Electroceramics

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Lecture - 32

This lecture, we will basically start a new topic, which is pyroelectric materials. It is again part of module five itself. But, before we go into pyroelectrics in detail, let us just have a review of what we have done. We started in this module with the discussion on ferroelectric materials, piezoelectric materials; you know the distinction between these materials. From the crystallographic point of view, these materials have to have non-centrosymmetricity; which means they do not have a centre of symmetry. Now, additionally, if it is a non-centrosymmetric, then it is piezoelectric. That is a sufficient condition for piezoelectricity. But, for pyroelectricity and ferroelectricity, material needs to have a polar axis. Now, in addition to having polar axis, in ferroelectricity, you need to have this reversible polar axis by reversing the polarity of field and also materials have a Curie temperature; beyond which polarization disappears. Now, this is true about even pyroelectric materials as well.

We discussed ferroelectric materials in the context of phase transitions, etcetera, the domains and variety of applications that we looked at. Piezoelectricity again, which is nothing but coupling of mechanical and electrical order parameters. And, they are the piezoelectric coefficient, is a representative of piezoelectric response of the material. And, as a result of this piezoelectric effect or the converse piezoelectric effect, you can have variety of applications, which can be in actuators, transducers, sensors, etcetera.

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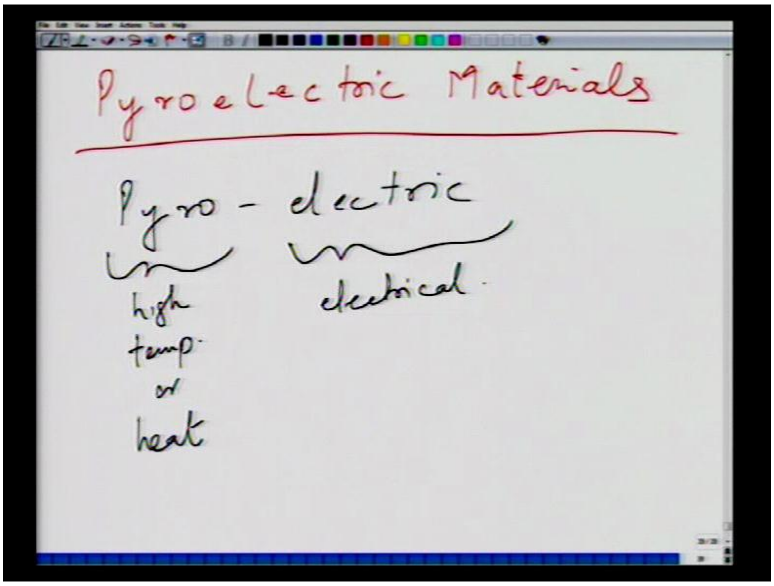

Now, the third class of important material in this non-linear dielectric category is pyroelectric material. Now, as a name itself suggests, you have pyro and then electric. Pyro essentially means high temperature or temperature let us say heat – or heat. And, electric means electric – something do with the electrical things. So, it is the coupling between thermal and electrical things, which gives rise to what is called as a pyroelectric effect.

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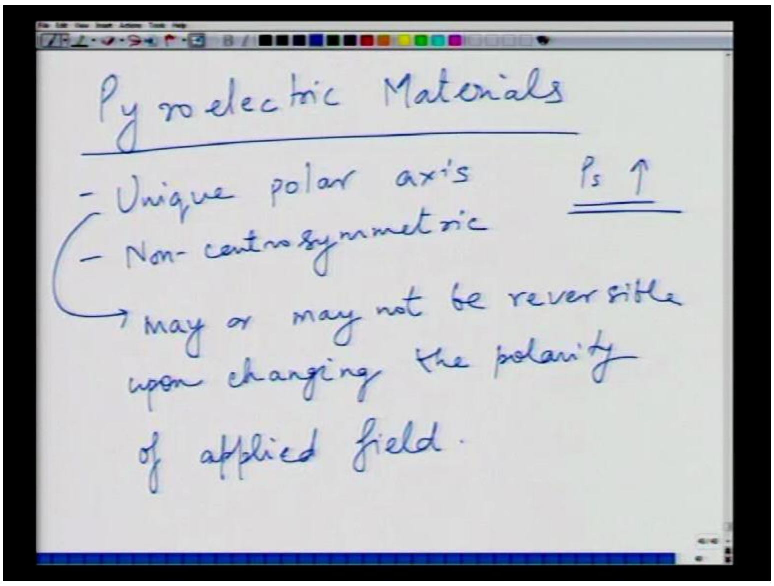

Pyroelectric materials – the characteristics are – you have one – they have a unique polar axis; which means polarization is along a certain axis. This is the unique polar axis. And, these have to be non-centrosymmetric. And, this polar axis may or may not be reversible by reversing the direction of applied field. So, this polar axis may or may not be reversible upon changing the polarity of applied field. So, this is a clear distinction between a ferroelectric and a pyroelectric material. In ferroelectric material, not only you have to have a non-centrosymmetricity; you also need to have polar axis, which is unique. But also, when you reverse the direction of applied field in the polar axis, the polarization along the polar axis reverses along the direction of applied field. So, that is the clear distinction between these two materials. And, if it is a ferroelectric material; because all the ferroelectric materials are piezoelectric and pyroelectric simultaneously. So, if it is a ferroelectric as well, it can be either single crystal or it can be poled polycrystalline material as well.

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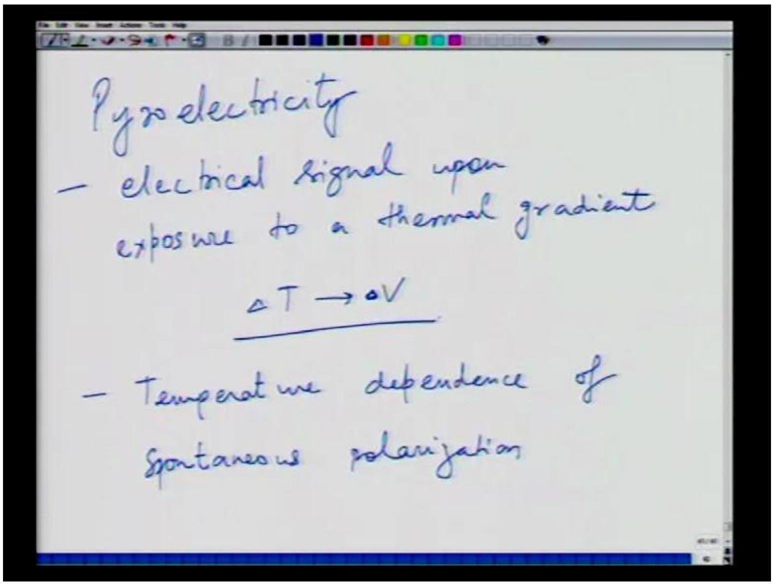

Basically, what is pyroelectricity? Pyroelectricity is an ability of the material to generate an electrical signal when it is subjected to a thermal change; basically, electrical signal upon exposure to a thermal gradient. So, delta T gives rise to let us say a voltage V or delta V depends upon how you define it. So, this is... Essentially, you can also call it as temperature dependence of spontaneous polarization, because as you change the temperature; as change in the temperature is sensed by the material, it has this ability to change... its polarization changes. And, this change in the polarization is detected as electric field or voltage or change in the voltage when you expose the material to a thermal gradient.

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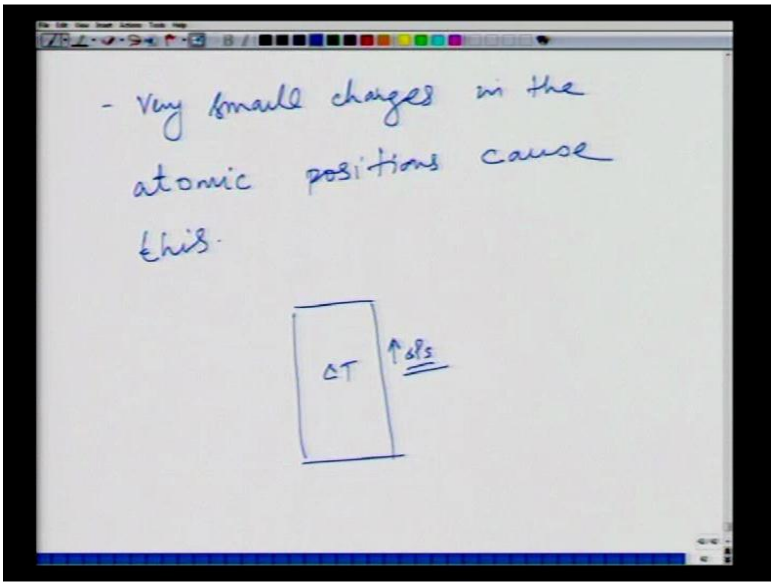

And atomistically, as you know, it could happen due to minute changes in the atomic positions. Very small changes in the atomic positions cause this. So, you have this material, which is subjected to a temperature difference; and then, you have this – along this axis, you have delta Ps. And, you know that, polarization is because of displacement of atoms. So, you have a clear distinction between the centres of negative and positive charges. And, the distance of these between these centres varies; the dipole moment will vary. As a result, the polarization will vary. So, naturally, this will cause you... So, any temperature difference, which leads to any minute change in the atomic position, causes the change in the polarization. But, the material has to be non-centrosymmetric. If it is centrosymmetric, all these displacements will cancel each other and they will give rise to zero effect at all.

And, if you keep the temperature constant for a long time, then this voltage will gradually drop to 0, because of leakage of charges through the material. So, basically, you can say that, this change in polarization, which occurs in the sample as result of delta T, which is applied to sample is nothing but change in the... or it can be measured sort of as a induced current; and, which can be converted into voltage.

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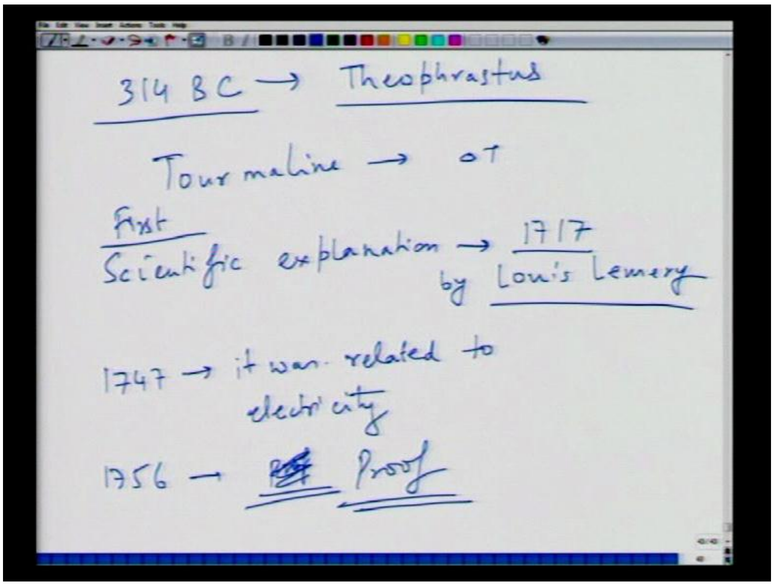

Now, historically, pyroelectricity was first observed in 314 BC by a Greek philosopher Theophrastus. This was just a visual effect; there was no quantitative or physics side of it. As an effect, it was first observed by Greek philosopher Theophrastus. And, he found that, small pieces of pieces of Tourmaline; Tourmaline attracted small pieces of, for example, straw or small particles or ash when it was heated. So, Tourmaline – when it was subjected to a temperature change, it tended to attract variety of things. But, this discovery did not lead to any scientific explanation. It was merely an observation. Scientific explanation came in 1717 by Louis Lemery. And, in 1747, it was... First, in terms of scientific explanation, this was the first scientific explanation. So, it may not have been completely correct. But this was the first attempt to scientifically explained pyroelectricity. In 1747, it was related to electricity. And, proper scientific explanation – proper scientific proof of this came in 1756. As a phenomenon, although pyroelectricity has a long history since more than 2000 year old, but the scientific explanation has started coming only in the 1715, 1720 onwards. And then, in the later part of that century, it led to some scientific explanation of this phenomenon with relation to the electricity.

