Electroceramics
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Lecture - 38

So, again in the start of a new lecture; so we will just review the contents of last lecture briefly, and then move on to the new lecture. And this is the last lecture of this module. After that we will have two or three smaller modules, which we should finish in three or four lectures. So, we just coming to the end of this course now.

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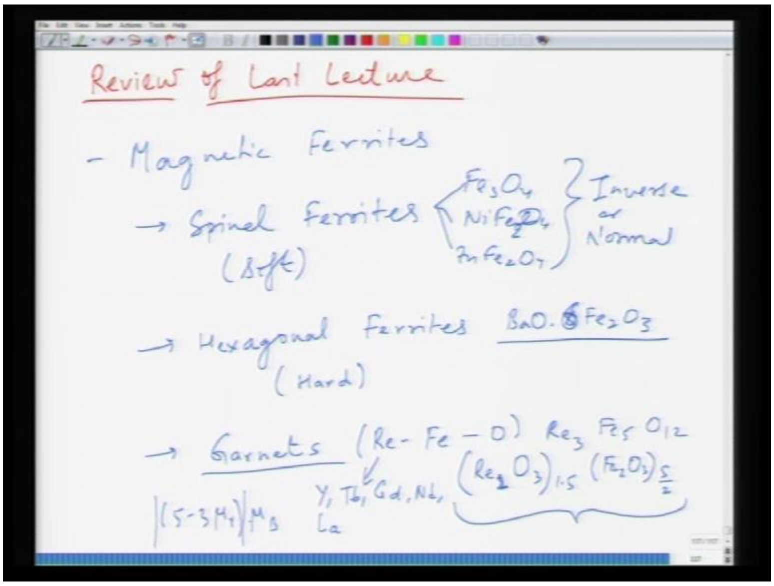

So, in the last lecture we discussed about so just let us say review. So, in the last lecture we talked about basically magnetics ferrites and as the name suggest itself. Since the name is magnetic ferrite most of these are iron containing compounds and that comes from the magnetic properties of iron. So, the first of these happens to be your spinal ferrites. And these spinal ferrites we discussed were variety of these F e 3 O 4 N i F e 2 O 4 z n F e 2 O 4 etcetera. And these were also classified as inverse or normal.

So, depending upon how the cations distribute themselves in the octahedral and tetrahedral interstices of FCC lattice made by oxygen atoms. These would be called either normal or inverse ferrites. And based on the distribution of these ions in the in interstitial sides you could you could work out what is the net magnetization. And this magnetization essentially if you take one side let us say tetrahedral side up and octahedral would be down, you can take either of them up or down. But the point is they are opposite to each other and it is a net magnetic moment of each of these sides. And algebraic sum of those two determines what is the net magnetic moment of the material. And as a result these materials happen to be quite magnetic in nature. They have large magnetic moment and they are soft materials, which means, they have an slim hysteresis loop. So, they are typically soft ferrites and then we talked about hexagonal ferrites in the hexagonal ferrites. We are mainly interested in barium ferrite barium hexa ferrite which was which is based on you know in the on the on the on the name magneto plum bite. And that is why it is called as M type ferrite as well.

Now, this is a hexagonal unit cell you can talk of this material as of its if B a o dot x F e 2 o three. And this essentially happens to be six essentially and this happens to have a mixing of F c c based and H c p based layers. And since F c c H c p packing fairly similar except that in F c c you have a B c a B c in a H c p you have a B a B packing. So, they they mixed with each other quite well and resulting in a structure which is hexagonal in nature. And this material also has a large magnetization as we discussed upon distribution based on the distribution of iron atoms. This because a iron here is them magnetic iron.

So, based on the distribution of these iron atoms you get a net magnetization. This material is highly an isotropic and as a result it is called as hard magnet. So, this is a hard magnet and then third case that we took was of garnets. And these garnets are basically based on mineral names. But they are, but they are magnetic iron containing garnets are magnet magnetic in nature and these could contain you know the. So, there yttrium or let us say not yttrium. So, they are the compounds containing rare earths or lanthanides iron and oxygen the general formula for them would be R e 3 F e 5 and o twelve. You can again break them into two oxides. So, this is let us say R e 3. So, essentially R e 2 o three 1.5 and then what you have F e 2 O 3 and then multiplied by such a factor. So, that it becomes 5. So, it is 5 by 2.

So, it is essentially you can that it is it is seven and a half plus four and a half that make up 12. So, this is what is essentially garnet is and garnet can be tuned quite well because you can use this rare earth atom as you there yttrium or terbium or you know gadolinium or neodymium or lanthanum. And depending upon the magnetic strength of each of these iron you have a net magnetization of the material and which essentially is nothing, but five minus three mu r into times mu B. Or you could write three r three mu r minus five. So, basically you take mode of this.

So, so essentially depending upon the strength mu r which is the strength of the magnetization or magnetic moment of these are earth ions. You get the net magnetic moment. And this can this is of course, tunable and again these structures can be made in single crystal form. They can made in oriented form. So, as a result micro structural tuning of these materials is quite important and determining the properties of these materials and also the composition which determines both the magnetic moment as well as the curie temperature. Or is the temperature of operation let us say. So, this is essentially is summary of what we discussed last time.

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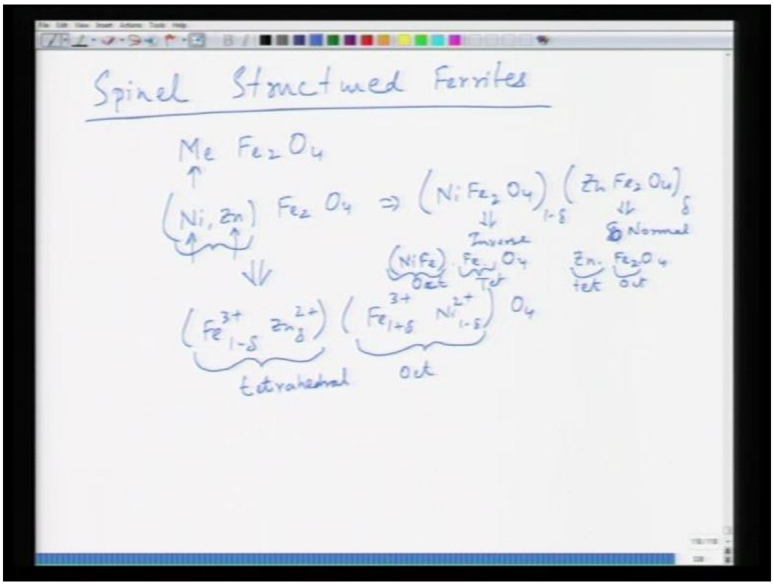

And we will now take up is essentially one more thing that we that that we sought of did not discussed last time was especially in the case of spinal ferrites. Now, in case of spinal structured ferrites; let us say now the formula let us say is M e F e 2 O 4 where M is some metal ion.

Now, this metal ion you can make it look like as if it is a N i z n F e 2 O 4. So, it is a mixture of nickel and zinc now here you see that nickel is a magnetic ion. But zinc is not a magnetic ion. It has a zero magnetic moment, but by careful mixing of these two you can achieve magnetic moment which is actually higher than the parent compound. So, the distribution when you mix zinc in there the distribution happens to be F e 3 plus one minus. Let us say if delta is the level of non stoichiometry a level of mixing. Let us say then z n delta and that is two plus and then F e one plus delta three plus and N i 2 plus 1 minus delta. And the way these ions have distributed themselves is because nickel. So, this is nothing, but you can say N i F e 2 O 4 into z n F e 2 dot z n F e 2 O 4. And if you look at here this is one minus delta. And this is delta. Now, this happens to be a normal spin inverse spinal and this happens to be a normal spinal here. The distribution would be N i F e dot F e O 4.

And so, and so, would be a B 2 essentially a B dot B O 4 and this would be z n dot F e 2 O 4. So, here nickel and iron atom go to a side which is the tetrahedral side and nickel and iron atom go to the octahedral sides. One of the iron atom goes to tetrahedral sides and here zinc goes to tetrahedral sides. And both the iron atoms go to octahedral sides. When you mix them together you make sure that iron atoms going to tetrahedral side in nickel ferrite combine with the zinc atoms which go to tetrahedral sides. So, that is what you see here that iron and zinc combine with each other going to tetrahedral sides. And nickel and iron are combined with each other to go to octahedral sides. So, this is octahedral, this is tetrahedral and that is how you distribute these irons with respect to each other. Now, here beauty is when you calculate. Now, it is fairly straight forward to calculate the net magnetization. You just have to you just have to use the values of iron nickel and zinc and multiply them by one minus delta and delta and one plus delta wherever it is applicable.

