Advanced Ceramics for Strategic Applications
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Lecture - 25
Superconductivity

In this lecture we continue our discussion on superconductivity. In an earlier lecture, we have already discussed various aspects of superconductivity. Its definition, the different parameters like the critical current density, the critical temperature, the critical magnetic field and so on. We have also discussed the 2 varieties of superconductors; one is called the type 1 and this type 2 superconductors.

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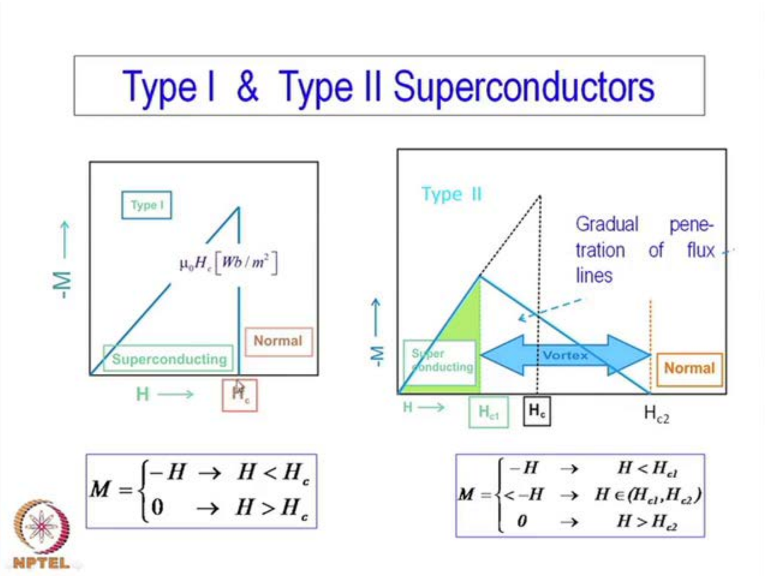

$$M = \begin{cases} -H \rightarrow H < H_c \\ 0 \rightarrow H > H_c \end{cases}$$

$$M = \begin{cases} -H & \rightarrow & H < H_{c1} \\ <-H & \rightarrow & H \in (H_{c1}, H_{c2}) \\ 0 & \rightarrow & H > H_{c2} \end{cases}$$

Let me try to repeat few of the things which we have earlier discussed. These are the 2 diagrams we discussed last time. This is the type one superconductor the characteristics of the type one superconductors. So, for as the magnetization versus magnetic field is concerned there is an abrupt change of magnetization and superconductivity is lost at a particular value of magnetic field, which is known as the H c. Whereas, in type 2 superconductors, this diagram has been corrected now. This is this was earlier written as type 1, but actually type 2 superconductors and there will be H c 2.

So, we have 2 different critical field strengths; one is H c 1, another is H c 2. So, beyond H c 1 there is no abrupt change in characteristics of the material. It does not change certainly or immediately to a normal state of material from superconducting state instead there is a gradually change. So, you have a dual kind of dual phase which is known as the vortex region.

So, slowly from in a super containing state there is no flux penetration. Whereas, a normal state there is complete flux penetration whereas, in the vortex phase at the vortex there is limited amount of flux penetration. And, as the magnetic field increases more and more flux lines penetrated. And, finally at a level, at a value of H c 2 complete penetrations takes place and the superconductor is converted to a normal material. That means, in no longer superconductor. So, that we have earlier discussed.

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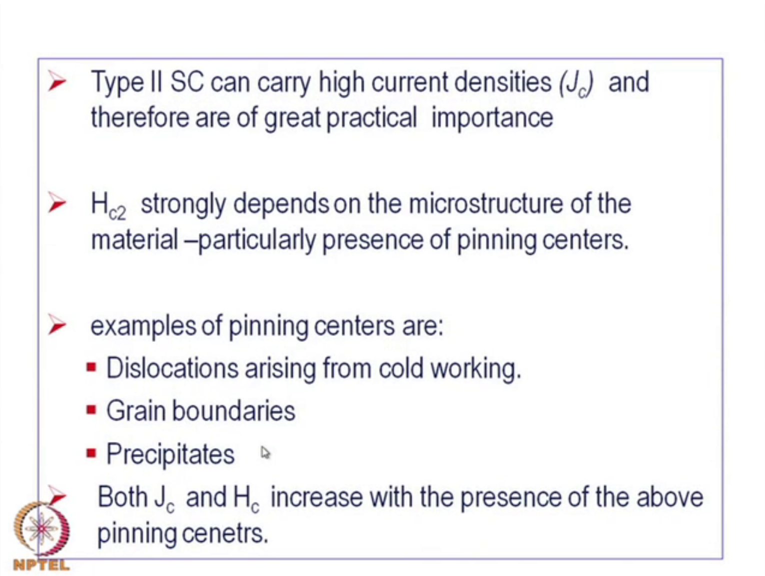

We have also discussed that the type 2 superconductors carry much larger current, the current density; the critical current density is much higher, in case of type 2 superconductors. And, therefore they have a great practical important also there is another advantage of the type 2 superconductors. Since, there is no sudden change from superconducting state to the non superconducting state there is a gradual change. So, there is no catastrophic failure of the material; so for as magnetic field is concerned or the current density is concerned. And, therefore it is more prefer when we are talking about any practical device. H c 2 that is the 2nd or the high field critical magnetic field is strongly depends on the microstructure of the material.

So, it is not the intrinsic property of the material; one can play with it from the way material is prepared and how the material is processed and so on. In particularly, presence of pinning centers if you can some of introduce some pinning centers which actually acts as a barrier to the flux penetration through the material. Then, the value of H c 2 can be extended and the zone of useful of magnetic field enhances. So, you have a better material; so by introducing the different kind of pinning centers one can really increase the H c 2 value. What are the pinning centers? This also is briefly discussed.

