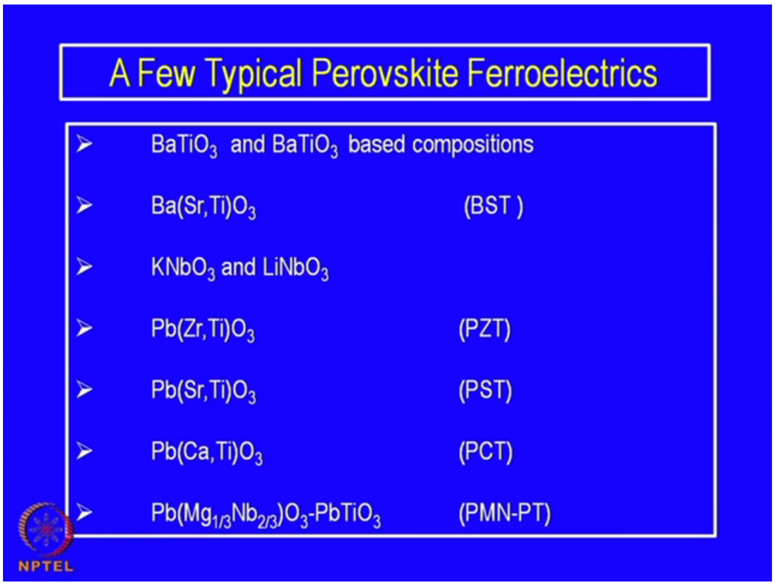
Advanced Ceramics for Strategic Applications
Prof. H. S. Maiti
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 20
Topic - Ferroelectric
Piezoelectric and Pyroelectric Ceramics (Contd.)

Let us continue our discussion on the properties of ferroelectric ceramics, under the broad subject of ferroelectric, piezoelectric and Pyroelectric ceramics. We have already considered some of the properties, some of the crystal structures of the perovskite and let us continue with that discussion.

(Refer Slide Time: 00:50)



To start with today, we will look at few of the important perovskite ferroelectrics. Perovskite is family of compounds having a particular crystal structure and we have a huge number of compounds available in that group. However, all of them are not industrially important or technically not so important. Some of the perovskite which are very very important from the application point of view are listed here.

Barium titanate we have discussed; that is the most important member of the perovskite family. However, it is not the pure barium titanate always used. I mentioned in the last lecture, that many of these capacitor materials or dielectric materials; are based on the barium titanate are many different additives are always added to stabilize the capacitance value or enhance the capacitance value and to reduce the temperature dependence of the dielectric constant particularly near and slightly; however the room temperature. So, many different compositions available; sometimes they go into the solid solution with barium titanate either substituting barium site or titanium site or sometimes they remain as a second phase interior.

So, we have a huge family of dielectrics based on barium titanate and barium titanate best composition; I am not going to details of that. But they are many standards; industrial standards available depending on what kind of dielectric somebody needs. But can be specifications are require for a specific device and so on. One important compound specific mention we made about the barium strontium titanate. Here, barium site has been substituted partly by strontium. So, it is a mixed titanate of barium titanate and strontium titanate and sometimes it is refer to as BST.

This is very a important compound once again from the dielectric point of view and stable dielectric behavior. These are used primarily in the thin film form and this is another very important group of material compound which is used in this category of ferroelectric materials. Then there is another group of materials called niobates. Instead of titanates one can have niobates; like potassium niobate or lithium niobate whose they are also tantalets, titanium can be replaced by tantalum. But in this case you should notice the composition; it is again ABO3 type of compound; perovskite type familiar compound. In perovskite type, actually a is normally divalent and b is tetravalent; however in this niobates, it is actually a site a is monovalent, where as b site is pentavalent.

So, 1 plus 6, 1 plus 5 is 6; there are also in the normal perovskite 2 plus 4 is equal to 6. So, instead of 2 divalent and tetravalent they have been replaced by monovalent and pentavalent and that is how the charge neutrality is maintained. So, this family is also has certain interesting property and they have been used in different kind of optoelectronic devices and so on. So, that is another group of perovskite with different composition deviated composition and they are also very important from practical point of view. Then you have another mixed titanate; it is lead zirconate and lead titanate solid solution of lead zirconate and lead titanate. Normally, known as PZT which is very very important group just like barium titanate; next barium titanate PZT another very important material used in industry.

However, it is not so much used as a capacitor material; it is used in some cases, but links to extent where as its main application is in the piezoelectric. We have, we will discussing in few minutes; what is piezoelectricity and what are the characteristics and what they are used for? So, we will discuss PZT; lead zirconate that context in more details. Next, we have a lead strontium titanate. So, that is also known as PST; it is again a solid solution of lead titanate and strontium titanate. And that also is a useful material for some of applications more or less in the same purpose. But the properties slightly different, the specifications of the devices we have to be different.

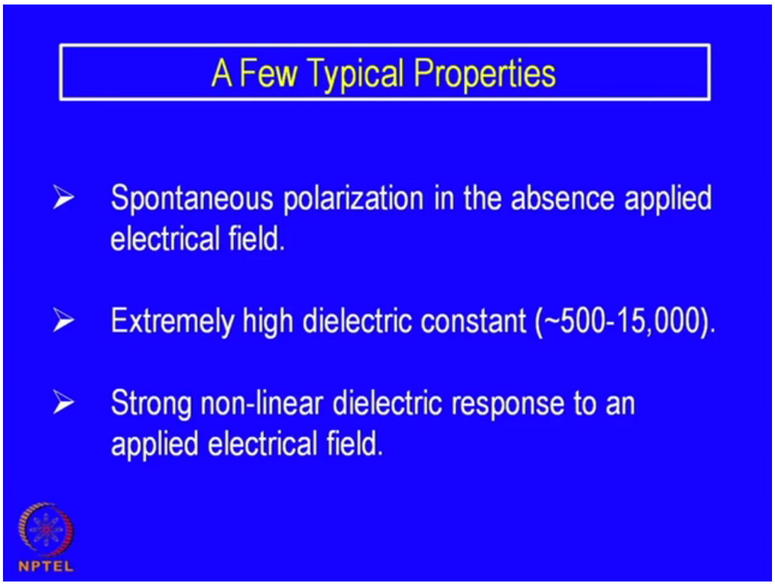
Then, you have lead calcium titanate; that is also PCT. That is also used as dielectric material and again in specific devices, these can also be used in that form. The last book in this series is actually, what you called lead magnesium niobate. In that basic compound is lead magnesium niobate; perhaps a solid solution is normally used with lead titanate. So, it is lead titanate and lead magnesium niobate in sort this is known as PMN-PT. Now, this is a completely different group of compounds. Other than perovskite, they really do not belong perovskite family, they have been slightly different crystal structure.

