**Advanced Ceramics for Strategic Applications**
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**Lecture - 18**
**Electrical Phenomenon in Insulators (Contd.)**

Let me continue about discussion on the electrical phenomena in insulators; as we have discussed last time, these are basically dielectric materials. And they are used as capacitors when they are placed on the materials are placed between 2 electrodes. We have discussed various aspects, various parameters of the dielectric phenomenon.

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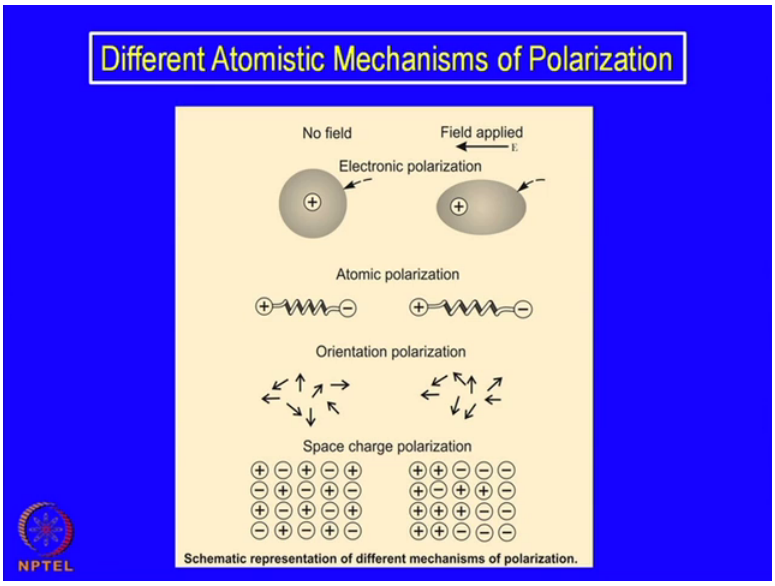


And, also discussed different atomistic mechanisms of polarization, because the dielectric constant; actually arises from the polarization of the insulators under the influence of external electric field. And there are were different mechanisms by which this polarization takes place. Basically, polarization means there is a dipole or creation of dipoles or dipole moment, so it is increase of the dipole moment that leads to polarization. We have discussed 4 different mechanisms of polarization namely the electronic polarization, atomic polarization or ionic polarization, orientation polarization, and also space charge polarization.

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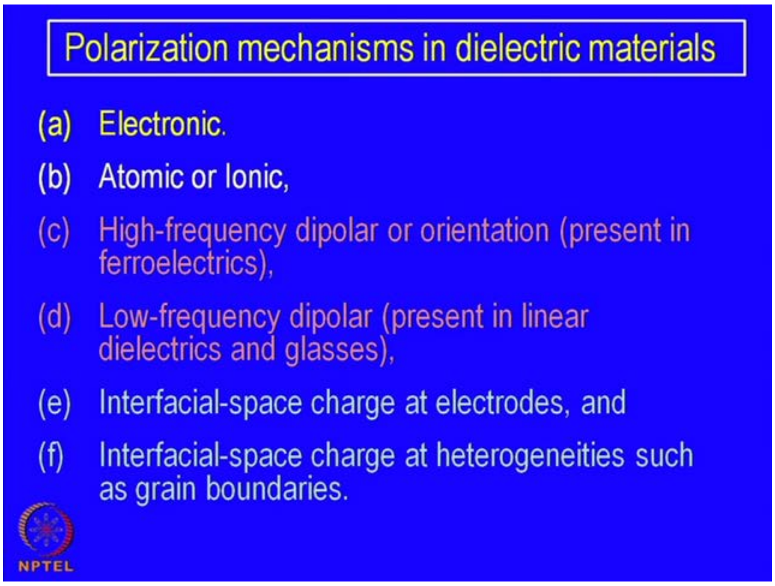


We have also looked at very briefly; there are little sub classification of this four types of polarization. 2 of them have been in classified or subdivided into two groups each particularly the orientation polarization, we have a high frequency version as usual low-frequency version. High-frequency version is applied to primary ferroelectric materials about which will discuss later. And low-frequency the dipolar version is primarily applies to classes. For the space charge polarization also we have two different categories; one is the interfacial space charge at the electrodes which we have discussed.

And, just like the electrode electrolyte is an interface gain boundaries in particularly polycrystalline ceramics is are also place a part. So, for as the interface polarization is concerned. So, that creates certain boundaries where space charge can accumulate, and therefore the dielectric polarization can take place.

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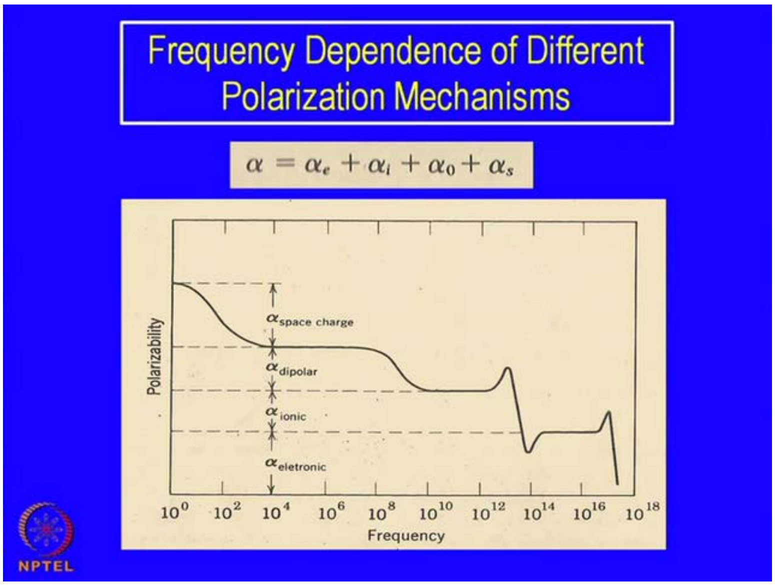


Next thing is if you have a electric field not a d c field, but a alternate field a c field. Then there will be frequency and the frequency dependence of these kind of mechanisms are not same. Because these are there is some charge transport or charge movement displacement of charge from one side to the other. So, it needs some time. So, the relaxation time the frequencies at which these changes can take place are different for different mechanisms. One can visualize the electronic polarization where only the displacement of the electron cloud or the deformation of the electron cloud takes place. And this can take place at very high frequency or very high-speed.

So, the relaxation time is very small and therefore, it can respond to almost any kind of frequency which is applied from outside. Whereas, if you look at the space charge polarization that is the slowest process in this over categories; because it needs slightly longer range of transport of charge species, in this case primarily the ions and the mobile ions.

So, that is time-consuming and therefore, the time required for the movement or movement back and forth is much larger or the relaxation time is larger. So, it can only respond who ever low-frequency region. So, if you plot the polarizability the alpha which is been defined earlier the polarizability as a function of frequency from a wide range of frequency from almost 1 hertz to about 10 to about18 hertz. In these frequency range 4 different mechanisms respond in 4 different ways; as a slowest process of course is the space charge.

So, it can respond only a low-frequency. So, if you increase the frequency the space charge will not be able to respond; so there will be a plateau. So, at this low-frequency all the 4 mechanisms are operating including the electronic ionic dipolar or actually orientation polarization and the space charge polarization. So, if the frequency is very low all the 4 are operative. So, the dielectric constant as well as the polarization is much larger whereas, if you if once increase the frequency slightly then they will be plateau. And this plateau actually corresponds to 3 remaining mechanisms.