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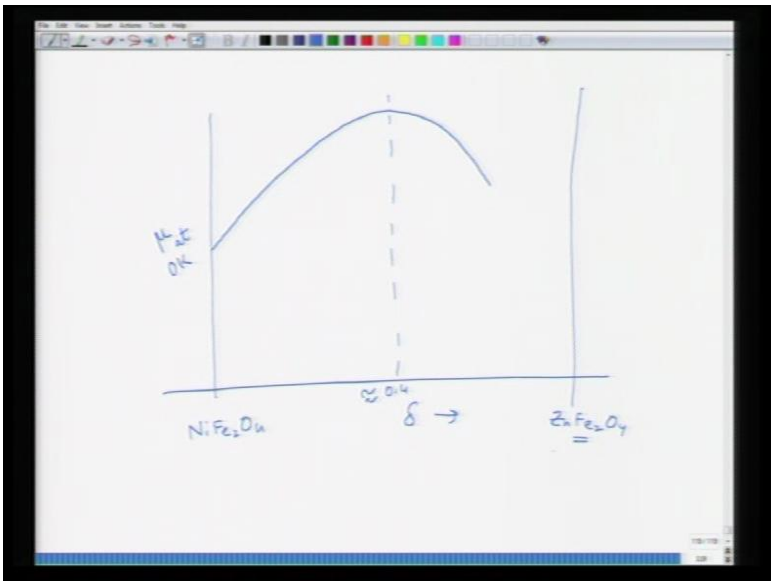

Now, the beauty of this is that when you plot this magnetic moment verses percentage verses delta. Now this magnetic moment verses delta. So, let us say if this end is nickel ferrite and if this end is zinc ferrite and this delta is the level of doping or level of mixing and then what you see is that. So, this is mu at zero k. So, this goes through a maxima something like this and this maxima occurs at around roughly point four. So, it is around point four. You get a maxima in the magnetization and this is and after that then again it decreases and then of course, you go to z n F e 2 O 4 which where zinc has 0 magnetization. All the magnetization comes because of F e atoms. So, this is how it looks like and it becomes zero for you know z n F e 2 o 4.

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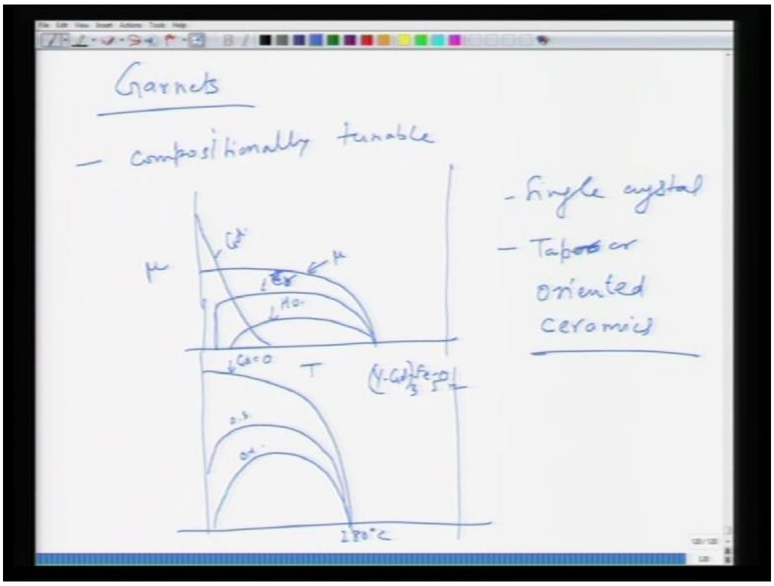

So, now, the thing that we are going to discuss is another thing about garnets is that that garnets are compositionally tunable. So, as a result when you make a plot of the magnetic moment verses temperature then you for variety of materials. For instance a changes in the curie temperature or the temperature window of operation it changes like this. So, for instance if this is a if this is the window for yttrium. Let us say this is the window for holmium. And this could be sorry this could be window for erbium. This could be window for holmium etc. So, gadolinium will give you window like this. So, depending upon the element you put its temperature window of operation during which the magnetization is more stable can be obtained. So, for instance if you take if you take a y g d F e o compound which means yttrium and Galenium substitute for each other; so, three F e five o twelve then for certain concentrations.

So, if you if you take for if you take for x is equal to 0 which is your g d is equal to 0 then you get a window like this and magnetization temperature of above 280 degree centigrade curie temperature. And if you go for instance point three and point four you get something like this. So, depending upon the composition you get a temperature of a window of operation for these garnets; so this which is compositionally tunable. Also these garnets can be fabricated in various forms. They can be formed in single crystal form. They can also be formed in tape form or oriented ceramics and as a result of some magnetic anisotropy this changes the magnetic properties of these ceramics.

So, now what we will do is that we will shift our attention. Now towards the properties of these magnetic ferrites which effect their magnetic behavior.

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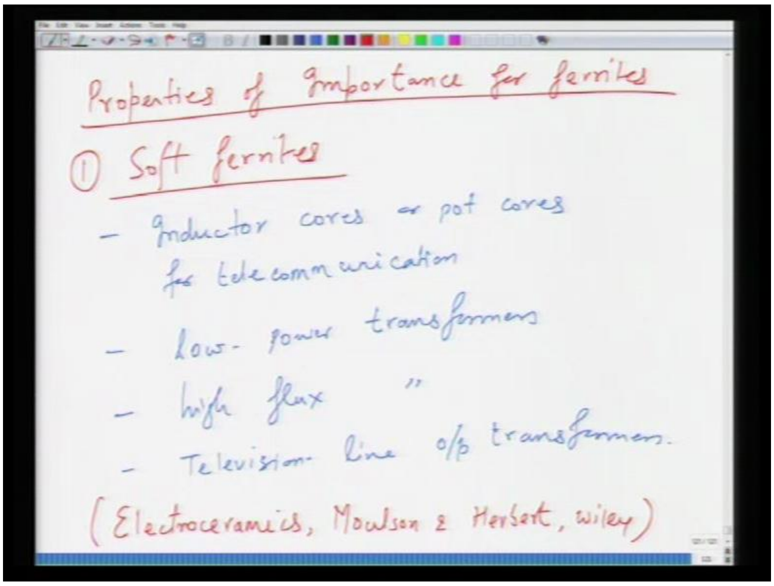

So, we will now look at the properties of importance for ferrites. So, first is the case of let us say soft ferrites and soft ferrites are typically your cubic spinal ferrites. And here they are used in applications like inductor cores or also called as pot cores. For telecommunications they are also used in low power transformers and high flux transformers. And you can also have television line output transformers and many applications you can use them for. And if you want to go into details about the applications you can go through the book of electro ceramics as a reference by Moulson and Herbert and this is Wiley publications. So, is a excellent book for talking about variety of applications. So, this is a nice book as a reference reading.

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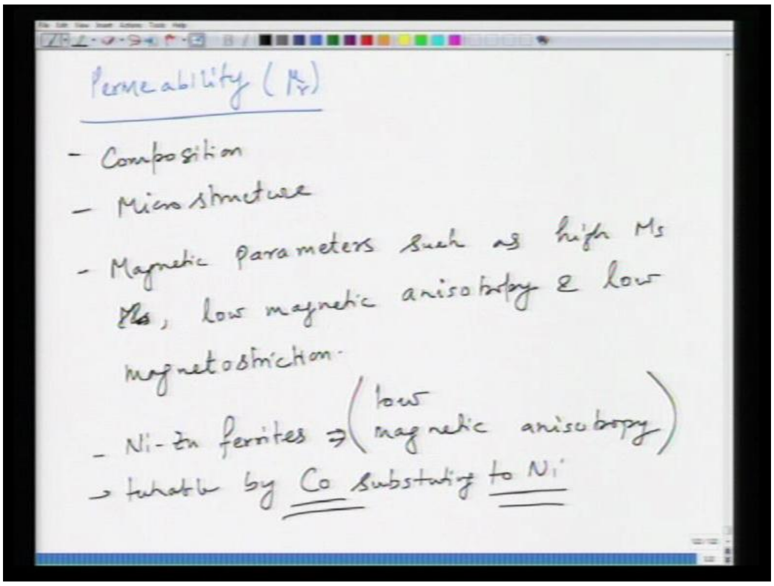

So, one of the properties of importance is permeability mu mu R. And this mu R is dependent upon things like composition composition is one of the important factors which in determines this and another is micro structure. How the grains are? What is the grain size? What is level of porosity? etc which determents this and it is not a very straight forward to determine this. But it depends upon various magnetic parameters as well. So, magnetic parameters such as your saturation magnetization M s and then M s or let us say high M s low magnetic anisotropy. And low magneto striction magneto striction is essentially the coupling of magnetic and elastic properties and which is low in these materials.

