Nano structured Materials-Synthesis, Properties, Self Assembly and Applications

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Module - 4
Lecture - 32
Dielectric Properties – I

Welcome back to this course on nanostructured materials, synthesis, properties, self assembly and applications. We are in the module 4 and today we will start the lecture number 4 of module 4. And today we will start the first lecture on dielectric properties and in nanostructured materials and the dielectric properties. And it will be 2 lectures of which today we are going to discuss the first lecture on dielectric properties. Previously in this module we have had 3 lectures on photocatalytic properties of nanostructured materials. And now we start on dielectric properties of nanostructured materials. Before we start on nanostructured materials and their dielectric properties

I would like to tell you some basics about what is a dielectric and what are the properties associated with a normal dielectric material? That is a bulk material what kind of dielectric properties to they have which are good dielectric materials etcetera. And in today's lecture, we will cover those basic aspects of the dielectric properties of any material. And then in the next lecture, we will do specifically the dielectric properties of nanostructured materials. So, then we will understand what happens when the dimensions become small, what are the changes in the dielectric property of the materials. So, today's lecture will mainly revolve on the fundamentals of dielectrics, and what are the different properties associated with any materials related to their dielectric properties.

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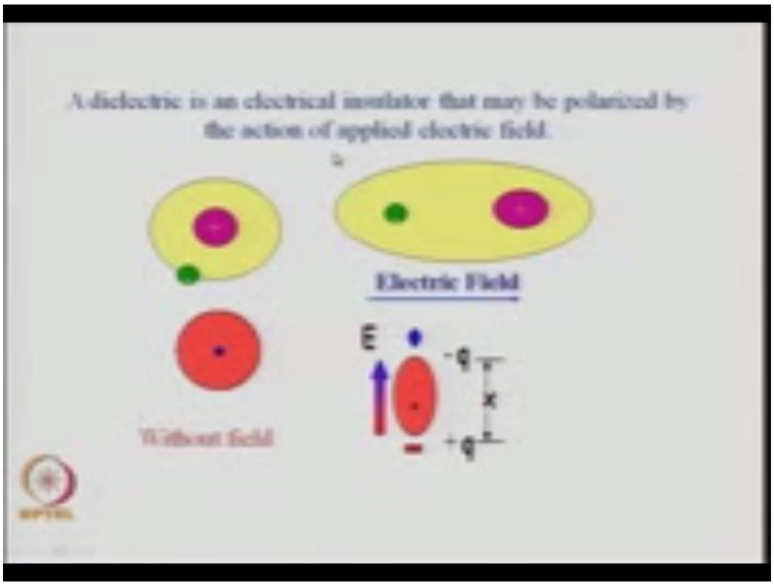

So, a dielectric is an electrical insulator that may be polarized by the action of applied electric field. That means in general a dielectric is something, which is non conducting which has a high resistivity. So, it is like a electrical insulator and this material can be polarized by applying a electric filed. So, the, if you look at a material suppose it has got the, a positive and a negative field associated with the material. If you apply an electric field then this positive and negative charges can be separated so this is called kind of polarization. So, this kind of particle without the field may give you an average polarization which is 0. Whereas, in the presence of the electric field there will be a resulting polarization and that polarization will need to a dielectric constant.

Now, so this can be looked at like this that without field you have a it it looks like this then you apply a field there is a in this direction. Then there is the charge separation. And you get you can calculated by dipole moment which multi which is a product of that charge and the distance by which it is the charges are separated. So, charge separation is x and the amount of charge is q then the product q and x gives rise to the dipole moment. And if you have a one dipole then that is the dipole moment for that one molecule if you have one mole of such molecules. Then they resultant dipole moment or resultant dipole moment per unit volume is called the polarization. And that in turn higher the polarization will lead to high dielectric constant.

So, this is common with any material where you can create this kind of dipoles in the presence of an electric field and so polarizable materials are good dielectrics, because you can separate the charges and create the dipole moment. And hence create a large polarization and hence that will give rise to a large dielectric constant. So, the most important point is a dielectric is an electric insulator and its exploration can be change in the presence of a electric field.

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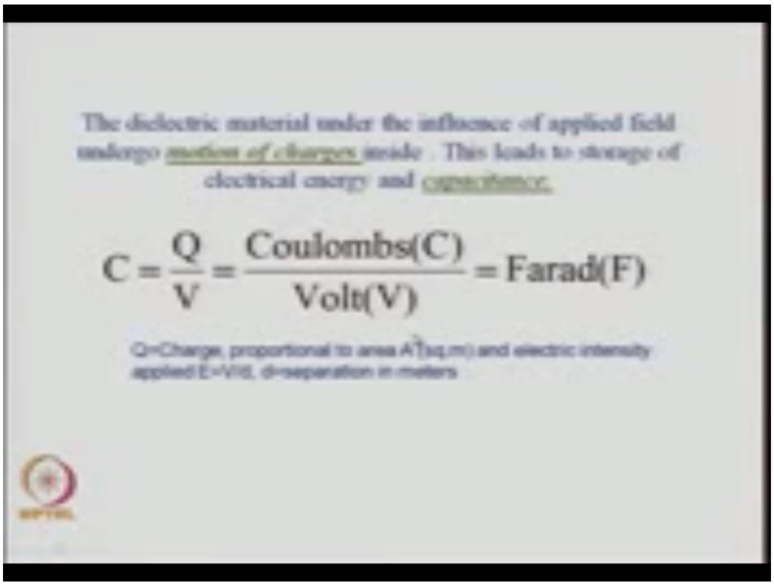

Now, if you want to calculate the amount of polarization etcetera or the charges certain numbers are involved. So, if you want to define a dielectric material the property with people talk about is the capacitance. And this capacitance C is related to the charge which develops at one of the ends. So, it can be an electrode, 2 electrodes at one electrode you have a positive charge is developing and on the other side negative charges developing. So, the amount of charges Q and this is the potential that you have applied as the electric field or potential electric potential which you applied is V.

Then the charge divided by the potential gives the capacitance a since the charge can be measured in coulombs. And the potential is measured in volts coulombs per volt will give you the unit of capacitance which is Farad. And so one Farad is one Coulombs per volt and the electric field is actually related to the potential divided by distance. So, the distance if it is a then the electric field is related to the electric potential V divided by the distance d in meters. So, you can calculate the capacitance in Farad by knowing charge and the potential that you have applied.

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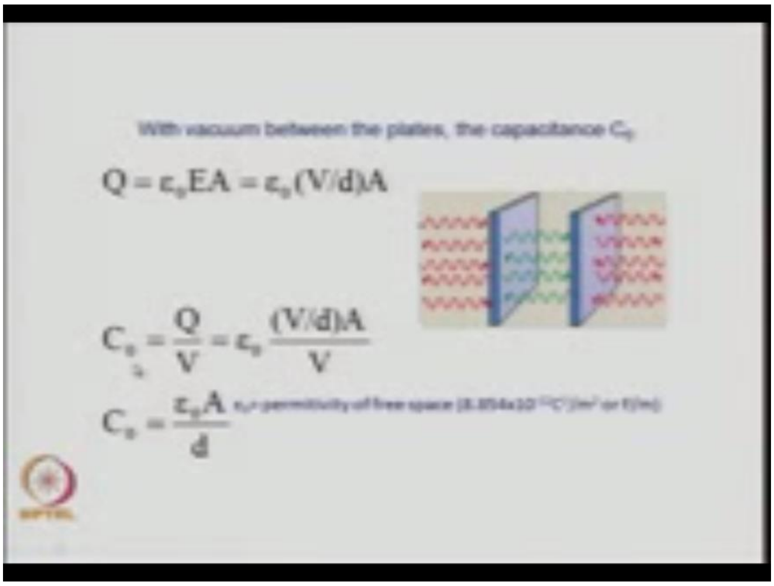

So, in a case where supposed you have these 2 plates and they are have separated by distance d that d is small d is here that is the distance between the 2 plates. And if you apply a potential which is V and area of cross section of this material is A. Then the total charge capital Q, which is developed or one of these electrodes is given by this equation where epsilon naught is called the permittivity of free space. And E is of course, the electric field which is equal to the electric potential by the distance.