Therefore, the space charge mechanisms will not be operative any more. So, the polarizability as well as the dielectric constant and polarization will reduce as a function of frequency. And 3 of them will be operative at this frequency range of around 10 kilo hertz also. Whereas, once again if you reduce increase the frequency we have about 10 to the power of 10 hertz is around giga hertz range. Then we will find the 2 of them as been disappearing both the space charge and the dipolar, ionic and electronic will still be there because their relaxation time is much shorter. And so they can respond to very high frequencies; till at higher frequency more than 10 to the power 14 so almost optical frequency region.

It is only the electronic polarization or the electronic mechanism will be operative; and other 3 will not be operative. Therefore, the dielectric constant polarizability all of them will reduce. So, at very high-frequency we have only electronic polarization mechanism operative and the polarization or polarizability with much smaller. In general as a increasing frequency you can see the polarizability as well as the dielectric constant slowly decreases over a wide range of frequency. And you can also see that total alpha at any given frequency is actually the summation of all the 4 polarizabilities the electronic polarizability, ionic polarizability, orientation polarizability as well as the space charge. So, these are the summations of 4 different mechanisms which will give rise to the overall polarizability or overall polarization and dielectric constant.

So, the dielectric constant actually as a function of frequency will automatically always decrease because the different mechanism when we operate in different frequencies. So, that is a common phenomena of any dielectric material. The frequency as the frequency increases the dielectric constant will slowly reduce. In association with that or associated with this phenomena there is another phenomena also takes place this which is given in this picture.

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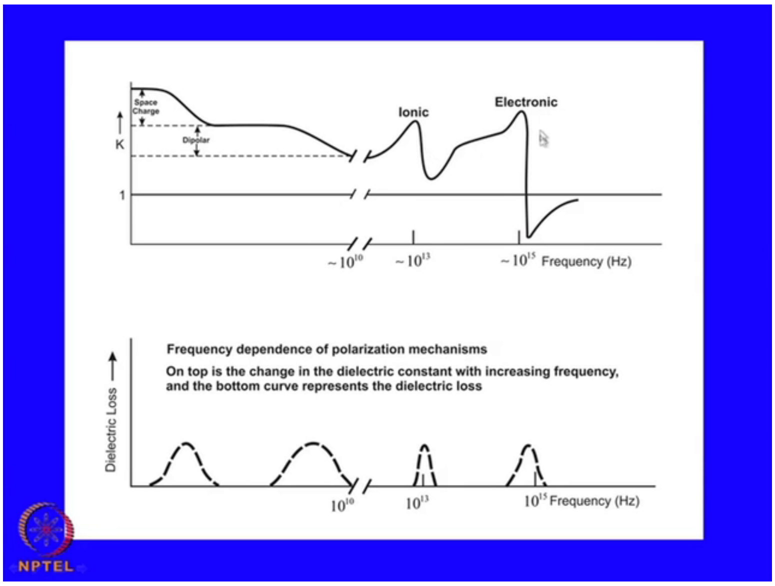


This is also the same picture also although it has been drawn in an slightly different way it is not exact manner in which the other one was drawn, but basically it also represents the same thing. You have a space charge polarization, you have dipolar polarization and then we have ionic polarization and the electronic polarization. In these 2 cases of course as in the earlier case also there is a peak through which it goes is not slightly differently than the other 2. So, it has a resonance peak here.

And, therefore, they behave slightly differently even in the polarizability there is a peak, but normally there will be peaks there will be peaks in the dielectric loss of course this particular quantity or the parameter has not been introduced so far in this lecture. We will try to found out later on what is the dielectric loss for the time being. Let us see whenever there is a transition from 1 mechanism to the next mechanism or 1 mechanism is getting off as because the frequency increasing there is a loss of energy.

So, there is a dielectric; what we call the dielectric loss is this basically determines or basically represents a loss of energy at that point. So, all these transitions will be associated with some dielectric loss or a energy loss at the frequencies where the transitions is taking place. So, this is the additional information which is their in this particular picture compare to the previous picture. So, it gives on top is the change in dielectric constant; all the polarizability is basically proportional and the increasing frequency and the bottom curve represents the dielectric loss. So, this is the typical frequency dependence of dielectric behavior of different materials.

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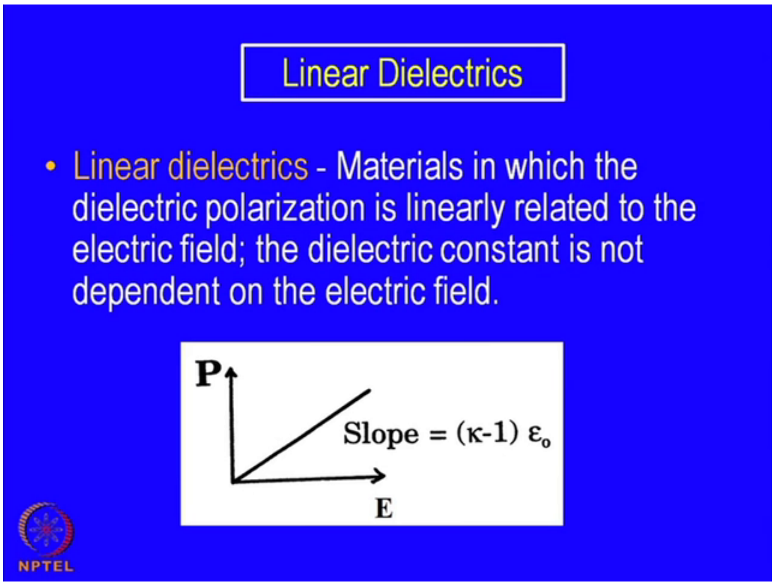


Well so for basically we are talking about the dielectric material. There is a dielectric constant and there is a polarization as a function of applied electric field and this there are impact 2 varieties of dielectric material. What we are discussing so far is actually called the linear dielectrics. These material the material the group of materials in which the dielectric polarization is linear related or is proportional to the applied electric field. The dielectric constant is not dependent on the electric field so the proportionality is basically the dielectric constant. And therefore, because of this linear relationship; these group of material a group of material which will talk later they are called linear dielectrics because the slope represents the dielectric constant.

So, it is a plot of polarization versus applied electric field and it becomes straight-line; and the slope is actually the dielectric constant. So, since the dielectric constant is independent of the applied electric field it is called the linear dielectrics. So, the group of materials which depicts this kind of phenomena of this kind of relationship are known as linear dielectrics. Most of the materials common materials, ceramic materials like porcelain, silica, alumina or calcium oxide or most of the insulating oxides even nitrites, borides etcetera all have linear dielectrics except a group of mixed oxides which are known as ferroelectric material which will be discussed later in the class, in next class maybe.

So, these are most of this materials are called linear dielectrics except a group of materials which are called ferroelectric material, piezoelectric material those are a non-linear characteristics. So, these are so one can distinguish between the 2 groups of material depending on the characteristics of variation of dielectric constant is function of applied field.

