Texture in Materials
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Module - 10
Texture in FCC, BCC and HCP materials
Lecture - 48
Texture in FCC polycrystals

Good afternoon everyone and today we will be doing module 10, that is we will be starting Texture in Face Centered Cubic, Body Centered Cubic and Hexagonal Close Packed materials this is lecture number 48 in which we will be doing Texture in Face Centered Cubic poly crystals.

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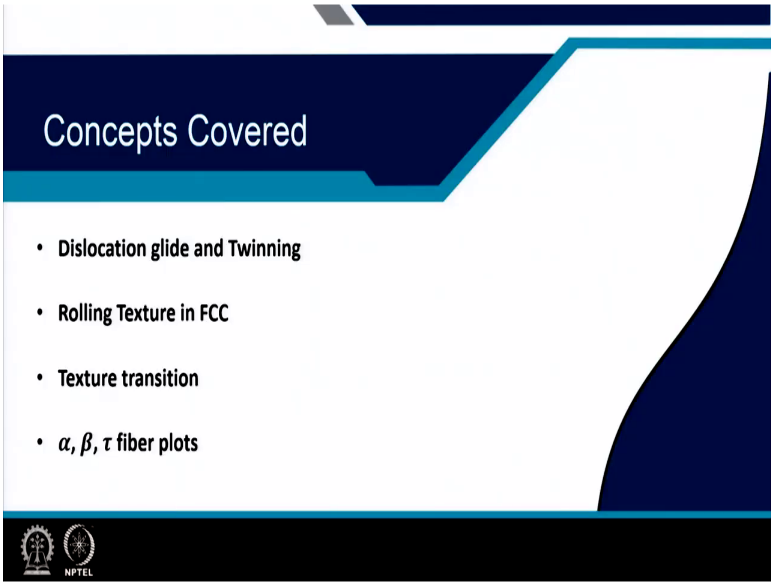

So, the concepts that will be covered in this lecture will be dislocation glide and twinning in case of face centered cubic material rolling texture in face centered cubic material we will look into pole figures and ODF and then we will go into transition texture that is texture transition during you know change in the stacking fault energy of the material and then we will talk in detail about alpha, beta and tau fiber plots ok.

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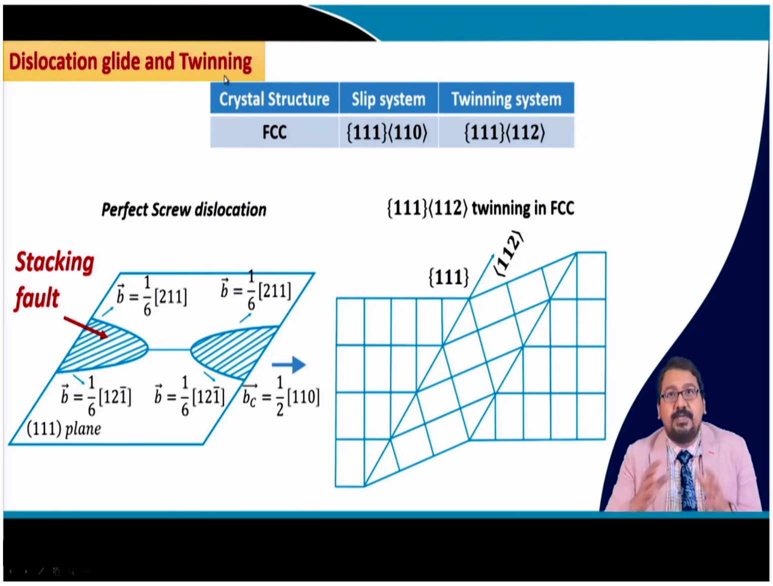

So, dislocation glide and twinning in case of face centered cubic material. We have discussed about this in previous lectures also and we have discussed regarding this in great details. We know that face centered cubic crystals that is FCC has a close packed plane which is 111 and like that there are four 111 planes present in it in a single crystal often abscessing.

Now, in each 111 plane there are three 110 directions that directions are the closest pack directions. So, there are 12 4 into 3, 12 slip systems present in face centered cubic material all consisting of different 111, 110 type you know slip plane and slip directions that is the slip system.