There are 3 varieties of pinning centers, one can think up. One is the dislocations so dislocations, as we have discussed previously in connection with the defect structure of the material these are crystalline defects. So, all crystalline materials are supposed to have some dislocations. And, dislocations have basic defects which can which can control the plastic property, mechanical deformation, plastic mechanical deformation of any material. Both elements or in metals or inter metallics, they have a certain amount of elastic deformation beyond the elastic limit. In fact, in case of metals it is much more whereas, inter metallic compounds will little harder. And, however even then one can cold work it.

Cold work is nothing but it is metallurgical term basically. It is basically deformation, plastic allow material to deform plastically under high pressure. So, by deforming you can introduce dislocations and as you deform more and more, more dislocations you gets generated. So, the dislocation is become difficult for the lines of magnetically lines of force or flux lines to penetrate through this dislocation barrier. So, that acts as a pinning centre. Then, you have another kind of defects in a crystal. Particularly, in poly crystal material it may not be there in the single crystal but in poly crystal material, it is certain invariable will be there. So, it is the junction between or the boundary between 2 neighboring crystals and that is a 2-dimensional boundary.

So, these boundaries also act pinning centers. So, it becomes difficult for the flux lines to penetrate through the boundaries. Therefore, if you have more and more grain boundaries the penetration is difficult. So, H c 2 value can be extended further. In addition if you have if one have precipitates. Precipitates (( )) within the that means a second phase within the matrix of the primary phase. So, there are this precipitates some isolated particles, fine particles. And, depending on the particles density depending on the inter particular spacing once again, one can abstract the penetration of the flux line.

So, all these defects, all these irregularities when the crystal crystalline when the crystalline material can act as a pinning centers. So, in most cases it has been taking help of in practical application or practical devices; whatever once to make out of these semi conduction super conduction materials.

Both J c and H c, J c is the critical current density above which again a super conduction material changes to non super conduction states. And, that of course relates to the magnetic field. So, J c is different for different at different magnetic fields. Similarly, H c is the pre at different current densities. So, that H c can increase with presence of the above pinning centers. So, once again it is processing which is very important, so far as the property at concerned.

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Nb – 40%Ti alloy, T_c = 4.2 K,
Magnetic field strength = 0.9 H_{c2}

Microsctructure	J_c (A / m^2)
Recrystallized	10^5
Cold worked and recovery annealed	10^7
Cold worked and precipitation hardened	10^8

We take one example, one particular example of a once again a low temperature superconductor. It is Nb 40 percent titanium alloy with a Tc of 4.2 k. Now, magnetic field strength we have taken for this current and density measurement, their about 0.9 of H c 2. So, slightly lower about 10 percent lower than the H c 2 value; that is the highest value up to which one can expect superconductivity. So, if it is a re-crystallized material, re-crystallized means? Once again a metallurgical term re-crystallized means, a material has been cold worked. That means, a given a lot of mechanical deformation a significant amount of plastic deformation have take it as already taken place. So, plastic deformation means increasing the dislocation density.

So, a cold worked material as always has a higher dislocation density, but re-crystallized means these dislocation densities can be reduced or can be annealed out. If the temperature is raised above it is re-crystallized and temperature. So, with increasing temperature more and more energy is given to the system. And, therefore it is easier for the dislocations to move across or move out of the crystals. So, by that process by the crystallization actually one reduces the dislocation density. So, there are 3 kinds of situations, 3 extends of different dislocation and density re-crystallized material has a lowest dislocation density. Whereas, cold work next one the cold worked and recovery annealed it is also annealed.

So, this is a lowest dislocation density is a next lowest and this is the highest. So, cold work and precipitation hardened, cold worked increases the dislocation density and precipitation hardened also. In addition, one is introduced a certain precipitates both together. This particular condition the material has the largest amount of pinning centers large number pinning centre. And, this is relatively low density of pinning centers and this is the list among the 3. And, accordingly one can expect the highest current density is here about 10 to the power 8 per meter square and then this is slightly lower one order of magnitude lower 10 to the power of 7, and this is much lower 10 to the power of 5.

So, just by changing the microstructure increasing or decreasing the dislocation density; one can vary the current density almost of 3 orders of magnitude. This is quite interesting. In addition to the intrinsic property of the material one can actually modify the property of large extend; just by changing the dislocation density or the density of the precipitates. So, this is a very interesting and observation this is very interesting phenomena. So, for as the low temperature superconductors are concerned.

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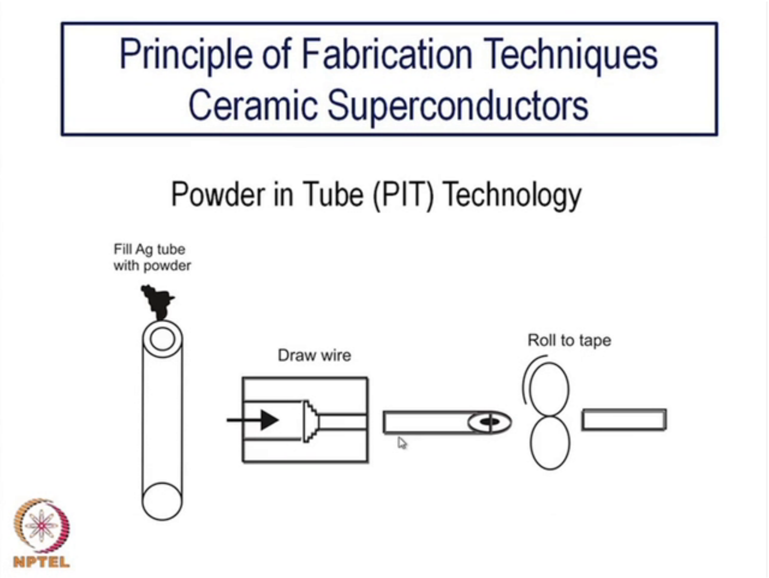

Next, we like to see how the superconductors are fabricated. Normally, since a basically current carrying device one like to have some materials of the superconductors in the form of wires in case of metallic materials or inter metallic materials. So, called low-temperature superconductors. All metallurgical processes are used whether it is melting casting then followed by rolling or wet drawing and so on. So, all the metallurgical technique are basically used although there is a variation in the plasticity or the brittleness of the material at the elemental form are much softer material. Whereas, the inter metallic compound which we have discussed earlier are much brittle material or harder material. Even then one can use the conventional metallurgical techniques to do or to make the wet drawing and so on. So, I am not discussing that to large extent here.