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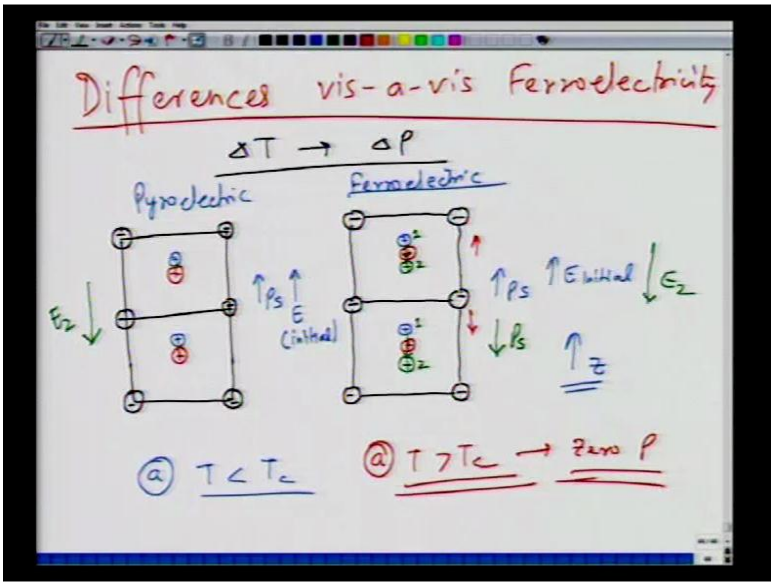

Now, in order to distinguish from ferroelectricity, we are saying that, when you subject a material to delta T, you have delta P. And, this is what is measured as a electrical signal. Now, in terms of differences vis-a-vis ferroelectric material; you have let us say a pyroelectric material here. Let us say these are all negative ions. In the centre of this unit cell, you have a positive ion sitting somewhere; let us say here. So, this is the equilibrium position. And, we are drawing it at T less than a T c. So, below the Curie temperature, when a spontaneous polarization is finite, you have this central atom, which has to be positive atom. It is shifted in the up direction. So, below T... Below temperature lower than Tc or at temperatures lower than Tc, this is the case with the pyroelectric. And, similar picture if you draw for a ferroelectric; these are all anions – negatively charged ions; cation sitting here. As you can see, both of these materials have polarization vector in this direction, because the central positive ion is shifted along this, let us say if this is z axis; along this z axis. Now, this material is ferroelectric. And, both these pictures look fairly similar below Curie temperature.

Now, what happens when you take the temperature to... Let us first examine the effect of electric field at temperatures lower than Tc. So, what do we do when we apply electric field? Let us say, initially, the position was in this direction. So, let us say, initially, the electric field was also in this direction. The initial direction let us draw with this E. So, this is initial; and, same case here. Now, when you reverse this direction of electric field, this is E 2. So, you are reversing the direction of electric field. Now, what should happen for a ferroelectric? For a ferroelectric, this atom must move to position on the other side. So, this is a new position that the atom will take. So, this is the position 1 and this is the position 2. So, position 2 will correspond to the first direction of the electric field; position 1 will correspond to the first direction of the electric field; position 2 will correspond to the next direction of the electric field. So, it has changed its direction, the central atom as you reverse the direction of applied field; which means the polar axis, which was along plus z direction earlier, it has become to minus z direction. As it has changed to minus z direction, as you change the direction of applied field. However, in a pyroelectric, you do not see any change; it still stays in the same position. So, no matter whether you reverse a direction of applied field, the Ps – the polar vector always stays in the plus z direction. So, this is one crucial difference between pyroelectric and piezoelectric.

Now, when you take this material above T c; let us use a different colour. At temperatures greater than T c, which is a Curie temperature; at temperature greater than T c, for both piezoelectric and pyroelectric, it will turn to this position, which is a central position. So, no matter whether you applied field in this direction or in that direction, it will not matter; the positive ion will stay at the centre of this cell giving rise to zero polarization. So, this is the crucial difference between a ferroelectric and pyroelectric. At T greater than T c, both of them behave similarly. But at T less than T c, reversal of electric field, direction of applied field leads to change in the reversal of Ps along the direction of field in a ferroelectric. While in the pyroelectric, below T c, you have a polar vector, which is along let us say one particular direction; Ps will be along that particular direction no matter... So, if you change the direction of applied field, it does not change; it still stays in the same configuration. So, this is the crucial and very fundamental difference between a ferroelectric and a pyroelectric.

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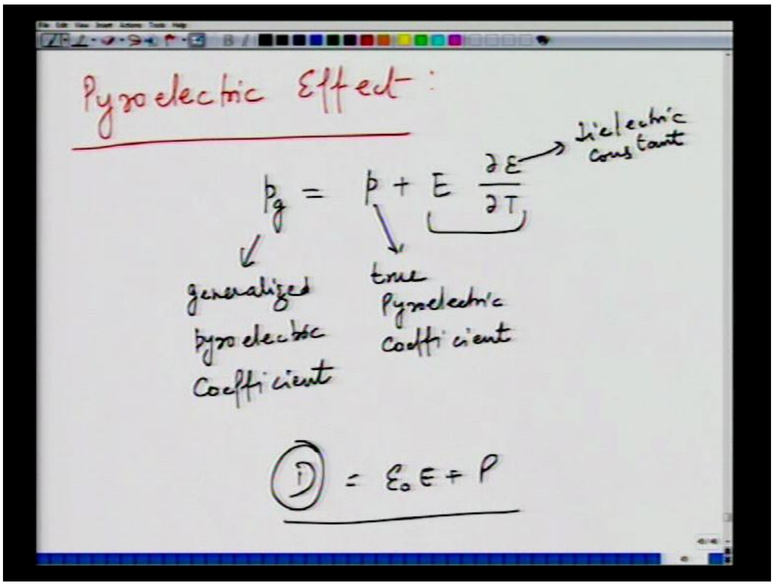

The pyroelectric effect essentially is described as p g is equal to small p plus E del epsilon over del T. This is the equation, which is used to describe the pyroelectrics. And, this p g is nothing but generalized; and, small p is the true pyroelectric coefficient. So, p g is the generalized pyroelectric coefficient; small p is the true pyroelectric coefficient. And, e is the electric field; and, epsilon is the dielectric constant. So, basically, this last term in this expression is nothing but it relates to the change in the dielectric permittivity versus temperature. And, this is what, is essentially the effect that you measure when you subject this material to change in the temperature. So, this dielectric permittivity is related to polarization and which is what you measure as a result of application of thermal gradient to a pyroelectric material. Since polarization is a vector, you know that... Now, before we go to the generalized form, this equation essentially derives itself from the fundamental expression of dielectric constant. So, this dielectric displacement D is related to you know that, epsilon naught E plus the polarization term. And, when you differentiate this D versus temperature, then you get what is called as a pyroelectric coefficient. So, all you have to do is that, you have to differentiate that fundamental expression D, which was given as epsilon naught E plus P; where, P is the polarization. So, you differentiate this equation with respect to temperature and all you get is this expression.

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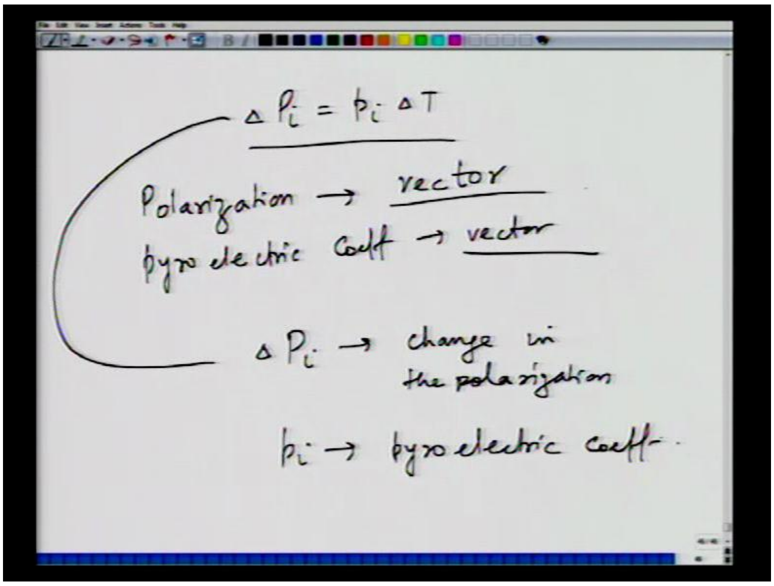

A more generalized form of pyroelectricity is delta P i is equal to p i delta T. And, this as you can see from the previous expression, you can get it. Now, this is typically expressed in the vectorial form since polarization as you know is a vector quantity. If you remember module four, you know that, polarization is not a scalar; it is a vector. Since polarization is a vector quantity, pyroelectric coefficient is also a vector. So, you must remember this. So, generalized form is delta P i is equal to p i delta T; where, delta capital P i is the change in the polarization and i depicts the direction; and, p i is essentially the pyroelectric coefficient along i.

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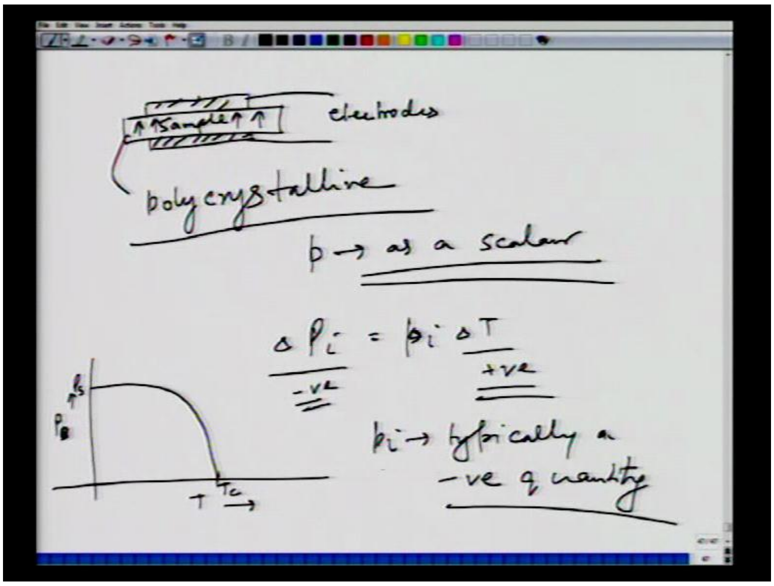

However, typically, what happens is that, in reality, you have a sample. And, this sample is connected to the electrodes on the both sides. And, these electrodes measure essentially the change in the polarization. Since basically, the polarization, which is measured perpendicular to the electrodes; and, since most of the time the samples happen to be a polycrystalline material; you take them... So, pyroelectric coefficient in such a case; this is a polycrystalline samples. And, what you get basically, an averaged quantity. As a result, for most of these practical applications, you take small p as a scalar; which is not a correct representation. But, for practical purposes, it can be thought of as a scalar.