So, it is a in fact this group of material is called relaxal ferroelectrics; it is not a normal barium titanate like ferroelectrics. Their properties also slightly different; in fact it is little difficult to prepare this compounds, inside this compounds. There is always a tendency of different phase coming up which is called pidochloro phase. And we will discuss these relaxal piezoelectric groups is just coming up recent time in very important manner.

We will discuss may be will spend one full lecture on relaxal ferroelectrics; how they are made, how their structures are and what are the specific properties inside. Compare to barium titanate, the the susceptibility peak or dielectric peak of barium titanate is little different. It is little broad peak and it also depends on the frequency. So, its frequency dependant peak; so the mechanisms are slightly different and it has a much border peaks. So it is there is a instead of single relaxation time, there is a spectrum of relaxation times and that as a result you have much boarder peak in these group of compounds.

Of course, it has a very important property, in addition to the dielectric property dielectric behavior, some theoretical understanding of this phenomena is important, for what kind of ferroelectric transition is taking place in this material; that is also lot of theoretical interest. But in addition there is a one important property what is called electric stance. So, these are mostly used as electrostictive materials. We will discuss what is electrostictive or electrostictive property; it is little similar. There is some analogy with the piezoelectric behavior or piezoelectric behavior PZT, but it is little different than piezoelectricity. So, we will discuss this practice and a crystal structure and various different compositions of this group of materials as relaxal dielectric may be at a later class. With this we go to the other important aspect of perovskite materials.

(Refer Slide Time: 10:10)

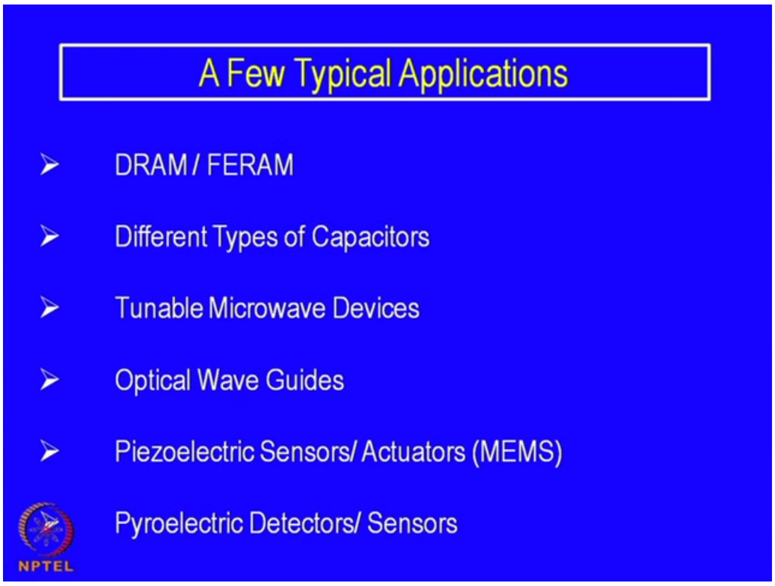


That is what are the different properties? We have already discussed most of them; it is just a consorted picture of what are most important properties we exploit in a different ferroelectric devices or the dielectric devices. They have, we know we have discussed several times; that they have a spontaneous polarization in the absence of applied electric field. So, that comes from the particular crystal structure, particular deviation from the symmetry. So, they have spontaneous polarization which leads to domain structure and that also leads to dielectric Ferro electric hysteresis. Then they have a extremely high dielectric constant. All these ferroelectric material that is one of their major characteristics. They have a very high dielectric constant compare to any another linear dielectric they have a very high dielectric constant; no one can make use of them miniature of purposes. So, that the capacitor is very thin and tiny.

The dielectric constant here of course here it is listed here 500 to 15000, but under certain circumstances, it can be further increased to 30000, 40000. And in very special circumstances it can be go up to more than 50000. However, higher is the dielectric constant normally higher is the loss also. So, it depends on which particular property you want to exploit in the device weather it is the high dielectric constant or low loss. If it is low loss, normally dielectric constants are little low. Whereas, if you want to go for high dielectric constant material, you have to accept that the 10 delta value little high. So, that a loss is also, that may be loss of energy; there may be some amount of heating and so on.

There is of course we have already discussed the strong linear dielectric response to an applied filed. So, non linear non linear dielectric response is also sometimes used in some of the devices. These are basic characteristics of ferroelectric of our interest. There are many other aspects which may not be of that much impressed. So, the application potentialities are concerned.

(Refer Slide Time: 12:36)



We have a then few typical applications some of them we have discussed in passing. For example, very important application is DRAM dynamic random access memory. That is non volatile memory used in extensively in the micro electronics or computer technology and so on. So, controls circuits in so on. So, a non volatile memory is another application. Basically, it is a capacitor charging and discharging of a capacitor corresponds to 0 and on state. So, it gives you the binary code; so by charging and discharging you get these 2 codes. So, there is a large number of large number of array of such capacitor; very tiny capacitor, not discrete capacitor. They are all array of capacitor fabricated on site or on chip on chips, chips itself. So, that is the reason we get even the so it is such a tiny; your pen drives and so on and day by day you can see pen drives are decreasing. That means, capacitance the volume of each capacitance is going down every day. So, from DRAM which was used primarily not the linear dielectrics.

We have graduated or up graded FERAM; ferroelectric random dynamic access memory because it has a much have dielectric constant, so miniature which more efficient with FERAM. So, the current technology is basically a FERAM; not the DRAM. Then you have in fact these FERAMS are already the particular compound, but these extensively used for these is actually BST not your barium titanate is BST barium strontium. And that is the material which is extensively been used for DRAM, for many different purposes.

Because there are not only the dielectric property, when you making a device or designing device; not only dielectric property, there are many other aspects have to be consider. It is stability, it is a cyclic ability, it is aging characteristics and many all these. And how it is compactable with the rest of the materials like the electrodes, silicon chips and so on. So, taking all these property into consideration, although the prime property is dielectric constant, but many other physical and chemical properties also have been considered; one you need to design a particular device for certain applications.