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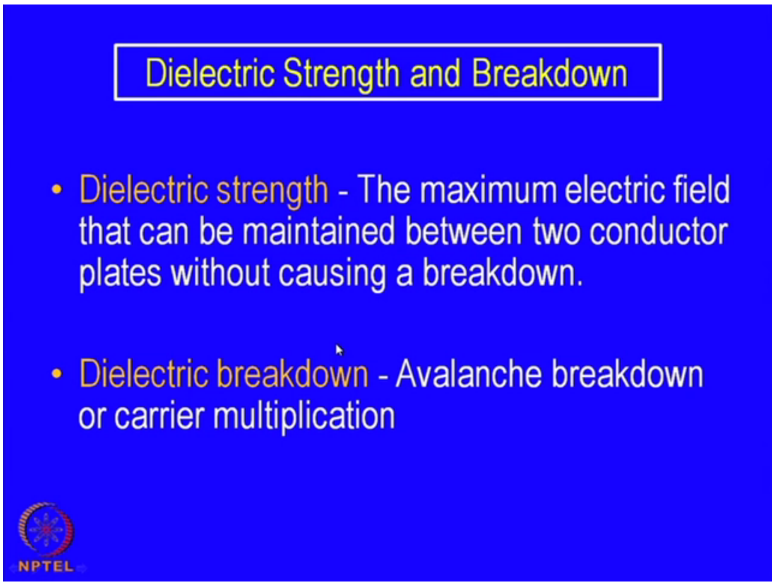


So, these are characteristics of linear dielectrics. Two more phenomena is also important one is the dielectric strength. When we apply electric field against dielectric material we say it is polarized and as a result you have generation of dipole moments and so on. And it stores energy by through a process of polarization, but can we can we apply any voltage we like? The answer is no. We have a limit limit of electric field which we can apply for each material. So, the materials are also characterized by the maximum electric field that can be that can be applied on this materials. Beyond that this material what we called breakdown takes place, so there is a dielectric breakdown.

And, that means there is a leakage current; there is heavy leakage current and the material almost become a conductor. In fact what happens? There is a avalanche breakdown or a carrier multiplication. That means, initially the number of carriers are low when it is actually what acting as a insulator or a dielectric material, but if the dielectric; the applied voltage crosses the dielectric strength of that particular material then the chemical bonds between the atoms actually breaks down; and the material almost becomes a conductor.

So, is a heavy short-circuit and there can be an explosion because suddenly a very high current will flow through the material because we have applied a very high-voltage. And therefore, there can be an explosion and a big spark and so on. So, that is what we called a dielectric breakdown. So, it is very important to know what is the limit of the applied field which can be which can be exposed to? So, dielectric strength and the dielectric breakdown. So, dielectric breakdown is a limiting phenomena when the dielectric when the applied field exceeds the dielectric strength. So, normally it is hold per centimeter or hold per mete and that is how it is expressed.

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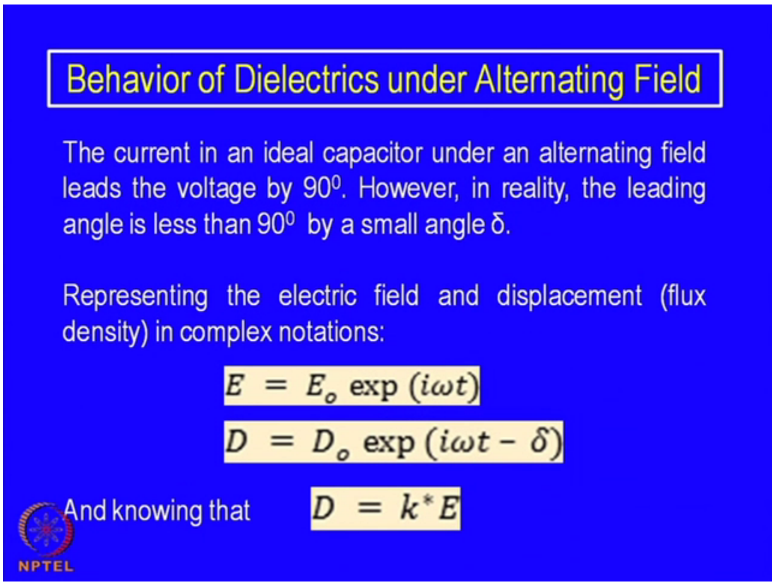


Behavior of dielectric under alternating field we have started discussing about it little while ago, let us look at it little more details about this. The current in an ideal capacitor under an alternating field then leads the voltage by 90 degree from the electing electrical engineering points of view. 1 knows that whenever they the capacitor, the voltage and the current are not in phase with each other. So, current normally leads the voltage by 90 degrees. That is ideal situation when there is no loss, there is no leakage current, there is no the insulation is almost perfect or the resistance of the insulating material is infinity.

So, if that happens the current leads the voltage particularly in case of a alternating field since certain voltage by 90 degrees.

So, however since there is a finite resistance always or small conductance some very small amount of current goes through it passes through it. So, there is a the current actually does not lead by 90 degrees, slightly less than 90 degrees and that angle is known as the delta. So, it is less by an angle delta. Now, the expressions for different parameters under the alternating field are like this represents the electric field and the displacement the flux density in complex notations. When we are having a alternative field then we have to use a complex notations like is E equal to E 0 exponential i omega t; omega is the angular frequency, t is the time and i is the imaginary quantity.

And, the corresponding displacement the effect to electric field that the induced flux density is actually D equal to D 0 exponential minus i omega t minus delta. So, this is actually a kind of the effect of voltage that means the current the kind of current. And knowing that D and the E is related by this complex quantity and the dielectric constant. And in this case it is K star it is not K prime which we have used earlier. Now, use the K star because it is a now a complex quantity; and therefore D equal to K star into E.

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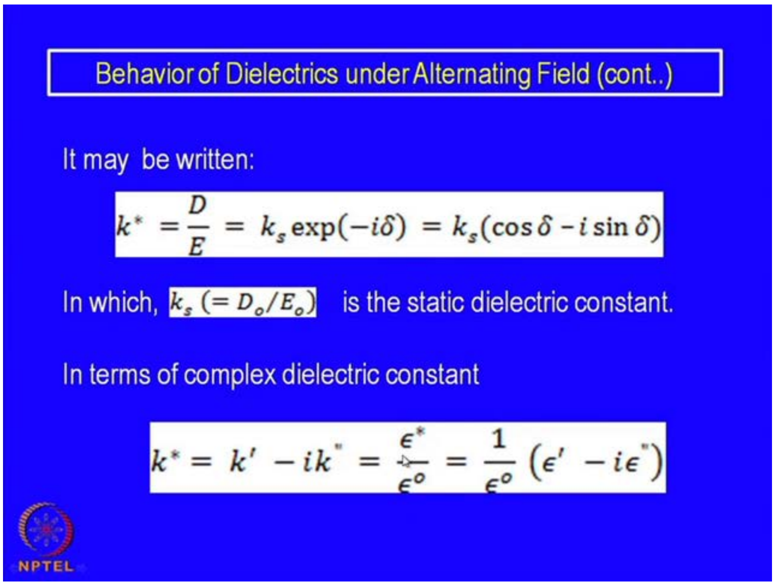


So, this we can further written K star as D by E equal to we can divide them into 2 components; 1 is the real component another is imaginary component. So, 1 is K s exponential minus i delta and that equal to K s cos delta minus i sine delta. So, there are

2 difference components; 1 is the real component another is imaginary component and K s K s in this case is actually what we called us static dielectric constant that means d c field; on the d c field whatever the K value of the dielectric constant on the d c field that becomes k s that is very low-frequency dielectric constant.

So, in which K s also is represented by D 0 by E 0 which we have seen earlier; these e 0 and d 0 this are 2 constants. And basically they are the low-frequency constants low-frequency values is the static or in other words 1 sometimes called the static dielectric constant there is no variation of frequency here. In terms of the complex dielectric constant then k star equal to my K minus K prime minus i k double prime equal to that is the expression of the complex quantity complex dielectric constant. And that can be again represented in this manner once again we can introduce a permittivity which is one a complex permittivity

So, when the d c field we do not use complex permittivity, but in a c field the same permittivity becomes complex quantity with an imaginary term. And the then we can write 1 by epsilon prime minus epsilon double prime i epsilon double prime sorry there is a little mistake epsilon 0 should be subscript these should be subscript like K s.