Apart from that, the twinning that occurs in face centered cubic material are mainly 111, 112 type twinning which produces you know in materials which could not deform by slip that is which could not deform by 111, 110 slip system because of its low stacking fault energy deforms by formation of deformation twinning. We have shown here the 111 plane and how the 112 twins starts to develop in the 111. So, we can see if we look let me take the pointer if we look into this figure we have shown the 111 plane and in this 111 plane. We have shown that a perfect dislocation that is the 110 dislocations is has formed at the center whereas, it has been divided into two partial dislocations that is 112 type dislocations and here is the stacking fault.

Now, we have already discussed this in detail that the stacking fault energy is related to the distance between these two partials and if it is high then this distance is lower and if it is low then the distance between these partials are very high right. Now, during the deformation as in poly crystalline material more than one slip system that is minimum 5 slip systems are required to deform a poly crystalline aggregate successfully, thereby if a dislocation is gliding that is in a 111 plane. It is gliding a along 110, it forms partials because the partials have lower energy and they glide at 112 directions.

Now, this is a single slip and this is a single slip that occurs within two part shells. But in order to have 5 independent slip system this particular slip may need to cross slip this particular dislocation the screw part of the dislocation may need to cross slip to another 111 plane in order to sustain the requirement of minimum 5 independent slip systems. But in case of high stacking fault energy the partials come together and become full 110 to you know cross slip into another 111 plane and to sustain a deformation that needed minimum 5 independent slip system; that means, in this manner the material provides 5 independent slip system. In case of low stacking fault energy material where the distance between the partials are very large then during the deformation the stress the plastic the applied stress could not generate enough plastic strain or stress in the materials so, that the two 112 partials come together to become a full 110 vector in order to cross slip into another plane.

Before that the stress you know concentration at certain areas of the microstructure say the grain boundary triple junction would be the most stressed area are enough to introduce twinning that starts to occur during the deformation. So, you see that deformation in face centered cubic material poly crystalline face centered cubic material depends upon the high stacking fault energy or low stacking fault energy of the material.

In case of high stacking fault energy material large number of slip activity involving 111, 110 type will occur whereas, in low stacking fault energy material twinning activity will take place apart from a little bit of slip. Moreover, in case of high stacking fault energy there will be a large amount of dynamic recovery whereas, in case of low stacking fault energy materials the dynamic recovery that is the cross slipping of the screw dislocation and thereby the climb of the edge dislocation will be restricted.

Therefore, you see the texture revolution will vary between the deformation texture revolution will vary for high stacking fault energy material and low stacking fault energy machine.

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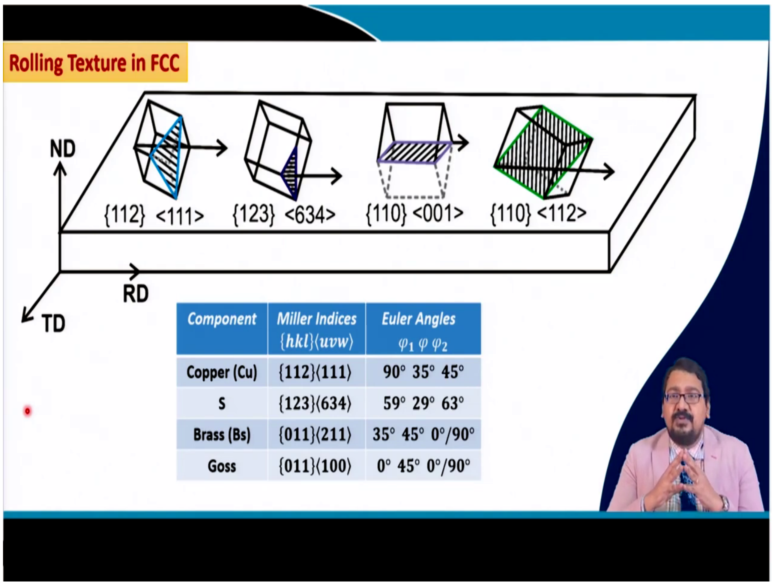

So, if we look into the typical rolling textures in FCC material, it consists of you know the 112, 11 type 111 type of component which is basically known as the copper component and this forms due to a large amount of slip activities that is for by the activity of 111, 110 type slip system in the material.