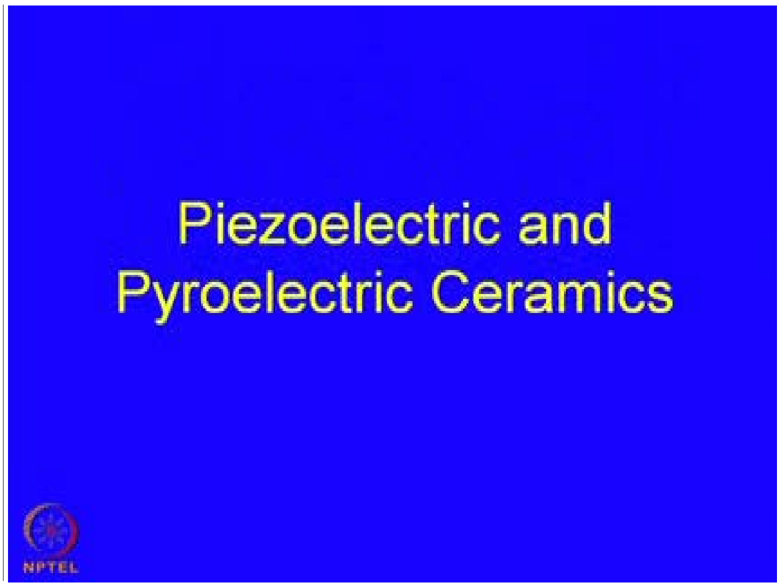
So, we are not going those details at this point of time, but at just not the dielectric constant. And, that is the reason not the barium titanate it has been it has gone though the barium strontium solid solution of barium titanate strontium. So, it is not the dielectric constant alone to handle the value is also of very important consideration. So, we go to the next group of applications that different type of capacitors well FERAM is also one kind of capacitor, but it is a integrated capacitor in a in the form of array a large number of array where as discrete capacitor are also there. So, these capacitor primarily refer to multi layer capacitor chip capacitor.

We call it as multi layer capacitor also has another name that is the chip capacitors. Till now, micro wave devices this is also other device made up dielectric, optical wave guides optical wave guides transparent materials many of these ceramics can we made into transparent form or single crystal form. Particularly, lithium niobate and potassium niobate that kind of crystals one can make grow transparent crystals and can use as optical wave guides. Piezoelectric sensor actuators particularly in names kind of technology is called the micro electro mechanical systems. It is very similar to VLSI technology but is not that miniaturized.

So, they are many miniature systems in the mems area is also available. Both sensors actuators of course we will find later on that an piezoelectric piezoelectricity as well as the ferroelectricity they are interrelated. So, barium titanate for example, an piezoelectric material and they also been used, but that pyrroelectricity coupling coefficient and the actual value of coefficient may be slightly different. But otherwise barium titanate is also a good piezoelectric material. So, it one can make a different kind of sensors and actuators made of these materials. But will see later on that the most utilized or most important compound which is used as a piezoelectric material is basically PZT or lead zirconate titanate. And, we have other property similar in the same group of materials that is what we called pyroelectric materials also discuss with briefly. What is pyro electricity? And, what it is used for there are pyroelectrical detectors and sensors in the same group of pyroelectric ceramics.

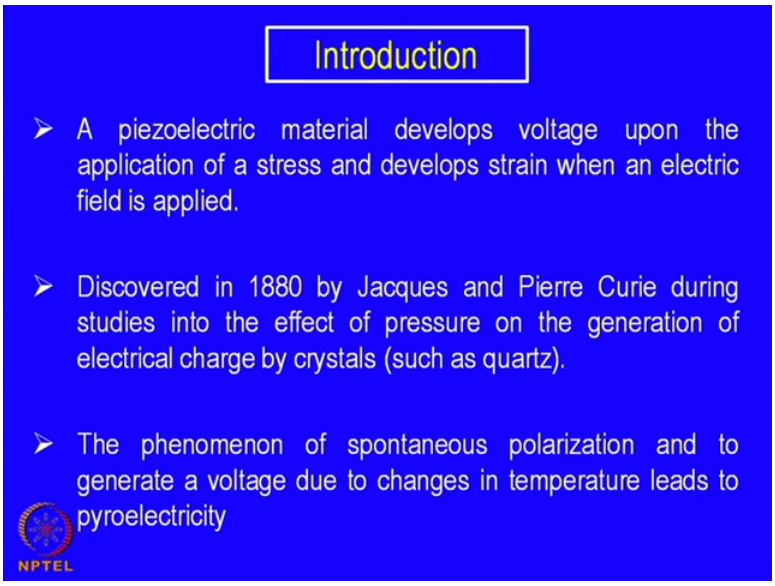
So, many some different ceramics are good piezoelectric property what is that; we discuss it later. So, that more are less complete our discussion of ferro electric materials for the time being. We have left with only one group of materials that is relaxal ferro electrics; we will discussed that later class.

(Refer Slide Time 19:20)



But now we go to change over our discussion to piezoelectric and pyroelectric ceramics that also very important electro ceramics group of materials. And, let us try to understand what is piezoelectricity and what is pyroelectric ceramics?

(Refer Slide Time: 19:40)



While to introduce the subject piezoelectricity. A piezoelectric material develops voltage upon a application of a stress and develops strain when an electric field is applied. So, this is a material this is a group of material where there is a in correlation between mechanical stress and polarization or electric field. And, electric field produces strength and that is the deformation. And, when the crystals or the materials are deformed mechanically or stressed mechanically. So, that mechanical stress generates polarization and consistent voltage. So, one can really generate voltage with by applying a strength. This a very very interesting group of materials where you can convert one form of energy into another; mechanical energy can be converted into electrical energy or electrical energy can be converted into mechanical energy.

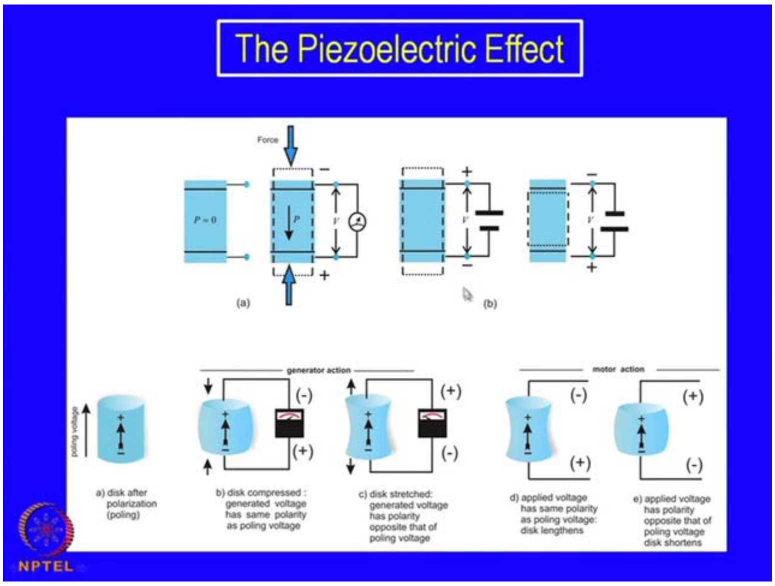
So, it actually acts as a good transduction. Using that transduction effect one have both kind of things; one can sense some form of parameter and also one can actuate because there is mechanical deformation. So, there is a volume change or geometric change and that geometric change can be utilized to make a movement; physical movement. This group of material or this particularly property was discussed a way back in 19th 1880s by once again Jacques and Pierre curie during the study effect of pressure on generation of electrical charge by crystals.