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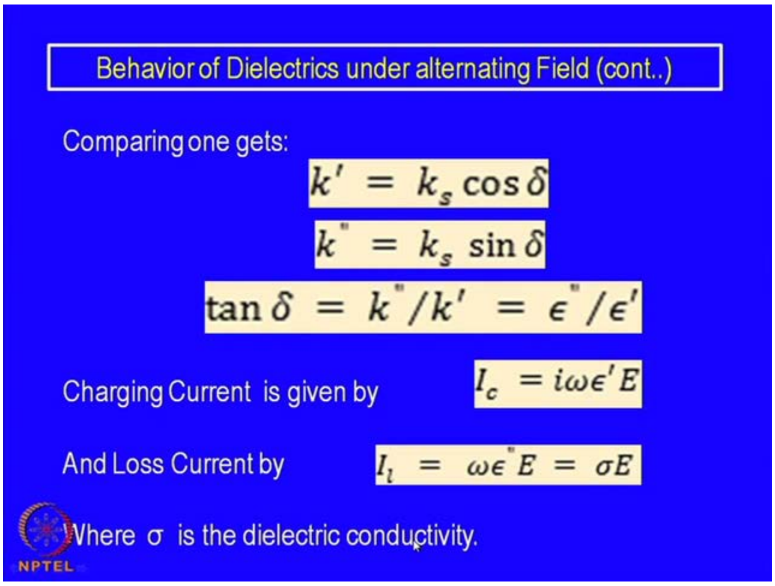


While to continue the same discussions K prime the real part of the dielectric constant can be represented as K s cos delta and K double prime equal K s sine delta. Accordingly you can have a ten delta equal to K double prime by K prime also equal to K epsilon double prime by epsilon prime. Now, from these equations 1 can find out there are 2 components of the current; 1 is called the charging current which is actually out of phase; charging current is the out of phase with the voltage we apply or the electric field you apply.

So, i c is equal to i omega epsilon prime e is the applied field. Whereas, the last current which is in phase of the applied field equal to omega epsilon double prime E; E is the electric field which can also be written as sigma E this is from the kind of ohms law and the electric field than the current. So, this becomes a constant which is equal to sigma. So, we have a sigma or the conductivity which is called the dielectric conductivity and it is a product of 2 parameters. One is the omega the frequency and the imaginary part of the dielectric permittivity; these product these 2 quantities actually is the sigma or this is this is different from d c conductivity. So, d c conductivity the value will be different where as the ac conductivity this sigma is that is why it is called the dielectric conductivity.

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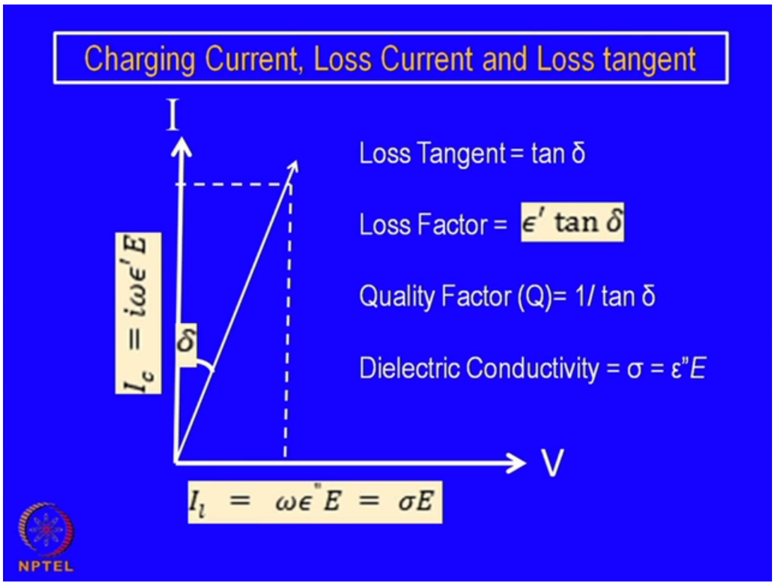


As we have just discussed that there are 2 components of the current; 1 is the charging current which is out of phase or 90 degree a head of the electric field or the voltage in this case. So, this is a plot of vector diagram for voltage or current against voltage. So, you have both of them are right angle to each other. And this is the charging current this expression which is a head of 90 degree a head of voltage and the loss current which is in phase with the voltage. So, if you find out the quantity ideally it is it should be 90 degree, but it the resultant current is actually along this line; which is at an angle of delta from the current axis. So, this is what we call the loss angle.

And, this is normally small and you know if the loss current is more, if this quantity is more than this will be more inclined and the delta will increase. So, higher is the lost current higher will be the delta. And from this also higher is the conductivity higher will be the delta. So, delta is actually a major of the loss of energy loss of energy which is conducted away through the through the dielectric. Ideally there should not be any conduction, but in reality there is some conduction and that is major the conductivity is the major of how much loss can take place higher is the conductivity higher will be the current and higher will be the loss. Now, there are few parameters which characterizes the dielectric materials or the capacitors.

These are the 4 different characters, 4 different parameters which characterize the performance or the quality of the dielectric material or the capacitor made out of the dielectric material. First of all is the loss tangent; this is the characteristics of the material of dielectric material with which a capacitor is made. So, it is independent it is a intrinsic property it is intrinsic property of the material it is not the intrinsic property of a capacitor because capacitor contents some geometric factors. So, the capacitance value also includes some geometric factor, but the dielectric constant as well as a loss tangent or dielectric loss or the material parameters and the intrinsic property of the material.

The way you prepare it the way we synthesize it or the particular crystal structure the chemical composition and so on so. Then we have a loss factor loss factor tan delta is just lost tangent. So, there are different parameter used in the literature; loss factor is epsilon prime multiplied by tan delta. So, this is not the loss tangent and loss factors are 2 different quantities. So, the loss tangent is only tan delta whereas loss factor is tan delta multiplied by the real part of the permittivity.

There is another parameter is also used also used to designate how good a capacitor is that is what is called a quality factor or sometimes called q factor. This q factor is nothing, but the inverse of tan delta. So, higher is the loss lower will be quality factor. So, that means who will have a always try to find out where the loss is lowest. So, higher is the quality factor that means the tan delta values is low. And therefore, that is better material better material or better capacitor. So, that is quality factor. And finally, which we have already discuss the dielectric conductivity sigma that is epsilon double prime multiplied by the electric field E. So, the dielectric conductivity also is a parameter which determines how much is the leakage current and higher is the leakage current higher will be the tan delta and lower will be the quality factor. So, and the loss factor will also be low they will be high. So, these are the 4 parameters based on this angle angle between the resultant and the current axis.