On the other hand, let me concentrate on the other fabrication technique which is little bit different than the normal metallurgical fabrication techniques. This is for the ceramics superconductors that is which are known to be brittle materials and ceramic synthesis a ceramic not only synthesis, but also the fabrication techniques are quite different from the metallurgical techniques. Now, ceramic powders are synthesized by different techniques there is normal powder synthesis techniques can be applied. Because it is basically starts with different kind of cations and then get them oxidized. So, it can be a it can be a soft chemistry root.

It can be powder synthesis techniques solids states synthesis technique like if you are talking about yttrium barium copper oxide. We can take yttrium oxide, barium oxide, copper oxide put them together. All of them are powders mix them together and heat at high-temperature normally in a controlled atmospheric condition. So, that is the powder preparation technique one can also use sol gel technique, co-precipitation techniques and combustion techniques and so on to make the powders. So, these are basically available in the powder form synthesized with right kind of composition, chemical composition and of course on the stoichiometric. Stoichiometry is very well important in case of ceramic superconductors because almost all of them have certain amount of oxygen deficiency and, that oxygen deficiency as to be controlled very accurately.

So, that you get the right kind of property. So, centering under control condition with a right kind of oxygen partial pressure is very important. So, you can get different powders, but that is not the end of the story. The powders have to be fabricated in the form (( )). So, ceramic (( )) application is almost impossible is not that easy. So, what you technique is used is called powder in tube powder in tube technology or in sort PIT. We take advantage of the flexibility or the plasticity of a particular metal in this case the silver. Sliver is quite chemically, quite compatible with most of the cuprite materials and at the same time it has a right kind of softness as well as plasticity.

So, instead of mixing instead of mixing silver and powders together which may not have the right the desired property? Instead of that normally what one does is to take a silver tube a close end one end close silver tube. And, in that you fill the hollow part or inside of the tube is filled up with ceramic powders of the right composition and the right stoichiometric. So, that is compacted as much as possible. And, then that silver tube or powder silver filled up silver tube filled up with the powder is actually wet drawn. Either it can be wet drawn or it can be rolled.

So, it can be rolled to make strips and it can be wet drawn to make wets. So, both the possibilities exist. So, that you have a layer of silver outside. And, inside is filled up with this ceramic superconductors or ceramic powders. After the rolling or wet drawing one has to do a heat treatment; so that the powders inside gets entered and you have a continuity in the powders. So, with that kind of technique or powder in tube technique is quite useful one making silver filled up with or silver where filled up with ceramic powders. So, that the normal structure that structure of course, is not shown here.

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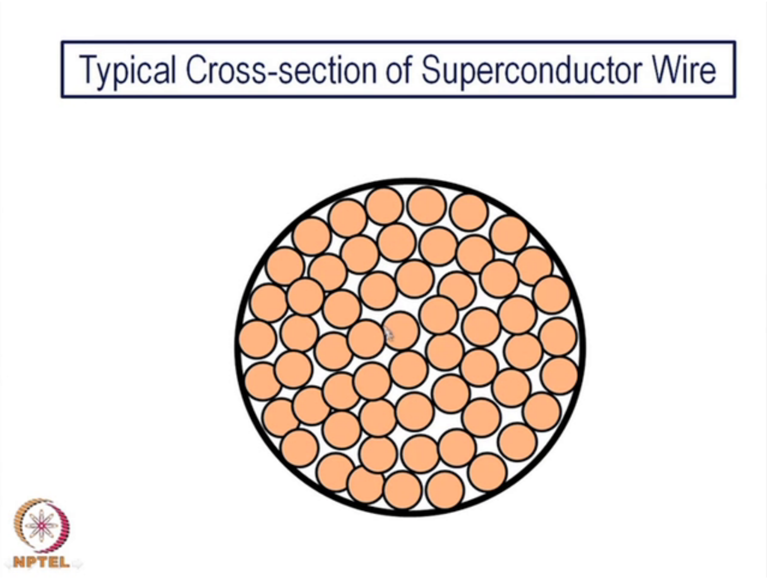

But I have shown, but I am showing you another structure. This is some kind of a cross-section not the particular single wires impact. This is a configuration of a cable one can see one can say cable these are all the cross-section of single wires. And, so there is a large number of put together and form a cable much for larger diameter. Of course these particular figures have shown not only for the ceramic superconductors. But these kinds of cross-section are also designed for low temperature superconductor or metallic or inter metallic superconductors which are normally used for lower temperature.

There are some white spaces, white regions and the darker regions or the colored regions basically a single wires. These have been filled up in fact in the there have been put in the matrix of copper, metallic copper. So, all the super conductor the superconductor cables which are normally fabricated or actually embed single stand wires single stand wires are actually embedded in a matrix of copper. Now, copper of course is not a super conductor, but it is a very good thermal conductivity. So, this kind of system is used. So, that one can avoid thermal (( )) at very high temperatures, very high current densities. So, current density of this are extremely high.

So, as you can see in the last slide about 10 to the power of 5, 10 to the power of 8 amps per square centimeter a square meter which is a very high value. And, therefore, such high values of current when it is flowing through a cable. If there is a defect in the cable or a particular wire strength there is possibility of heating up. So, if that kind of situation happens in a locally the material were transformed from superconducting state to a non-superconducting state normal state. So, naturally they are will develop lot of resistance and at that particular point there will be very very high hotspots. So, if such hotspots develop it is necessary to remove the heat very quickly from that particular zone. And, copper being a high thermal conductivity material helps a in dissipating the heat from the local region and that is how saves the cable.

So, all the even low-temperature superconducting wire stands are actually embedded inside a metal like copper. So, if you are talking about a silver cladded silver cladded super ceramic superconductor; silver also acts as a in the same manner. Silver provides that of a thermal conduction which avoids any hotspots or thermal (( )). So, this may all however however the copper is not right material in case of ceramic superconductors, it is good.