And A is the cross sectional area this epsilon naught is on permittivity of free space that means in this medium right now is vacuum. And hence when you calculate this you use epsilon naught for any real system where you have a material A dielectric material. Then this equation will get modified, because then you do not have a vacuum inside normally epsilon naught the permittivity of free space is given by this quantity. And this equation we already dealt so the capacitance in of 2 parallel plates in vacuum is called C 0. That is capacitance in vacuum with nothing in between the plates and is given by this equation.

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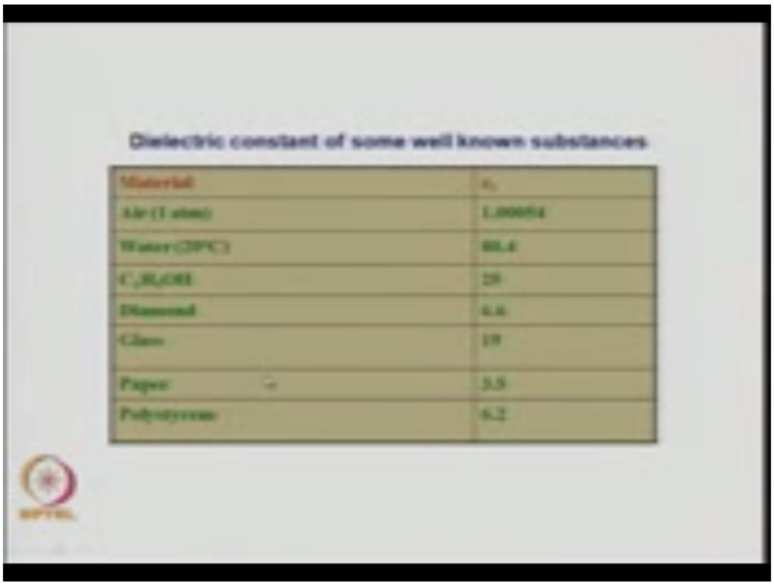

Now, if you have different materials in this in between the plates you can have air; you can have water; you can have silica or carbon dioxide or something. Then that will modify this capacitance and that will be called the capacitance C of that material right. Now, this is capacitance in the absence of any material. So, capacitance from capacitance you can calculate what we call the relative dielectric constant epsilon r. And that is related to the epsilon of the material divided by the permittivity of free space. So, these called a relative dielectric constant and the related dielectric constant epsilon r for air at one atmosphere is around one.

So, air has approximately one dielectric constant similarly, water has approximately a dielectric constant of 80 which is quite high, because water molecules can be polarized hence water has a high polarization. And so the dielectric constant of water is quite high as we see it is around 80 is the highest in this list. There are other materials say diamond has a dielectric constant of 6.6 or paper has a dielectric constant of around 3.5. So, these are low dielectric constant materials this is a high dielectric constant material. And of course, air has a low dielectric constant, so these are some numbers. And the relative dielectric constant does not have any units, so it is a dimensionless quantity.

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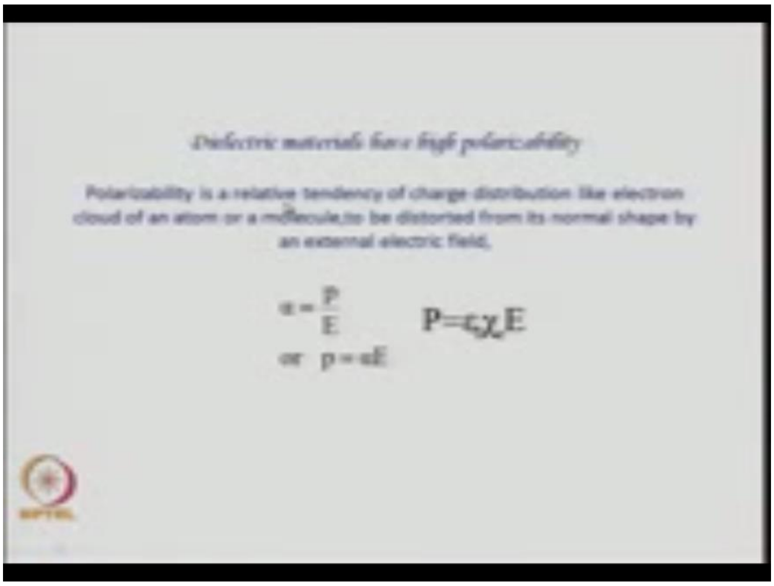

And that is why you do not see any units with the dielectric constant now, as we mentioned earlier that if you have a high dipole moment. We will have a high polarizability and high polarization and so the polarization and polarizability are related and the polarization is also related to that dielectric constant. So, here they it is an equation for the polarizability of a molecule say alpha and alpha is equal to the polarization divided by the electric field. Now, if you have a large number of molecules is maybe for one molecule for large number of molecules. You have the polarization which is capital P the small p is the polarizability and capital P is the polarization. That is say for one molar molecule, what is the polarizability and that is given by capital P and it is proportional to what is called the dielectric susceptibility.

And it is directly proportional to the applied electric field. So, epsilon naught is again the permittivity a free space and this is called the electric susceptibility. And the polarization is directly proportional to the electric field the polarizability is directly proportional to the electric field also, because anyway P small p is related to capital P. So, both are directly related to the electric field but the constant here is polarizability the constant here is the permittivity multiplied by the electric susceptibility. So, basically if something is polarizable; that means you can deform the electron clouds of the system. That means you can a separate the negative and positive charges then it has a high polarizability or high polarization.

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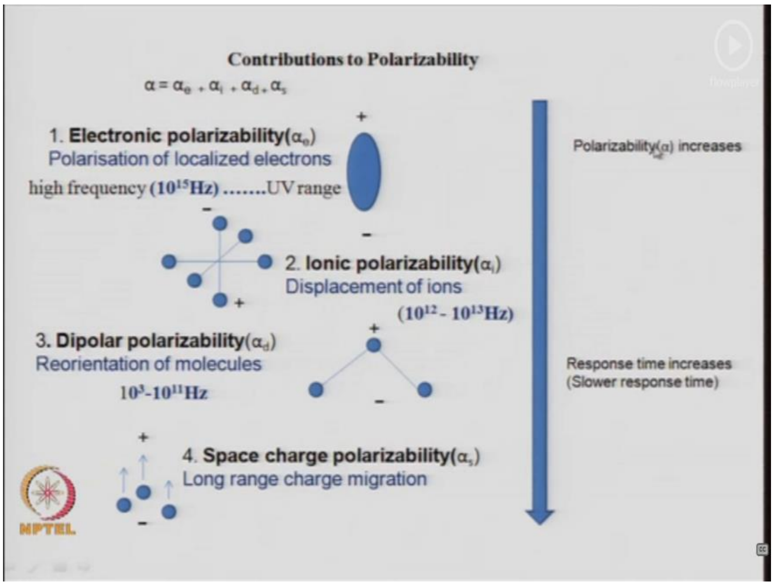

And it will have a high dielectric constant now the polarizability alpha can be due to several reasons. And so the contributions to the polarizability of a molecule comes from for different factors. And these 4 different factors are the electronic polarizability which is alpha E the ionic polarizability which alpha i and the dipole polarizability which is alpha d and the space charge polarizability which is alpha s. So, what is the electronic polarizability alpha E the when you have the electrons which are getting polarized the electrons are very light and. So, it you have a very high frequency of 10 to the power 15 Hertz. That means the electrons can follow the variation in the electric field at a frequency of 10 to the power 15 Hertz which is very fast. That means only few things can change as fast as 10 to the power 15 Hertz electrons can do that and that is in the ultra violet range.