Moreover, at the same time there is a formation of S type of component during the deformation because of the involvement of slip activity along with a slight amount of recovery right. This component is 123, 634 type component and it is shown schematically like this. On the other hand, you will see that Goss component will start to develop in a material during recovery dynamic recovery and recrystallization processes. In case of materials with low stacking fault energy brass texture which is you know 011, 211 type texture starts to develop because of the activity of deformation twins and the you know the inactivity of the recovery system. Moreover, you will see that a large amount of Goss component which is 011, 110 forms in both you know high stacking fault to low stacking fault energy material.

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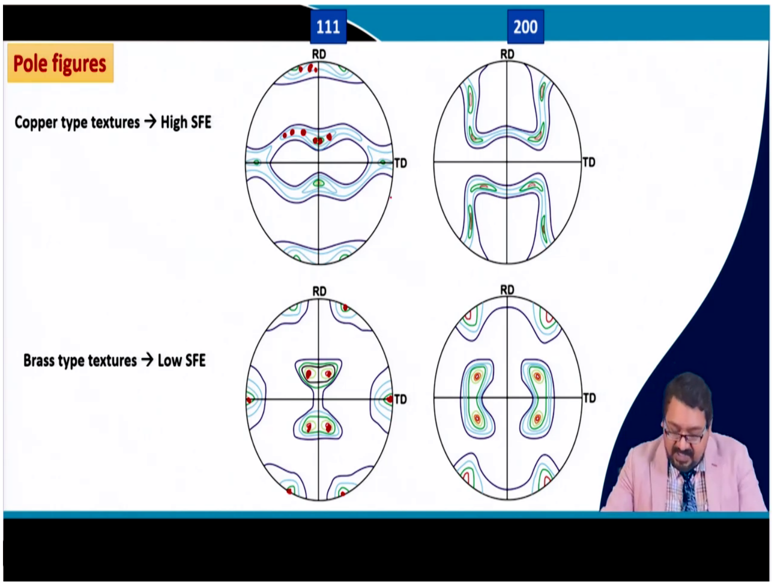

Now, we will look into that how the you know the pole figures of the high stacking fault energy and the low stacking fault energy basically you know varies. You can see if we can basically look into the 111 pole figure and 100 pole figure or one can say 200 pole figure because of its reflection for the FCC material in XRD. So, we see that there is a substantial difference between the pole figures for the high stacking fault energy and the low stacking fault energy.

The high stacking fault energy pole figure the deformation pole figure these are rolling textures of FCC material having high stacking fault energy and low stacking fault energy. The high stacking fault energy texture is known as copper type of texture usually materials such as aluminium copper. Which are medium to high stacking fault energy materials copper it has 60 millijoules per meter square high stacking fault stacking fault energy, in case of aluminum it is nearly 200 millijoules per meter square whereas, brass have a low stacking fault energy of about 20 millijoules per meter square.

The deformation surely varies in case of aluminum and copper with respect to brass because brass deforms mainly by the formation of lots of twin and they it is brittle in brass there is no recovery dynamic recovery in the material during the deformation. So, if we if I take the highlighter pen and we see that in case of copper type texture, we will find the copper component somewhere here and the S component somewhere and here. And the brass component which will be weaker forming here and then again we will be obtaining you see the brass component and the S component and copper component like that there will be copper S and brass component present here and it will be repeated all the positions. But in case of you know the low stacking fault energy material the 111 you know pole figure will show mainly the strong you know brass components right. So, these are the brass components which are present here. So, we can see the that the texture evolution during deformation or during plastic deformation of the material varies because of its stacking fault energy.

At high stacking fault energy, large slip will produce a texture the 111 pole figure will look something like this whereas the 100 pole figure will look something like this and it will also have dynamic recovery into it whereas. In case of low stacking fault energy material only brass texture will be developing and thus the texture will look completely different from the high stacking fault energy material.