So, essentially this permeability depends in a quite complex manner on high saturation magnetization low magnetic anisotropy and low magnetization. Typically the magnetic an isotropic falls of quite rapidly as the saturation magnetization falls to a low value near the curie temperature. Because as you know as you increase the temperature to field temperature, the saturation magnetization decreases. So, as a result this magnetic anisotropy decreases which is understandable because of thermal forces become becoming dominant. And as a result you have low permeability of these materials. Now, in case of nickel z n ferrites this magnetic anisotropy is low and this can be adjusted by basically it can be tunable, by it is tunable, by substituting small amounts of cobalt, by cobalt substituting to nickel.

So, this cobalt is very important element in tuning the composition of magnetic ferrites. And here its it can change the it can change the anisotropy behavior of these nickel ferrites by cobalt addition. Now, another thing which is important is the centering atmosphere centering atmosphere can affect your magneto striction properties. But it can also a micro.

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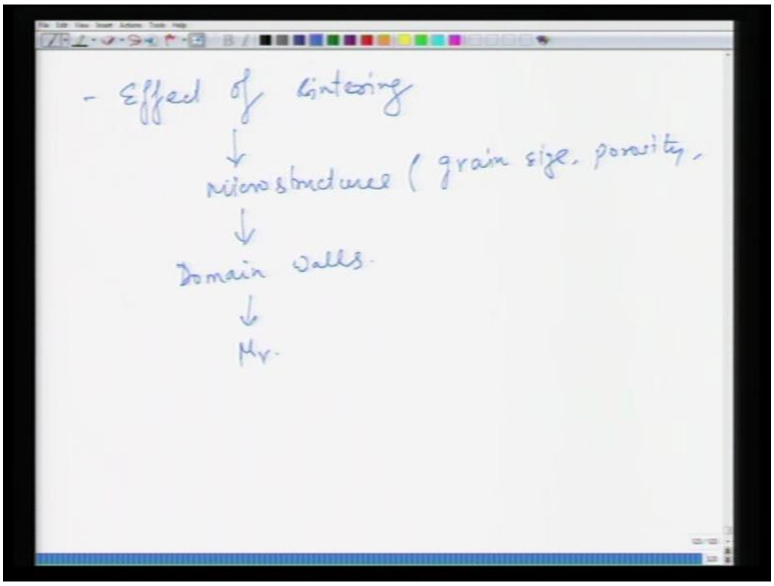

So, so you can have effect of centering. Now centering as you know is a densification process and this densification process the way you carry out what temperature, what atmosphere, what time. This determines the densification of the ceramic and this densification essentially controls the micro structure. Micro structure will mean grain size porosity grain size would mean grain boundary as well and the type of grain boundaries whether they are insulating, whether they are conducting etc

So, essentially this makes a dominant contribution to your domain domain walls or dominant effect on the domain walls. The way they move and that is how you change this and this has a dominant effect on mu R. So, essentially if you have if you have a grain, if you have a micro structure which leads to pining of domain walls then or if you have kind of porosity. Then this sought of reduces the permeability of the material. I will show you I will show you show you some of the effect of this.

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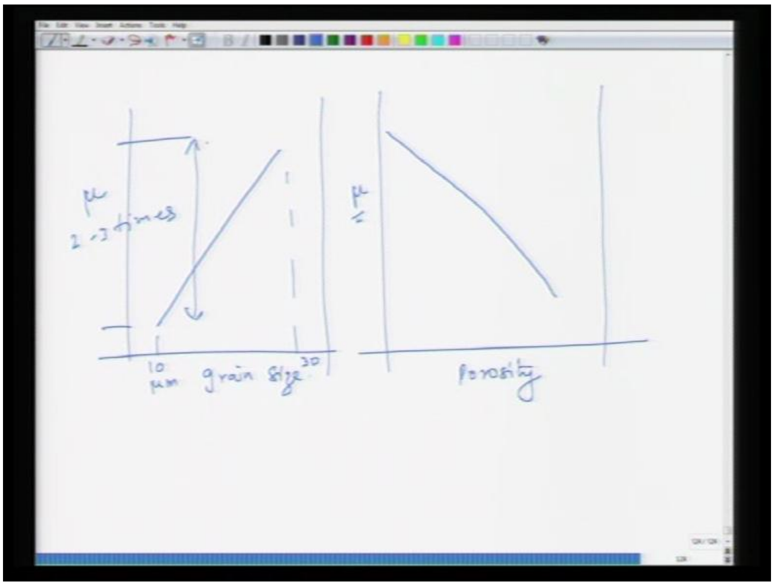

So, for instance, so if you look at for example, in some system the variation of mu as a function of grain; size the model system then it increases as you increase the grain grain size from. Let us say 10 micron to something like thirty microns and this increase in permeability can be two to three times. So, this is the effect of grain size and then you can also do it by. You can also study the effect of change of fractional porosity. So, porosity also has a dominant effect.

So, so it is sought of tends to reduce the permeability of ferrite materials. So, both grain size and porosity are function of the way material is made and this has a profound effect on the properties especially the permeability of ceramics.

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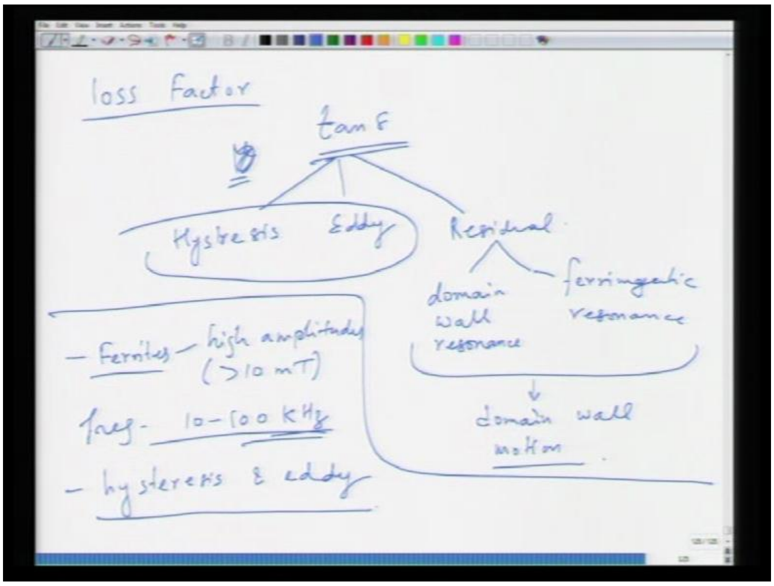

Another thing that is of importance is the loss factor loss factor is you know is nothing, but tan delta. And this tan delta has contributions from various sources. And this sources could be you know your hysteresis sources. It could be eddy current losses and it could be just the residual losses. And these residual losses are not easy to be quantified or identify. but they are typically associated with your domain wall resonance and your ferry magnetic resonance because simply because permeability complex property. So, when you look at it as a function of frequency you are going to have a resonance. And this and when typically in the in the high resistivity ferrites where hysteresis and eddy current losses are low the residual losses can be quite high. And this can lead to lot of problems and this is essentially being related to domain wall motion.