And so this polarizability at high frequency is basically due to polarization of localized electrons and that is in the ultra violet range. If you a consider the ions to be moving at as a function of the applied electric field then it is called the ironic polarizability. And that is given by the notation alpha i and here in the in the presence of the field ions start moving. So, there is a displacement of the ions and this occurs at a frequency of around 10 to the power 12 to 10 to the power 13 Hertz. So, if you apply an electric field which is has a high frequency than 10 to the power 13 Hertz. Then these ions cannot change as a function of the varying directions of the electric.

And so they will not be able to contribute if the applied electric field has a frequency of more than 10 to the power 13 Hertz. Then only the electrons can change and they will contribute to the polarizability. So, the ionic polarizability becomes important only at frequencies lower than 10 to the power 13 Hertz. And then they contribute through the polarizability which is called a factor alpha i. If you apply a field which is much slow in changing that mean the frequency is much lower say 10 to the power 3 group to 10 to the power 11 Hertz that is called dipolar polarizability. And that is seen in the in molecule say as water where you dipolar polarizability ionic polarizability can be presence of positive.

And negative ions so suppose there is a titanium here which is positive charge and this negative charge. Then they can have some kind of charge separation then it will be rise to ionic polarizability in dipolar molecules where there is no real charge. But there are dipoles so there is some delta positive and delta negative charges and the molecules by their orientation can change their polarizability. And that is called the dipolar polarizability and that occurs at a frequency range between 10 to the power 3 to 10 to the power 11 Hertz much slower than the ionic polarizability or the electronic polarizability. The last one is the space charge polarizability alpha s where you have very low frequency can change polarization.

And this normally is found in materials where there is long range charge migration that is like when materials are conducting. And then there is long range charge migration. And so this space charge polarizability then contributes and actually this happens at very low frequency. So, when you add these frequencies the contributions to the polarizability so at thus low frequency region if you see then obviously we will have contributions from all these 4 because all these 4 can change their polarization at very low frequency. So, the low frequency alpha if you consider will be very large, because it will have contributions from all these 4 polarizabilities. Whereas, a high frequency polarizability will have only contribution from alpha E.

Because alpha i alpha d and alpha s will be 0 at that frequency there will be hardly any change in the polarizability. Because they cannot follow the high frequency at which the field is changing. So, polarizability increases as you go from electronic ionic in this range where you lose see the space charge polarizability. The value will be very high be very high after total alpha, because it will have contributions from all the 4 polarizabilities. So, if that s once time increases that means you have more time and smaller is the frequency you have a high value for the polarizability.

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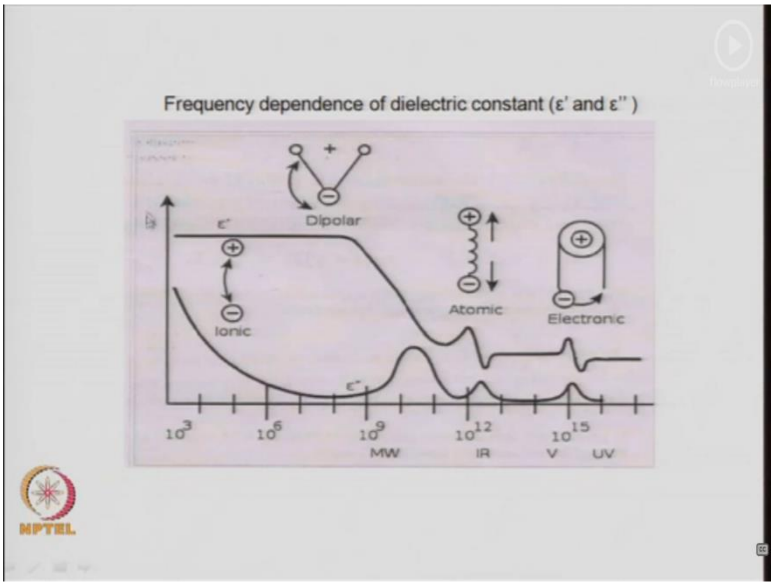

Now, this can be shown as a plot where you show on the y axis the dielectric constant. You can plot either the real part of the directly constant which is alpha prime or the imaginary part of the dielectric constant which is alpha double prime. So, of you plot the alpha prime then it is show the variation like this. So, this is the value at low frequencies so on the x axis you have frequency. And you have 10 to the power Hertz 10 to the power 6 10 to the power 9 which Gigahertz or this is the microwave frequencies and then 10 to the power 12 Hertz, which is the infrared frequency. And then you come to 10 to the power 15 and more which is the ultraviolet region.

So, the real part of the dielectric constant here is very high, because it has contributions from space charge ionic dipolar and electronic polarizabilities. And hence all those 4 polarizabilities will be responsible for the dielectric constant which is alpha prime. The real part of the dielectric constant, so you have the ionic contribution. You have the dipolar contribution; you have the orientation or the atomic contribution and you will have the electronic contribution. So, the 4 contributions which we discussed sometimes the named are also change for example, we are calling here dipolar polarizability. And then we are calling it as ionic polarizability whereas, here we are calling it as a atomic polarizability which is a same as ionic polarizability.

In some books it is written as a atomic polarizability. So, this the real part of the dielectric constant. So, it goes from the very high value at low frequencies to low values at high frequencies. And if you look at the other plot this is for the epsilon double prime which is the imaginary part. The epsilon double prime is the imaginary part of the dielectric constant and epsilon prime is the real part of the dielectric constant. So, the epsilon double prime shows a maximum where the real part of the dielectric constant shows a drastic change. So, wherever be the epsilon prime is changing rapidly that frequency, you will see a maximum in the dielectric loss.

The epsilon double prime gives rise to the dielectric loss the imaginary part of the dielectric constant gives rise to the dielectric loss. The real part of the dielectric constant is what tells you about the high value of the polarization. Or the dielectric constant is very high and this maximum is about the dielectric loss. And so wherever there is this sharp change in the epsilon prime you see a maximum in the epsilon double prime. So, these 2 go hand in hand the top one is the epsilon prime variation the bottom one is the epsilon double prime variation. And this side you see only electronic contribution to the polarizability. And electronic contribution is at high frequencies in the range of 10 to the power 15 Hertz which lies between the visible U V region and that is the high frequency region.