So, for is the inter metallic or the elemental superconductor are concerned, but in case of ceramic superconductor copper is not used for obvious reason. So, because copper is one of the elements present in the ceramic superconductor itself. So, the stoichiometry may get changed or there will be reaction between the metallic copper and the cuprit superconductors. So, to avoid that copper is not used, but the more compatible metal silver is used. Silver of course it quite costly than copper, but there is no other alternative.

So, if that is one of the disadvantages one can say, but it is in not very costly. It is affordable in some application area; it is certainly fair accordingly. So, a metal all superconductors either in the powder form or in the or in the (( )) farm their embedded in a metallic matrix to avoid local the hotspot generation. So, that is why I have shown this particular picture of a typical cable cross-section of a cable; whether it is low-temperature superconductor or a high-temperature superconductor.

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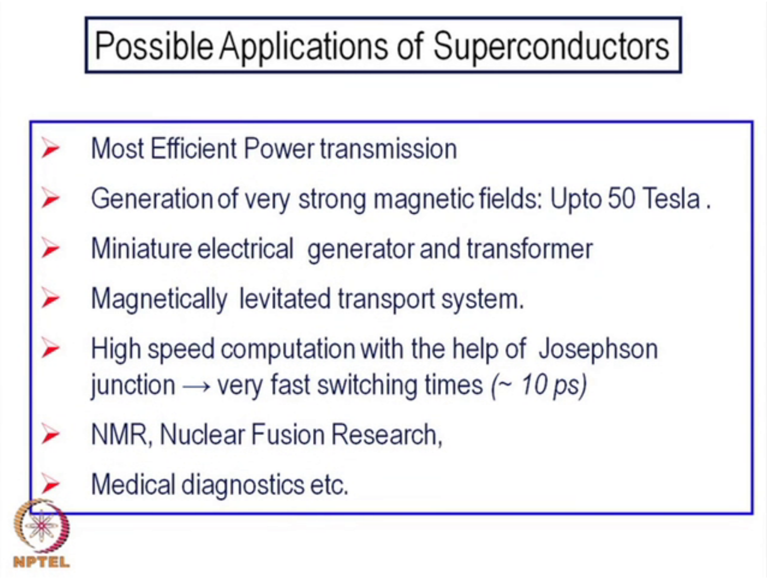

Well, then we come to the most important of the most important parts of the discussion is what are the different application of superconductors. We have understood that the superconductor cables are the superconductor material can be carry very large currents. And, of course it can also generate a high magnetic field. So, the 2 most important application of superconducting material is most efficient power transmission. That means, if you are talking about the electrical cables.

One can really make miniaturized cables are very small dimensional, small cross-section cables to transmit huge amount of power. In fact a particular cable of normal dimension can carry almost one mega watt of power if necessary. So, this is one area where efficient power transmission can be done. However, it is not still not economic because one as to understand the superconductivity, the property of the superconductivity is available only at very low temperature. So, you need cryogenics systems. As I forward to mention one point is most of the low temperature superconductors the cryogenics is liquid helium. You need liquid helium to cool these materials were these materials comes superconductors; the boiling point of liquid helium is about 4.2 Kelvin.

Whereas, the boiling point of liquid nitrogen which is much cheaper or else magnitude cheaper that is around 77 k. So, that was one of the driving force for you know improving or increasing the ceramic superconductor critical conduction of ceramic for superconductors. So, all the low temperature superconductors if you one to use low temperature superconductors we need a cryogenic system where liquid helium have to fading into the system. So, without liquid helium one cannot get a superconductivity of the low-temperature of superconductors.

Whereas, for high-temperature superconductors is possible to use liquid nitrogen which is much cheaper. And, that was one of the driving force for increasing temperature. Of course the ideal is if a one can get superconductors at room temperature. So, there is no question of any refrigerant needed to operate the system. So, there is still a lot of advantage if one can make use of liquid nitrite at least as a refrigerant. So, the systems cables have already been designed and in experimental cables are in use for transmission of very large power from one point to the other. Of course there is a inbuilt refrigerators in system. Then, of course the second more important application is generation of very strong magnetic field. Well, we have electromagnets; normally the magnets are prepared by coils copper coils and some magnetic materials.

And, so, but there is a limitation how much magnetic field one can use. That may not be more than 10 power show. However, if you need very high magnetic fields very high magnetic fields one has to go for superconducting cables and that is called superconducting magnets. So, one can generate magnetic fields up to 50 tesla or nearly more than 50 tesla and that an big advantage. So, in some cases in some cases in fact there is a no other alternative than to use superconducting magnets there are certain applications one can think of. So, one can generate or one can transmit huge amount of power through a cable superconducting cable. And, also using such cables or using some wires one can make a very high magnetic fields, miniature electrical generators and transformers.

So, most of these things in whatever electro magnets electromagnetic devices one can one use that can be miniaturized because you are talking about cables carrying very large currents. So, and also high magnetic fields. So, therefore, whether it is a transformer or a motor or electrical generator a dynamo and so on. So, electrical both the electrical generators and transformers and even electrical systems like motors can be complete miniaturized very very large extent almost 110th of the size one can get using superconducting coils. But once again in suspension there the cost is certainly deurant, it is very deurant in some cases. And, therefore, the applications have to some extently limited. Magnetically levitated transport system well using the meissner effect one of the most interesting application of superconductors is the magnetically levitated trains. It has already been demonstrated in a in a prototype in different parts of the country, particularly advanced advanced can increased like Japan Germany.

So, where magnetically levitated frames. That means, a train or a transport system which is not resting on the on the floor, but are on the real lines. But it is floating because using this magnetic levitation the Meissen effect one can float. One can float in air certain amount of wet because it is a superconducting phase or superconducting materials are perfectly diamagnetic. So, if there is a magnetic lines of force it will repeal each other. So, by that process one can levitated a very strong magnet over a super over a superconducting material. So, it will just float in air. And, therefore, a if you can design a transport system with just with little bit of between the real lines rails. And, the they carriage and it can move very very fast speed at very one can reach a speed of 500 kilometers per hour very easily.