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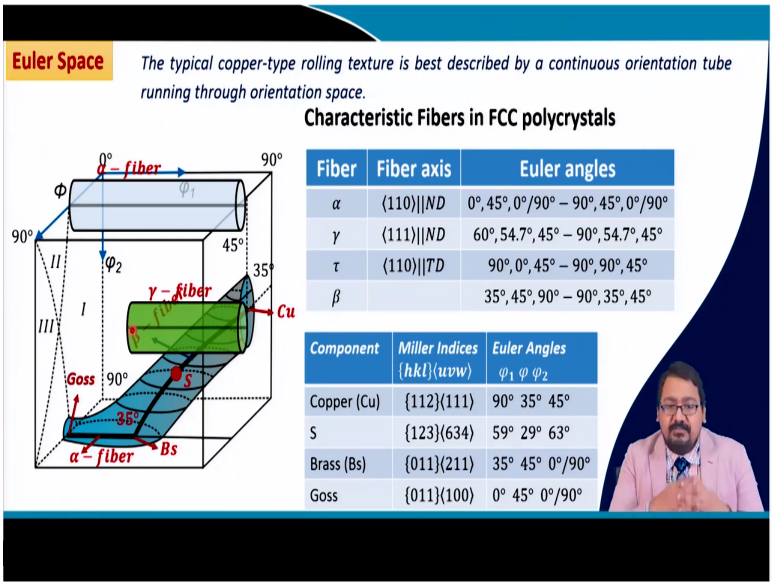

If we look into the Euler space you will see and this slide I have shown earlier in some earlier lecture 2 and you will see that it has mainly alpha fiber, the fiber. Which goes from Goss to brass and we know that when we have discussed this earlier that while deformation a large number of activities occur inside the material. This includes slip activities dynamic recovery and even sometimes recrystallization during the deformation process this leads to formation of a large number of texture components in the material and these texture components have large spread.

Now, why this texture components have large spread? Because you see that the material is made up of a large number of you know grains it is made up they are made up of multiple millions and millions of grains. So, during the deformation the applied load plus the grain boundary contiguity really changes the stress tensor and makes it quite complex. So, the stress that is incorporated in each grain and even different parts of the grains are different and this leads to the formation of the you know the copper component and the S component, the brass component, Goss component at different positions though its position does not change much with respect to the ideal. But it is produced at a it is it evolves in each of this part of the grain and even in different grain at slightly different position.

So, it has a large spread and because of the presence of the spread, the formation of the copper to the S to the brass are actually they are linked up like a fiber, like a tube and therefore, it forms. For example, here the formation of copper component, S component and brass component forms a beta fiber in the beta fiber if we look into it starts from Euler angle which is you know 35 degrees phi 1 equal to 35 degrees and then phi equal to 45 degrees and phi 2 equal to 90 degree. That is from the brass to it goes to the S and then it goes to the copper, which is you see 90 degrees at phi 1, 35 degrees at phi and 45 degrees at phi 2.

Likewise, we can see that alpha fiber forms which is from Goss to brass and you can see that alpha fiber is a fiber, which is parallel to phi 1 and therefore, it is a ND fiber because phi 1 is the rotation along ND right. In case of Goss and brass the ND remains constant and therefore, it is 110. Therefore, it is called the 110 fiber too you can see from this table and the you know the alpha fiber goes from 0 45 0; that means, it goes from here phi 1 equal to 0, phi equal to 45 and phi 2 equal to 0 right or phi 2 equal to 90 degrees. So, we can look into this and this is a fiber which is parallel to you know phi 1 and this is also an alpha fiber, this is also an alpha fiber. So, the Goss component is also present here and the brass component is also present here. Likewise, there could be you know a gamma fiber a gamma fiber is a fiber which is also parallel to ND because it is parallel to phi 1 and; that means, it is phi 1 is a rotation along ND.

So, this gamma fiber is also called the 111 fiber because the 111 remains constant that is the 111 plane for the gamma fiber remains constant big and remains parallel to ND. It starts from 60 degree at phi 1, 54.7 degree at phi and 45 degrees at phi 2 and it completes at 90 degrees to phi 1 and you see 54.7 degrees to phi and 45 degrees to you know phi 2.