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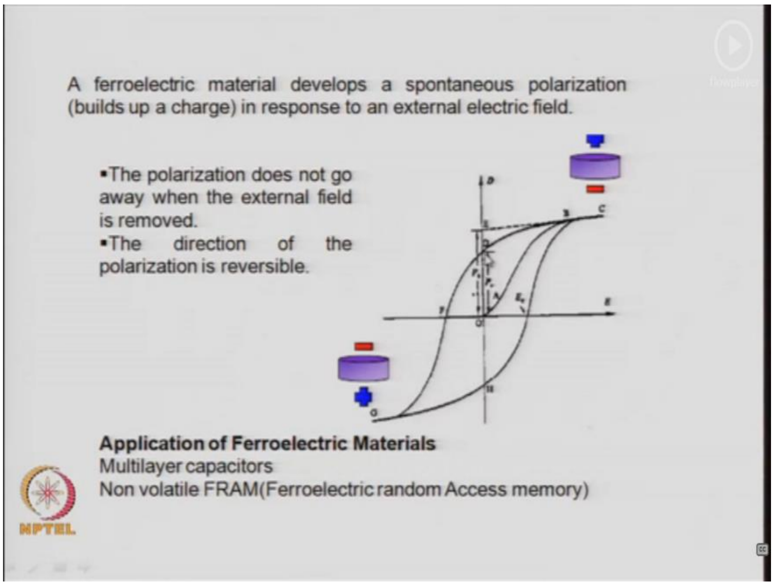

So, you have different mechanisms for the normal dielectric materials. Now, there are certain dielectric materials where the polarization is present even in the absence of an applied electric field in all these cases the polarization is a function of the electric field. And these are simple dielectric materials, but then the polarization this spontaneous polarization is there without the presence of the field that mean. Suppose, you have this plot is called a hysteresis loop for a ferroelectric at 0 field, also if you have a value for the polarization. Then you can you call it normally a ferroelectric. So, a ferroelectric material shows a hysteresis loop of this way.

So, initially it is 0 as you increase the field the polarization at the dielectric displacement increases. And then comes back as you reduce the field, but does not go to 0. It goes to a value even at when the electric field is 0 and this is called the remnant polarization if you plot it as P and if you want to make this P go to 0. Then you have to apply a field in the negative direction and at this point the polarization really comes to 0. And this much of electric field which has been applied in the opposite direction to bring down the remnant polarization to 0 is called the coercive field.

So, this kind of hysteresis loop you start from 0 you come here and you get what is called the saturation polarization. Then as you are going down you get what is called the remnant polarization and then to bring it to 0 you have to apply field in the other direction. And then they cycle continues this called the hysteresis ferroelectric so this is different from a normal dielectric. And there are many applications of ferroelectric materials as multilayer capacitors in non volatile ferroelectric random access memory for various kinds of storage. And they are of tremendous applications so we studied what are some other properties of the dielectrics.

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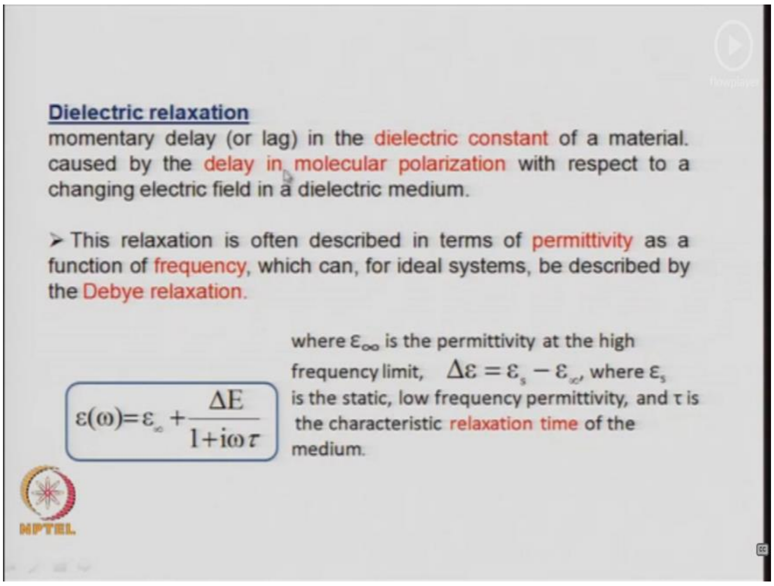

And what is the ferroelectric material now in dielectrics there is also something called the dielectric relaxation. And the dielectric relaxation is the delay or lag in the dielectric constant of a material due to a delay in the molecular polarization when you are changing the electric field. So, with respect to a changing electric field in a dielectric medium if there is a delay of the movement of the dielectric constant following the change in the electric field. So, how the electric field vector is changing the polarization is is the lag in the dielectric constant following the change in the electric field. And that is called dielectric relaxation many times it is explain in terms of variation in frequency and is also called the debye relaxation.

So, the dielectric constant as a function of frequency is the quantity of interest here to understand this dielectric relaxation. And this dielectric constant as a function of frequency or omega is shown here is related to the dielectric constant at very high frequency. We write infinity as if it is infinite frequency, but actually it means the frequency is very high certainly for 15 10 to the power 16. And then this is called the high frequency dielectric constant and normal dielectric constant for any frequencies related to this plus 1 factor where you have this frequency. And you have the characteristic relaxation time tau in built here.

So, this is an equation where the dielectric constant as a function of frequency related to the frequency at very high frequency. The dielectric constant at very high frequency and also to the difference of the dielectric constant at high frequency and the dielectric constant at low frequency. So, epsilon s is called the static dielectric constant or when the the frequency is going to 0 nearly 0. So, epsilon s is the value of the dielectric constant when the frequency is nearly 0, that is called a static dielectric constant. And the difference between the high frequency dielectric constant and the static dielectric constant this is delta epsilon and that actually is here the delta epsilon. And these values epsilon s which is the static or low frequency permittivity and tau here is the characteristic relaxation time of the medium.

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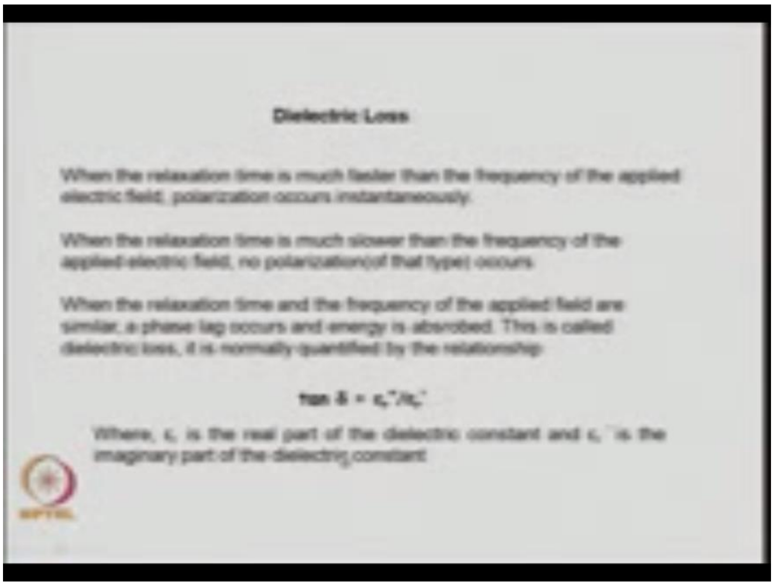

Now, when the relaxation time is much faster than the frequency of the applied electric field then polarization occurs instantaneously. And when the relaxation time is much slower than the frequency the low polarization will occur. So, this relationship between the relaxation time and the frequency of the applied electric field is very important to understand. And suppose the, if relaxation time and the frequency of the applied filed are similar then there is an absorption of energy. So, this absorption of energy is called a dielectric loss and is normally given by this quantity tangent of delta which is equal to the relative dielectric constant. The imaginary part of the relative dielectric constant divided by the a real part of the relative dielectric constant. The ratio of these 2 gives you the dielectric loss also called the tan delta and this quantity tan delta or dielectric loss is as important a property. Because it tells you that energy is a absorbed its al last from this system. So this loss in energy is what we are calling it as dielectric loss here and is given by this equation.