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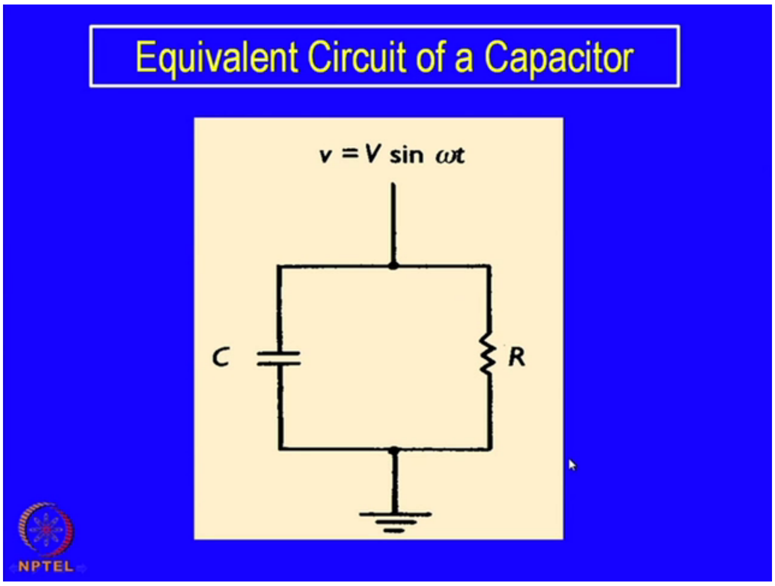


Now, any capacitor can have equivalent circuit that means capacitor is not an ideal capacitor. So, it has a finite resistance or a finite conductance. And therefore, a real capacitor can be represented in this manner in a r what we call r c circuit it is a very simple circuit; where a ideal capacitor and the resistance is put in parallel. So, the real capacitor has a ideally this resistance should not have been there it is infinity, but since there is a finite resistance you have a resistance also have to put in parallel with the capacitors. So, that is what we know? That is the known as the equivalent circuit of a capacitor.

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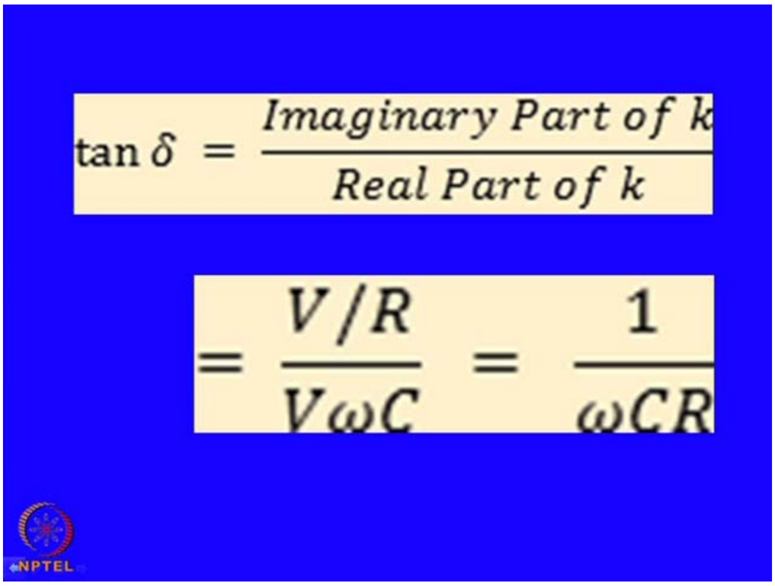


Based on this equivalent circuit parameters; if this is C the capacitance and capacitance of a ideal capacitor and then this is R. From this equivalent circuit parameters also 1 can find out the parameters which we have already discussed tan delta. In this case the imaginary part of the k and real part of the k that we have already seen. And in terms of in terms of the equivalent circuit parameters; this tan delta can be represented like this V by R; R is the equivalent circuit resistance and V omega C C is the equivalent circuit capacitance and V is the applied voltage. So, tan delta is like this V by R is the imaginary part of the k and the real part of the k is V omega C. So, ultimately it is 1 by omega C R. 1 by omega C R in terms of the parameters of the equivalent circuit.

So, the tan delta can also be represented or measure by this by this expression provided; we knows the equivalent circuit parameters. In fact the reverse is also true if you find out the tan delta and also the voltage 1 can also find out what will be the equivalent circuit parameters C and R values; by measuring as a function of frequency impact.

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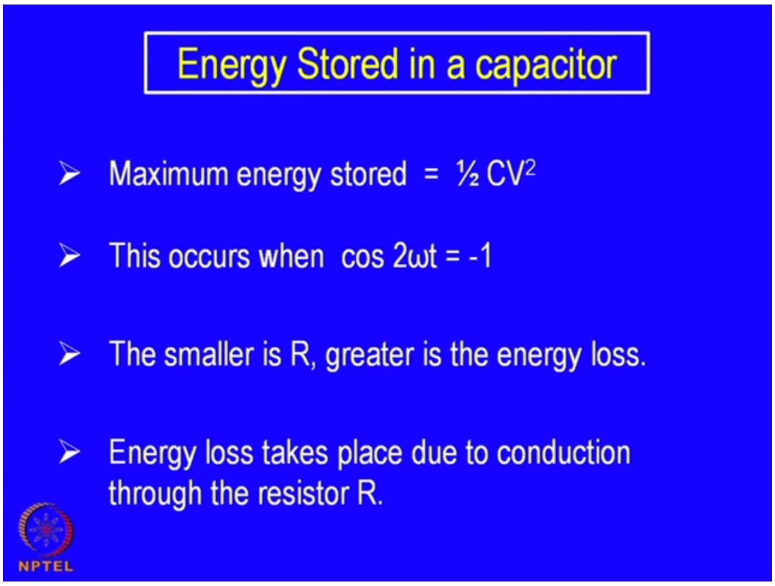


Now, we have already discuss that 1 of the major purposes of capacitor using a dielectric material; to construct a capacitor is basically to store electrical energy in the system and use it whenever is needed. So, the maximum energy that can be stored is actually equal to half C into V square; V is the applied voltage. This occurs this stored energy occurs is a dependent on frequency it is not the same at all frequencies. So, depending on the frequency the amount of stored energy will vary and the maximum energy is stored, when the cos 2 omega t equal to minus 1. So, it is a frequency dependent as well. So, that is also another important aspect one must remember.

This we have already seen earlier this smaller is the R greater is the energy loss. Smaller R means higher conductance, and therefore more leakage current and therefore more energy loss. So, part of the energy is more greater part of the energy is lost. Then what it can be store? The energy loss takes place due to conduction through the resistance that is already the same thing is been repeated here.

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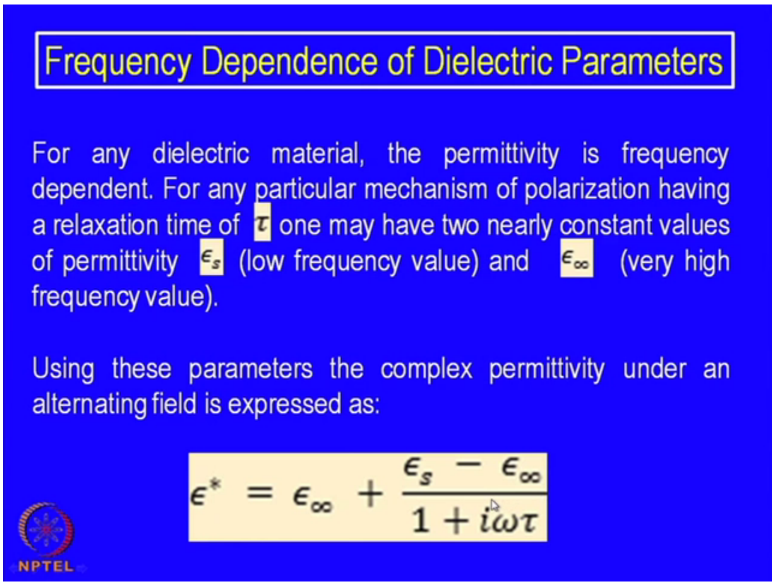


Now, we have discussed little bit about the frequency dependence. So, in were discussing about atomistic mechanisms of dielectric polarization. Now, we look at it also from a different angle frequency dependence of dielectric parameters has a whole not only just the dielectric constant polarization and so on. So, we are not discussing here polarization we are trying to look at the overall dielectric constant. How it depends on frequency? For any dielectric material the permittivity is frequency dependent or that is because polarization is frequently dependent; for any particular mechanism of polarization having a relaxation time of tau.