Likewise, we can see there is a formation of tau fiber the tau fiber looks like this and tau fiber is a fiber which is parallel to phi. But it forms at after a rotation of 90 degrees along phi 1 and therefore, the tau fiber is basically the TD fiber and we have explained this thing previous in previous lectures more in more detail and thus the tau fiber which forms between 90 0 45 to 90 90 45 is basically the TD fiber.

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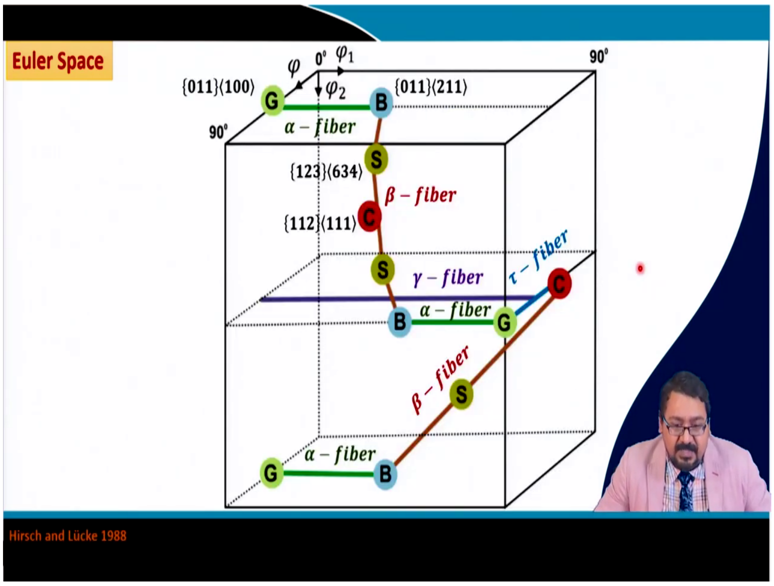

Now, if we look into detail of this, we can see a typical Euler space for the rolling texture of the face centered cubic material and we can find out that this Euler space starts from Goss fibre to brass fiber and it is known as the alpha fiber. You can see that this alpha fiber is repeated 3 times and we have discussed this because of the symmetry of the cubic crystal by 120 degree along 111, which is a threefold symmetry, the alpha fiber you can see the Goss to brass fiber forms here.

Gauss to brass fiber forms here, Goss to brass fiber also forms here. If we look into the beta fiber beta fiber also forms 2 times where you see the brass to the S component to the copper component is the beta fiber. Then the copper to the S to the brass component again is another beta and you can see that the again the copper to S to brass is another beta. So, the beta fiber also develops you know 3 times in this material and on the other hand there is a tau fiber between the copper and the Goss fibre that can be expected.

So, all of these fibers can form during you know rolling of a face centered cubic material and the intensity of the fiber at different points that is the intensity of the fiber. For example, high stacking fault energy will be higher in the copper and the S component and will be lower for the brass and the Goss component whereas, the low stacking fault energy will have high intensity near to the brass and the Goss component whereas, it will have a lower intensity at copper or the S component.

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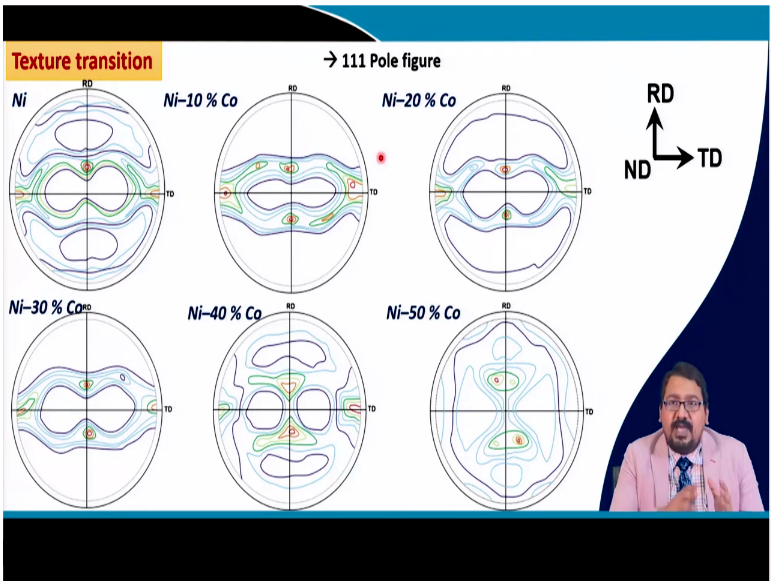