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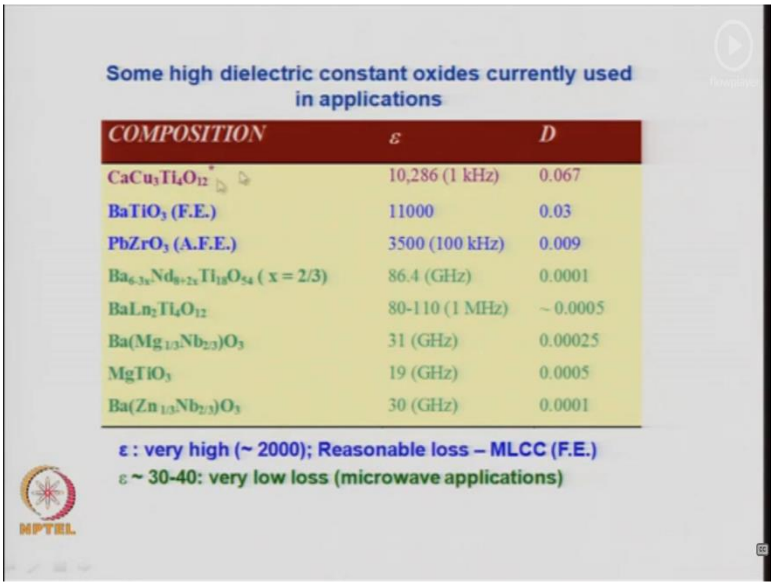

Now, a we earlier discussed some materials with some known material say air walker etcetera simple solvents simple materials. And showed that the dielectric constant can vary between 1 and 18 some compounds. But there can be materials which have very high dielectric constant especially in ferroelectric materials. And some of these materials are listed here where you see you can have a material like calcium copper titanium oxide where the dielectric constant epsilon is around 10000. And this is of course, at a particular frequency when you mention the dielectric constant it is important to know the frequency if the frequency is very high.

Then this can be call the high frequency dielectric constant if the measurement is done at very low frequency. Then the dielectric constant is called a static dielectric constant and the epsilon and D D here is the dielectric loss. They are similar to what we were discussing as epsilon prime and epsilon double prime is here shown as D capital D is called the dielectric loss. And epsilon double prime is related to the dielectric loss. So, you see the low values of dielectric loss means low loss in energy means it is a good material for applications. And this high value of dielectric constant tells you it is again a very good property for application of materials. And normally ferroelectrics will have high dielectric constants like 11000 in barium titanate.

And that of course, depends at on temperature and also on the frequency at which you are measuring as you go higher in frequency. The dielectric constant will decrease, because the contribution will come only from electronic polarizability. As we discussed earlier at low frequency all the different mechanisms of polarization will contribute to the overall polarization and hence will contribute to the overall that the constant. So, these are some of the important oxides many of them or most of them are being used today in the market for applications. And the some of them have very high dielectric constant of around more than 2000. If these are the examples and some of them have reasonable loss so there will always be some loss dielectric loss. But the lower the value of the loss better is the application, so there are different kinds of applications for which different materials are suited.

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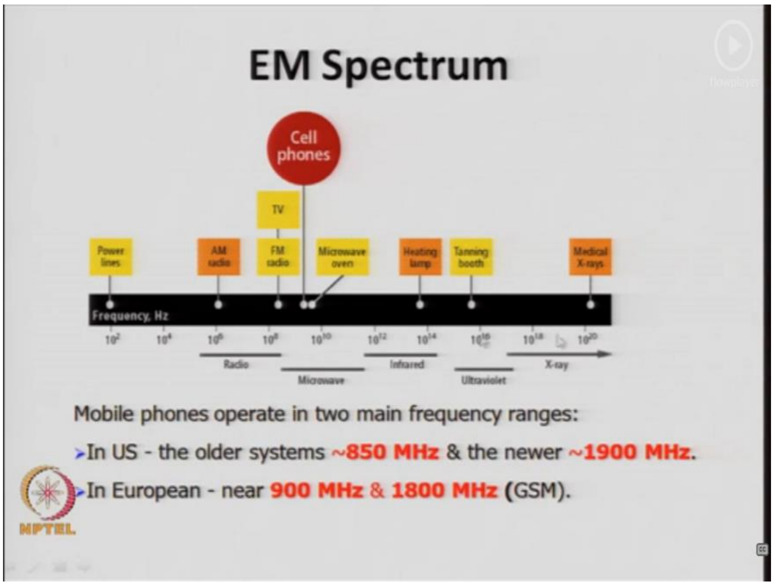

So, we will discuss some of these soon now if you look at the a spectrum of energy now you have applications at all ranges of energies. For example, the radio wave region which is around here so the radio functions at around frequency of one Megahertz or. So that is where the amplitude modulated radio works now a today's we have this F M radio which means the frequency modulated thing. And which works at a slightly higher frequency of around 10 to the power 8 Hertz. So, these are radio frequencies. Then we have cell phones which work in the microwave region. And so you have this region where microwave oven a works etcetera so the microwave oven works at 2.45 a Gigahertz.

So, this is the Gigahertz region the similarly, other applications listed depending on the energy which they energy at which they are working in the corresponding to the electromagnetic spectrum. So, the mobile phones normally in use are around 850 megahertz to 1900 megahertz that different types of mobile phones with different frequencies. And they all come in the microwave region of the frequency spectrum so what are the microwave dielectric properties? Because you have so many applications in communication based on satellites based on cell phones. Hence microwave dielectric materials are we have become very important in the last 2 or 3 decades, because of the tremendous use in the communication and satellite industry where all these used microwave dielectric materials.

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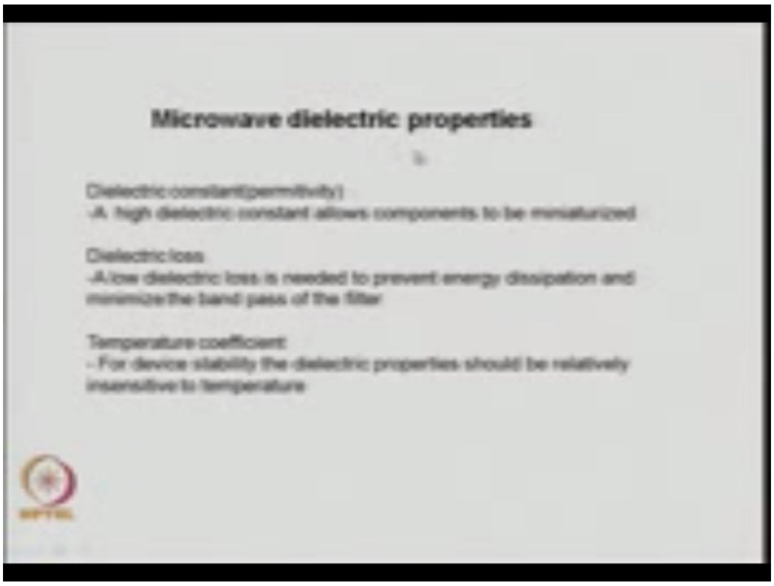

Now, these microwave dielectric materials should have properties which are good and at the Gigahertz range of frequencies. So, it should have a dielectric constant and that would make it possible for the components to be miniaturized. So, smaller the size of component light will be your ultimate device or more devices can be put on one bulk device if you can make a material of much small size with higher dielectric constant. So, you want to reduce the size of the component that you use but keeping a maintaining the dielectric properties.