Now, looking at the... Now, what happens if you look at this expression delta P i is equal to small p i delta T. Typically, what happens to... When you increase the temperature, let us say, delta T is positive. So, when you look at the polarization of the material, polarization of the material goes like this. So, this is Ps and this is temperature or polarization; this is Ps. So, as Tc goes to equal to 0, now, the typical behaviour is the polarization drops as a function of temperature. So, when you increase the temperature; which means when delta T is positive, this delta P i is negative. As a result, P i is typically a negative quantity. And, this is essentially because of decrease of polarization as increase in the temperature.

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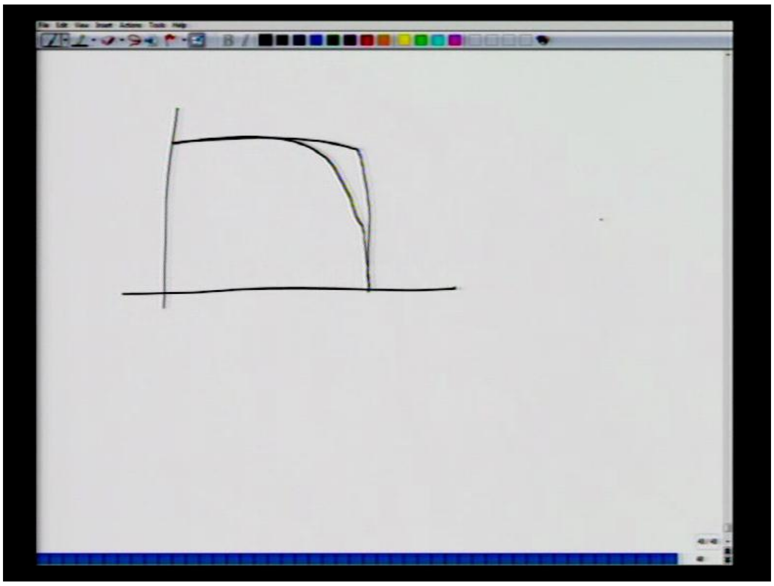

And, depending upon also the nature of transition, for a ferroelectric material, you can have a sudden transition in the polarization or you can have a gradual transition in the polarization. So, depending upon whether you have first order or second order transition, the magnitude of delta P i will also be different for both of these different kinds of effects.

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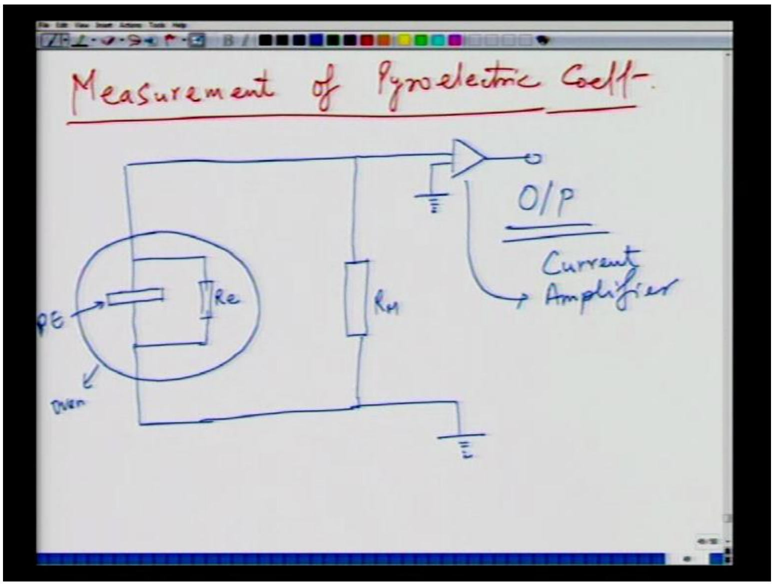

Now, how do you measure the pyroelectric coefficient? Because the moment you know that, it is an important quantity, you need to revise methods how to measure it. And, one of the simplest way of measuring a pyroelectric coefficient is you have a circuit like this. This is the pyroelectric material, let us say, P E. And, this is connected to a resistor, let us say, R e. And, this whole thing is kept in an oven. So, let us say, this is in oven. And, the circuit goes to... And, this is connected; also, again another resistance, which you can think of as a reference material R M. And then, this signal goes to a current amplifier. And, this is where you measure the output. So, this is the simple circuit for a pyroelectric coefficient measurement. So, you have a pyroelectric material in connection with the resistor, which both of them are kept in an oven. And, this is connected in parallel to another resistor, which you can think of as a reference.

So, essentially, in this previous diagram, this is basically an amplifier. Since the signals are smaller, you need to use an amplifier to amplify the signals. So, this is essentially current amplifier you are measuring. As I said earlier, the change in the polarization is measured as an induced current. So, you need to measure that current, typically that current. Since pyroelectric, ferroelectric materials happen to be insulating in nature, the current which is passed through these materials is very small. As a result, you need to use amplifiers to amplify the signal.

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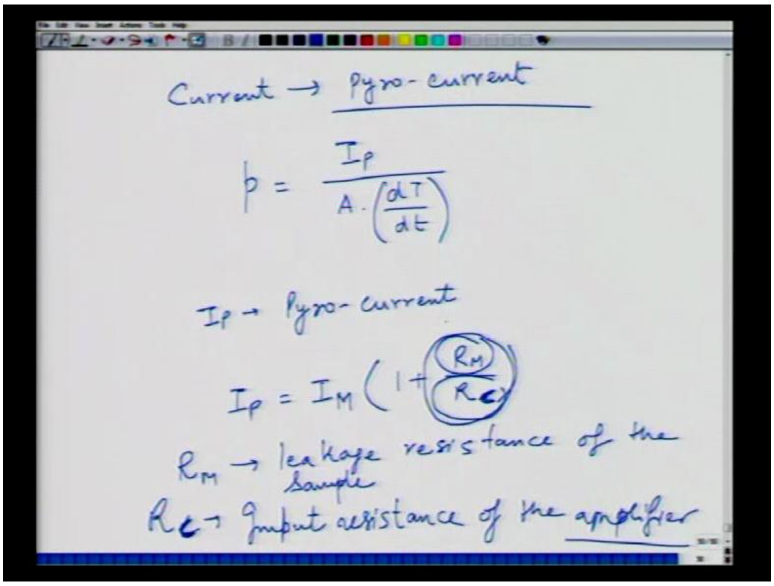

Basically, this current is essentially, which passes through an amplifier, is called as a pyro-current. And, pyroelectric coefficient as a result, is given as I P, which is a pyro-current divided by A – area divided by dT by dt. So, rate of change of temperature. So, I

P here is the pyro-current. And, this I P is given as I M into 1 plus R M by R e; where, R M is the leakage resistance of the... Essentially, this R M, which I should not connect using a solid line, rather a dotted line; this is essentially the leakage resistance of the sample. R C – this should be R C. And, this R C is the input resistance of the amplifier. Essentially, if R M was very small as compared to R C; which means the leakage resistance of the sample was very small as compared to amplifier; then, this term goes to equal to 0 and I P will be equal to nothing but I M, which is essentially the current, which is measured across the sample, which is the same. And now, this term is used to amplify the...

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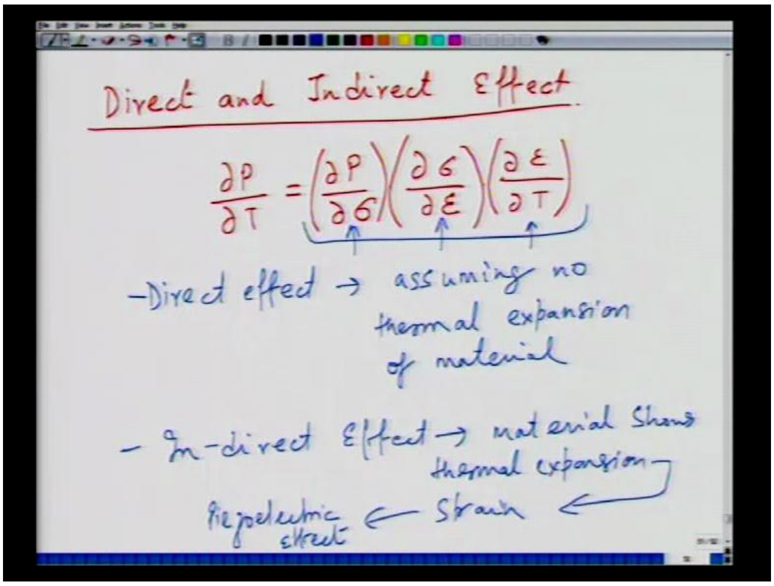

And, in pyroelectricity also, you have what is called as a direct and indirect effect. Essentially, since all the pyroelectric materials are piezoelectric as well. When you heat or cool the material, you have thermal expansion coefficient or thermal expansion playing up of the material. So, this induces thermal stresses in... As result of thermal depoling or poling, you have thermal stresses built up in the sample. And, these thermal stresses give rise to their own polarization. And hence, they change the overall polarization. As a result of this coupling between temperature, stress and polarization, because you know that the material is pyroelectric, but at the same time it is piezoelectric as well. So, you cannot discount the effect of stresses, which are playing up during the thermal poling of the material. So, this del P by del T, which is change in the polarization can be expressed in differential terms, which take each of these factors into account. So, this del P by del T can be expressed as del P by del sigma into del sigma by del epsilon into del epsilon by del T.

Now, you can see this very clearly. You have temperature effect on the strain; strain effect on the stress; and, this stress effect on the polarization. So, you have got all the three effects distinguished, which are all built up into the one term, which is the del P by del T, which is the overall expression. Naturally, when we started saying that the material was subjected to difference in the temperature, we were only worried about the change in the polarization. But, microscopically, when you look at it; when you change the temperature material back and forth, then as you change the temperature, because material has a finite coefficient thermal expansion; as a result, it expands or contracts. And, this expansion or contraction gives rise to strain. This strain gives rise to stresses. And, these stresses give rise to change in the polarization. So, depending up on the magnitude of the each of these terms, the net polarization will change accordingly.

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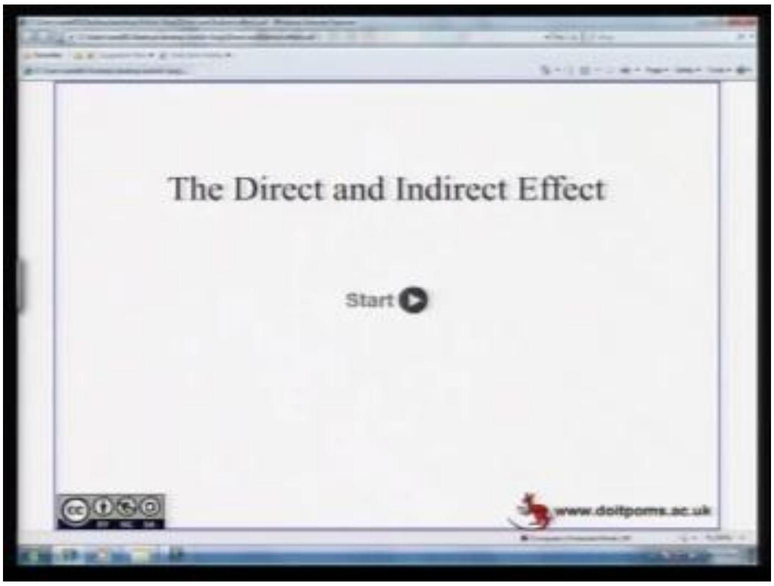

I will show you an animation based on this and then we will move forward to further file parts of this lecture. This is again taken from doitpoms dot ac dot uk, which is the university of Cambridge materials resources library. So, we acknowledge the help of this site.