If we look into this type of transition in texture that happens due to the change in the stacking fault energy. I am giving you one example of nickel and you can see that texture in case of pure nickel is a totally copper type texture because this is a pole figure of 111 and you can see the typical pole figure of 111 looks like this for a high stacking fault energy material. And once if you if we start with addition of cobalt and 10 percent cobalt is added and still it remain copper type and 20 percent cobalt is added it still remain a copper type. So, its stacking fault energy is slowly slowly reducing, but its still in a range where the all the slip systems are still activated and it is behaving like a medium to high stacking fault energy material and there is no twinning in this. But as it lowers down to 30 and 40 percent of cobalt, we will see that slowly slowly you know the brass type structure starts to develop. So, there is a slow change in the texture component from the copper type to brass type and finally, you will see that after addition of 50 percent weight percent of cobalt the brass type texture starts to develop.

So, this type of transition in texture due to the change in the stacking fault energy material change in the stacking fault energy of the face centered cubic material is known as texture transition.

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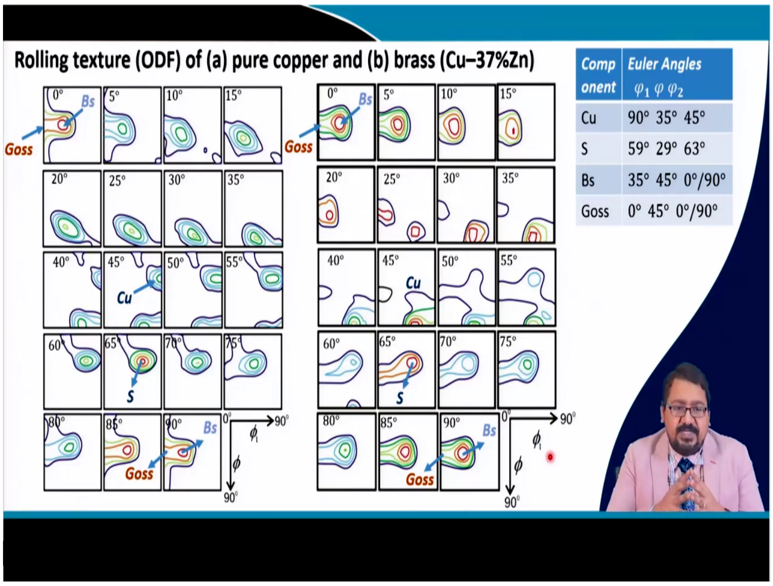

If we look into this texture transition by using orientation distribution function we will see that this is an example of pure copper and pure and brass which is basically copper you know 30 percent zinc not 37 percent 30 percent zinc. You will see that in case of high stacking fault energy that is for pure copper texture at a 45 degree section of phi 2 a strong intensity of copper fiber will be observed.

Whereas, at 0 degrees of phi 2 a week intensity of brass and a weak intensity of Goss fibre will be observed whereas, along with the copper fiber. We will see at 63 to 65 degrees of phi 2 a strong S component fiber S component could be seen and the same brass and Goss type components or the alpha fiber could be observed at 90 degree of the phi 2 section.

Now, if we look at this part on the right hand side we will see the ODFs that are formed during rolling for the row stacking fault energy material. If we look into this you will see that the copper component has almost disappeared whereas, the S component is also very weak and strong brass and Goss component have developed in it. So, this change in the you know intensity of the texture components that can be observed in case of ODFs decides also can decide that whether it is coming from a high stacking fault energy face centered cubic material or a low stacking fault energy face centered cubic material.