So, lot of research is being done on the development of such microwave dielectric materials which. So, high permittivity in the Gigahertz range and so low dielectric loss and low dielectric loss means prevent it prevents energy dissipation more than the dielectric loss more is the dissipation of energy. So, low dielectric cause loss materials are required to prevent energy dissipation and at the same time it should have a high dielectric constant. The other thing is that the temperature coefficient of the dielectric properties especially the dielectric constant should not change much.

So, you must have a temperature coefficient of nearly 0 that means if you change the frequency the dielectric constant should not change much as a function of temperature. So, at a particular frequency if you check the dielectric constant and then change the temperature and again check the dielectric constant at the same frequency the 2 should be nearly equal if it has changed a lot. Then you cannot use them in many applications you need a coefficient temperature coefficient which is as close to 0 as possible especially for material which show microwave dielectric properties. So, in my microwave dielectrics other then the dielectric constant.

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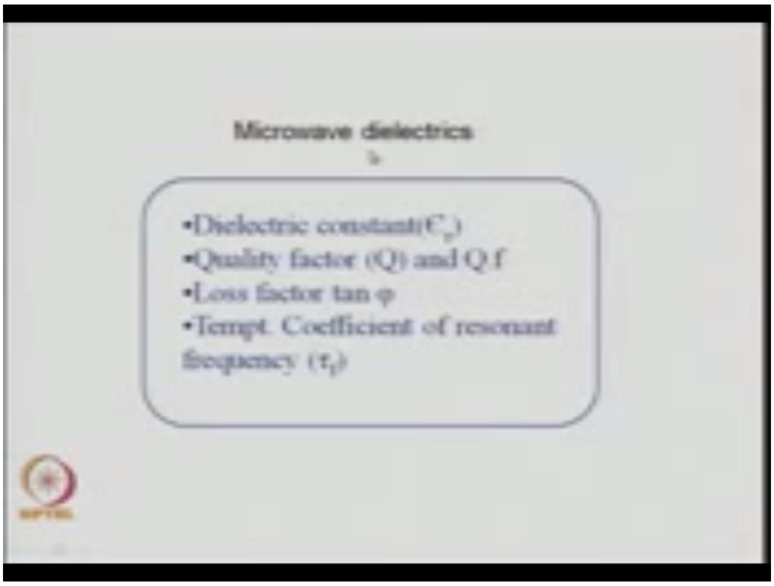

And the dielectric loss there is there are other like quality factor which is the inverse of the dielectric loss. And the most important quantity is the temperature coefficient of the resonant frequency which we just mention that the temperature coefficient should be close to 0 of the resonant frequency. That means if you vary the resonant frequency temperate coefficient as a function of temperature. They should not be much change so these are some of the points for somebody to keep in mind when he is designing a new microwave dielectric material.

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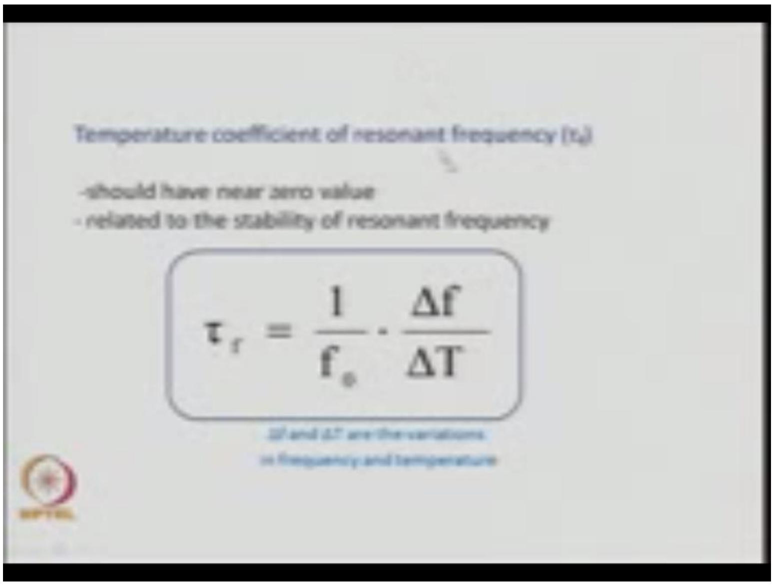

So, the temperature coefficient of resonant frequency tau f should have near 0 value. And is related to the stability of the resonant frequency by this equation the tau f is given by 1 by the frequency multiplied with change in frequency as a function of change in temperature. So, these are the variation in frequency, and these are variation in temperature and what happens to the temperature coefficient of resonant frequency, this you want nearly close to 0.

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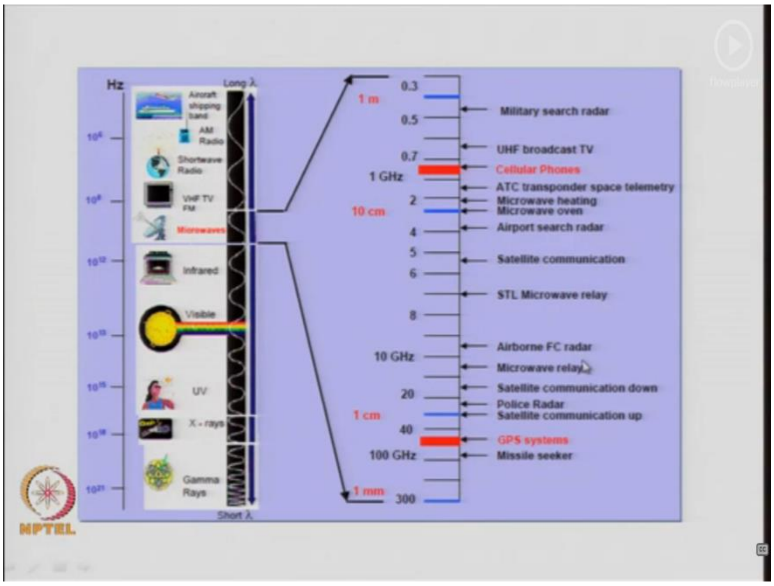

In a microwave dielectric material so this is again an expanded scale from around 0.3 Gigahertz to 300 Gigahertz. This is a range of frequencies at which the microwave dielectric materials work. And are of tremendous importance due to their applications in a ultra high frequency broad cast in microwave heating in satellite communication in radar techniques in many police radar airborne radar. So, many applications in the defense and the strategic industry are very much dependent on these microwave ceramics. Because of there are unusual properties at microwave frequencies. So, these are all different frequencies as you can see frequencies of 1 Gigahertz is here at which cellular phones are working.

Then you have in this manner increasing amount of frequency so 1 Gigahertz to 10 Gigahertz to 100 Gigahertz. And is the range where mostly defense works which is where you have missiles and all the frequency involved is around 100 Gigahertz and in communications. You are working at around 10 Gigahertz etcetera, ordinary cellular phones are working of the order of one Gigahertz. So, all these many of these gadgets you are in the microwaves that is this window can be expanded to include a large number a materials. And above the microwave is the infrared visible etcetera and below the microwave are the radio waves and other short waves.

