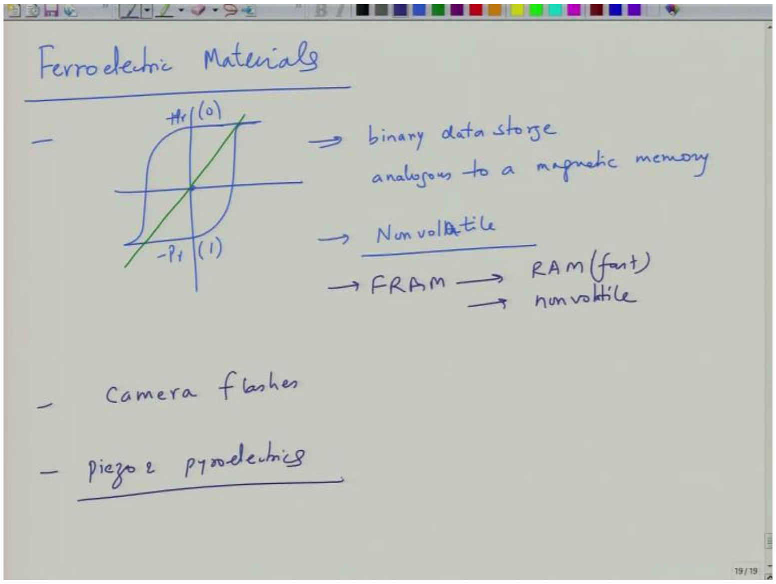

Now let us look at what we call as ferroelectric materials so every ferroelectric materials can ofcourse be used as a piezoelectric and pyroelectric and similarly every pyroelectric can be used as a ferroelectric. But in addition ferroelectric material has a very important use which is to be used as data storage so just like magnetic material it has this state of + P_r and $-P_r$. This $+P_r$ can be zero and this could be one so basically this can be used for binary data storage analogous to a in a manner analogous to magnetic memory.

And this will basically lead to non volatile data storage means the memory will not be lost non volatile. So basically the data will not be lost when the power is lost because you know this is at zero field so at zero field you have two states in a normal RAM this is the curve you have. So RAM always needs power but RAM is fast and magnetic memory slow so if you can make a ferroelectric random excess memory which will do the function of RAM because it is fast.

But it will also be non-volatile which means it will not lose the data and ferroelectrics are also used for simple application like camera flashes etc., and there of course used as piezo's and pyroelectrics. So this is what we have done in this course let me now summarize the course in this course what we have done is we have look at various aspects related to dielectric materials.

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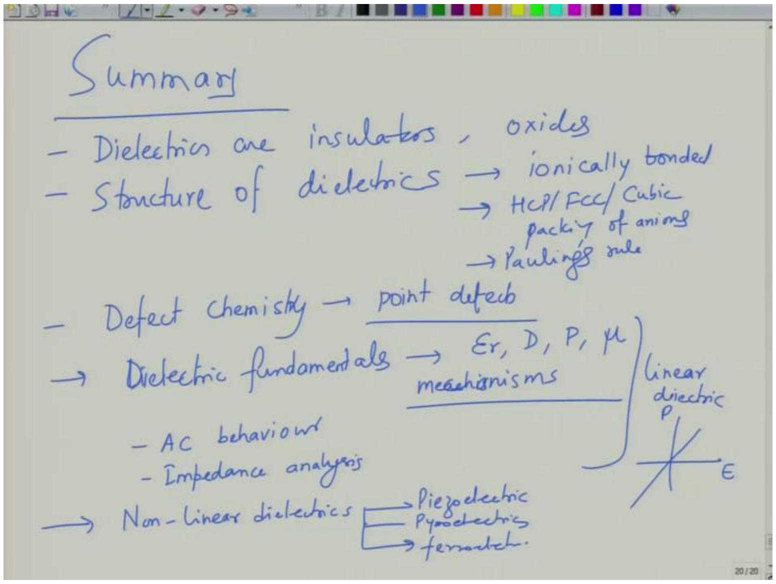

So just in a summary let us say, dielectric material as we know are basically electrical insulators and most of them happen to be oxides that is why we initiated with our discussion on structure of dielectric materials we looked at what is the role of bonding and cryptography in forming the structure of dielectric materials and we saw that most dielectrics are ionically bonded and they may generally HCP based FCC based or cubic close packing cubic packing of anions.

So structures are based on HCP, FCC or cubic packing of anions where cations go and occupy the in between them and for these what they follow generally what we call as Pauling's rules which are based on electro statistics considerations where the idea is to bring the idea is to ensure that cations and anions stay away from each other but they are close to each other. So cations and anions are closed to each other but anions like ions are away from each other and unlike ions are closed to each other.

So that you have minimum electro static energy system so we looked at various structures of the dielectric materials after that we looked at what we called as defect chemistry. Defect chemistry is extremely important because presence of point defects basically from the perspective of point defects and point defects will mean the presence of vacancies of oxygen presence of vacancies of metal interstitial oxygen interstitial.

They give rise to extra electrons or holes in the system and they also depended upon temperature and partial pressure of oxygen as well as impurity concentration presence of these point defects which is very important from the consideration of dielectric behavior. If you have lot of defects in the material may turn very conducting as a result it may not be useful as a dielectric.

But on the other hand if you have if you have methods to control these point defects for example by using appropriating temperature by using appropriate conditions for synthesis in terms of partial pressure oxygen or by using doepends which can reduce the amount of these defects one can use this defect chemistry knowledge to tailor the materials and then we looked at what we called as dielectric fundamentals.

We introduced quantities such as dielectric constant and dielectric displacement polarization dipole moment and so on and so forth. We looked at what are the mechanisms of polarization and we saw that polarization happens at various frequencies which is determined by the smallest to biggest entities so electronic polarization, ionic polarization, dipolar polarization, interfacial polarization and we move from electronic to ionic to dipolar to interfacial as the frequency decreases.

Because the size of the entities also becomes larger and basically the electronic and ionic polarization are depicted by resonance at certain frequencies below which you have these act below these become active whereas that dipolar and interfacial polarization show relaxation mechanisms and correspondingly you see certain behavior dielectrics and then we looked at the AC behavior the basically what happens in AC field time dependent analysis and then we also looked at the impedance analysis.

So this was basically from the perspective of what we call as linear dielectrics the dielectrics in which the polarization versus electric field behavior is linear. So when you plot P versus E it is linear then we move to learn about new dielectrics or different dielectrics which are called as non linear dielectrics and in that category we may mainly learnt about piezoelectrics, pyroelectrics and ferroelectrics.

So while normal dielectrics like linear dielectrics are used for typical capacitor applications the piezo, pyro and ferro they are useful for variety of different applications you can use them as sensor you can use them as actuators transducers you can use them for imaging devices you can use them for memories. So they have fantastic behavior because they exhibit property which are not exhibited by normal dielectric material.

And we also looked at details of the crystal structure and the physics of these materials the elementary physics of these materials to understand their behavior. So this is basically the overall summary of this course in which we have looked at structure, the defects and the properties of these materials from the fundamental prospective and we also looked at some application these materials and have also suggested a few books about these courses in the beginning which you can read to improve upon your knowledge.

You will have weekly assignments we are sure they will be going on as the lecture go which will also test the knowledge of this course periodically. So that and it is recommend you do not depend only on the lectures are also read the books so we will stop here we hope you have learnt from this course the fundamental of these materials of course if you have any questions you can get back to us in the portal through by TA's or through directly to me and will be happy to answer your queries so hope you enjoyed the course.