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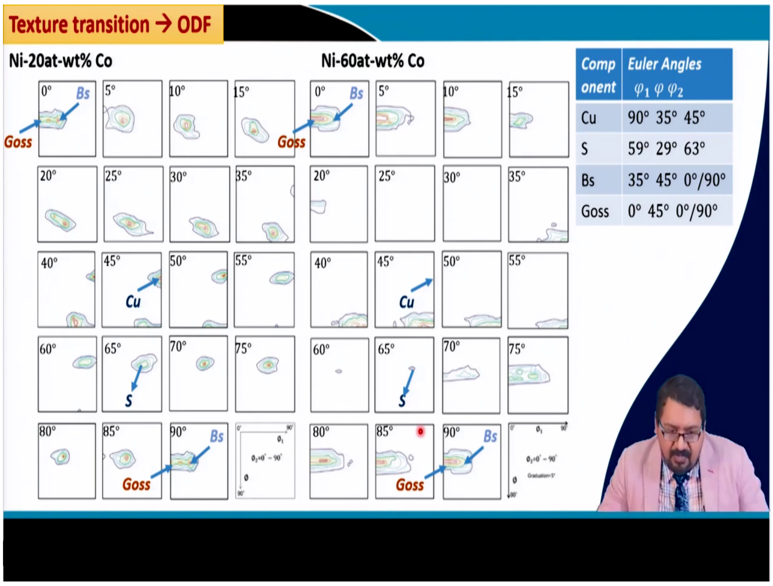

If we look into another example, we are looking into nickel with 20 percent addition of cobalt and 60 percent atomic weight percent cobalt added to it. In case of the 20 percent added cobalt nickel you will see a strong copper fiber along with S sorry S fiber present in it. So, there is a strong copper type component and the S type component whereas, in the 0 degree and the 90-degree section we will see weak brass and Goss component forming.

On the other hand, if we look into the nickel 60 atomic weight percent cobalt you will see strong brass and Goss component whereas, there is no copper component and a very weak S component has developed. So, this shows that there is a substantial change in the texture evolution in case of means deformation texture evolution. In case of face centered cubic material because of the effect of stacking fault energy and this could be observed in case of orientation distribution function and or Euler space and in case of if we look into the texture using the pole figures.

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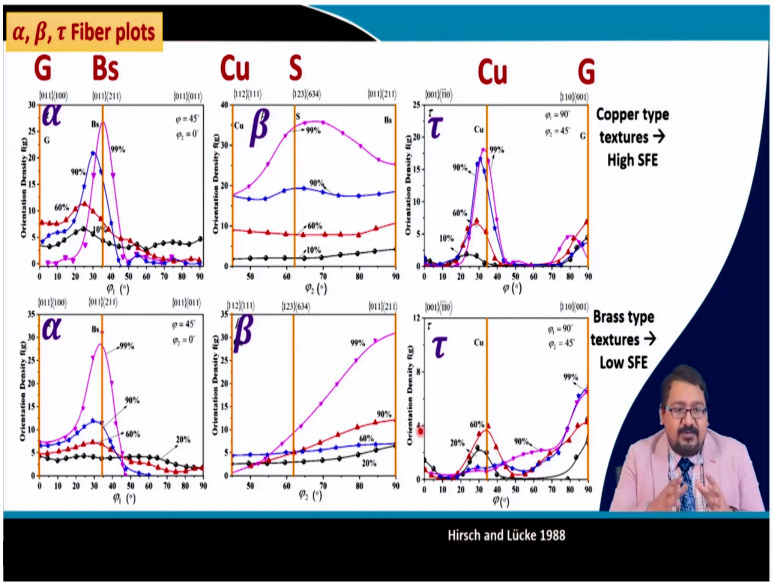

On the other hand, it is more important to observe the texture in terms of fiber and intensity plots. Here is the orientation density with respect to the different fibers that is orientation density means the intensity of the fiber. The orientation density is synonymous to MRD that is multiples of random distribution and we can see the presence of alpha beta tau fiber, in case of high stacking fault energy material and in case of low stacking fault energy material.

If we look what we have done is that, we have done our rolling from you know and have shown the rolling texture in case of you know say for example. Let us take an example that let us say that this is aluminium and this is for brass and we have given a deformation rolling of 10 percent rolling reduction and then say 60 percent rolling deduction and then 90 percent and then 99 percent rolling reduction and we see that how the texture is evolving.