So, that time it was primarily not the synthetic materials but primarily natural materials. And, quartz was one of the very important piezoelectric or piezoelectric property of dielectric material which available in nature. And, that was been studied that has been studied in fact today; even today quartz has been a one of the most produce in very large quantities. And, it is used as a as a electronics devices primarily for frequency generation. In fact most of our electronic instruments today has a quartz based frequency generator whether it is quartz clock or computer or computer every system today has a frequency generator for time counting.

We have a then the phenomenon of spontaneous polarization. Once again we have spontaneous polarization in this case and to generate a voltage due to changes in temperature leads to pyrroelectricity not piezoelectric property. And another consequence of a spontaneous polarization coming up where one can generate voltage by changing the temperature. So, in the previous case the piezoelectric property we have piezoelectric material; we have a generating a voltage by a mechanical stress in a piezoelectricity.

Once again one can develop voltage by changing temperature. So of course it is little different from called a thermo electric effect. It is not exactly the thermo electric effect is different because generation the origin of the 2 phenomenon are different. So, piezoelectricity is different from so called thermo electricity.

(Refer Slide Time: 23:42)

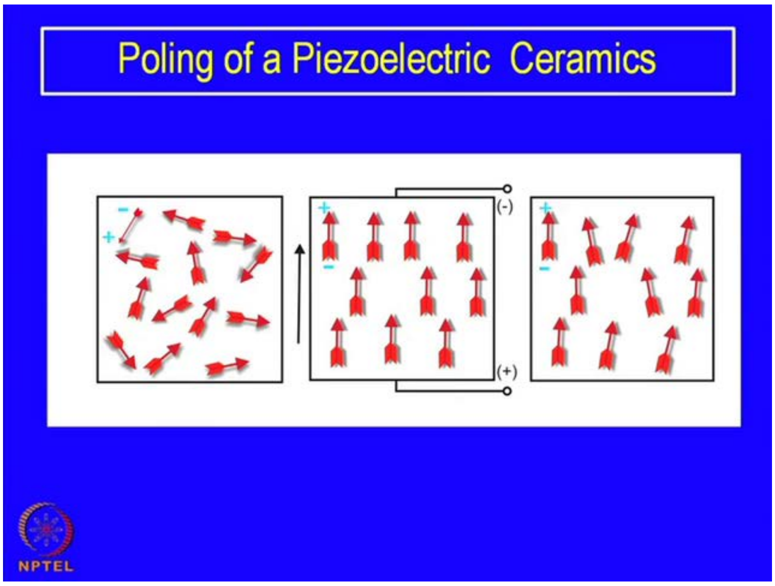


Well how we can demonstrate what the piezoelectric effect is? In this diagram one can see; this is a piezoelectric material to start with there is no voltage, no pressure. So, p polarization is 0. Then, if we applied a compressive stress here from 2 sides there is a deformation; very minute deformation of the crystal or the material. And that deformation sets up a polarization dielectric polarization here. So, by deforming you can actually generate a dielectric polarization and consequently you get a voltage there. So, that is the difference between normal dielectric and piezoelectric. This also dielectric material, but different nature this is also have spontaneous polarization; only thing the deformation or the sensitive much more sensitive to mechanical stress.

So, by applying mechanical stress you actually polarize it. And, that polarization comes certain form of voltage. The reverse is also true this is a reverse that means you applied electric field and make the changes in dimension. One is to understand which the dimension which direction it will change we discuss them in a little while. So, depending on the application of the voltage either it will compress or it will expand and expand in different directions or change its dimension in different directions.

So, that all we have to understand. So, there are 2 different process; one is reverse of the other this is what we call direct piezoelectric effect. And, this is what we converse piezoelectric effect reverse of direct piezoelectric effect. One in one case where applying mechanical stress polarize or generates voltage in other case we are applying voltage generating mechanical stress and strain as well. Now, in all piezoelectric material we have a process called poly because come back to let us go there next slide.

(Refer Slide Time: 26:32)



This is what do mean by basically poling. Piezoelectric material are also correct right represents to spontaneous polarization. So, just like Ferro electric material you have spontaneous polarization, permanent dipole movement within in the solid. And, initially they are in random in nature. If you do not apply electric field they quite random in nature they oriented in all different in all possible directions.

So, that the net dipole moment is 0. However, when you applied electric field they get align; all of them they get aligned in the particular direction depending on the application direction of applied field. So, in this case the direction of applied field is here. This is an all the dipole moments or the dipoles all the aligned parallel to an positive charge pointing to the top depend upon direction of application of the field. So, all the positive charges are actually directed towards negative charge applied negative charge or negative electrode of applied voltage.

However, if you remove the applied voltage then there will be little bit of very adjustment slight misalignment, but it still remain more or less aligned. Now, that depends on what is the actually remnant polarization. If remnant polarization is very high then this will retain. If remnant polarization value of polarization is not that high then it may change over to its original position very quickly.

So, piezoelectric materials most remnant polarization effect quite high. And, therefore even after removal of applied field the dipoles tend to remain oriented in the direction of applied field which was applied for the (( )). So, the processing of poling is very important step in fabrication or preparing preparing piezoelectric material for device making or to see the effect of different parameters like pressure and so on.

So, all piezoelectric materials actually hold before it actual used in a device. This is what we called poling. Normally, all piezoelectric materials just like Ferro electric materials are the curie point or curie temperature piezoelectricity is a last change over to a Para electric situation. So, there is no permanent dipole movement anymore. So, before the polling normally done slightly below the curie temperature where the movements of the dipoles becomes easier.