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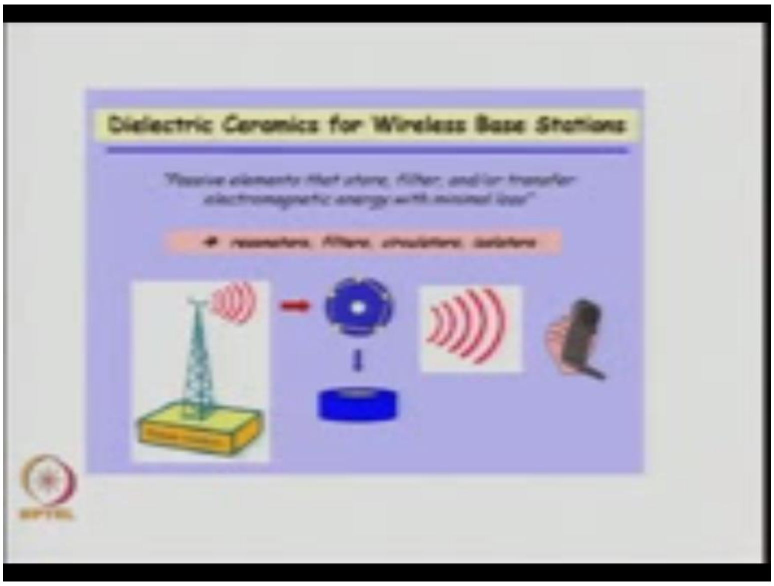

So, microwave dielectric materials has tremendous importance as mentioned as in communication. So, here an example is given where you use a dielectric ceramic for base station. So, there is a base station where you have elements like which can store energy or filter energy or transfer electromagnetic energy with minimal loss. Those kind of materials are required at the base station which will then really the signals the microwave signals.

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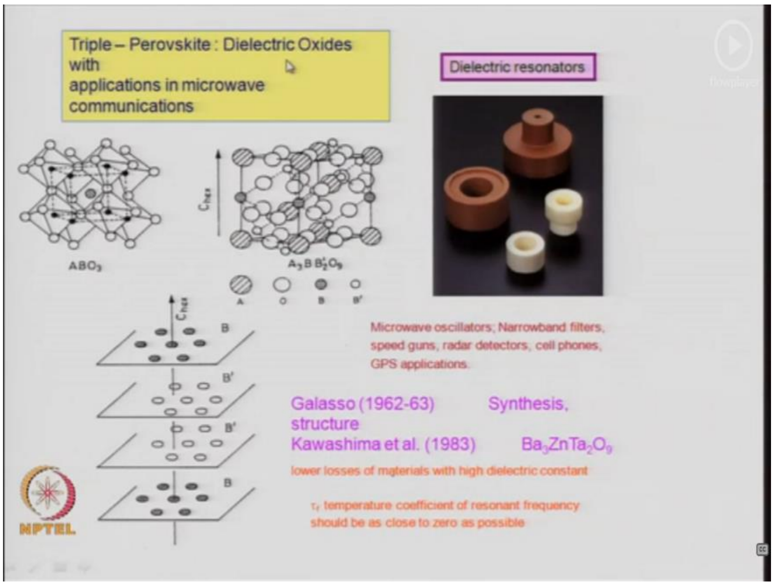

The example of a microwave ceramic material are sum up the dielectric oxide are having the structure of the triple Perovskite. These kinds of materials are used already in use in the market in microwave communications. And the triple Perovskite structure is very popular for microwave dielectric materials the first compound was synthesized Kawashima et al. And shown that it is a very good dielectric in the microwave region and the formula of the compound is B a 3. And using these materials some of the best dielectric resonators have been made and these dielectric resonators are used as a oscillators narrow band filters speed gun radar detectors G P S applications etcetera.

So, you need dielectric resonators which work in the microwave region and that is provided by this type of oxide. And there are many new oxides based on this structure which is called the triple Perovskite structure. This is the ideal Perovskite structure where you have a atom of A B O 3 at the Q B Q B octahedral cytrical. And then at the corner of the cubes you have this B atoms surrounded by then octahedral of oxygen's and these octahedra share corners. And if you look at it is this the Perovskite structure and if it orders that means it has a particular arrangement of the a ions and the B ions. Then you can get a ordered structure many different types of ordered structures are known in this particular case.

However, it leads to a hexagonal unit cell and in the hexagonal unit cell once you draw. Then you can find out the planes where the a atoms are where the B atoms are where the B prime atoms are. And if you will see that you have a stack of B B prime B prime B alternately along one particular axis. And that is the this axis around his body diagonal in the Q and if you make the body diagonal of the Q as the C axis of the new triple Perovskite cell then the layers will look like this. So, you have layers of these metals which you have forming say you have got B atom as zinc.

So, you have zinc here and you have zinc in this layer and then in between you have the tantalum so formula then becomes B a 3 is zinc T a 2 o 9. These are very important materials known from 1990 80. And still they remain to be some of the most useful microwave materials why they are important, because they are high dielectric constant. And their temperature coefficient of resonant frequency is as close to 0 as possible. So, triple Perovskites are very useful as dielectric oxides with applications in microwave communications. And hence the research in this area in the past 25 30 years as concentrated heavily on the applications of these materials.

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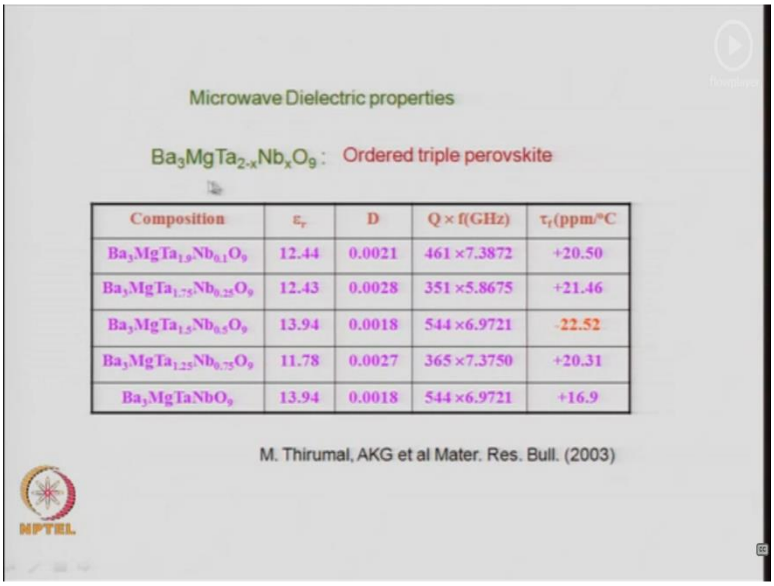

Composition	ε_r	D	Q × f(GHz)	τ_f(ppm/°C
$Ba_3MgTa_{1.9}Nb_{0.1}O_9$	12.44	0.0021	461 ×7.3872	+20.50
$Ba_3MgTa_{1.75}Nb_{0.25}O_9$	12.43	0.0028	351 ×5.8675	+21.46
$Ba_3MgTa_{1.5}Nb_{0.5}O_9$	13.94	0.0018	544 ×6.9721	-22.52
$Ba_3MgTa_{1.25}Nb_{0.75}O_9$	11.78	0.0027	365 ×7.3750	+20.31
$Ba_3MgTaNbO_9$	13.94	0.0018	544 ×6.9721	+16.9

This is an example of how you can make new compounds in having the same structure by substituting. Now, B a for tantalum and undergoing the same type of analysis measure the dielectric constant, the dielectric loss; the quality factor and the temperature coefficient of resonant frequency and these values are in p p m per degree centigrade. So, whole lot of measurements have been done these only one example we show where real numbers are shown to you about the dielectric constant of the dielectric loss of triple Perovskites. Now, part from the B a 3 z n 2 T a 2 o 9, there is a whole lot of new of materials which are known to be microwave dielectrics. For example, if you change zinc to magnesium you get B a 3 M g T a 2 o 9.