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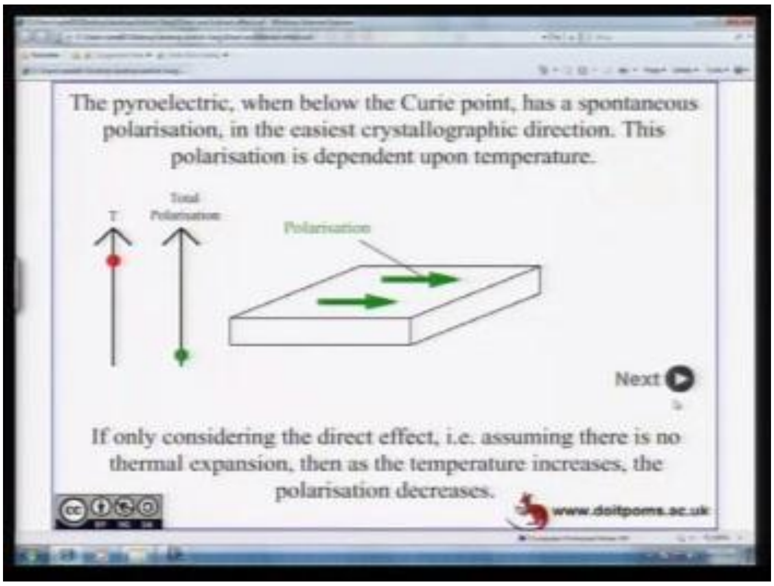

If you start this; if you read the first line; below the Curie point, the pyroelectric has a spontaneous polarization. And, this is in the easiest crystallographic direction. And, this polarization as we know is dependent upon the temperature. At low temperature, which is much lower than T c, we know that polarization is very high; which is fine because that we know that. And, as a result, you have polarization built in the material. Now, if you only consider the direct effect; which means there is no thermal expansion; there is no thermal contraction; or, basically, there is no effect of temperature on the lattice parameter. Then, as the temperature change increases, the polarization decreases; which is fine. That is what we talked about earlier.

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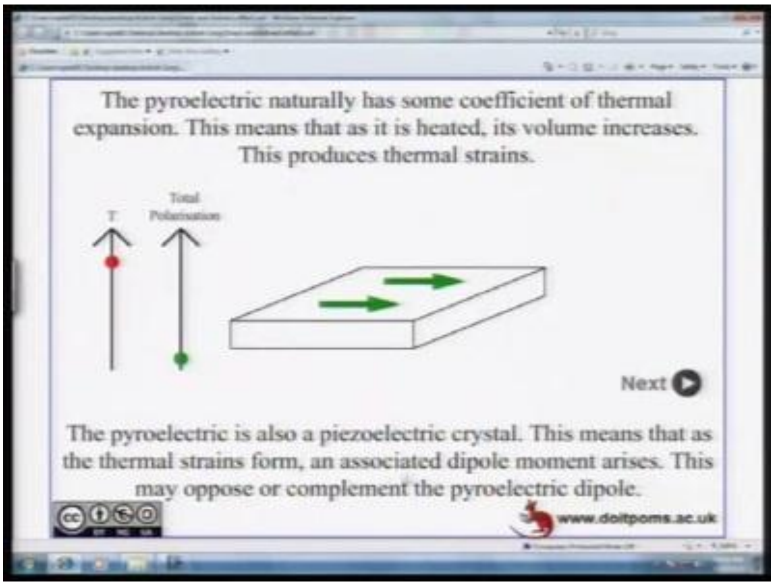

In reality, what happens is since every pyroelectric, every material has a coefficient thermal expansion and pyroelectrics are not any exception to this rule; which means that, as you heat this pyroelectric material, the volume will increase, because typically, materials expand as you heat them. And, as the material gets heated; as it gets bigger, it produces thermal stresses or thermal strain rather, because this delta A, which is the change in the lattice parameter, is nothing but thermal strain. So, this thermal strain since the pyroelectric is also a piezoelectric material; this means this thermal strain... this means as the thermal strains form, the associated dipole moment also arises, because we know that, pyroelectric material – the strain gives rise to dipole moment or polarization. And, this will typically oppose the pyroelectric dipole.

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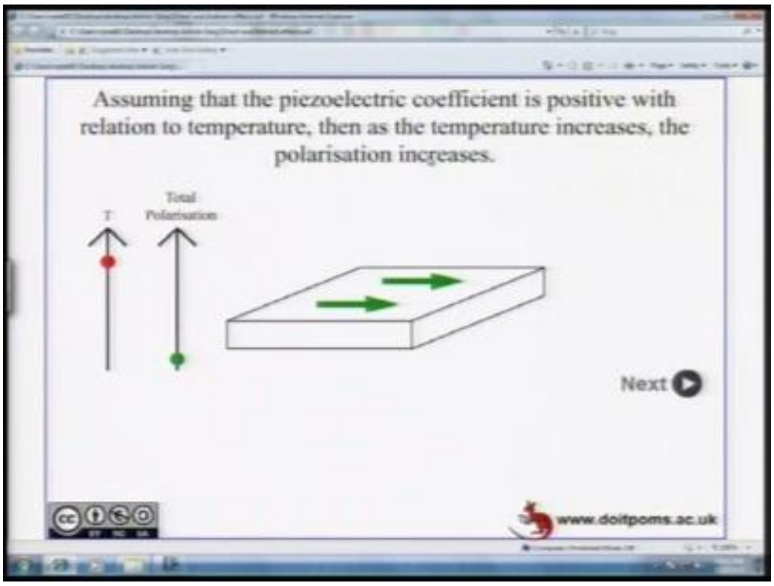

As a result, assuming that the piezoelectric coefficient is positive with respect to temperature; which means, then, as the temperature increases the polarization increases. So, as you increase the temperature, you are increasing the strain; which means polarization is increasing. So, this is what you see here. This is as you increase the temperature, the overall polarization has gone down; but, this piezoelectric term has increased the polarization by some magnitude.

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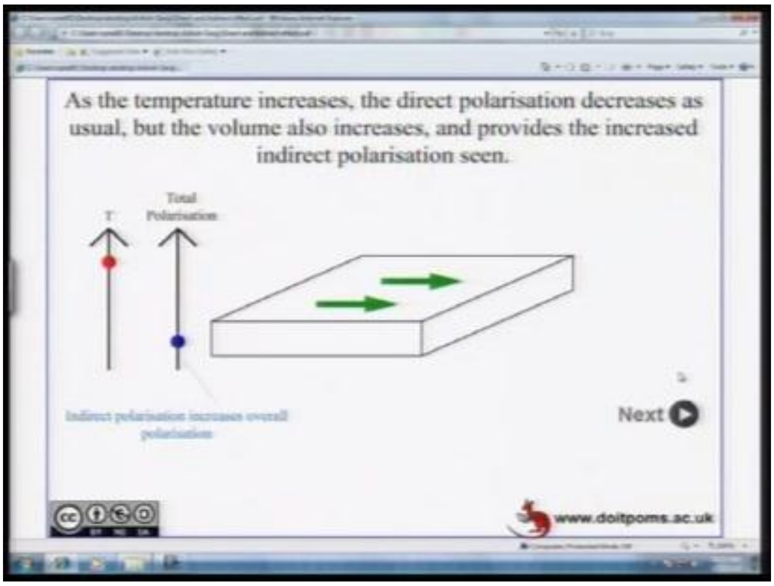

As you can see that, indirect polarization increases the overall polarization. In reality, the polarization must have been somewhere here; or, ideally, in the case of the direct effect, the polarization must have been here. But, this indirect effect, which is due to piezoelectric behaviour of the material, has increased the polarization from here to here. So, if you look at the previous for example; this was the initial polarization; and, when you start applying that, when you start taking the indirect effect into account, this green ball, which was earlier there has jumped to the blue boll. So, this is as a result of indirect polarization, because of piezoelectric effect. And, this is simply because the piezoelectric coefficient is positive.

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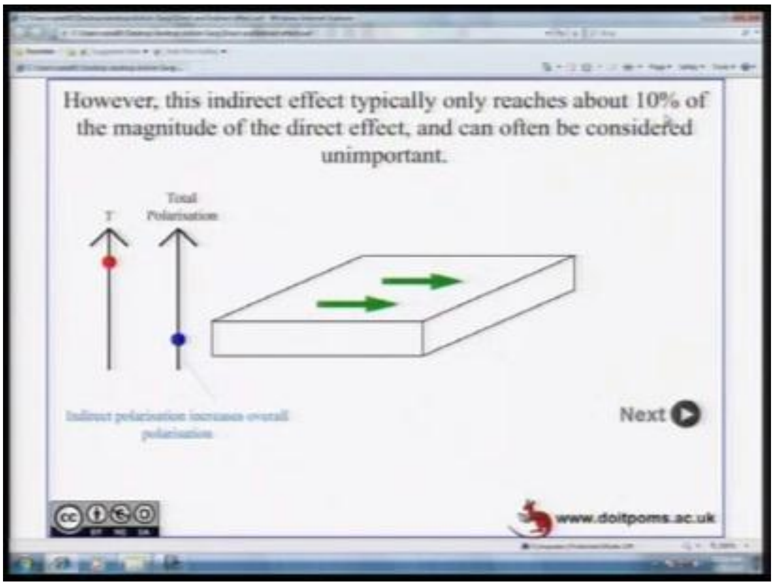

However, this indirect effect typically reaches about 10 percent of the magnitude of direct effect and often is in unimportant. Since we are not talking about very large changes in the polarization because of indirect effect, often these effects can be neglected. However, from the point view of understanding, it is important to know that, when you subject the material to change in the temperature, not only its polarization drops as a result of direct effect, but you also have this piezoelectric effect built in the material, because all the pyroelectrics are piezoelectrics. As a result, you have the piezoelectric effects coming into picture.

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So, this is what essentially it is.

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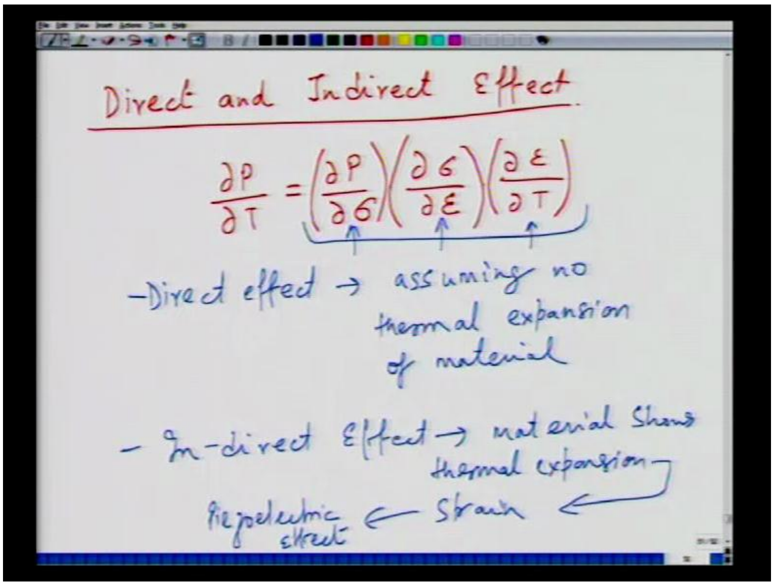

Now, we will look at some of the common pyroelectric materials. Examples of some... Let me just do certain things here. Essentially, what we are saying is that, direct effect is essentially, assuming no thermal expansion of material. Indirect effect material shows thermal expansion, which gives rise to strain. And, this gives rise to piezoelectric effect and which will change the polarization. So, essentially, what we have here established is that, although most of the times for pyroelectric materials, we are worried about direct effect; which means we do not take into account the piezoelectric effect built in the material. However, from the point of view of sake of understanding and also from the point of view of materials, which have large indirect effect contribution, it is important to understand this reality. So, this is essentially the... And, this formula expresses all these effects built in. So, you have strain, change in the temperature giving rise to strain, change in the strain giving rise to stresses; and, change in the stresses giving rise to change in the polarization. And, depending upon whether piezoelectric coefficient is positive or negative, you will have accordingly the changes in the polarization.