So, there kinetic process is faster close to curie point. So, polling is normally done in a warm environment normally in liquid; while so close to the curie temperature. And, then applied relative high voltage for long enough time. So, that it allows sufficient time for dipoles to align themselves with direction of applied field. So, that is the process of poling which is regularly has to be made for any kind of piezoelectric materials or piezoelectric ceramics; going back to earlier slide in this we are coming back to this discussion. So, here we have already polled the materials and this is the direction of poling. And, as a result of poling already the disk after polarization that is the after poling that means after polarization a all the dipole have been aligned in a particular direction.

So, one can identify which particular side or faces of this material positively charge or which one is negatively charge. So, after polling it is no longer a completely neutral material because domains are not completely random. So, it already aligned in and therefore there will be a positive surface and negative surface. So, it was not there before poling; before poling there is no surface is positive or negative; but after polling this change has taken place. So, if now we apply a mechanical stress. We can identify we can identify which particular surface will generates positive voltage, positive plate or positive electrode or the voltage or the other is a negative.

So, if this is the poling direction; positive in the top and negative in the bottom. And, it try to compress try to compress the material along the axis along the axis of poling; this is the polling axis. So, along the axis then it generates a negative charge on the positive side; and the positive charge or positive pole on the negative side. So, the disk compressed generates a voltage and has same polarity has the polling voltage. So, this is how is it has been become positive because negative voltage originally applied and that is why it is become a positive charge.

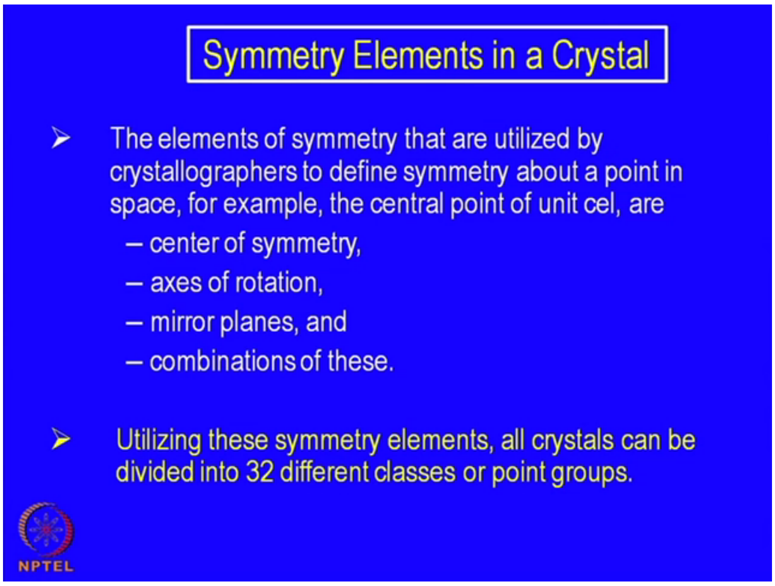
So, same voltage is applied in this manner. So, that is how it determine the direction of the voltage generated. If you reverse it not put it tension then reverse voltage is generated. So, it becomes positive and it becomes negative. Now, in addition to that one has to also notice while you compress it will not only changing its dimension along the axis, but also changing its dimension in the orthogonal direction or the right angle. And that is the, because of the poisons effect because if you compress on this side that is basically because of the mechanical deformation. For any mechanical deformation you will have Poisson effect.

So, when you compress it dimension diameter will increase that is what is happen here. That is also means stress is we are applying a stress in this polling direction, but there is a compounded of stress in orthogonal direction as well. And, that that is making it to increase its dimension. And, in similar manner if you put in tension load there will be a reduction in dimension that is again repeat same reason. So, the dimensions are changing not only in the direction of field dimension of the application of the mechanical stress on the normal stress we calling. But also in the orthogonal directions or perpendicular direction. That is also an important application impact one has to consider by then we are applying this kind of phenomenon. This is a reverse of this what is been describe here. We are basically applying voltage and generating a mechanical deformation a same thing happens here also.

We are applying voltage along the direction of poling direction; and then depending on the direction of the charge developed within the material and the kind of polarity of the field. Either you get a compression or you get a in this case tension in this case compression. Now, this 2 together is called motor action because in a motor your applying electrical field or electrical energy is converted to a mechanical energy that is a function of motor electrical motor. And, so here this is also called motor action because application of electrical field is converted into mechanical energy, electrical energy is converted into mechanical energy and that is why it is a motor action. Whereas it is a generator action reverse of motor where mechanical energy is converted into electrical energy.

So, these are the phenomenon of piezoelectricity because there are 2 energies are coupled together and one is getting converted to rather transducer effect. So, that is the main criteria of piezoelectric effect. Now, this is a already discussed this is a poling or piezoelectric ceramics; and that is a bearing on the what kind of transducer effect we get in material.

(Refer Slide Time: 37:13)



Well, piezoelectricity is related also to crystal structure. Just like Ferro electricity was related crystal structure of the material; piezoelectric also a closely connected to what kind of symmetry what kind of symmetry particular structure has crystal has. So, there is always relationship between the crystal structure and physical properties particularly in this group of materials.

So, let us try to we discuss briefly, while we discussing the crystal structure. The symmetry elements in the crystal right there are various symmetry elements. In fact there are different points groups; these symmetries are comes from the group theory. So, the elements of symmetry that are utilized; we are not discussing in very great details but one can remember this few points. The elements of symmetry that are utilized by the crystallography to define symmetry the about a point in a space.

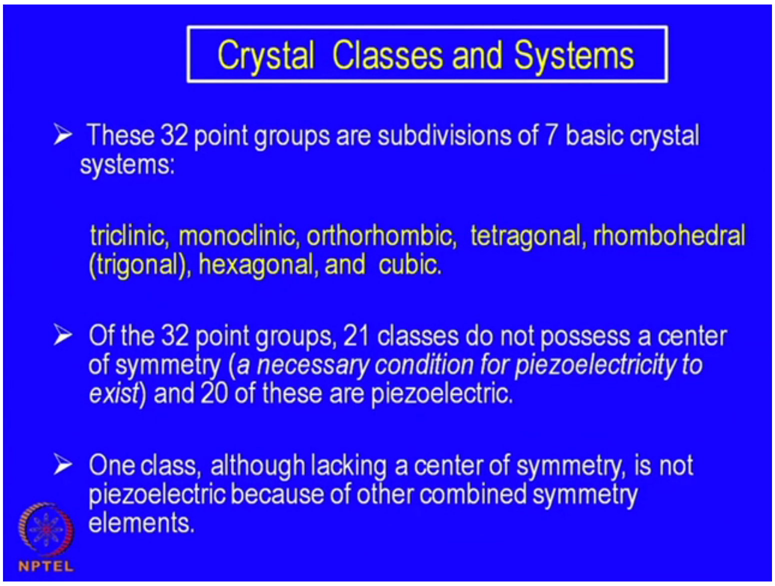
For example, the central point of the unit we have discuss unit cell. So, we find out the symmetry elements those geometric configurations. There are 4 different ways one can describe the symmetry elements one is centre of symmetry. For example, in a cube centre of cube is the centre of symmetry around that point all are symmetric diagonally opposite directions.