So, but once again one can designs such things technically it is visible, but the cost is secondly prohibitive. So, it is still not been commercialized, but demonstration has already been made. There are other defects or other devices which is which is based on what we called a Josephson junction. The high-speed compression with the help of Josephson junction a very switching time which are very fast switching time can also be designed.

And, applied impact the research is still going on to take advantage of these very high switching speeds of the order 10 picoseconds so on. I talk little bit of Josephson junction in a few moment minutes of in addition to the computer application. There are many other applications where one can use and some of them are already in use. NMR the nuclear magnetic resonance and nuclear fusion research. One nuclear fusion research is very well connected to the high field magnetic, high magnetic fields. Very high magnetic fields are required for nuclear fusion research were actually the plasma has to be contained with any container. And, that is only possible by applying a magnetic field very high order of a magnetic field.

So, whenever you have accelerators nuclear accelerators in a accelerators research you need superconducting magnets of very high magnetic fields. And, therefore, one can use one actually uses superconducting magnets. Medical diagnostics is another area where basically an n m r technique nuclear magnetic resonance technique has been used. It is not only that superconducting materials can be used to make a very high magnetic fields. But also it is used to sense very very feeble magnetic fields extremely feeble, extremely weak magnetic fields and without superconducting devices.

Such magnetic field or a sensing of such magnetic field is just not possible. So, in the area of medical diagnostic it has been very useful technique. And, it is already in use with this is an area where in spite of cost because it is high it is because of almost essentiality or no there is as such there is no other alternative. So, one has by practical application or the commercial application of this is a magnetic diagnostics. Some of them, I will go little bit details let us see what next.

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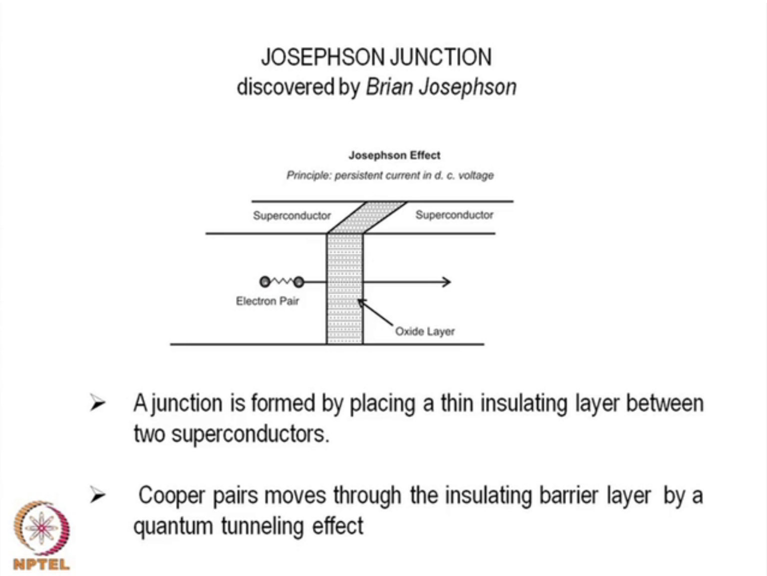

Josephson junction this is a super conduction junction have mentioned that Josephson junction is useful for some of the as a sensor. So, it was discovered of brain Josephson. And, basically it is a it is just like a p-n junction or semiconductor junction. You have 2 semi superconductors separated by a small insulating layer. This is these kind of junctions are very common in semiconductor physics and semiconductor devices. So, here also like SIS devises semiconductor insulator semiconductor devices.

Here, it is also SIS stands for here is superconductor. So, there are 2 different superconductors separated by a insulating layers and the charge or the charge carrier can go through these insulating layer through by a so called tunneling process. So, that is what is what is called Josephson junction. It has many different electronic are very sensitive characteristics, but we will not the discuss most of them. Except, that a junction is to give little more details of that. The junction is formed by placing a thin insulating layer between 2 superconductors; I have already mentioned and well cooper pairs have not introduced.

So, far when you discuss briefly about theory. What are the charge species, which actually carries the current in this case? And, why they do not have any resistance in their in their path will come in a minute? How exactly the behave or what is the basic physics behind the transport phenomena here? The cooper pairs these are actually know as these are actually charge carriers in a superconductor.

So, these cooper pairs moves through a insulating barrier layer by a quantum tunneling effect that is what I was mentioning. So, just like any other tunneling effect superconductors. Here, also you have a tunneling effect particularly when there is insulating layer oppose these insulating layer there is a limit to the thickness. There are primarily in the level of angstroms these are all in the thin film forms not in the bulk condition. So, the sol junction is actually just like microelectronics have thin film technology which can be used for making these kinds of junction.

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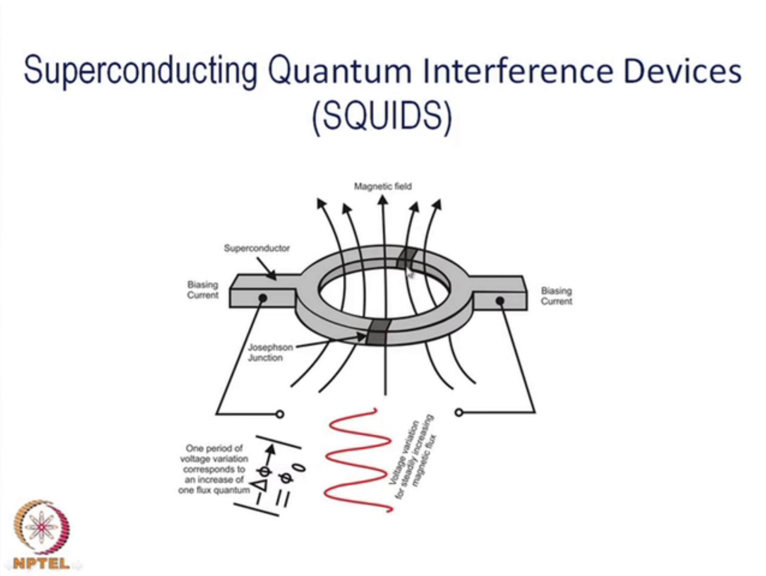

Based on this Josephson junction there is a very important device we has been made and used in factors. That is called squids superconducting quantum interference device. Well from the construction point of view design point of view it is nothing, but a 2 a double Josephson junction like this reforming there is forming heading. These are insulators here; this is one insulating point, this is super Josephson junction, one Josephson junction and another Josephson junction here. These are superconducting wire superconducting materials primarily in the thin film forms and then these another superconductor. So, is a pair of Josephson junction and one can give some biases her one can find out what is the flux density.