Now, in case of ferrites which in case of ferrites which operate at high amplitudes. High amplitudes would mean anything in the access of 10 milli tesla. So, 10 milli teslais a quite high amplitude of field and frequency is of the order of fifteen to 110 to the 100 kilo hertz. Typical now here the power dissipation is mainly hysteresis and eddy currents in such application. These are the two main mechanisms of power losses. In case of ferrites another parameter of importance for ferrites soft materials is their electrical resistivity.

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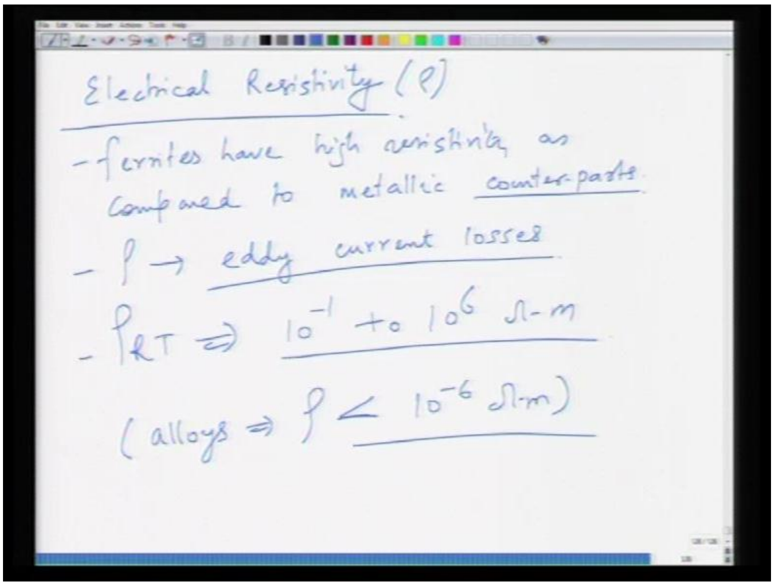

So, electrical resistivity is something that you know it is it depends upon type of material that you have and typically ferrites although have high resistivity as compared to metallic counter parts. But it is a still of important because this resistivity determines as we discussed earlier eddy current losses. And this could be quite significant if the resistivity is low. And typically the room temperature resistivity for ferrites lies in the range somewhere from 10 to the power of minus 1 to the 10 to the power of 6 ohm meter. So, this is the quite a quite a quite a lot of variation in the resistivity and this depends upon composition micro structure etc. And ad this is and all this is mainly orders of magnitude higher than Ferro magnetic alloys. So, in case of in case of alloys rho would be anywhere between. So, it is typically lower than 10 to the power of minus 6 ohm meter.

So, you can see that there is a difference of at least a few order of magnitudes in the resistivity of these ferrites. So, the definitely they are more resistive as compared to alloys. But it is still the resistivity is tunable by changing the composition. So, for instance if you look at the data for nickel and nickel zinc ferrites.

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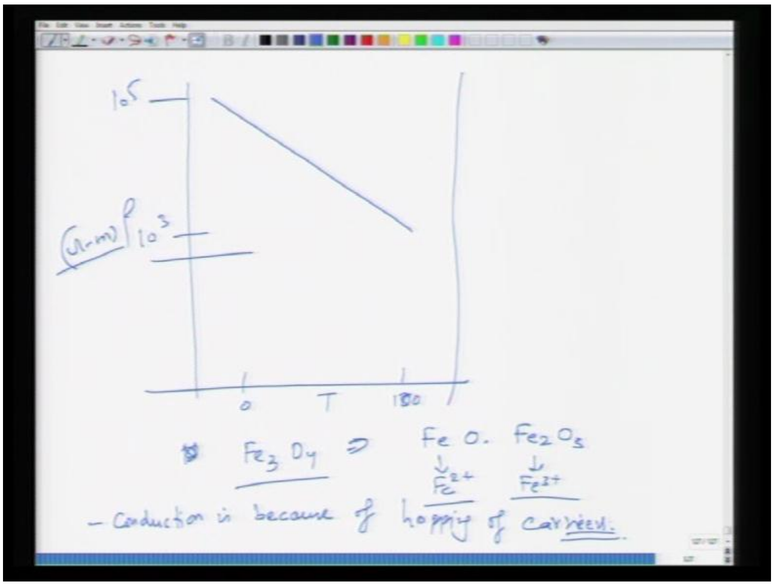

So, if you plot it as a function of a temperature rho verses t the rho verses t plot goes something like this. So, if you if you if you take this somewhere from zero to hundred and fifty degree centigrade or hundred degree centigrade. This variation in resistivity is of the order of it is about two to three orders of let us say this would be somewhere around 10 to the power five. And this would be somewhere around 10 to the power three ohm meter. So, about two to three orders of magnitudes the change in the resistivity is observed when you change the temperature by about hundred degree centigrade. And the conductivity in these materials essentially if you remember a module three I think when we discussed conduction in ceramics. So, these materials typically. So, you have n i. So, let us say you talk about F e 3 O 4 now F e 3 O 4 of course, has F e o dot F e 2 o three. So, you have F e 2 plus ions and you have F e 3 plus ions and here you have side fluctuation valence fluctuations. And this valence fluctuations gives rise to hopping of electron. So, essentially conduction in these materials because you have mixed valence conduction is because of hopping of carriers and this is between the equivalent sides.

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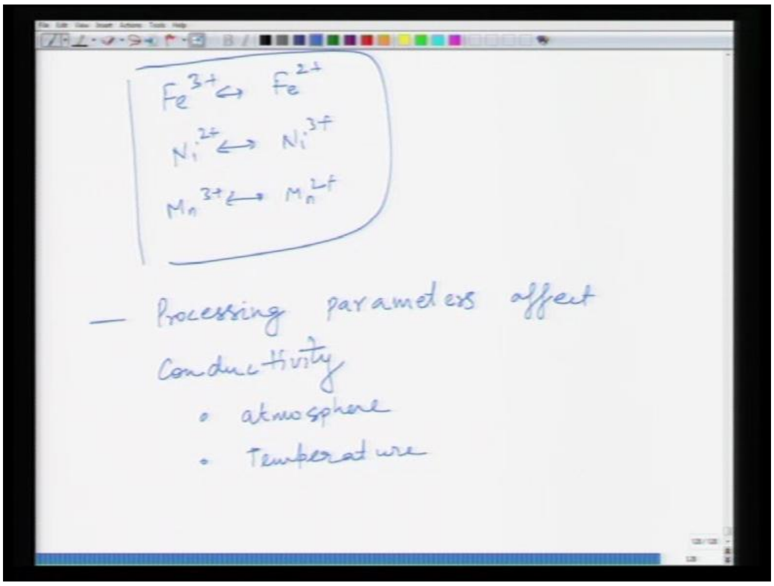

So, for instance you can have you can have this fluctuation from F e 3 plus 2 F e 2 plus or back and forth. You have similarly nickel as well nickel can also exist in N i 2 plus and N i 3 plus state you have a manganese manganese 3 plus 2 manganese manganese two plus state. So, since all these detransition elements they are susceptible to their change in the oxidation states. This carrier hopping becomes a major problem in terms of increasing the conductivity of these materials.

However, you can change the conductivity of these materials by careful processing processing parameters such as conductivity or resistivity. So, depending upon parameters like you know atmosphere temperature all of these etcetera etcetera. They give rise to the changes in the micro structure and composition of the material which lead to essentially change in the conductivity of the material. So, essentially you can control if you if you for instance if you if you if you use the atmosphere which allows the reduction of F e 3 plus two F e 2 plus. Or if you use the atmosphere which promotes the oxidation of F e 2 plus 2 F e 3 plus then you have then you have you can control the resistivity of these materials.