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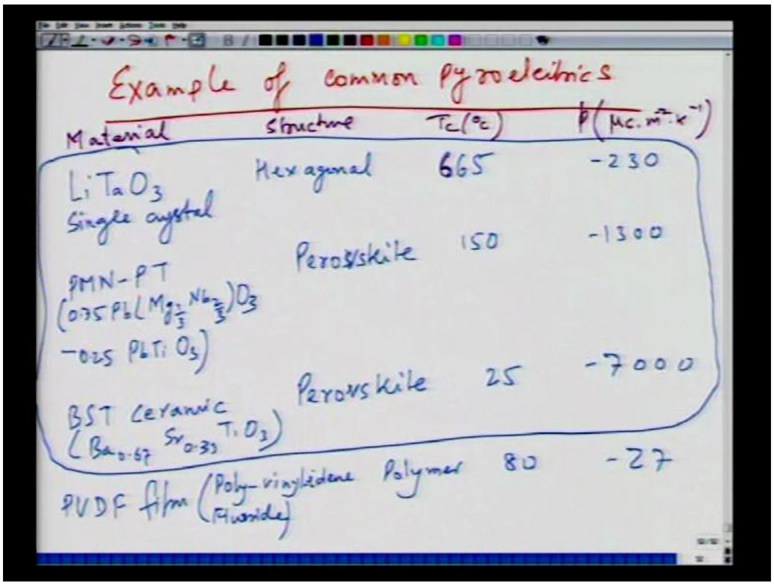

Examples of some common pyroelectric materials – for instance, one of the important one material is Li Ta O 3, which is lithium tantalite; it has a hexagonal structure and it has a... This is... Let me just defined this table. This is material, structure, Tc in degree centigrade; and then, pyroelectric coefficient in microcoulomb per meter square per Kelvin, because as we know, p is nothing but delta p by delta T. So, microcoulomb basically coulomb per meter square per Kelvin – micro is just added, so that the quantities are views are perspective. So, this value is 665. And, this is minus 230 for lithium tantalate single crystal.

Another material, which is of importance is often referred as PMN-PT; PMN is essentially 0.75 of lead, magnesium 1 by 3, niobium 2 by 3, O 3. This you must remember from the mixed perovskite discussion in the module one. And, 0.25 of lead titanate, which is PbTi O 3. So, this is the mixed perovskite. You have perovskite as simple as lead titanate; then, you have a perovskite, where A ion is lead, but the B ion is occupied as a mixed occupancy of magnesium and niobium. And, this is a very important material. It has a perovskite structure. And, it has a Tc reasonably high – 150 degree centigrade. And, this is a very large pyroelectric coefficient of minus 1300 microcoulomb per meter square per kelvin. So, this is a very important material from this point of view.

You can also have BST ceramic; BST is barium 0.67, strontium 0.33, Ti O 2. So, this is basically solid solution of barium titanate and the strontium titanate; where, A site is partially occupied by barium or strontium ions. And, this again has a perovskite structure. And, it has a Tc of 25 degree centigrade. So, it is a room temperature or lower kind of material, but has a very large pyroelectric coefficient. And then, you have PVDF, which is a polymer; which is not a ceramic; which is called as a poly vinylidene fluoride. And, this has a... Basically, it is a polymeric structure and it has 80 degree centigrade of T c, which is reasonably ok. And, it also has reasonable pyroelectric coefficient. But, from the point of view of ceramics, these three materials stand out. And, they have either high Tc or high pyroelectric coefficient, which is very important for commercial applications.

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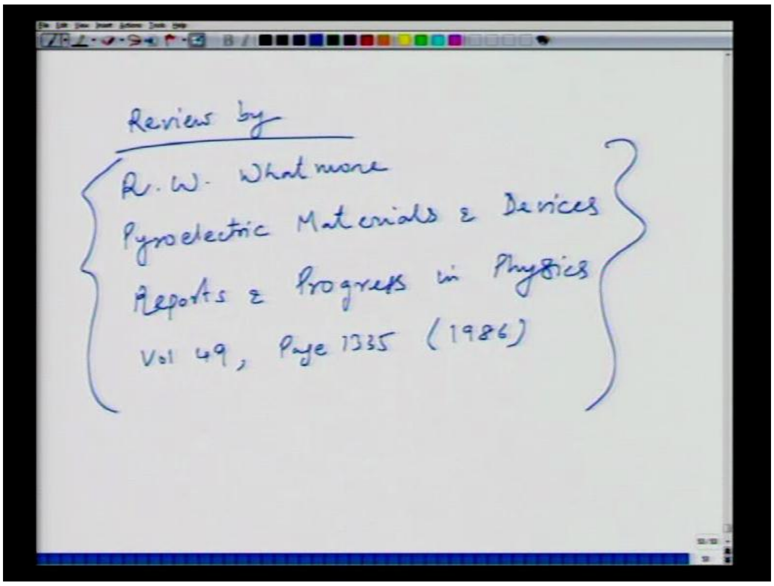

If you want to go to details of discussion on variety of materials, I would suggest, you look at review by Roger Whatmore – R. W. Whatmore. And, this is in... Basically, the paper title is pyroelectric materials and devices. And, this is in journal, Reports and Progress in Physics, volume 49, page 1335. And, this was published in 1986. So, this is a very nice review article by Professor Roger Whatmore, who is of Cranfield University, UK. This is... Who is now at Cranfield University, UK. When he wrote this review, he was in a private company. So, you can go through this review to have a more detailed discussion on variety of pyroelectric materials.

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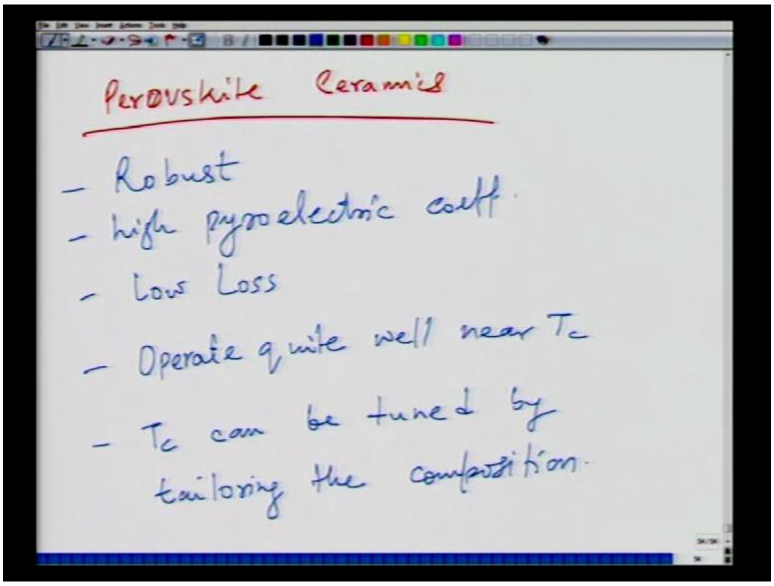

Just to look at variety of these materials, typically, PVDF; I will not discuss the materials, which are not ceramics. So, we will just focus our attention on perovskite ceramics. Typically, perovskite ceramics have... They are generally robust; which means they are environmentally strong material; they do not degrade as a function of temperature. So, when you thermally pole them up and down, they do not degrade. So, they are robust. And, they are also insensitive; rather insensitive to moisture and vacuum. So, very sturdy kind of materials. And, they have typically high pyroelectric coefficient and they have low loss characteristics; which means the induced current that you generate in the material as a result of change in temperature. That should not be lost out; it should be detected. As a result, the material must have low loss characteristics. And, they operate quite well near T c. And, depending upon the material, the T c's can also be quite high. So, you can say, the Tc can be tuned by tailoring the composition. So, this is a general guideline for perovskite ceramic materials.

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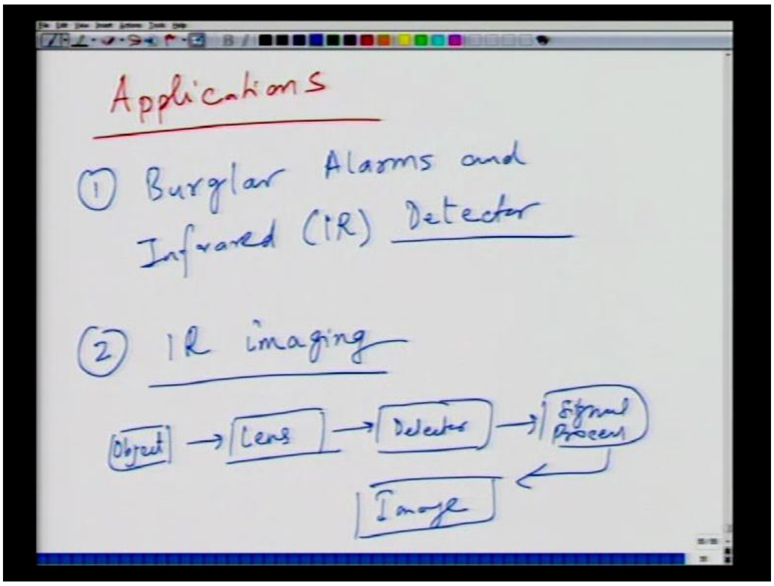

Now, we look at the applications in which pyroelectric materials are used. Looking at the fundamental physics of pyroelectric material, where delta P is proportional to delta T. These are used in applications, where change in temperature is the input. For instance, one of the important application for these is burglar alarms and infrared or IR detectors. Essentially, you have a alarm, which has a pyroelectric material. And, when an intruder passes in the vicinity of this alarm, the alarm detects his presence by change in the temperature, because human body has a certain temperature as compared to ambiance and this signal, which is delta T. And, these are materials quite sensitive; these alarms are also very sensitive to the presence of material even to a large distance. And, this change in the temperature or ambient triggers and change in the polarization; which triggers an alarm. However, in order to counter the effects of thermal expansion, one needs to use an identical reference material to counter these extraneous or unwanted effects. And, these are sensitive up to a distance of about 100 meters, which is a very large distance.

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I will show you an animation based on this IR detector. Again, this is taken from university of Cambridge website – doitpoms dot ac dot uk. We have to acknowledge their assistance – pyroelectric materials as infrared detectors.

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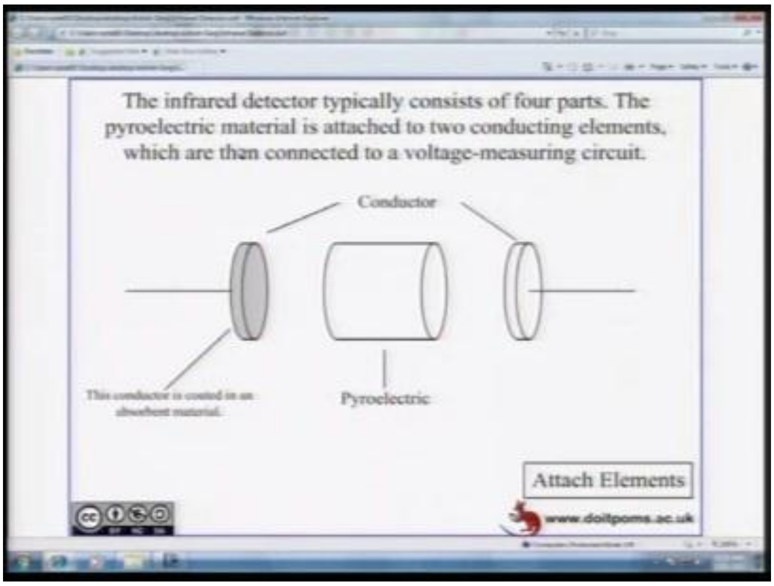

This IR detector typically consists of four parts. And, the material is attached to two conducting elements. Conducting elements are nothing but basically... so that they could be connected to a voltage measuring circuit. So, these are the two conductors, which are... You can think of them as electrodes. And, this is a pyroelectric material.