So, one period of voltage variation corresponds to one increase of one flux quantum. So, you can control the flux quantum very very precisely and by that process impact. These kind of system the magnetic field that means these number of flux lines can be found out. Depending number of flux lines passing through this ring one can find out certain generation of voltage. And, that voltage is can be generated even with a very very small number of fluxes. And, therefore, this system or this becomes a sensing device over a very feeble very feeble magnetic fields.

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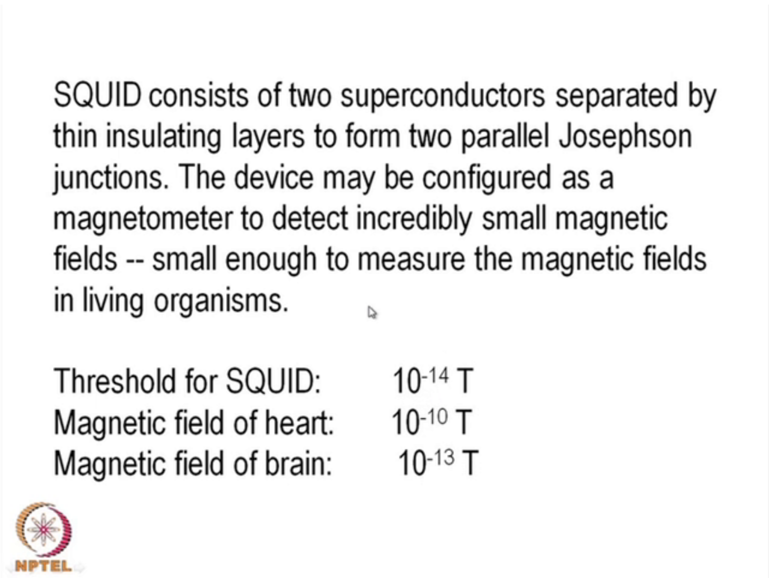

And, this kind of SQUID magnetometers are available. They are not only use for medical diagnostics, but there are also used for other measurement in physics experiments. So, SQUID magnetometers are also available for measuring or the measuring the magnetic characteristics of different materials with very high sensitivity. Now, SQUID consists of 2 superconductors separated by thins insulating layers to form parallel Josephson junction that has been explained from the particular diagram. And, the device may be configured as a magnetometer which basically measures the magnetic strength or magnetic field strength.

To detect incredibly small magnetic fields small enough to measure the magnetic fields in living organisms. Well, in our various organs we have some magnetic fields particularly heart and brain they have some magnetic inbuilt magnetic fields. So, that kind of magnetic field is like this. In our brain the magnetic field is of the order of ten to minus 13 tesla whereas, in heart is about minus 10 tesla. Now, this kind of feeble magnetic field cannot be measured cannot be measured or sense other than this kind of squids based on superconducting materials. And, the resolution power resolution power squid is 10 to the power minus 14 just below that of available in brain.

So, these kind of squid system; squid based NMR or superconducting NMR or Josephson junctions. Such kind of magnetic fields can be generated. And, that kind of magnetic resonance imaging using squids are available on a commercial basis these days obviously or understandable reason there extremely costly. So, this is one very important application of besides high-power and high magnetic field application at a very low magnetic field also.

One can use superconductors to detect that. Well, with this we have already discussed different kind of parameters, different experimental parameters which are used for to characterize superconductors. Some of the application areas and some of the very exotic applications like SQUIDS, and some of the very important applications like magnetic deviated transport systems some of which has not been commercialized.

But the technical possibility exists. And, whenever we have a room temperature superconductor may be some of these things will the light of the day. With the last few slides, I have just mentioned what is the theory, what is the physics behind it? Well, there is not much cooper discuss the total physics, but I will just give you some glances. What exactly the physical principles or physics of the quantum physical theory which can explain the superconducting behavior or the phenomena of superconductivity. So, start with this is called the BCS theory, the Bardeen copper Schrieffer theory more well-known as BCS theory.

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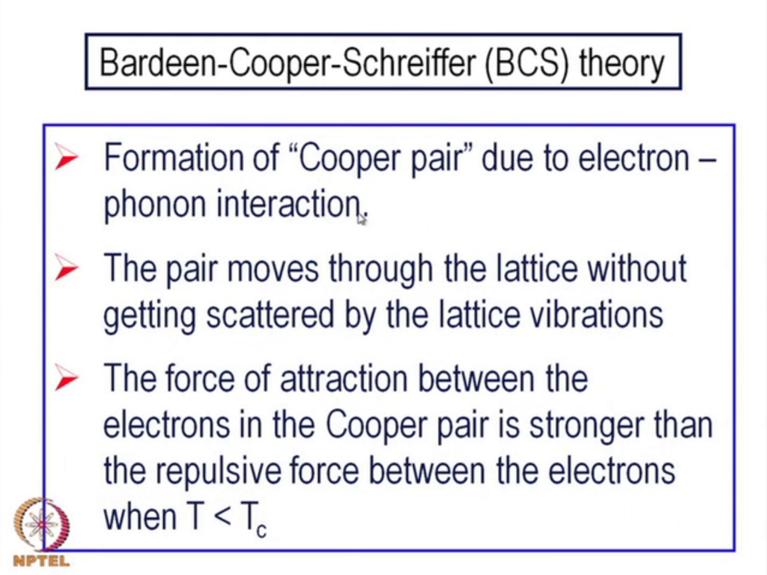

It basically says formation of cooper pair. Earlier I mentioned about this particular term the formation of cooper pair due to electron phonon interaction. So, basically it relates to the free electron and the phonon interaction which leads to a pair formation which is a very unusual situation. But at very low temperature such things can happen a pair forms a cooper pair what we called a cooper pairs 2 electrons comes closer and they are not separated.