We have said earlier that for any process there is a time constant. And that is the relaxation time that is the characteristics time which it needs to for displacements because the charge is getting displays from 1 point to the other. So, there is a time constant and time is necessary for that moment to take place or the change to take place. So, 1 may have 2 nearly constant values of permittivity. What we call? Epsilon s or the static dielectric constant or static permittivity or it is basically a low frequency permittivity and a very high-frequency permittivity. Both of them are more or less constant over a period of over few frequency ranges some frequency range.

Using this parameters the epsilon s and epsilon infinity 1 can write the complex permittivity under an alternating field in this manner. Once again epsilon star equal to epsilon infinity plus epsilon s and epsilon s minus epsilon infinity 1 plus i omega t. So, this is the overall expression of the permittivity in terms of 2 constant. 1 is epsilon infinity another is a epsilon s which is low-frequency permittivity and the high-frequency permittivity; both of them are constants but it goes through a congestion.

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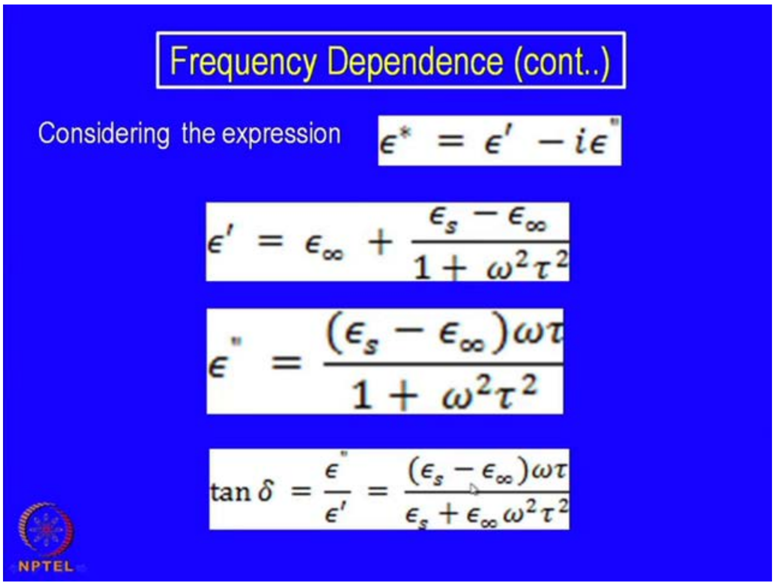


Like we will see that in minute. So, this are few more equations this is we know any complex quantity can be represented in this manner. So, we have a real quantity real part and the imaginary part to the imaginary quantity. And the earlier equation can be subdivided into these parts this components. So, here actually we are trying to find out the real part of the permittivity as a function of once again 2 quantities epsilon infinity and epsilon s these are the 2 constant and their frequency dependent by this process. And tau is the characteristics temperature characteristics time constant for this particular process. Similarly, you have epsilon double prime which is the imaginary part of the permittivity and once again it is related to these 2 quantities and constants and then a frequency omega as well as the tau is the time constant or the relaxation time of that particular process.

And, just by dividing 1 by the other 1 can get tan delta equal to this kind of a expression. Once again the 3 or 4 parameters which are used here is a epsilon s minus epsilon infinity omega and tau.

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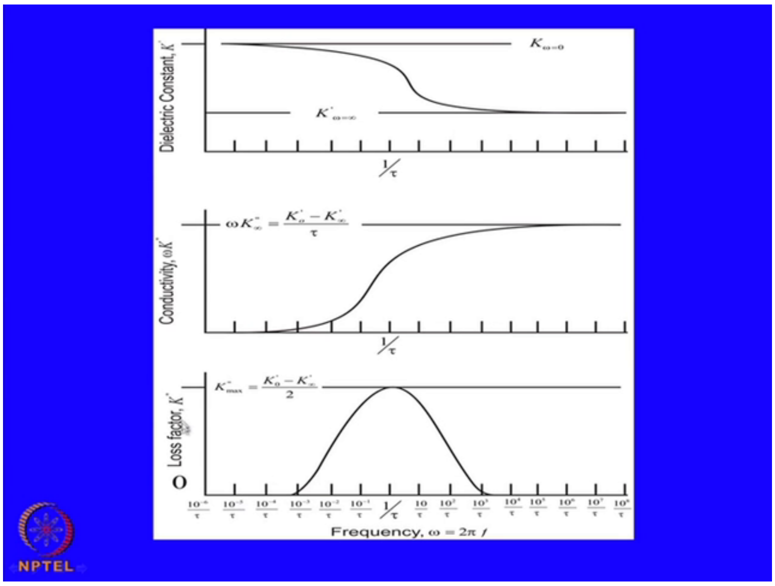


Now, you plot these parameters 3 parameters has been plotted here. 1 is the dielectric constant or basically which is proportional here it has been plotted k prime which is proportional to also to epsilon prime which has been used in the equation previously. So, this is either k prime or 1 can say epsilon prime. This is actually conductivity or omega into epsilon double prime. And this is loss factor or the loss tangent; loss factor is actually k double prime or k epsilon prime into tan delta. So, it is basically a loss curve, this is a conductivity curve and this is the dielectric constant curve.

So, in a any material it is a very general characteristics of any material. This is the frequency dependence of the dielectric constant of the dielectric parameters this is your dielectric constant. So, at lower frequency dielectric constant is large or higher than the higher frequency. So, these 2 this is become almost independent of frequency in this region and here also it is almost independent of frequency. So, this value is known as the static dielectric constant or k at omega equal to 0. And this value is k at omega equal to infinity.

So, this is high-frequency value and this is low-frequency value. So, there is a independent frequency independent region then there is a transition and then once again a frequency independent region. So, this is a very general characteristic of any dielectric so for as a frequency dependence is concerned. Thus the reverse takes place so for as the dielectric conductivity is concerned or k double prime or epsilon permittivity imaginary part of the permittivity. So, it goes to once again the transition at the same frequency and this frequency characteristics frequency is one by tau that is the inverse that is the inverse of the relaxation time. So, that is the frequency so omega tau is actually equal to 1. So, if you plot as a function of omega tau this will be 1.

So, at the inverse of the characteristics relaxation time characteristics time constant we will get the transition. So, this from lower higher value to goes to lower value. In these case it is a lower value to the higher value. And at the same frequency the loss factor of tan delta goes through a peak. So, this is when the time constant is equal to the frequency. And the time constant is equal to the inverse of the frequency of course or frequency is the inverse of time constant relaxation time.

Then, there is the whole process is in phase with the applied field and there whole there is a large loss x plus, so and the area and this curve actually the total energy loss. So, higher is the frequency higher is the conductivity higher will be the peak and so on. So, this is ideally in a capacitor we try to look for where the loss is less? Because if the loss is high not only your losing lot of energy, but also because of the current higher relatively large current the whole material will get heated up. So, there will be (( )) heating.

So, therefore, when in practice a dielectric material you should also you should look for a dielectric material where the loss is low. That is the normal practice of course there are applications. There are application were dielectric loss we intent intentionally like to have a higher dielectric loss because where we need heat. For example, in a microwave heating microwave heating actually we need more energy loss from the less amount of energy should be stored in the dielectric whereas; more amount of energy will be used up for heating the material. So, if such applications of course 1 needs to have a higher loss factor, but most of the other applications, that will need a low loss factor material.