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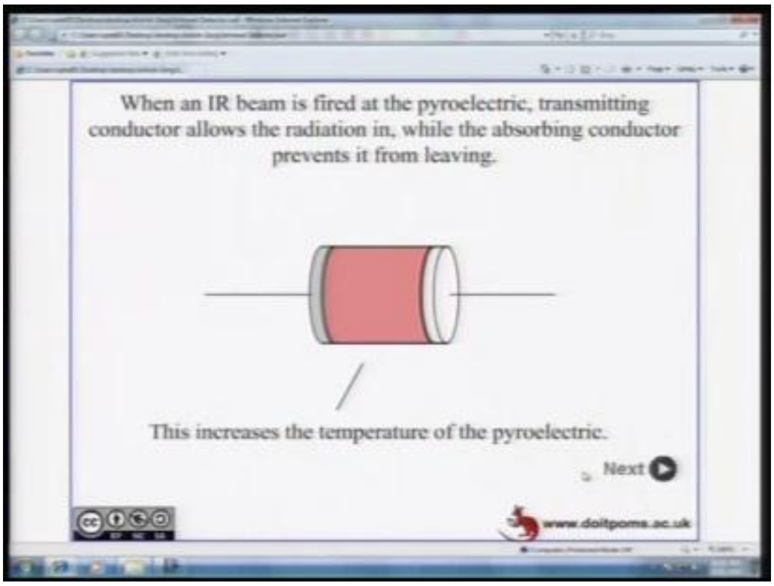

And, when you put them together, they look like... And, when you send an IR pulse to this material; naturally, this IR pulse is nothing but it is a long wavelength radiation, which represents the ambient. And, this increases the temperature of the pyroelectric.

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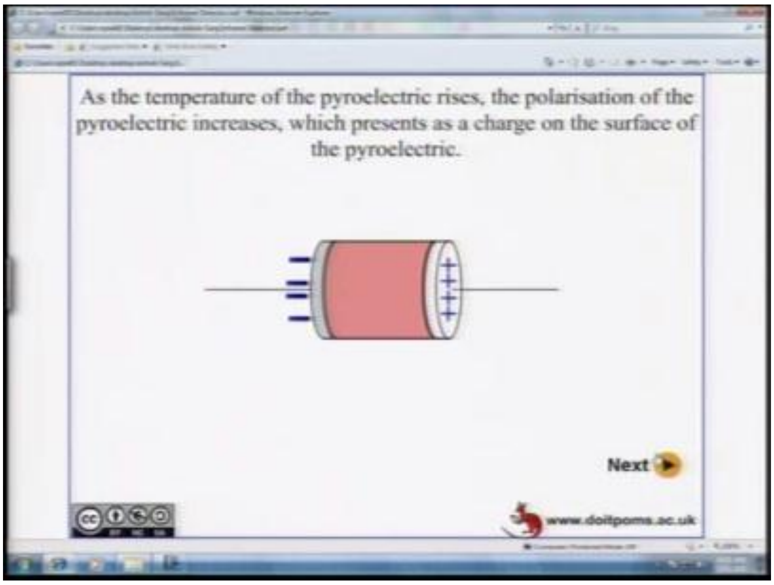

As a result, you develop a polarization on the surface of the pyroelectric.

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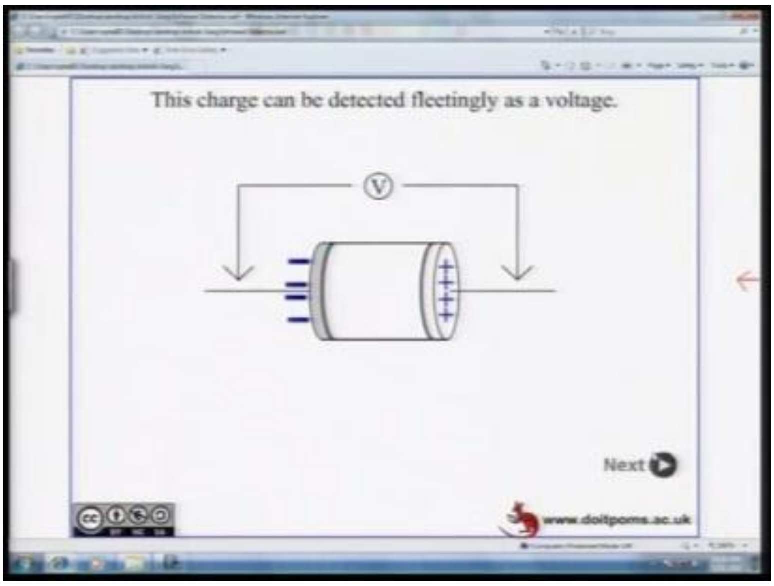

And, this can be detected as a voltage.

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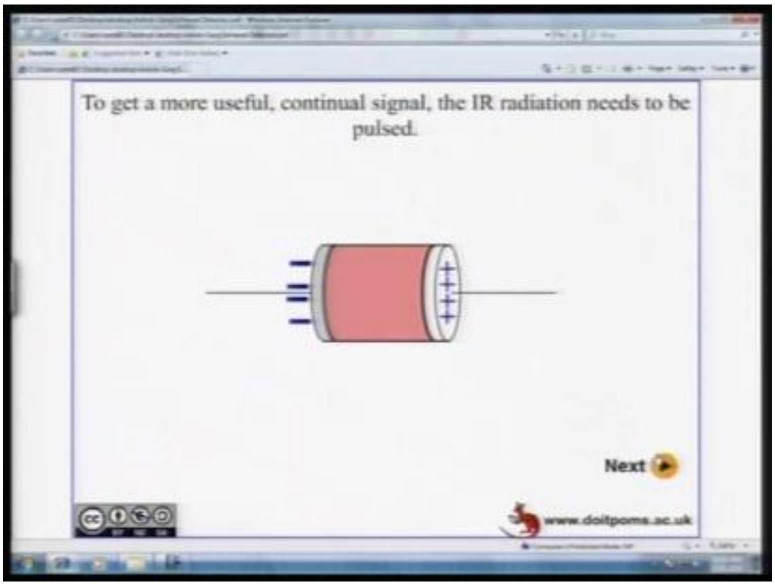

You make it more useful. You can provide a continuous radiation in the form of I R pulses.

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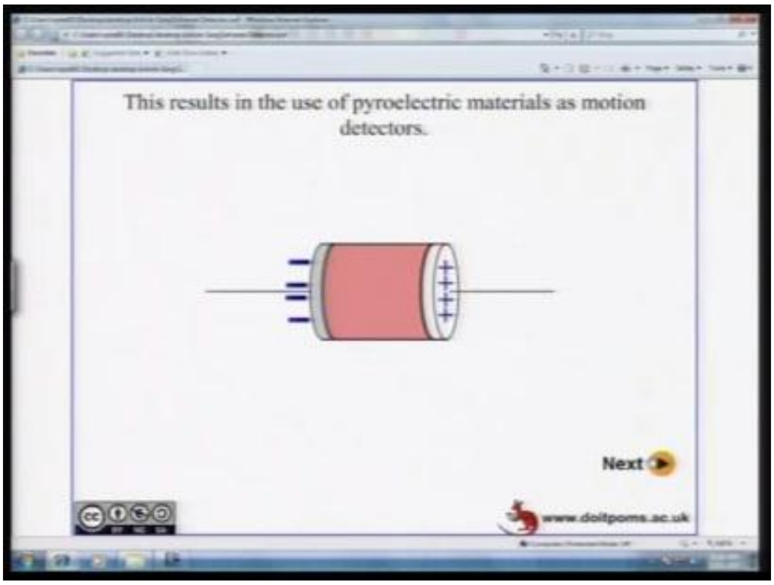

When you do that, you have a pulse radiation and this is typically used as a motion detector.

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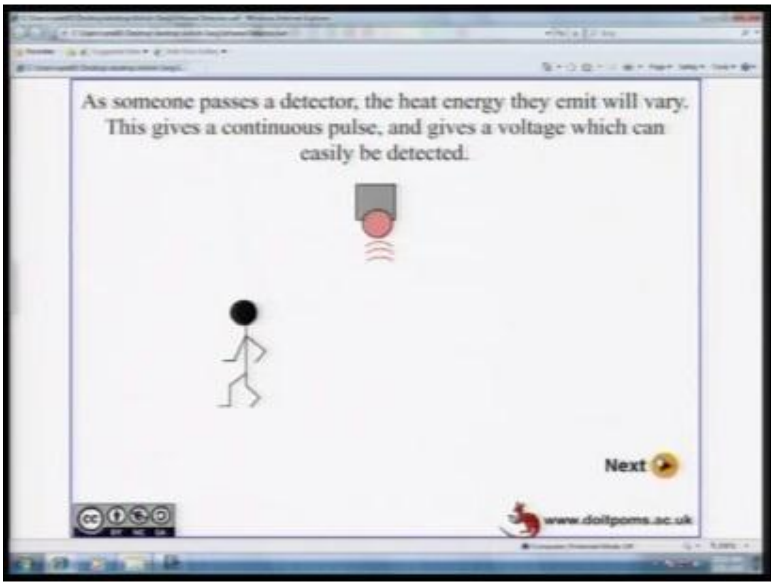

As someone passes in the vicinity of this detector, the thermal energy, which the humans or the object will emit – this will vary and this will give rise to a pulse. So, it is like a pulse IR radiation. And then, this generates a voltage, which can then be easily detected.

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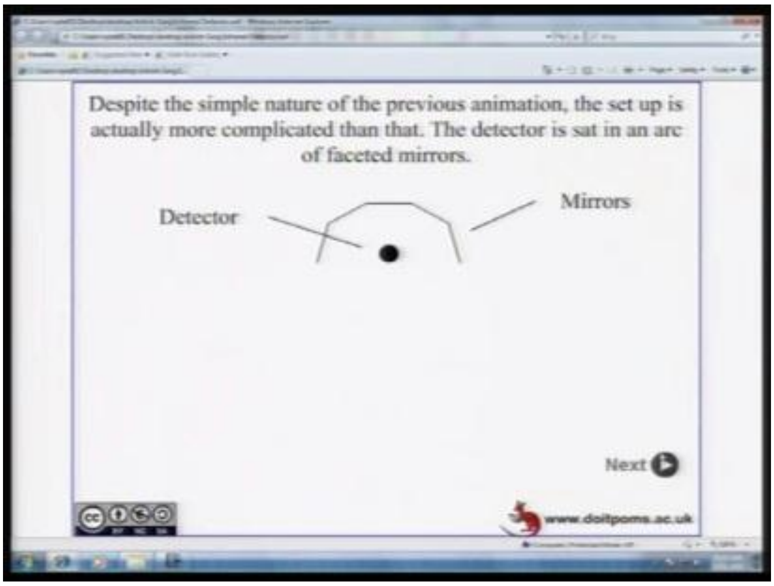

The set up of this; although it looks pretty simple on the paper, but the set up is quite complicated. So, basically, how you make the detector is it is put in an arc of faceted mirrors. So, you have these faceted mirrors, whose job is to reflect the radiations, so that the reflected radiations are not lost.