So, when the charge carrier is not a single electron, but a pair of electrons; that is usually termed as cooper pair. So, the pairs moves through the lattice without getting scattered by the lattice vibration. Normally, we have seen in any metallic material the electrons, the resistance comes from scattering of the electron from the atomic vibrations or the phonons lattice vibrations. But after the formation of the pair cooper pair they do not get scattered.

So, that the very very simplified form of how to explain the superconductivity under very low temperature conditions. The force of attraction between the electrons and the cooper pair is stronger than the repulsive force; which is obvious between the electrons only. When this happens is strongly temperature dependent. This phenomena is strongly temperature dependent and only below Tc. Such things can happen the pair of electrons pair of electrons instead of instead of having a repulsive interaction. They have a they have a attracting interaction and that is a special case of the electron phonon interaction. And, that is the very simplified form of the BCS theory.

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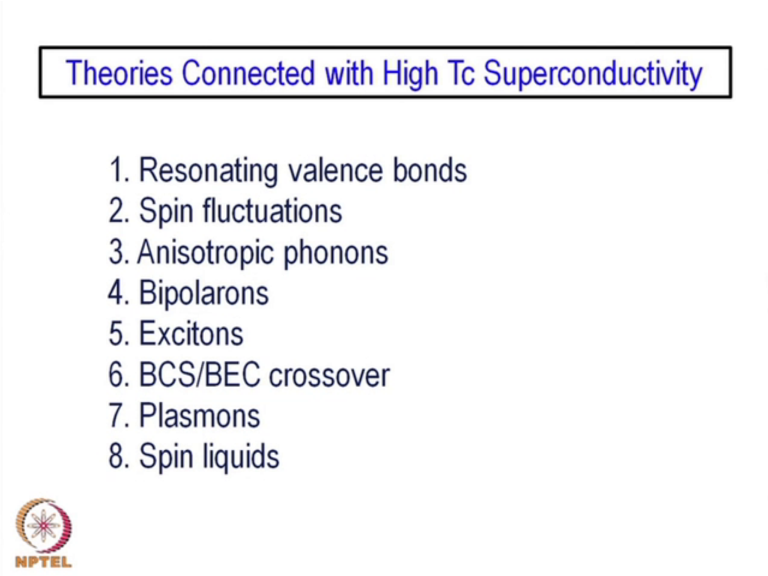

However, such theories have been questioned when there is a discovery of high Tc superconductors. In high Tc superconductor you are talking about high-temperature. So, what happened the low-temperature may not happen in high-temperature. And, therefore, there were question mark of the applicability of the BCS theory in the ceramics superconductors. And, immediately after the discovery of ceramic superconductor there are many physicists; well-known physicist have started working on it. And, they have proposed many different theories and went to them are going to the details of that take long long time.

So, we just mentioned some of them these are not complete list, but there are all possible theories, one is called a Resonating valence bond theory, Spin fluctuations theory, Anisotropic theory, Bi-polarons. These are impact these 2 are more important. The Resonating valence bond theory as well as the Bi-polar ion theory, Exactions theory BCS/BEC crossover theory, Plasmons, Spin liquids.

So, there are many aspects of these, once again am not going to be details of that except that just mentioning that BCS theory; which has been applied very well to the low-temperature superconductors has not is not quite accepted by the for the explanation of the high Tc superconductors. And, still research is going on many propogations, hypothesis put forward. And, I am sure in future some in (( )) decision are in (( )) acceptance will come. That is all super as the theory concern, I will not go to the details of that.

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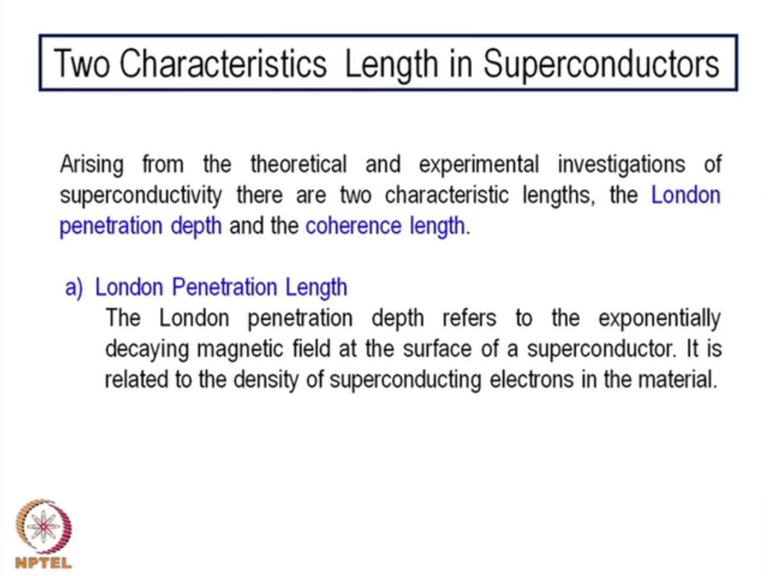

I forgot to mention 2 important parameters in addition to whatever; we have already discussed arising the theoretical and experimental investigations. These are link parameters is characteristics of some of the superconducting materials. Superconductors, there are 2 characteristics lengths; one is called the London penetration depth and another is coherence length.

So, these 2 are link parameters which characterizes different behavior, different characteristics of superconductors. Just make a definition of that the London penetration length, is the London penetration depth refers to the exponential decaying of the magnetic of the magnetic field; actually of the magnetic field at the surface of a superconductivity superconductor. It is related to the density of superconducting electrons in the material superconducting electrons in the material. Of course, one as to remember that in a super conductor high low Tc superconductor; it is primarily electrons the free electrons or the pair of such electrons actually charge carrying species, but in high Tc superconductors there are not free electrons.