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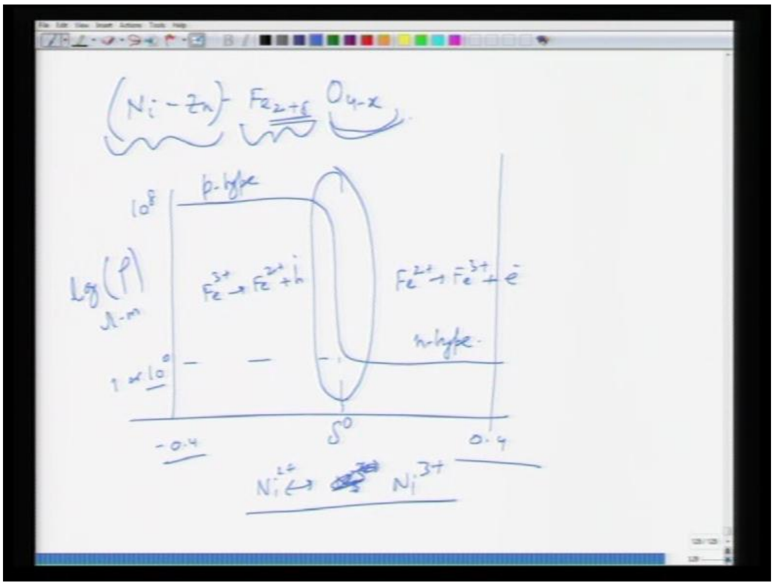

So, for instance in the case of nickel zinc ferrite. So, let us say composition. So, nickel N i z n F e 2 plus delta O 4 minus x. So, you have nickel zinc ferrite here iron is two plus delta which means iron can be little bit in the excess of deficiency which will affect the oxygen deficiency. Or excess because as you know that if you change the composition of one cation you are going to change oxygen stoichiometric as well. So, this non stoichiometric material and this goes this shows a change in the resistivity of this material. So, when you plot the resistivity log of resistivity ohm meter versus delta this iron value. So, it goes through several orders of magnitude change at around zero and so this goes to as high as 10 to the power 8 and this could be as low as 10 to power 0 or 1. So, about eight orders of magnitude change just by changing delta little bit here and there. So, this could be delta about point four this could be minus 0.4. So, you change the delta here and there above this boundary. And you have massive change in the conductivity of the material and this is essentially because of you have F e 2 plus 2 F e 3 plus conversion here and here you have F e 3 plus 2 F e 2 plus conversion here.

So, here you have. So, in this case it becomes you know your p type and here it becomes n type and of course, oxygen vacancies also play an important role. So, here you give rise to what is called as hole and here you give rise to what is called as electron and they change the conductivity of these material of course, you have computing factors like nickel two plus two nickel three plus. And you have oxygen vacancy playing its role as well. So, combination of these effects give rise to a large change in the resistivity of this material and this is an important point to note for these materials.

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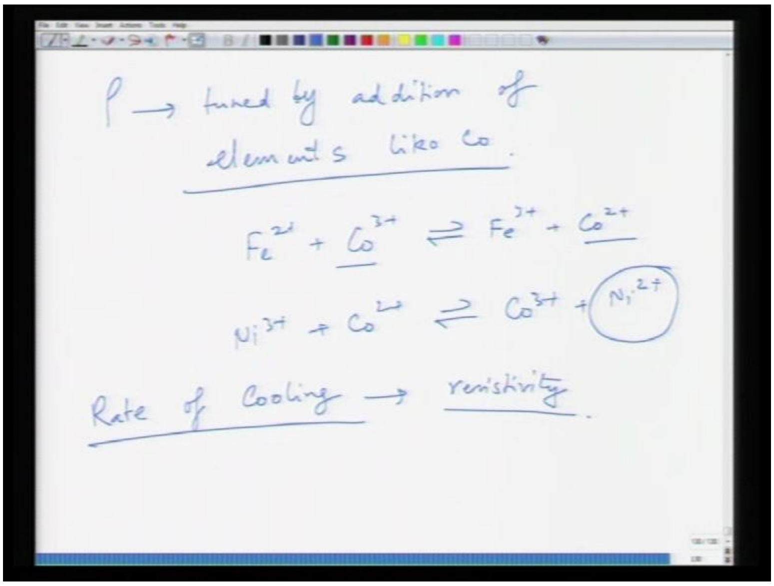

You can also the change the resistivity by addition of certain other atoms. So, so rho can be tuned by addition of elements like by cobalt. And this cobalt is something which maintains the iron in F e 3 plus state because this F e 2 plus c o 3 plus reaction gives rise to F e 3 plus plus c o 2 plus. So, cobalt convert itself from c o 3 plus to two plus and maintains the F e 3 plus F e 3 plus in 3 plus state. So, basically any F e 2 plus which was in the material will convert back to F e 3 plus. Similarly presence of N i 3 plus is also discouraged because of cobalt. So, N i 3 plus plus c o 2 plus will be c o 3 plus plus N i 2 plus.

So, So, this is. So, N i prefers in the presence of cobalt N. I prefer to be in the state of two plus another and iron prefer iron iron 2 plus state is preferred. And these factors increase the resistivity of this material likewise the rate of cooling has an important effect as well on resistivity and again this is something which is quite important because rate of cooling the way.

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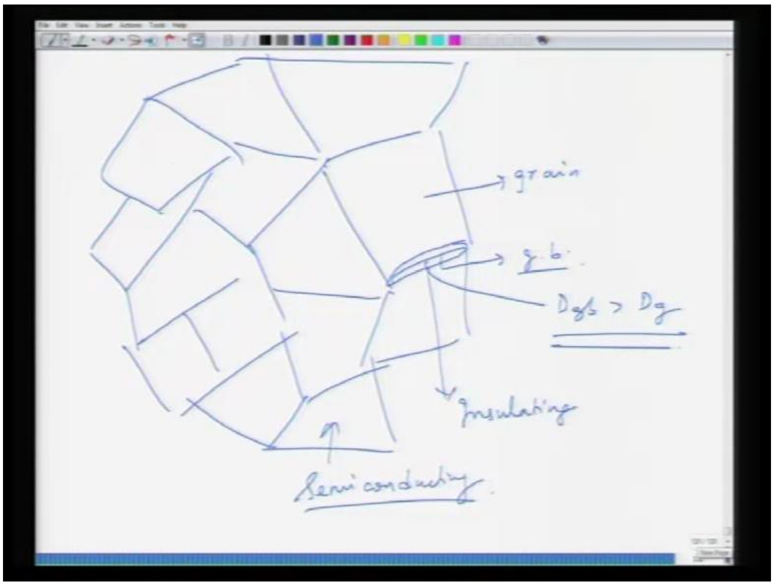

You cool the material the way you process the material. Let us say you have a poly crystalline material of variety of grains. So, now, this is your grain and these this is your grain boundary. Now, if you cool your material in such a manner. So, that your now typically you know that grain boundary diffusion is faster. So, grain boundary diffusivity. So, D g B is higher than D g which is D g is grain. So, as a result the grain boundaries get oxygenated more. So, the way cool them in the atmosphere the grain boundaries get oxygenated more. So, grain boundaries become insulating and the grains become semiconducting. And this gives rise to a behavior in which you have different regions of grain being semiconducting and different regions of grain being insulating. And this can be represented in the form of an electrical circuit which can be understood and then you can study various electrical parameters.

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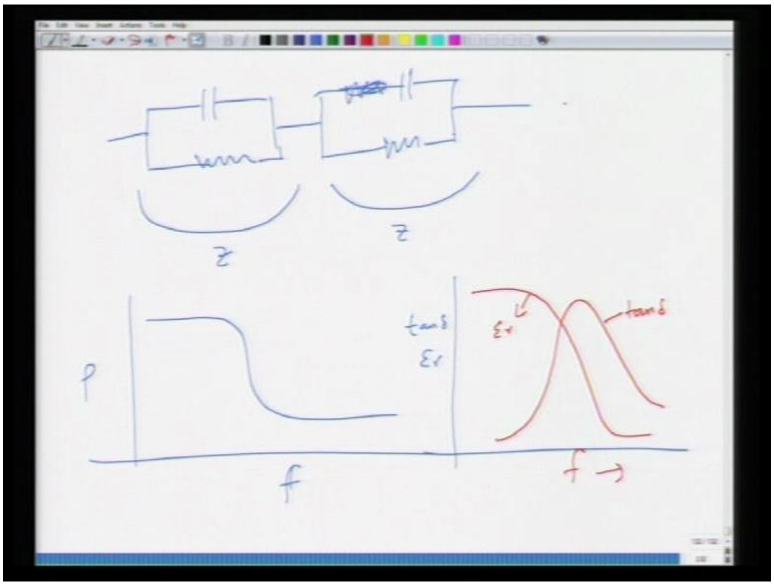

So, for instance hang on next slide. So, here since the grain and grain boundaries are different you can treat them as if they are shunted capacitors connected in series oops just like we saw in dielectrics. So, this will have its own impedance this will have its own impedance. So, when you. So, you have dependence of resistivity on frequency as well and when you plot the resistivity. It goes through some sort of frequency dependence and also you can you can note down the similar effect in the form of when you plot tan delta as well tan delta as well as the relative permittivity. So, the permittivity well let’s say goes like this and tan delta will go like this. So, so this can be basically modeled and various contributions can be extracted by doing proper analysis of this electric circuit.