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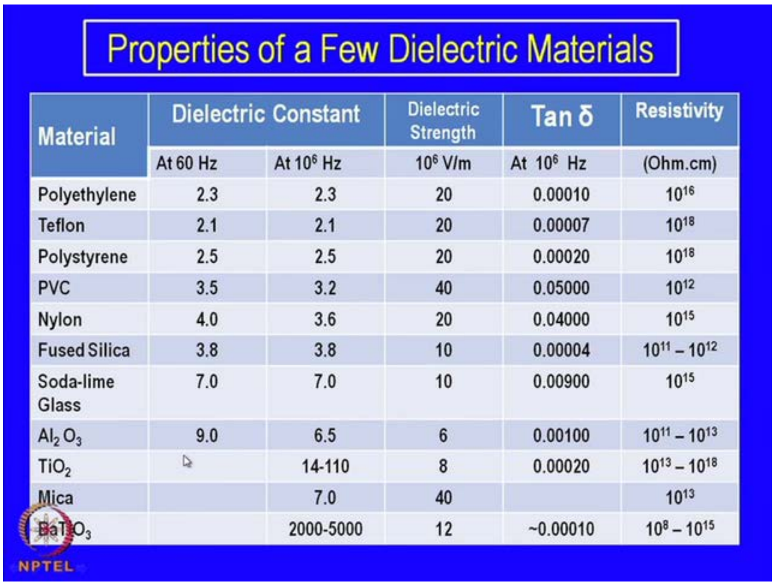


| Material | Dielectric Constant | | Dielectric Strength | Tan δ | Resistivity |
|---|---|---|---|---|---|
| | At 60 Hz | At $10^6$ Hz | $10^6$ V/m | At $10^6$ Hz | (Ohm.cm) |
| Polyethylene | 2.3 | 2.3 | 20 | 0.00010 | $10^{16}$ |
| Teflon | 2.1 | 2.1 | 20 | 0.00007 | $10^{18}$ |
| Polystyrene | 2.5 | 2.5 | 20 | 0.00020 | $10^{18}$ |
| PVC | 3.5 | 3.2 | 40 | 0.05000 | $10^{12}$ |
| Nylon | 4.0 | 3.6 | 20 | 0.04000 | $10^{15}$ |
| Fused Silica | 3.8 | 3.8 | 10 | 0.00004 | $10^{11} – 10^{12}$ |
| Soda-lime Glass | 7.0 | 7.0 | 10 | 0.00900 | $10^{15}$ |
| $Al_2O_3$ | 9.0 | 6.5 | 6 | 0.00100 | $10^{11} – 10^{13}$ |
| $TiO_2$ | | 14-110 | 8 | 0.00020 | $10^{13} – 10^{18}$ |
| Mica | | 7.0 | 40 | | $10^{13}$ |
| $BaTiO_3$ | | 2000-5000 | 12 | ~0.00010 | $10^{8} – 10^{15}$ |

Well here is a list; just give you some idea the different kind of materials use as a dielectric as use for capacitors both in the group of polymers or the plastic, which is a good insulator anyway and number of ceramic oxides or ceramic materials as such. So, starting with for example, first few was first 4 or 5 of them are actually plastics different kind of polymers. And these are the different typical values of the dielectric constant this is the dielectric constant 2 different frequencies of course; you can see there is difference been a between this value of the frequency on this value. This is about 60 hertz where as the other 1 is about 1 mega hertz; 10 to the power 6 hertz.

So, the variation of dielectric constant in this range is almost negligible very small. And you can see, but in general the polymers have a little lower dielectric constant than the ceramics For example, fused silica of course is a low dielectric constant, but soda lime silica glass has a higher dielectric constant compared to the polymers which is more or less the range of 224 whereas, this are about above 7. And aluminum oxide you can see there is slight variation here in the aluminum oxide even in this range that means this is 6.5 lower than the low frequency value 9.

These 3 ceramic oxides are very special as you can see neither titanium oxide nor titanium dioxide, mica. Mica is a natural mineral it is not a synthesize mineral; just natural flakes of mica can be used in fact has been used very extensively for over a longtime for making capacitors. And then the last 1 is barium titanium. It is a synthesize material is a mixed oxide of barium oxide and titanium dioxide and by heating them at higher temperature; 1 can make a compound having different crystal structure compared other than that of barium oxide or titanium dioxide. And 1 can have a dielectric constant of the very high order about 2000 to 5000 and in some cases it can be more than this value also.

We will discuss barium titanium details at a later stage. But compared to most of the other dielectric material; the dielectric constants of these kind of ceramics even titanium dioxide is around 100 whereas, these are in the order of 1000's. So, that is a very attractive feature of this particular dielectric material which incidentally is a ceramic material. Dielectric strength here is more or less same except in some variations, but you can see these are almost 10 to the power of 6 volts per meter which is of the very high order 20 mega volts per meter. Here of course the polymers have a relatively high breakdown strength or dielectric strength compared to those of ceramics.

Ceramics except mica except mica has a very high value of 40, but other ceramics are relatively low. But even then they are quite high tan delta the values of tan delta are of this order are all materials as you can see it is 10 to the minus 3, 10 to the minus 4 like that and tan delta for barium titanate or t i o 2 is slightly high aluminum oxide is about little higher than the others but mostly it is major 1 mega hertz.

And, the values are like this. Resistivity is obvious that all of them are very high resistance, but it varies to some extent, but most of them higher than 10 to the power 10 1 centimeter. So, these are the different in fact they are important dielectric materials used in industries for different purposes.

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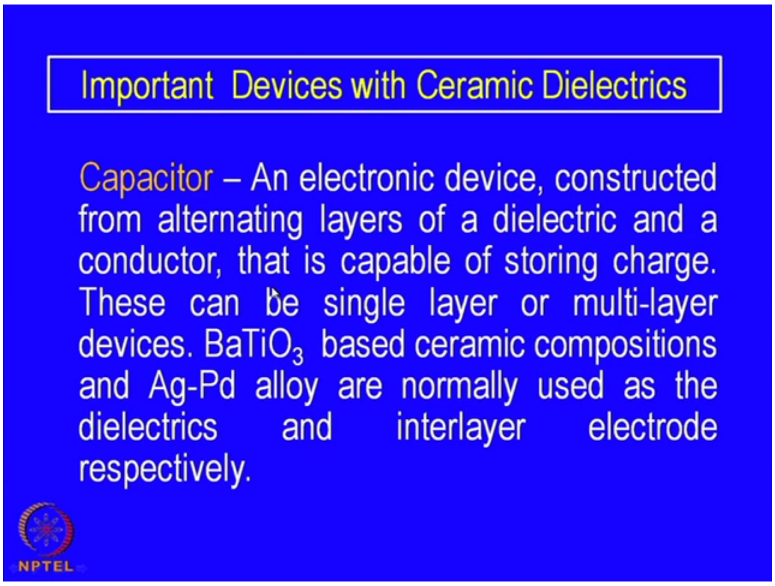


I discussed two important devices which are very commonly used made of ceramic capacitors or ceramic dielectric material; 1 is a capacitor. We have discussed that device on and off during our discussions this is nothing but an electronic device constructed from a alternative layers of a dielectric and a conductor. So, there are a dielectric is induced between 2 conductors basically that is a capacitor.

Let is capable of storing charge. So, 1 of the major purposes of capacitor is to store electrical charge for certain circuits or certain purposes. These can be single layer or multi-layer device. Barium titanate based ceramic compositions and silver palladium alloy are normally used as the dielectrics and interlayer electrode respectively. This is for the multi-layer capacitors of course the capacitors which so far we have discussed is basically a single layer that means single layer of insulator and 2 layers of electrodes metal electrodes. Now, it is possible it is possible to a make or design multi-layer ceramic capacitors in order to miniaturize the capacitance effect that means in order to miniaturize of the capacitance. So, within a small volume 1 can store much larger quantity of charge. So, that is the purpose of multi-layering.