There are more localized electrons so we talk about polarons or exactions and so on. So, that has been already discussed earlier. So, it is the penetration depth. So, how long particularly when you are we are talking about fluxes or repealed by the superconducting material, but the fluxes can it can be penetrate to some extent, it is up in the surface. So, not exactly like a mirror plane that its get reflected, but get penetrated to some extent and then comes back. So, that is one of the characteristics length of what we called the penetration length.

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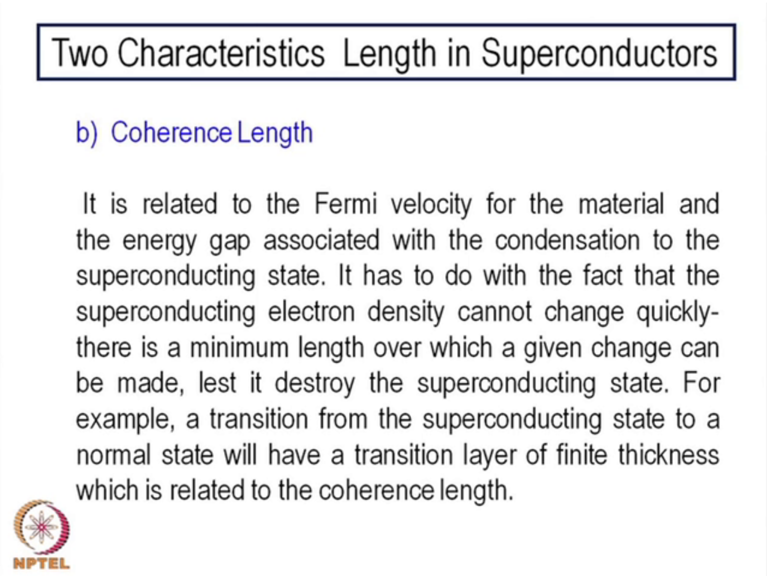

And, another is also important to study the characteristics this is called coherence length. So, it is related to the Fermi velocity for the material and the energy gap associated with the condensation to the superconducting state. So, it has to do with the fact that the superconducting electron density cannot change quickly. Because is if there is a superconductor and non superconducting states there are normal state coexisting together. So, suddenly there are boundaries and that boundary has a finite length between the superconducting and the non-superconducting; there is a finite length and that is characteristics of the coherence length. So, that is what has been mention there that the minimum length over which a given change can be made lest it destroy the superconducting state.

For example, a transition from the superconducting state to a normal state will have a transition layer is a finite thickness which is related to the coherence length. So, this is to some extent related to the domain boundary thickness of the domain boundary either in ferroelectrics or ferromagnetic material. So, there is no sudden change because it needs certain amount of thickness within which gradual change takes place from a superconducting state to a normal state.

So, that is what we called the coherence length. Now, these length parameters are important from the point of view. How to design the material, how to enhance the properties and how to particularly when you talk about the granular superconductor? How to increase the Hc2 value? We have talked about pinning centers by dislocations grained boundaries, precipitates, but it can also the nature of the grain boundaries also important to enhance this property. So, idea of the coherence length is important to understand and the design or modify the properties of superconductors. So, with this more or less we have come to the end of the discussion.

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Material	ξ_o (nm)	λ_L (nm)
Sn	230	34
Al	1600	16
Pb	83	37
Cd	760	110
Nb	38	39

Lastly, I will give you this is the penetration depth and this coherence length of few superconductors like tin, aluminum, lead, cadmium and so. These are the length scales the coherence length and nanometers and these are the penetrations. So, a material like aluminum the depth of penetration is much larger compared to this kind of which is not a superconductor, but the superconductor is much smaller. So, niobium, lead and tin they are actually much smaller penetration depth whereas, aluminum and cadmium the penetration depth is much larger. So, for any superconductors this applies penetration depth is much much smaller, whereas, for the coherence length here is like this.

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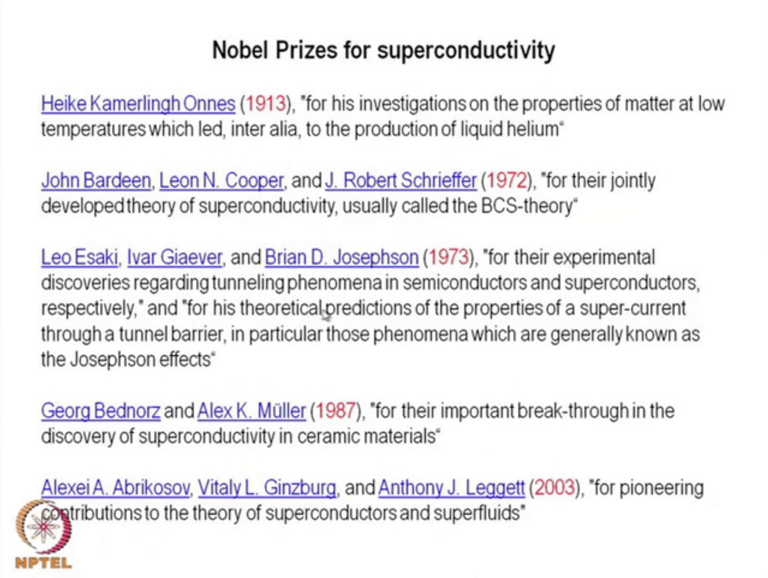

Lastly, (( )) I just try to mentioned that there are large number of noble prizes as been awarded in this area and started from kamerlinghonnes as late as 2003. So, almost 90 years; over the 90 years several noble prizes have been awarded on the superconducting area. The physics of superconductors still many things need to be understood. And, I hope many more noble prizes may have to be awarded; because the subject is still unknown to a larger extent and much more complex physics there than we have understood so far.

However, the material is very important and it is very unique material is on the extreme end in the conductivity scale. And, therefore, it is tremendous technological importance and possibly one day it will be cheaper and more and more commercial applications will come back. Well, with this let me complete the discussion of superconductivity.

Thank you to pay the attention.