And if we look into this if we look into the alpha fiber, the alpha fiber which contains you know Goss component and the brass component in it as the rolling reduction is increasing, the brass component you know orientation density increases right.

On the other hand, if we look into the beta fiber we will see that it is formation of copper S and brass fiber sorry brass component and with the increase in the rolling reduction the copper S and brass components are increasing right. On the other hand, if you look into the tau fiber and tau fiber, which is mainly the formation of fiber between copper and Goss and you will see that the tau fiber with the increase in rolling reduction, the copper components orientation density has increased hugely whereas, the Goss intensity has not increased.

So, if we look this this is the situation that happens for the high stacking fault energy material say typically aluminum for example, and in case of low stacking fault energy materials such as brass you will see that after the deformation a very high component of brass has developed one in the alpha fiber. Whereas, the Goss is still low in this case whereas, in the beta fiber we will see that there is no intensity peak at the S and in at the copper component right.

If you look into this beta fiber. If we look into this tau fiber you will see that with the increase in the rolling reduction, the intensity of copper fiber do not increase right it does not increase whereas, the intensity of Goss fiber increases with the increase in the you know rolling reduction.

So, we can see that there is in case of face centered cubic material normal poly crystalline face centered cubic material, the deformation texture depends upon the stacking fault energy and the deformation texture varies because of this stacking fault energy due to the variation of the slip and the twinning deformation modes.

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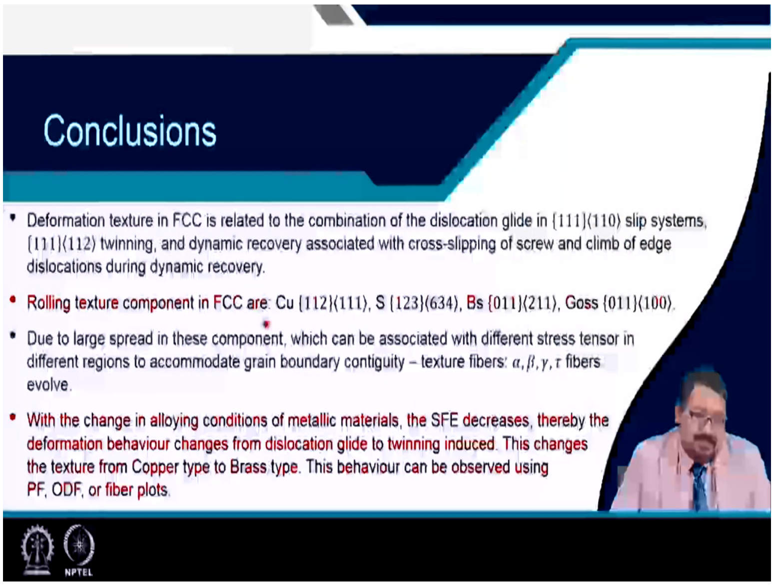

So, we can conclude that deformation texture in face centered cubic material is related to the combination of the dislocation glide in the 111, 110 slip systems and 111, 112 type twinning right. Also it includes dynamic recovery and which is associated with cross slipping of screw dislocation and climb of edge dislocation during this dynamic recovery process.

So, the rolling texture components in FCC materials are copper that is 112, 111, S which is 123, 634 brass Bs which is 011, 211 Goss which is 011 1 100. The intensity of these components will vary depending upon these deformation modes whether it is slipping or twinning and this deformation modes depends upon the stacking fault energy of the material right.

So, due to large spread in this component which is associated with different stress tensor in each grain or in different parts of each grains. So, the stress tensor near the grain boundary will be different at the center of the grain it will be different. So, in order to maintain this grain boundary contiguity, the components have large spread and therefore, they form in forms of a fiber that are alpha fiber, beta fiber, tau fiber, gamma fibers that we have explained in this lecture. Finally, with the change in alloying condition of the metallic element the stacking fault energy changes and or stacking fault energy decreases sometimes.

And thereby the deformation behavior changes from dislocation glide to twinning induced type deformation this changes the texture from copper type texture to brass type texture this behavior can be observed using pole figure ODF Euler space and in terms of fiber plots and this is known as texture transition.

Thank you very much.