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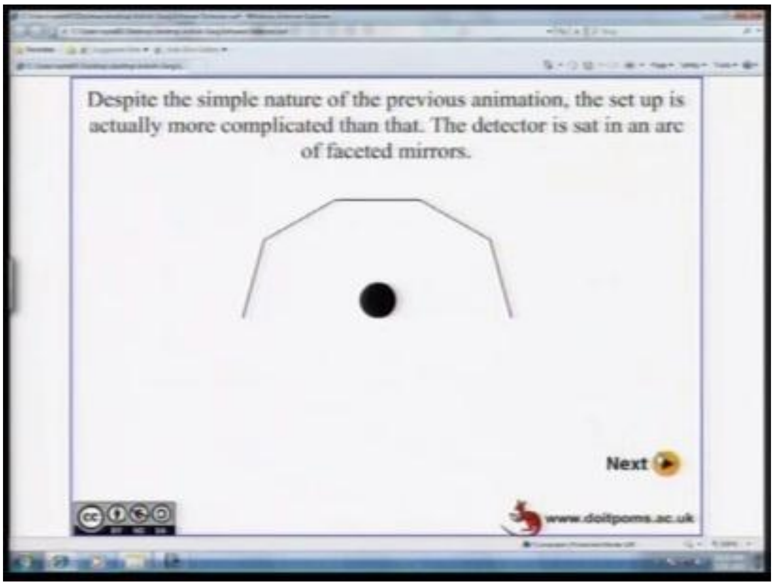

These are the... So, this is how it looks like. You have this detector, which is sitting inside this arc or a shape, which is made by the faceted flat mirrors.

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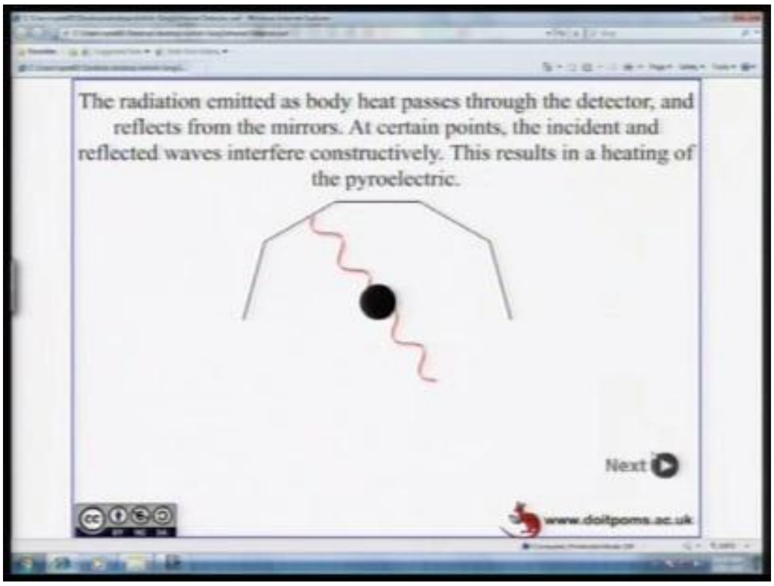

This radiation, which is emitted by the body, which is passing in the vicinity of the detector – it gets reflected from the mirrors. And, at certain points, the incident and the reflected waves have to meet constructively, so that they amplify the signal. And, this results in the heating of the pyroelectric. So, the input signal gets amplified by reflection from these mirrors. As a result, you have this heating of the pyroelectric.

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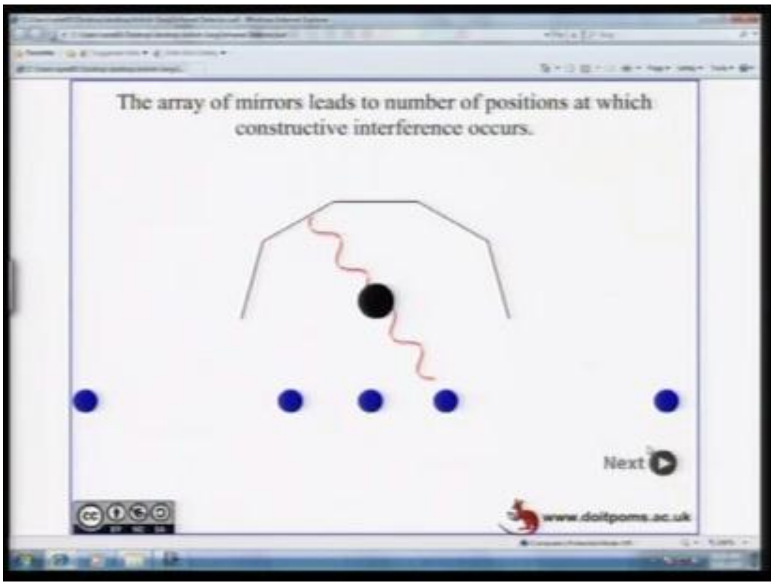

And, the position of mirror has to be in such a way, so that you have constructive interference at those positions.

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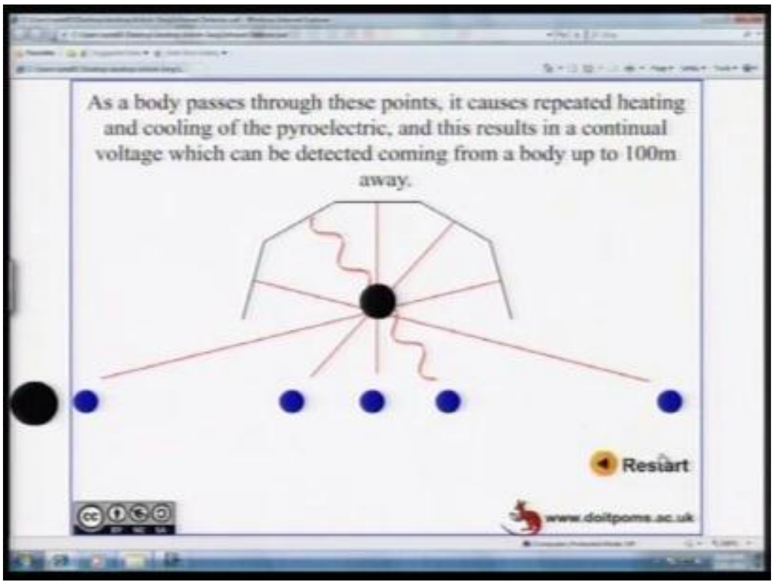

As a result, you have large signal, which results in large heating or repeated heating and cooling of pyroelectric. As a result, you have a continuous voltage. And, this has a sensitivity of up to 10, 100 millimetres, 100 meters. So, this is one application, whose animation just now you saw.

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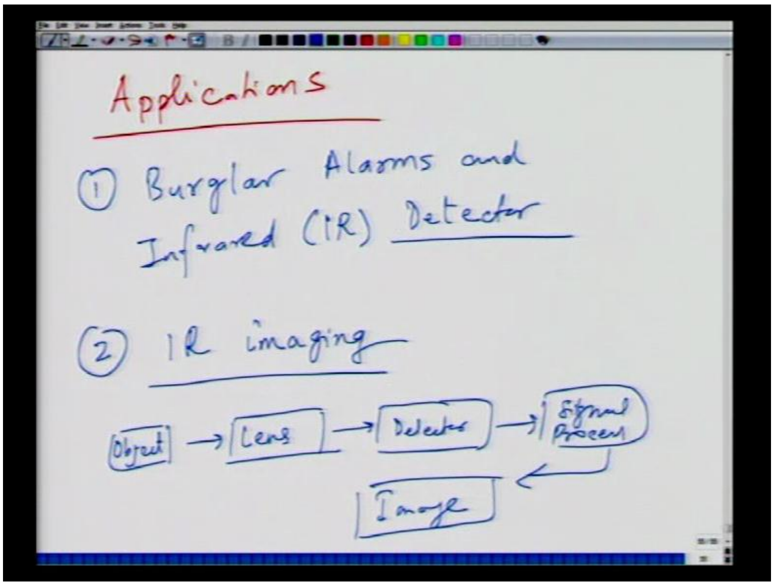

Another application could be IR imaging. Not only the pyroelectric materials can be used as alarm or detectors, they can also be used for imaging a particular, let us say, a body. The principle here is because the body has different parts and all of these parts are at different temperatures and these temperatures – changes in the temperature at each places in the body are different, they give rise to different signal in the pyroelectric. So, if you just scan the body, you get different polarization in different places, which can be used to create thermal image of the body. And typically, the image that you see looks something like...

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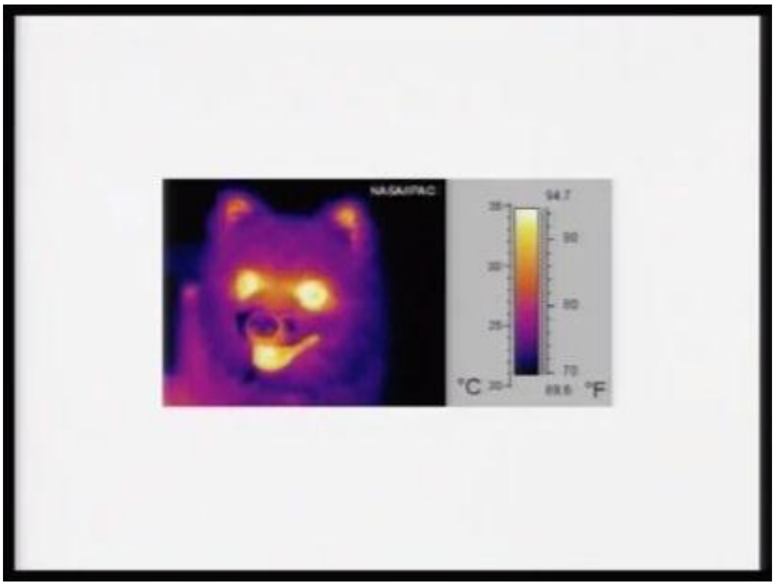

What I will again show you is like this. It looks something like that. So, this is the image of an animal. You can see that the parts... This is a scale, which is giving you the meaning of this colour coding. So, brighter the colour is, higher the temperature is; and, darker the colour is, lower the temperature it has. So, you can see that, which parts of the body have higher temperatures; you can see these ear lobes of this dog and these eyes and near the mouth, the body has higher temperature. And, other parts of the body have lower temperature. This is taken from NASA – this image. So, we can acknowledge their help with this image. So, this is how the thermal image is created from an animal or from a body. So, you can create this. These can be used for IR imaging applications. So, these are two important applications. In IR imaging, basically, what you do is that, you take an object. And, the image is passed through the lens. And basically, you have a special lens, which focuses the IR emitted by all of this object through the lenses. And then, these focused IR waves, which pass through the lens go to the detector and detector does the processing. So, you have signal processing. And, this gives rise to an image on the monitor. So, this how essentially it works.

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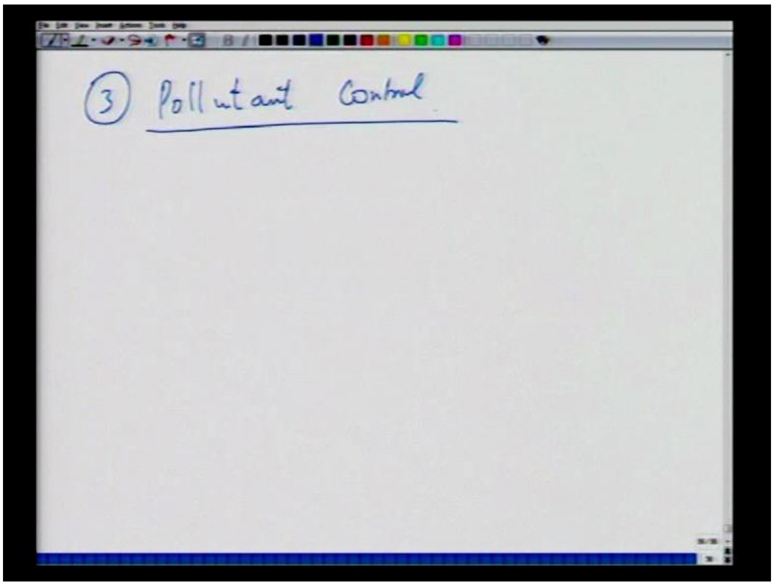

Finally, you have other application, which can be used in for pollutant control. And, pollutant control is a very important application, because nowadays, pollution is becoming a very important issue for the health of our society. And, essentially, pyroelectric – since they are excellent detector of IR radiation, they can easily detect this level of IR radiation, which passes through a gas sample. Since each of these gases have a characteristic wavelength, which it absorbs, we can measure this easily. And, I will again show you an animation based on this and then we can finish this part.