So, that is why it is called centre of symmetry. You can also have a axis of rotation that may also have symmetry element. That means, if you have a axis then if you rotated it, it comes to its original position; and you can kind of in distributed position. So, on axis can also a line actually either a vertical line or horizontal line or diagonal line. They may also acts as a axis of rotation that also a symmetry element for the consideration of the point group of symmetry point groups. Then, you can also have mirror planes looking at or coming back to axis of rotation the diagonal of a cube the body diagonal what you call a body diagonal of a cube is an axis of rotation.

A vertical plane a vertical line through the centre of the phases both bottom phase; and the top phase will draw a line for the vertical line that also act as a accessible rotation. Because you can rotate the cube around that axis at least by 90 degrees and comeback same configuration. So, these are actually 4 fold rotation, 3 fold rotation, 2 fold rotation axis and so on. Then, have another another symmetry element is mirror plain. You can consider a plain to be geometry or the through the volume of the itself and you can see the one half is a mirror image on the other half. So, that is also one can have a symmetry.

So, that is some symmetry around across a mirror or across a plain. And, sometimes there are combinations of these either a center of symmetry is combined with the axis of symmetry or a mirror plane is combined with axis of rotation and so. That also give rise to different other symmetry operation. So, considering all these kind of symmetries we have 32 different classes. All the all the possible geometries will have 32 different classes or the point groups. So, within that all the kind of geometries are the geometrics configurations can be classified or group together. So, in crystallography we will always consider 32 crystal classes and we have also discussed briefly during our discussion on crystal structure.

(Refer Slide Time: 42:18)



This 32 point group has been subdivisions of 4 basic crystal systems. So, there are and then we have bravis lattices and so on. So, there are basically 7 crystal systems. So, one distinguished between 32 crystal classes and crystal systems these are the basic difference between crystal classes and crystal groups. Some of these crystal classes are grouped under different crystal systems. So, we have 7 different crystal system and their quite familiar names to us by now these are triclinic monoclinic, orthorhombic, tetragonal, rhombohedral or sometimes called trigonal hexagonal and cubic. Their symmetries are different as in a imagine that cubic is most symmetric whereas triclinic is the most non symmetric.

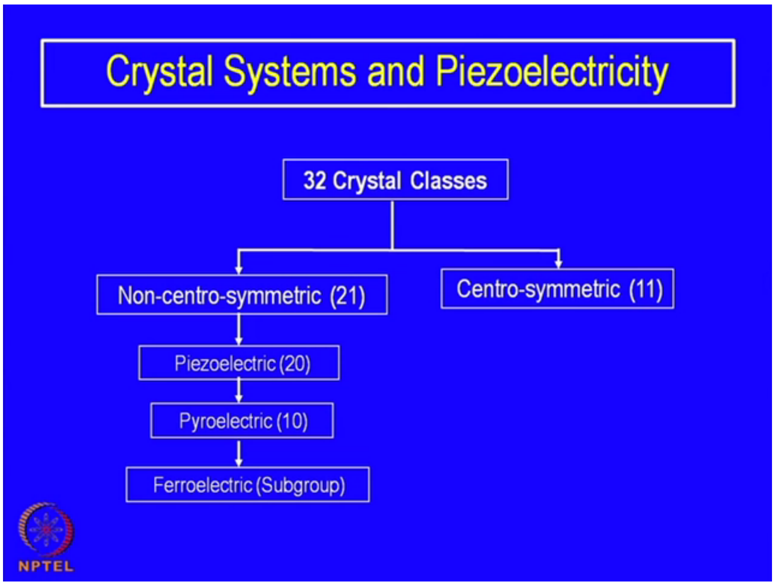
So, this is how the order changes. And, there will some kind of we have seen in case of particularly barium type net and there are 4 different polymorphs like cubic, tetragonal, orthorhombic and rhombohedral. So, these are different kind of symmetries and different kind of distortions. So, they have different level of symmetries. Now, after 32 point groups or crystal classes will be same thing sometimes they are referred to point groups or sometimes crystal primarily call them crystal class. 21 crystal classes do not possess the centre of symmetry.

One of the operations of the finding of the symmetry of a geometry is a centre of symmetry is 1of the 4. And, it has been found or one can visualize or one can find out different ways the crystal classes been generated. Out of the 32 crystal classes 21 do not possess centre of symmetry. A necessary condition for the pyro electricity to exist. And, 20 of these are actually piezoelectric that is a very important statement. For piezoelectricity to occur in a material they crystal or crystal structure must have certain conditions and that is it must not have a centre of symmetry.

So, any crystal class or any crystal structure having centre of symmetry will not be having piezoelectric property. And, that is a very important statement and thus it has to be remember all the time. So, out of 32 point groups or crystal classes 21 do not posses center of symmetry. And, they are the materials or they are the crystals in which piezoelectricity can be observed. However, out of 21 does not have although it does not have a center of symmetry, but also does not have piezoelectricity. But for a slightly different reason one class it has mentioned in the next line. One class although lacking a centre of symmetry is not by piezoelectric because of other combined symmetry elements.

So, 20 crystal classes do not possess the center of symmetry. And, all of them any material in this particular crystal structure or crystal classes will have piezoelectric property. Well they are effect may be small or big or large, but in principal they have the piezoelectric property in them. So, there are large number of impact as you can see out of 32, 20 have the piezoelectric property. So, piezoelectric property is basically a common property a many minerals and crystals and so on. So, only 12 crystal classes do not have that, but otherwise 20 of them have the piezoelectric property. So, in principal many materials do have a piezoelectric property.