And then that is also a very good dielectric material so there is a whole family of materials which have a similar formula say a 3 B B prime 2 o 9. And a can be angstrom barium and the B and B prime are typically a transition metal elements one has a size which is of the 3 transition metals and thus the other metal is of the 5 D transition metals. So, you can have a B a 3 zinc in B 2 o 9 and that is also a triple Perovskite. So, triple perovskites are very important from the microwave dielectric point of view. And the numbers that they show for example, B a 3 zinc T a 2 o 9 has which is one the world’s best materials for making dielectric resonators which is particularly true for microwave ceramics where we want to use them for dielectric resonators. And most of them are present in your mobile phoned where they have to catch signal in the coming in the microwave range and then they have to process it etcetera.

And these materials all show the temperature coefficient of resonant frequency is nearly equal to 0 the value of the dielectric constant is around 25 to 30. But the loss is extremely low and the one of the most important points of any microwave dielectric is that the loss should be low small. So, the loss can be of the order of 10 to the power minus 4 or 10 to the power minus 5. Then it is very good microwave dielectric if it is 0.1 or 0.01 then is it is not so good in a microwave for microwave applications. So, these are different points about microwave dielectric materials applied in communications.

And other in defense in radar technology where these materials are being used and you can think of many new compositions. This is one of them and I said you can make this compounds with magnesium with nickel you can change tantalum with niobiums. So, the formula will become a B a 3 zinc niobium 2 o 9. So, lot of variations are possible on this structure and many people have worked on this and have tried to improve these materials. This is one such case where we are looking at B a 3 M g T a 2 o 9 where the tantalum has been partially substituted with niobium this all these compounds of this form are also forming the, but Perovskite structure.

And it is the ordered triple Perovskite structure and it is having is a cell most of these to triple perovskites have a cell around 5 point something and that is a parameter. And the C parameter is along this direction which is of the order F 7.5 or 7 7.1 angstroms. So, that is the typical size of these units cells of these hexagonal ordered unit cells. So, you can see that in this cases the epsilon r is not that good it is between 11 to 12 the loss is also it is of 10 to the power minus 3. And the temperature coefficient of the resonant frequency which is given in units of p p m parts per million per degrees centigrade.

So, this has a value of around say twenty point 5 into 10 to the power minus 6 and you can have positive a tau F or negative tau F. And both were seen in these family of compounds where what one has done is vary the composition of tantalum and niobium. So, the composition of and tantalum and niobium is change so the formula changes with those changes in tantalum and niobium. But all of them show a dielectric constant of around 12 to 13 or 14 the loss of around 10 to the power minus 3 or 2 into 10 to the power minus 3. And the coefficient the temperature coefficient frequency is varying between minus 20 to plus 21.46. Now, one good thing is that this microwave dielectric properties is a bulk property. So, you can mix these 2 components; one having a positive and one having a negative. And if you mix them and in a equal proportions then more or less they will this together the value should be equal to 0.

And then that should be a very good material for material where you are requiring tau F to be equal to 0 that is temperature coefficient of the resonant frequency is close to 0. And that can be achieved by adding equal amounts of this and this or even this and this so this composition 1.5 point 5. If you codope with any one of the other 2 it should be give you better results than taking one of them alone. So, that feature is possible that you can mix 2 dielectrics with the different temperature coefficient of resonant frequency and then optimized the value of tau F that you get.

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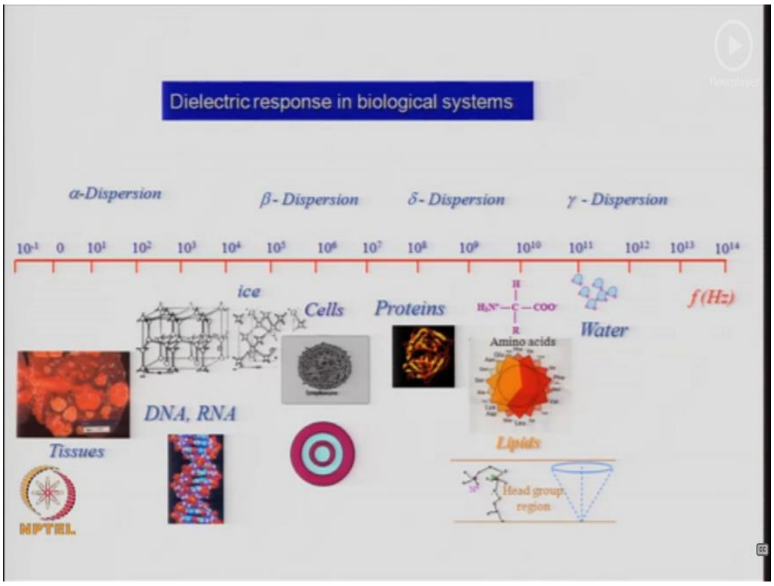

Coming to the last slide today, we have been talking of dielectric response in a materials which are mostly inorganic materials. But in the initial part of the slide of the lecture I also mentioned about the dielectric constant of water and water is there in many living beings also. Hence there will also be a dielectric property some dielectric constant of biological systems. So, that is what is being shown here that you see that in tissues are in DNA, RNA in cell in proteins in amino acids. And of course, in water which we discussed earlier which has a dielectric constant of around 80 you can see that all of them show dielectric response. That means if apply an electric field you will get some polarization and that varies at what frequency you apply the electric field.

So, the electric field is varying at what frequency depending on which system you are studying. For example, whether you are studying issues or you are studying proteins; you have different frequency range at which the dielectric constant will change. So, there is a dispersion which we call alpha dispersion beta dispersion delta dispersion, gamma dispersion depending on the region at which the material can follow the variation in the frequency of the electric field which is applied. So, the polarization follows the electric field the polarization can follow the electric field only if it is fast enough. So, in water where the polarization is fast enough and the dispersion can be seen at 10 to the power 11 Hertz where as in a tissue that variation in the frequency has to be very less at the frequency is between say around 0 to 10 10.

So, at 10 Hertz whereas, in DNA and RNA it is around one 1000 Hertz so you have say around 10 Hertz 1000 Hertz and so on up till around 10 to the power 11 12 Hertz. All these ranges you can see the dielectric properties are varying as a function of frequency. Only thing is if the system has a material which response to the applied field really quickly then you can apply high frequency. So, you can see the dispersion or the variation of the dielectric constant at high frequency if the system response to that high frequency if it does not. For example, if you are working with DNA, RNA or tissues where it does not the polarization is not as fast enough as the change in the electric field.

So, the frequency you have to apply is very low then only you can see the dispersion and so that is called the alpha dispersion. So, with that we come to an end of this lecture today. And in the next lecture on dielectric properties this was like a primer. We will talk about what happens to the dielectric properties when these materials these oxides etcetera become nano sized. Then how does it affect their dielectric properties.

So, thank you very much, will meet later.