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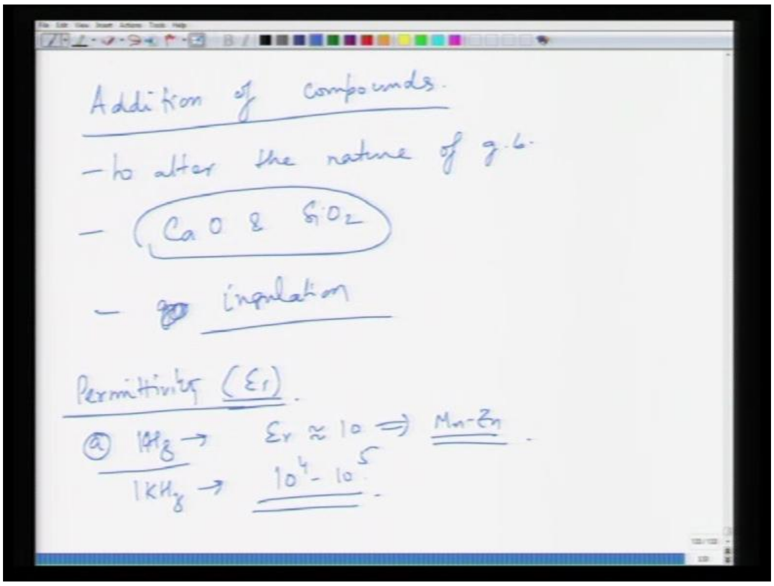

Finally from the point of relevant resistivity, you can also do you can also do addition of compounds and this addition of compounds essentially to promote essentially to alter the nature of to alter the nature of grain boundaries. And so, if you add compounds like calcium oxide and silica these can calcium oxide in silica preferentially deposit at the grain boundaries. And what they do is that this silicon and calcium substitution in the ferrite lattice leads in the regions which are in the vicinity in the grain boundary. This leads to regions in the vicinity of. So, increases the insulation of the regions which are in the vicinity of the grain boundary. So, it increases the overall resistivity of the material. So this is what essentially is about the properties of soft ferrites which are of interest. Another property which could be of important is permittivity epsilon r.

Now, typically at around one giga hertz the permittivity is about 10 for manganese zinc ferrites. But it can become very high if you go if you decrease the frequency to one kilo hertz. This can reach of the values of 10 to power 4 to 10 to the power of 5 and these are very high values. And this is essentially caused by this insulating grain boundaries in these materials. So, again the properties of certain properties of frequency dependence certain properties are impurity dependent certain properties are dependent upon the processing. So, it is a it is a very complicated game. So, the processing of these materials plays an extremely important role processing and compositional tuning of these materials plays an extremely important role to Taylor. The property of these material these materials, according to your applications.

And now what we will do is that we will look at some of the key properties of hard ferrites and in the context of hard ferrites.

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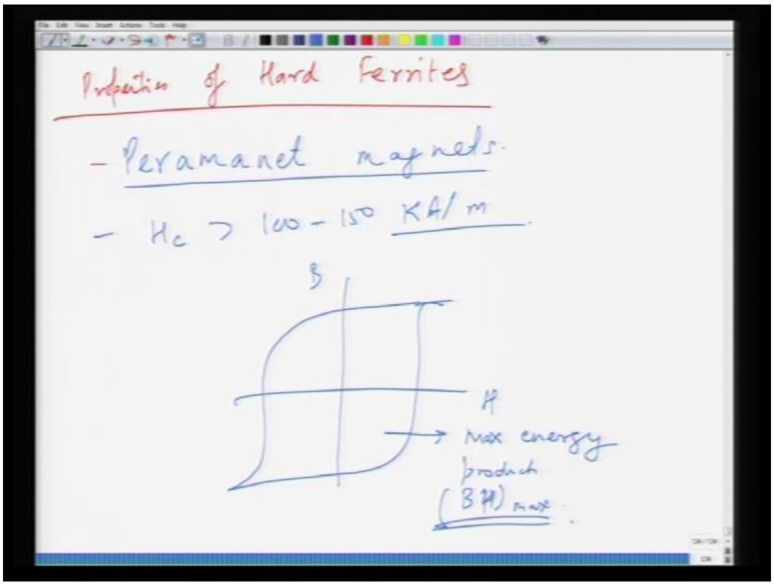

So, in the context of hard ferrites essentially when we talk about it is basically these are you know permanent magnetic materials. So, which means they need to have large coercivity. So, coercivity of these materials they call they are called hard because coercivity is typically higher than 100 to 150 kilo ampere per per meter. And this is very high as compared to your soft counter parts. And the one of the most important use is permanent magnets. They are also used in memories where you do not want the states to be reversed. You want the material to remain the magnetized until you do something deliberately. And for that you need to apply the very large field of course, and for these materials as we discussed earlier. They have a large if you draw the B H curve the area under the hysteresis is very large. And they are characterized by what is called as maximum energy product.

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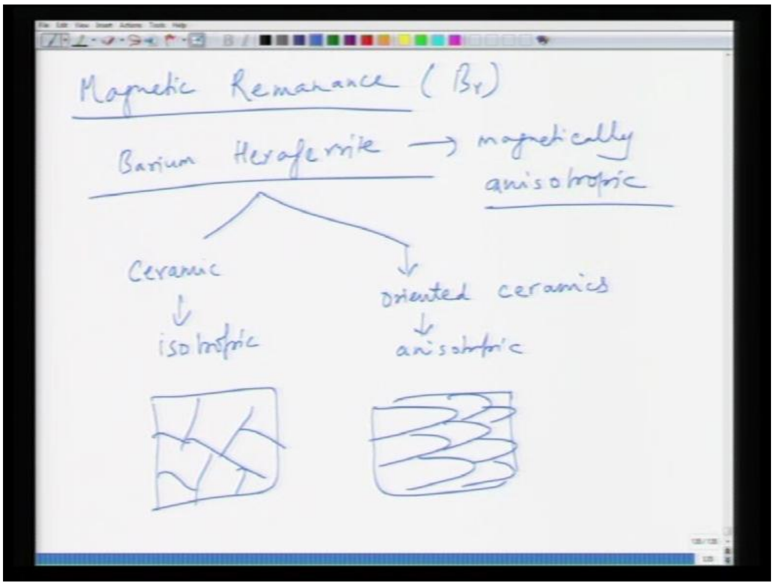

So, basically B H max should be as high as possible. The important properties of these materials the hard ferrites are things like magnetic remanence and magnetic remanence are is essentially a property which is again very important property. So, you can say B r and this is again a function of parameters like processing the composition etc of these materials magnetic remanence can of course be changed by things like. So, if you take barium hexaferrite; now if you take if you take this material to be now. There are various forms. You can make this ceramic. Now, this is magnetic anisotropic material magnetically anisotropic. So, your c axis it has magnetization along c axis, large magnetization along c axis. So, but; however, if it is in the ceramic form then the ceramic form it tends to be more isotropic because the grains are randomly oriented; so, as a result ceramic tends to be isotropic, but if you if you make it at the form of, if you make it such a way. So, that oriented you get oriented grains. So, which leads to formation of oriented ceramics this gives rise to you know more anisotropic nature.

So, you can have you know one scenario is like this you have grains like. So, you can have orientation of grains random and in the second case you can have grain structure like this and this can be achieved by proper processing.