(Refer Slide Time: 47:10)



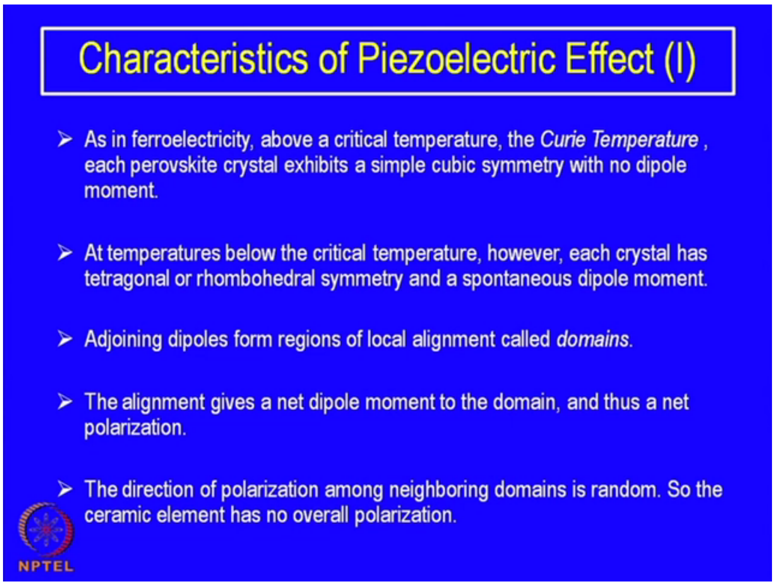
Well, this can be summarized in this form of a flow diagram; 32 crystal classes has been sub divided into 2 groups. One is non- centro-symmetric 21 of them and another group is centro-symmetric so 11. So, these 11 do not have piezoelectric property. Now, out of 21; 20 have a piezoelectric property as already mention for someone that is consideration it does not show piezoelectricity.

Out of this 20, 10 are Pyroelectric. All of them piezoelectric, pyroelectric and ferroelectric has certain commonality they have all are them have a spontaneous polarization. That means, they have some kind of a internal or geometric deformation in the crystal structure and that leads to the dipole movement. So, the dipoles are movements are already there. Out of the 20 different classes a piezoelectric material 10 are Pyroelectric; and then out of this 10 some are ferroelectric not number is exactly not known is not cannot be you know identified with the clearly, but some are ferroelectric.

So, from these it is one important aspect to remember; all ferroelectric materials are pyroelectric and also or piezoelectric. So, any ferroelectric material are supposed to have the pyroelectric property as well piezoelectric property. However, all piezoelectric materials need not be ferroelectric some of them are some of them are not. For example, quartz is a very important piezoelectric material extensively used in industry for particularly electronics industry, but it is not a ferroelectric. So, similarly, all ferroelectric materials are pyroelectric, but all pyroelectric materials are not Ferro electric.

So, that is the kind of inter relationship between them. So, it all depends on what kind of crystal class it belongs to. So, the materials the crystal class of the material is very important while there we can get some piezoelectricity or ferroelectricity. So that is the classification one can have.

(Refer Slide Time: 50:03)

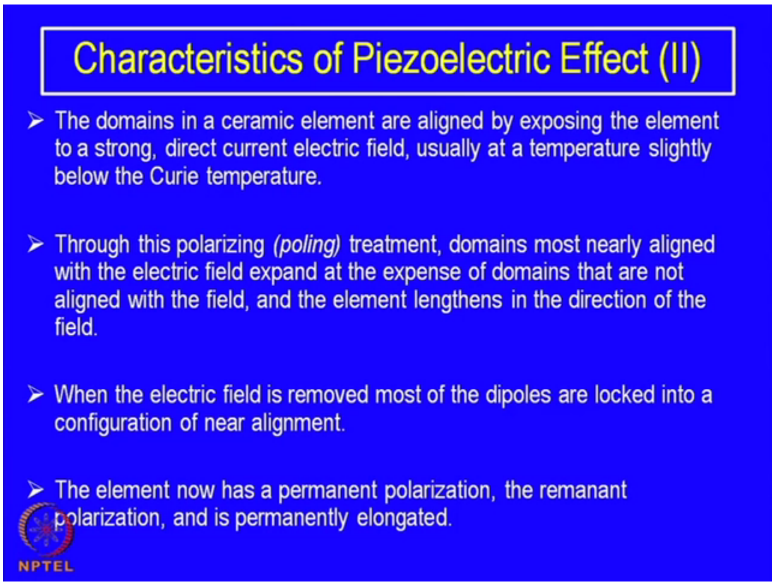


All there are some characteristics of the piezoelectric effects some of which we have already discussed. As in ferroelectricity above a critical temperature so there is also a critical temperature called the Curie temperature. So, each perovskite crystals exhibit a simple cubic symmetry and no dipole moment. Now, one is to find out there is always a phase transformation associated with this curie temperature. That means, curie temperature and the phase transition more or less occur in the same temperature. Although they have a slightly different origin and not exactly the same all the time, but there were very close.

So, above the Curie temperature there is a cubic symmetry and cubic symmetry means there is no dipole moment permanent dipole moment. So, just like ferroelectricity is lost beyond the Curie temperature, piezoelectricity is also lost beyond the cubic temperature. So, one can once again identify a critical temperature called the curie temperature. A temperature below the critical temperature that is the curie temperature. However, each crystal has tetragonal or rhombohedra symmetry and is spontaneous dipole moment. So, is very similar to the ferroelectric domain, ferroelectric materials we have discussed earlier. Adjoining dipoles once again we have domains just like ferroelectric domains we have a ferroelectric domains in piezoelectric materials as well. So, adjoining dipoles from regions of local alignment called domains. The alignment gives a net dipole moment to the domain, but thus a net polarization and but thus a net polarization.

So, each domain has a net polarization, but when it associated with neighboring domains with may be at different orientation. So, they cancel each other therefore, there is no net polarization and the average is taken over a large number of domains.

(Refer Slide Time: 52:46)

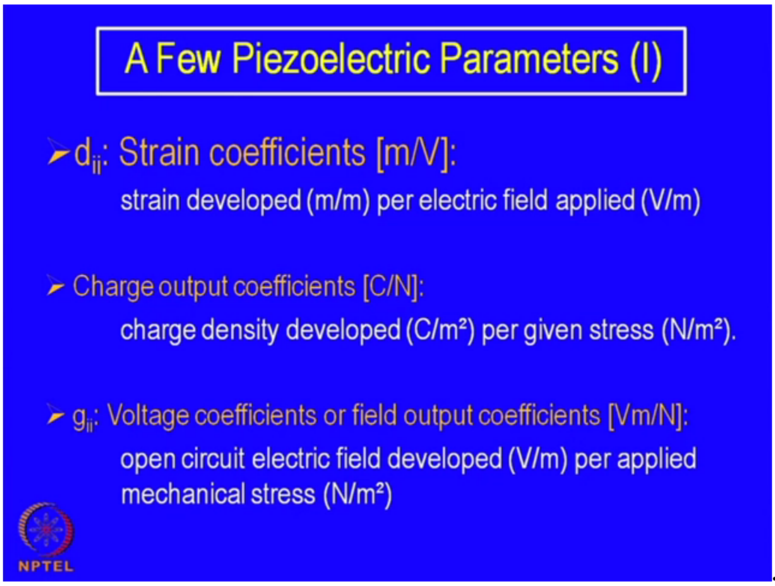


There are few more characteristics one can visualize. The domain is a ceramic element are aligned by exposing a element strong direct electric field usually at a temperature slightly below the curie temperature. That is the phenomena of poling. So, domains can be aligned externally and through a process of poling through this is polarization. Polarizing treating there is a poling treatment domains mostly nearly aligned to the electric field expands that is also discussed during the ferroelectric domains. So, which are little favorably oriented to the direction of the application of the applied field they grow and domains not so favorably oriented they actually sync. So, the the direction of the field and as a result of that there is a dimensional change also.