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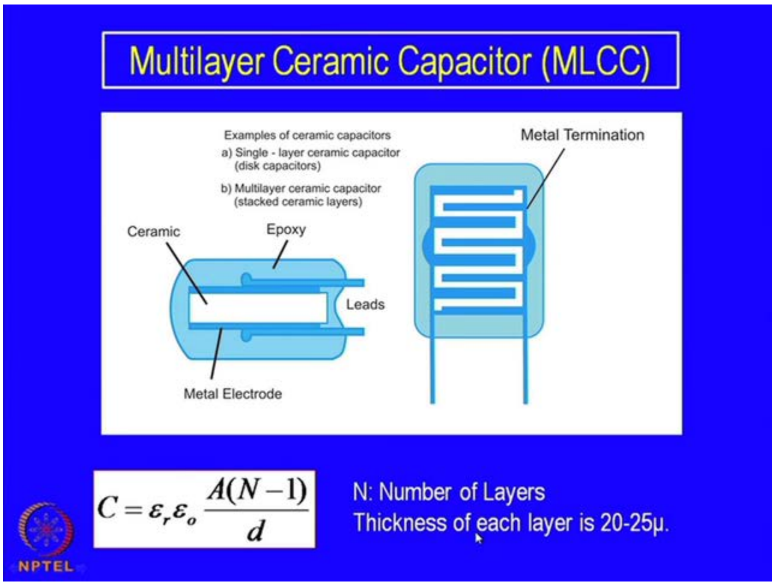


Give you some example however it is exactly done. It is actually what do we called the multi-layer ceramic capacitors or m l c c and it has been compared with a single layer capacitance like this. So, this is basically a single layer capacitor or sometimes called is disc capacitors is nothing, but a small ceramic disc may be a millimeter thick. And then on 2 sides on 2 surfaces circular surfaces you have electrodes. These electrodes are basically painted by thick film technology just metal pastes available and that can be pasted on this painted on the surfaces and that will make a few micron thick conductor. And that is again solder between the 2 leads. So, these are the 2 copper wire leads.

So, which can be solder on the surface of the ceramic disc on which a ceramic metal paste had been added. So, this is your ceramic disk then you have metal electrode in the form of a metal paste and then you have a epoxy which is basically a potting material. That means, it just gets insulated or protects it is from the other environments on the surroundings.

So, that is the very simple design of a capacitor. So, everything depends of course on the characteristics of this ceramic material. However, if you want to have a volume efficiency of ceramic capacitors because capacitors are needed in very large numbers in electronic circuits by using semiconductor devices like silicon chips. The whole system has been miniaturized to very great extent.

So, to compare or to make it compatible with that kind of miniaturization capacitors also needed to be miniaturized; and this is one way of miniaturization. This miniaturization, within but you have multiple layers. These white areas are actually ceramic disc ceramic layers and the blue ones blue ones are the electrodes. So, you have number of layers and number of electrode layers also. So, these layers impact at very thin layers unlike these capacitors which may be a millimeter thick this are only about 20 to 25 microns thick. So, by reducing the thickness actually 1 increases the overall capacitance because capacitance is proportional to a by d that is the area by thickness.

So, lower is the thickness higher is the capacitance. So, while just by reducing the thickness of the dielectric medium 1 can enhance the capacitance effect and also use much smaller quantity. Then you have another multiplier effect by large number of layers which has been added parallel; as you can see the alternate layers of the electrodes are extending not extending to the end. So, this is here not extending to the other end.

And, the other 1 is not extending the on the left-hand. So, actually these layers and then of course this are connected on this side and this is also connected on this side. So, this each individual layers or actually electrically they are parallelly connected. It will look at properly you will find they are parallelly connected so there is an additive effect.

Whenever capacitance are added in an parallel that in additive effect. So, each of these capacitances added parallely and therefore, within the same volume you have a much larger capacitance compared to this kind is of a design. So, compared to this capacitance this are much more miniaturized and one can usually much more efficiently. So, this is what we call the metal terminal which is connecting all the metal electrodes in between the alternate electrodes are connected on this side as well as on this side.

So, this is the at basic function of or basic design of a multilayer ceramic capacitor. And these capacitors can be enhanced by this factor A is the area, N is the number of layers minus one and d is the thickness. Lower is the thickness and higher is the N value the capacitance value increases for the same dielectric constant, because the material constant is not increasing; here not changing it is only the design which is enhancing the capacitance value thickness of each layer is over 20 to 25 micro.

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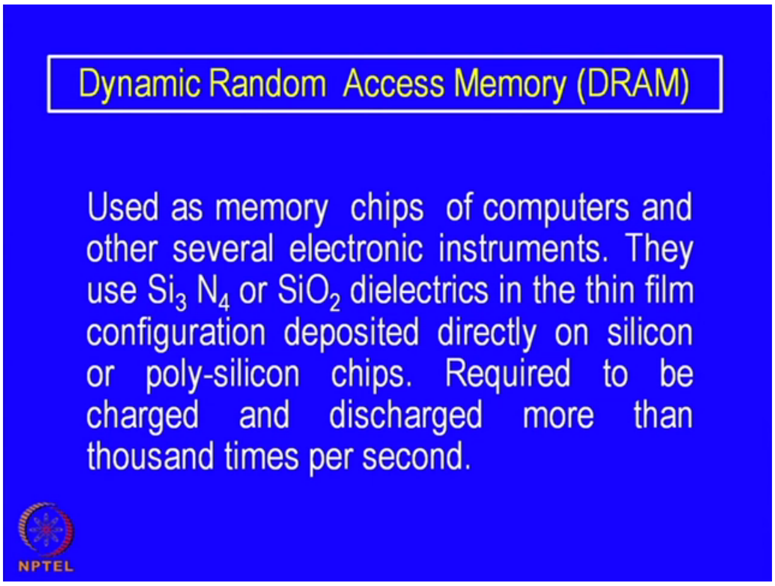


And, the last 1 another very important application of particularly barium the linear dielectrics are here used as a memory chips. That is dynamic random access memory or d ram which is quite common in computer technology based on the memory chip of computers. And these are computer memory chips and several electronic instruments they use normally because they are deposited or they are fabricated on silicon chips. So, it is a silicon compounds are better suited for this kind of a dielectrics.

So, silicon nitride and silicon dioxide dielectrics are normally used. But in this case it is in the thin film configuration not even thick film, not even micron a fraction of a micron. And deposited directly on silicon and poly silicon chips it required to be charged and discharged more than 1000 times per second. So, since dielectric layer is very thin fraction of a micron the voltage the breakdown voltage is very important here. So, you have to understand what is the breakdown voltage exactly of these materials.

So, that there is a no puncher, there is no short-circuiting while it is (( )). So, the random access memory actually works on a charging discharging characteristic of a very thin film dielectric or thin film capacitors. So, charged state is 0 state or 1 state or and the discharge state is the 0 state. That is how all the memory chips are fabricated. And of course the more recent advancement is in the area of changing the dielectric from silicon nitride or silicon oxide to barium titanate or barium (( )) based compounds they are called a c ram or ferroelectric random access memory.

So, these are the few applications. Very few in numbers of course there are many many different other applications may be will take up next class; when we discuss about the ferroelectric and piezoelectric material. So, we conclude here by saying that the ceramic dielectrics become a very, very important aspect of electronics industry primary for the dielectric property; and the kind of chip designs or kind of capacitor designs which has been used over the last several decades.

Thank you.