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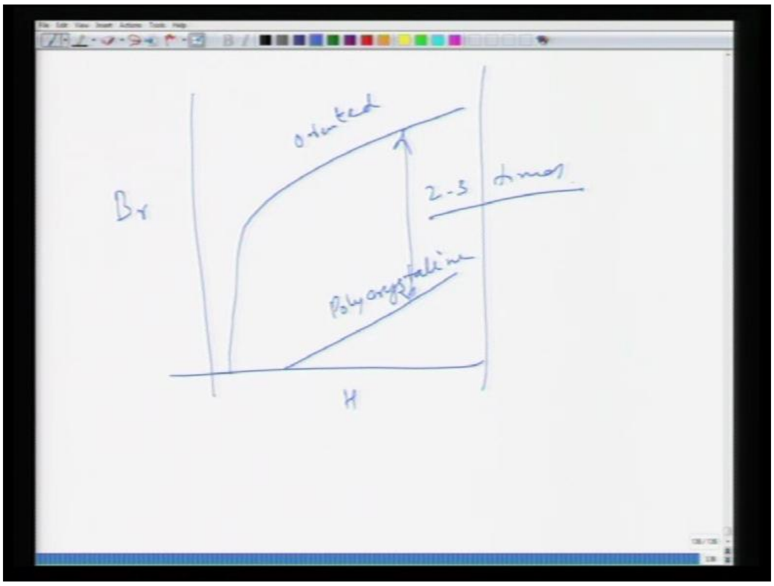

So, for instance if you look if you plot the magnetic induction B r versus H. So, for a for a for a polycrystalline the behavior would be something like this and for oriented barium hex ferrite would be like this. And this would be at least three or two times change in the in the in the properties.

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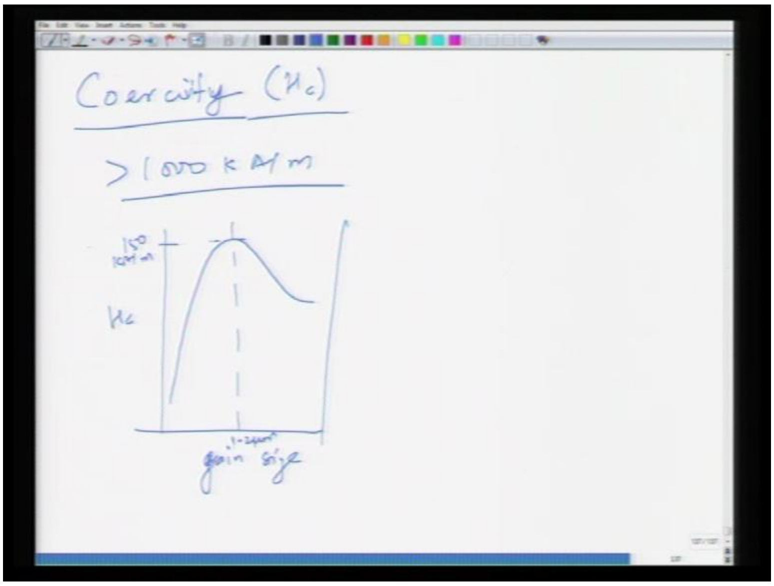

Then of course another parameter is coercivity which is H c. This H c essentially H c theoretically if you make it really well then it could exceed even a 1000 kilo ampere per meter. However, for practical materials it is a it is a in the low values and this coercivity is a function of a strong function of grain size.

So, when you when you plot it as a function of grain size. So, So, this varies somewhere something like this and this achieve achieves a maxima near about one to two micron. And this gives you values of the order of hundred and 50 kilo ampere per meter 130 to 150. And the reason it shows maxima is because there is a close interaction of the domain size with the grain size. So, the computation between domain size; the domain size, domain contributions and the grain contributions they reach a maxima at around one to two microns particle size in the in these materials. And so, these are the some of the important properties of soft ferrite hard ferrite materials. I will I will list some of the properties in a table. So, for a instance if you look at now soft materials first.

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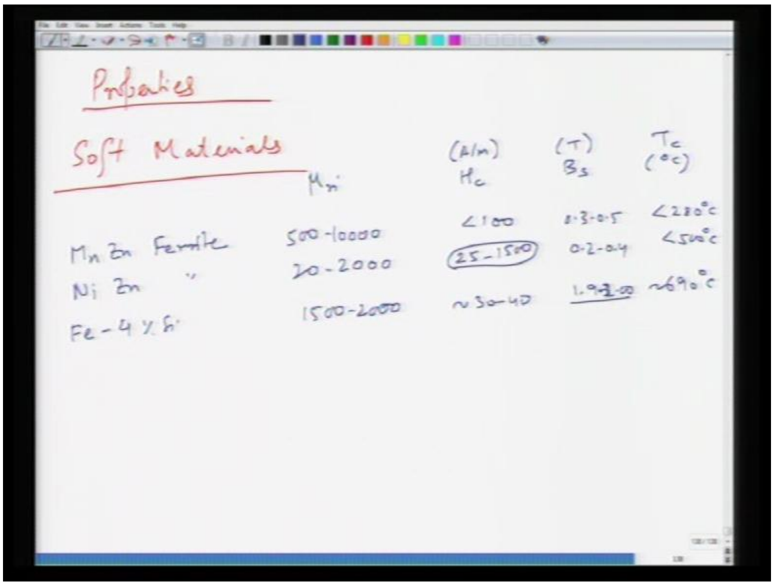

So, let us say we take example of manganese zinc ferrite and we take nickel zinc ferrite and we compare this with something like you know F e silicon four percent silicon alloy. And so, for such materials the permeability of these materials is of importance. So, for manganese zinc ferrite it could be anywhere between 500 to 10000 for nickel zinc. It could be anywhere between you know 20 to 1000 or 50 to 2000. And for iron silicon it could be somewhere around 1500 to 2000 and the value of H c which is in ampere per meter. It could be for iron silicon roughly about 30 205 30 for nickel zinc. It could be anywhere between oh sorry iron silicon would be about 30 40 here.

And manganese zinc could be anywhere any where below hundred. And for nickel zinc it would be it is rather higher. So, it would be somewhere like 25 to you know 1500. These are not sacroscant values, but somewhere around these and this is closed function of you know doping and processing and etc. And if you look at the B s value which is in tesla B s value for iron manganese zinc ferrite would be somewhere around 0.3 to 0.5. For manganese zinc it would somewhere around 0.2 to 0.4 and for iron 4 percent silicon it would be around 1.9 to two. And t c of these temperatures in degree centigrade would be and it is less than two 80 degree centigrade. For manganese zinc ferrite less than 500 centigrade, for nickel zinc ferrite and around 690 degree centigrade, for iron silicon and these t c’s will again depend upon the temperature composition and of these materials.

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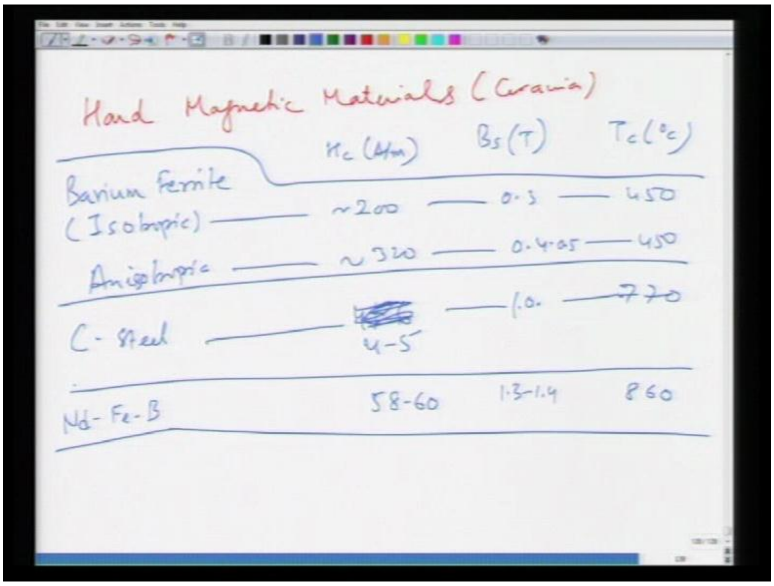

So, this is about soft magnetic materials, if we talk about hard magnetic materials or basically ceramics essentially. And then we talk about you know a barium ferrite typically barium ferrite. So, in first case we take isotropic and then we take anisotropic. And compare with something like you know carbon steel. So, isotropic the values we can compare are of the H h c which is ampere per meter B s which is in tesla and t c which is in degree centigrade. So, we are talking of the parameters which are of interest to these materials. So, isotropic barium ferrite shows a H c of about 200 approximately B s of roughly 0.3 and T c of about 450 anisotropic shows value of about three twenty. And this of about 0.4 to 0.5 and this is would be roughly this is would be 450 similar and carbon steel you will have about 1.6 very low. Oh sorry about 4 to hang on 4 to 5. So, 4 to 5 and this would be a roughly one and this is would be 700 and 70.