So this kind of poling also leads to some amount of dimensional change or domain. When the electric field is removed most of the dipoles are locked. That is what also we have discussed earlier through the illustration that there mostly locked because the remnant polarization is very high. And, therefore, we have it is not the remnant polarization alone it is actually the quarts field. So, its needs high cohesive field also to randomize them. So, both the remnant polarization is high as well as the cohesive field is also quite high. Therefore, one can retain the alignment.

The element after poling of course has now a permanent polarization and the remnant polarization and is permanently elongated. That is also as a result of poling the material getting polarized and there will be consequently some dimensional change.

(Refer Slide Time: 55:30)

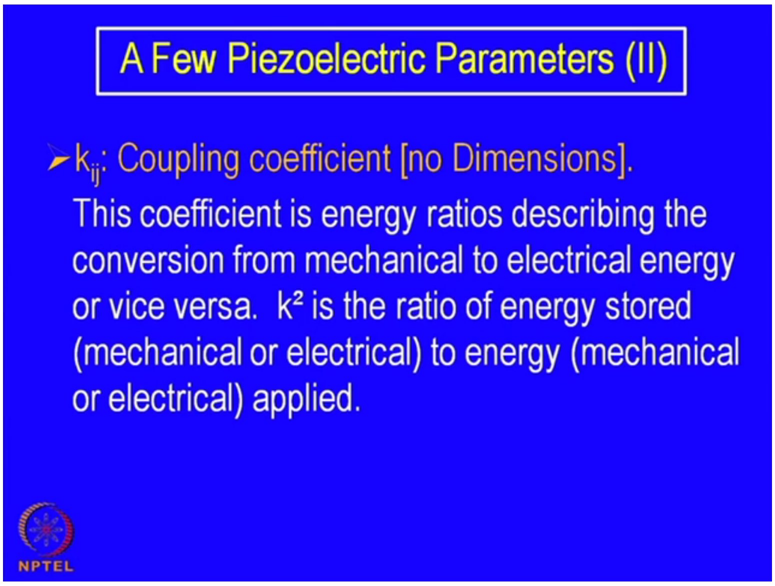


Well, we will just have a brief discussion on this. We will discuss them in details later on, but to start with we will introduce actually 4 different coefficient. One is the strain co efficient because the 2 parameters are interconnected; one is the electric field and the mechanical strain.

So, there must some coefficient which relates both of them. So, that is the strain coefficient is actually d i j it is not dii it is dij. And it is subscript which actually denotes direction of the application of the field and the direction of the consequent response. So, the strain coefficient is one parameter we discussed the property of materials and its unit is meter per volt for both. Then, we have a charge output coefficient whose unit is coulomb per Newton and that is the charge density developed coloumb meter square per given stress; stress is newton per meter square.

So, it becomes how much charge is actually generated and at a at kind of force you had applied. So, voltage coefficients or the field output coefficients these are denoted by gij again it is not ii gij. So, the open circuit electric field developed per applied mechanical stress. Once again it is very simple we applying mechanical stress and electric field generated. So, there must be a coefficient there must be a relationship between the mathematical relationship between the 2 and the coefficient gii and the unit is volt per meter; applied mechanical stress is newton per meter square.

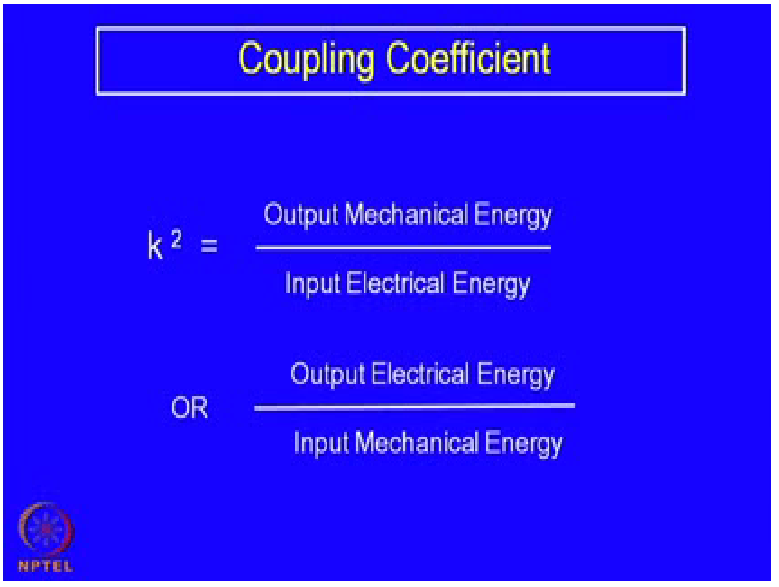
(Refer Slide Time: 57:40)



And, finally and very important parameter because it is a transducer one kind of energy is getting converted into another kind of energy. So, that is a coupling coefficients. So, it is basically a ratio there is no dimension. So, it is coupling coefficient it is the energy ratio described the conversation from mechanical to electrical or vice versa. And, of course k is a coefficient and k square is actually the ratio of energy stored mechanical or electrical to the energy generated are applied not generated applied.

So, it is a ratio of how much energy is getting generated one form. You are applying one form of energy and getting back another form of energy. So, there must be a certain amount of loss.

(Refer Slide Time 58:36)



And, so the coupling coefficient basically is the ratio of the 2 energies and therefore, a number.

So, k square actually output of mechanical energy, input electrical energy or output electrical energy or input mechanical energy. So, these are 4 terms by which the property of materials can be described. So, we complete this discussion for the time being. I will continue our discussion in the next class for the other coefficients. And, how we can generate different coefficients? What their significance? I would take it up in next class.

Thank you. Thank you very much.