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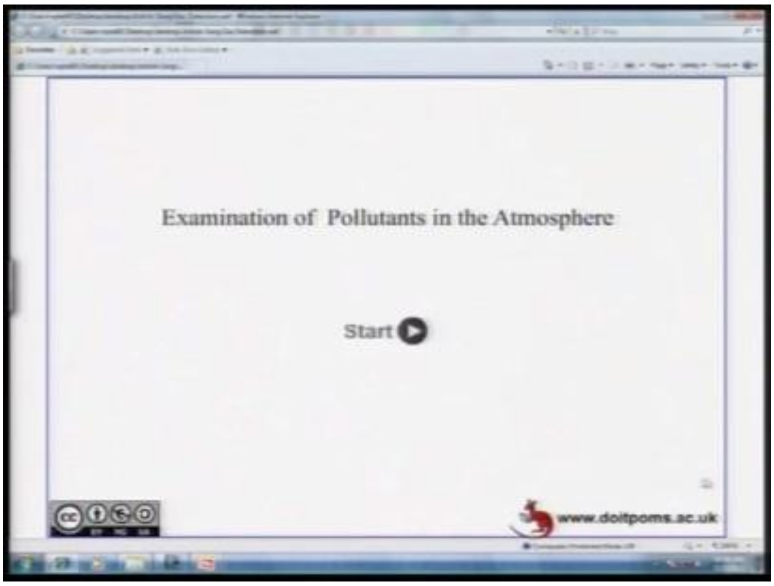

Again, we have taken this firm doitpoms dot ac dot uk. We acknowledge university of Cambridge for this.

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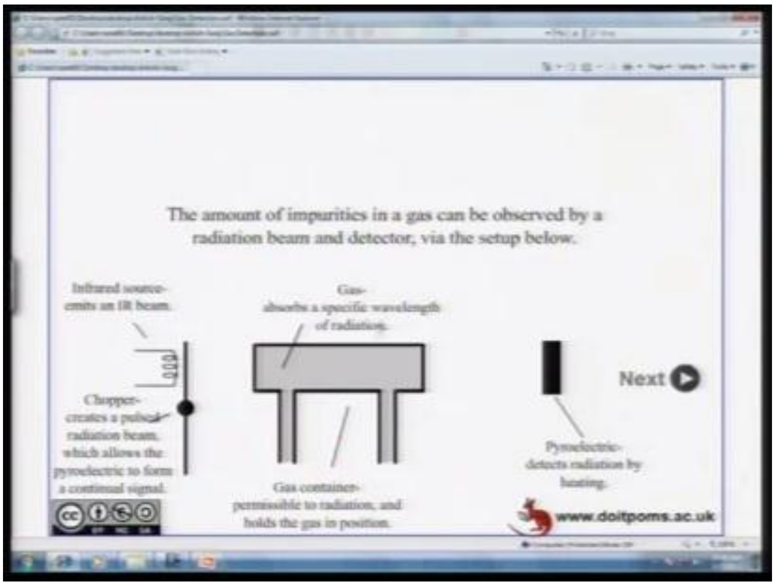

The amount of impurities in a gas can be observed by a radiation beam detector using the setup, which is shown below. This setup has an IR source, which emits an IR beam. And, you have the gas, which absorption characteristics towards specific wavelength of radiation and which is inside a container. Then, a pyroelectric, which detects radiation by heating.

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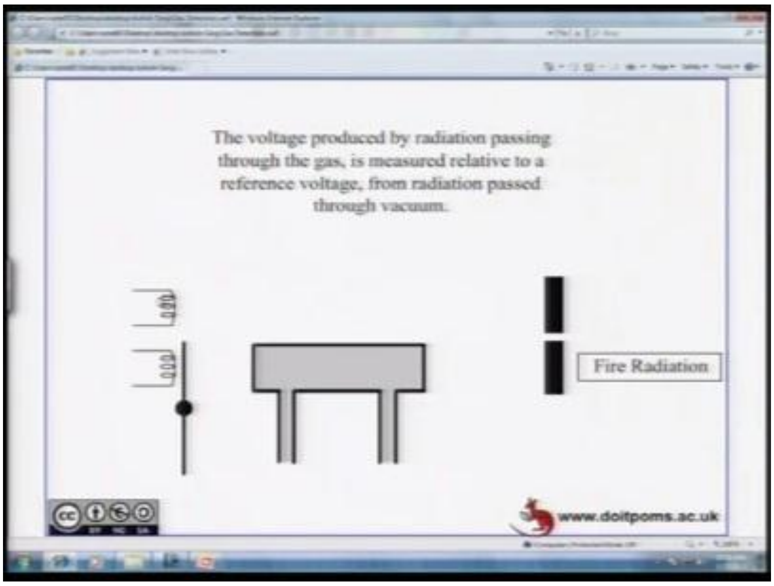

The voltage, which is produced by radiation, which passes through the gas is measured related to a reference voltage. So, you have to have a reference sample. One is the reference sample; another is the sample, which is used for measurement.

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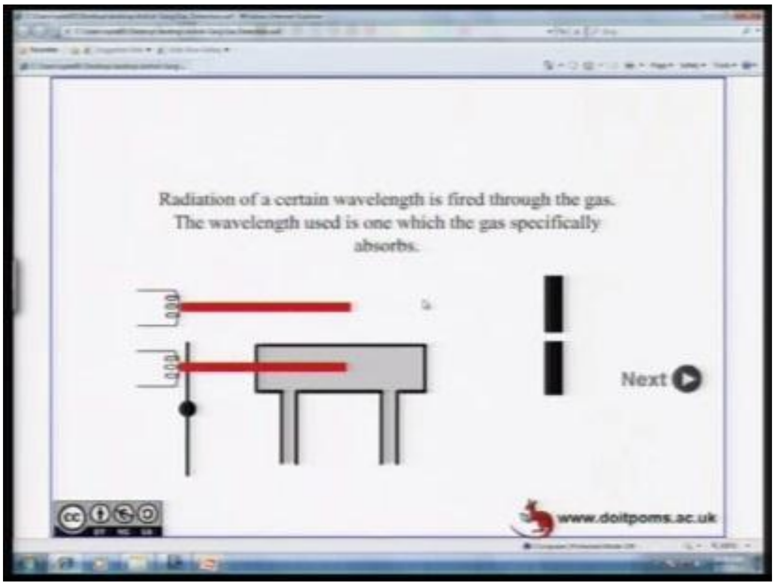

And, when you fire the radiation through the gas, then you have to measure with respect to this. So, the radiation of certain wavelength is fired through the gas. And, this wavelength, which is used, is corresponding to the absorption characteristic of the gas.

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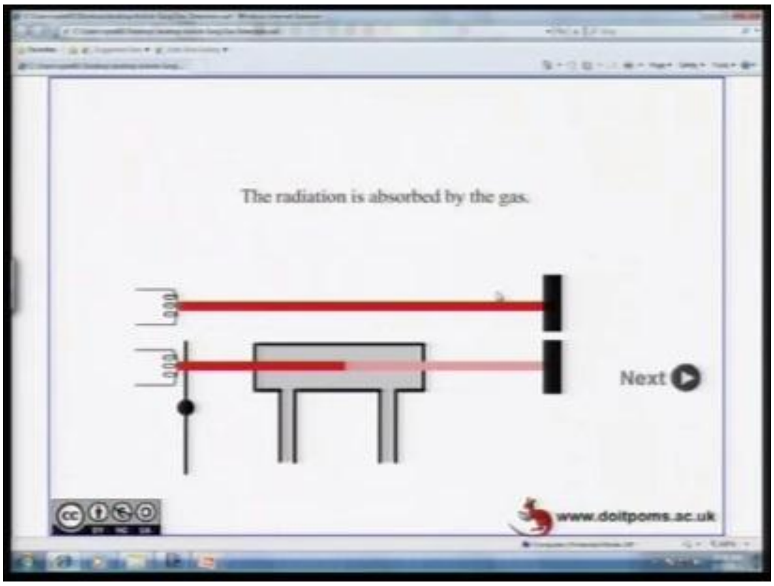

Essentially, the radiation is absorbed by the gas.

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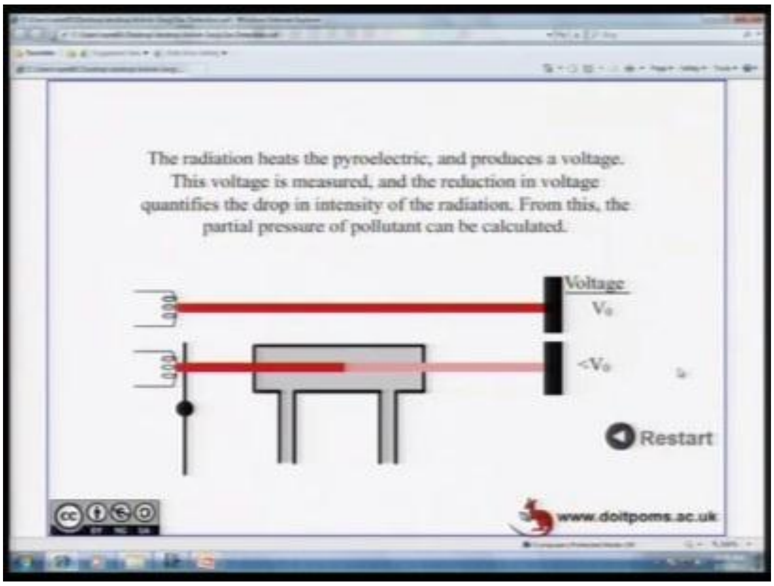

And, the comparison of these two gives you the characteristic; basically, what kind of gas you have or what kind of pressure of the pollutant that you have. So, this is how you do the detection of gases in using the pyroelectric material. So, we have finished this module here.

In this module, we looked at ferroelectric, piezoelectric, pyroelectric material. All of these three materials are technologically very useful materials. Typically, most of these materials – the way we use them in the ferroelectric form, because ferroelectric is always piezo and pyroelectric. Essentially, most of these ceramics, which we use, happen to be ferroelectric as well. And, they can also be used as pyroelectric and piezoelectrics since they have good piezoelectric and pyroelectric coupling coefficients. And, they can be used for variety of applications as we have seen. So, this sort of ends this module here.

The next module that we start, will have a discussion on another technologically important class of ceramic – electroceramics, which is going to be on magnetic ceramics. So, I hope I have tried to explain the things in as detailed as possible without making it too complicated. So, hopefully, it will help you in understanding the science of nonlinear dielectrics, which is ferroelectrics, pyroelectrics and piezoelectrics. And, there are plenty of reference books that you can go through. For example, books by Moulson and Herbert in Electroceramics. There are specific books on pyroelectricity and piezoelectricity, which you can go through as well; which are provided in the bibliography, which will be provided on the online site for the course.

Thank you.