So, you can compare the properties of hard magnetic ceramics like barium ferrite with respect to something a ferromagnetic alloy which is carbon and steel. You can also look at some neodymium based magnets like n d iron and boron. These are also permanent magnets. So, here the values are 58 to 60 and this would be about 1.3 to 1.4. And this would be about 160. So this is the comparison between these properties. But you can see that these properties are significantly different from what you got for soft magnetic materials and the applications of these materials they are used in variety of applications. So, I will I will not go through the details of the applications. Rather I will just least to the applications which you can go through and in any standard book.

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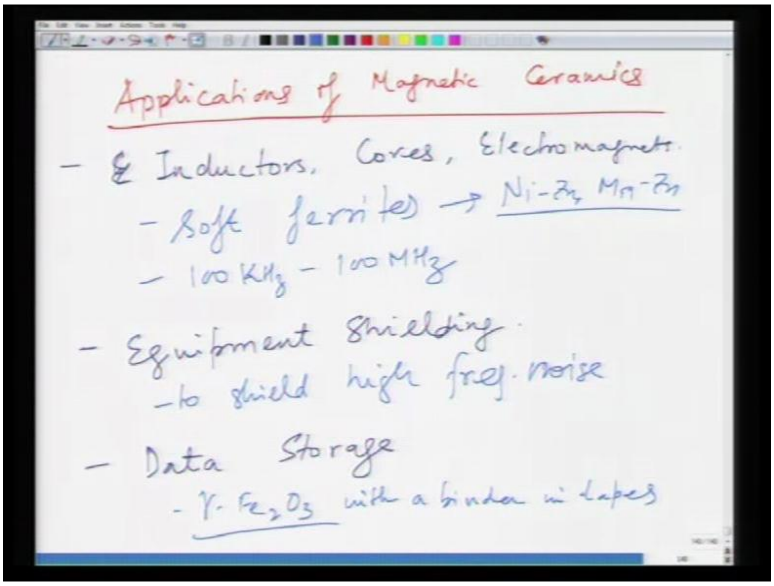

So, the applications of these magnetic ceramics; now, they are used in as is aid they are used in your as inductors cores in transformers etc and electromagnets. And here basically you use soft basically you use soft ferrites like nickel, zinc and manganese. Zinc ferrites and the frequency ranges are about 100 to 100 kilo hertz to hundred mega hertz. These are the frequency ranges and essentially they have high electrical resistivity, which result in low eddy current loses. And they are and they are also used in you know power transformers etc. They are also used for a electrics equipment shielding and this is essentially because of they are high impedance at high frequency currents. So, these basically, prevents the high frequency shield the high to shield high frequency noise.

Ah another application which is important for these is data storage and in case of data storage essentially you have you use gamma iron oxide. So, you use the elongated particles of these gamma iron oxide in a non magnetic binder. And basically it is like a composite alloy. And these have these essentially the size is such that. So, that its each particle acts as a single domain and this single domain has there major axis in the plane of the tape. So, this shows quite large magnetization and coercive field in this form can be as high as about 100 to 200 kilo ampere per meter. So, used. So, gamma iron oxide with the binder in the in the in the magnetic discs magnetic tapes essentially.

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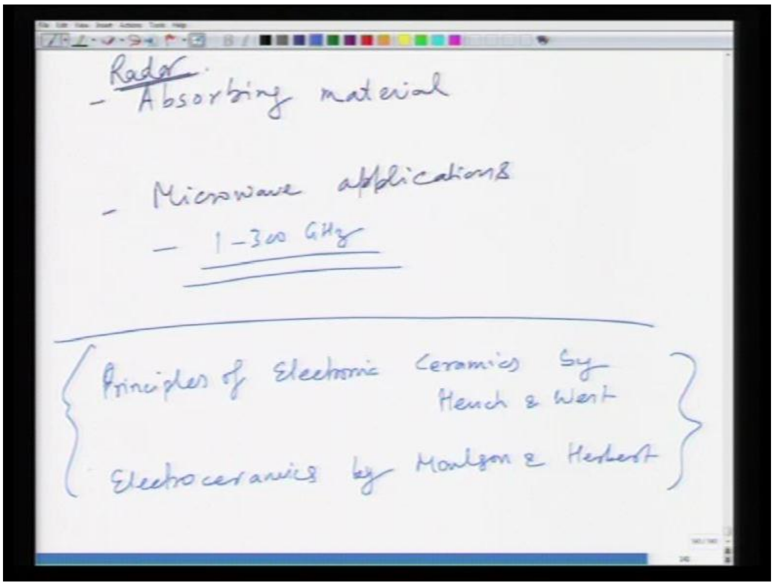

And last, but not the least another application which is which is important for these materials. They are used as absorbing materials. So, you can say radar absorbing materials. So, they can be used as coatings or on top of equipments to use the to absorb the radar signal. And they are also used for microwave applications, because of their usefulness in the frequency range from 1 to 300 giga hertz which is a few centimeter to a meter. So, and here you use things like magnesium ferrites and garnets etcetera. Lithium doped ferrites for these applications.

So, this is where we close this module. So, in this module what we learnt is essentially the basics of magnetism. We looked at the atomic level of reasons for magnetism which essentially arises from your orbital and spring magnetic moment ignoring the nuclear magnetic moment. And the sum of these two is responsible for the overall magnetism in the material. There are four kinds of various magnetisms you have diamagnetism which is essentially because of negative magnetization because of faraday's law. And essentially the magnetization induced or magnetic moment induced is opposes the applied field. And this is an effect which is present in all the materials. So, essentially all the materials are diamagnetic it is just that paramagnetic ferromagnetic ferri and anti ferromagnetic have extra additions which over shadow the diamagnetic additions.

So, for diamagnetic addition materials you have susceptibility which is negative for purely diamagnetic. But for other materials susceptibility is positive and depending upon the magnitude of susceptibility. You define them in the category of paramagnet ferromagnet ferrimagnet anti Ferro magnet. And then even in these you have different categories paramagnetic materials are materials where you have atoms with permanent magnetic moment which are randomly oriented with respect to each other because of thermal forces. However, in the ferromagnetic materials and ferrimagnetic ferromagnetic ferromagnetic and anti ferromagnetic you have a spontaneous alignment of spins in the regions called as domains with respect to each other. The parallel alignment because of exchange interaction gives rise to ferromagnetism and anti parallel alignment gives rise to anti Ferro or ferrimagnetism. And from the application point of view what is important is the ferromagnetic and ferrimagnetic materials because they have remnant magnetization and coercivity. And depending upon the area of this B H curve or M H curve you can define them into you can define them into soft and hard materials.

And then we discussed the various properties which are of interest in in variety of applications. The important thing to the important thing which this differentiate these different materials and different defects is a susceptibility and magnetization. And the way they vary with temperature in case of paramagnetic materials you have a curie be like behavior. So, it decreases in diamagnetic materials of course, you do not have a temperature dependence in paramagnetic material. The susceptibility essentially decreases to 0 at temperature T c, which is curie temperature in ferromagnets. The magnetization drops to 0 at T c and susceptibility also drops to 0 at T c. But inverse susceptibility drops to t c temperature t c. But the behavior is slightly different near t c because you have this curie. We saw coming to picture. So, you have slight deviation of magnetization at T c and then it slowly dives off to at theta. And then you have of course, have ant ferromagnetic materials which have neel transition and above neel transition. They are paramagnetic and below née transition they are ant ferromagnetic. So, this is sort of summary of this module this will be.

So, I have subscribed some books for you can read books by. So, principles of electronic ceramics by Hench and west and then electro ceramics by Moulson and Herbert, both are wiely publications. So, these two books will provide a good overview will provide you a good over view about the fundamental understanding and the applications of these magnetic ceramics. So, this module stops here. In the next module we will start our discussion on some exotic kind of materials; electro ceramics which are super conducting materials as well as followed by multiferroic or magneto electric materials. And then finally, we will look at how these materials can be made. So, that is the end of this module.

Thank you.