Electron Diffraction and Imaging

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Lecture – 18
Indexing Diffraction Pattern

Welcome you all to this course on electron diffraction and imaging. In today's class we will discuss about how to index diffraction pattern because whenever we do a microscopy to get crystallographic information about the sample we should be able to get information about the crystal structures essentially from the diffraction pattern. What for we index the diffraction pattern? Because when we do an examination of a sample in the microscope what we wanted to know is how different phases are distributed in that sample. This information is difficult to get in an X-ray diffraction.

In an X-ray diffraction we can get information about the crystal structures what all the crystal structures of the phases, but we cannot get any information about, how they are distributed, how the grains are oriented all this information we cannot get it that is precisely, what we can get in a microscope. And when we wanted to correlate microstructure to mechanical properties we should know information about not only how the what all the types of second phase particles are there what is their size distribution morphology and also how they are and what is the relationship between these various phases this information should also be obtained only when this information is available we can correlate microstructure to different types of properties may be mechanical magnetic and various types of properties.

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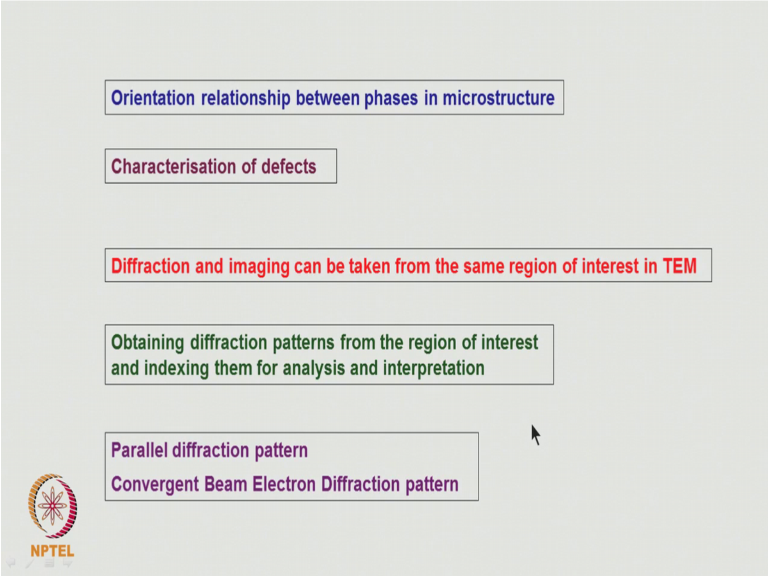

So that means, that to get information about the relationship between the phases we should know what is the orientation relationship between the few because in the real sample these phases are distributed and the relationship essentially in a 3 dimensional space.

If we get diffraction pattern we know that diffraction pattern is nothing but information about the crystal structure in reciprocal space. So, that reciprocal space information also shows that same relationship. So, by analyzing the diffraction pattern we can get information about the orientation relationship then another area in which we require is that all mat none of the materials are perfect materials they contain lot of defects the we know that the defects controls the property of the material we wanted to identify, what all the various types of a defects which are present in the material and how they are distributed for which electron microscopy is one of the best techniques.

When we wanted to characterize these defects we using electron microscope we should try to image them using different diffraction vectors and then try and from that visibility or invisibility criterion, whether the for which condition which g vector imaging the microstructure the defect is visible or not from that we get information about the defects structure. So, in all these aspects what we require is that we have to index the diffraction pattern which we obtain. Now not only obtaining a diffraction pattern indexing the diffraction pattern if you wanted to use this to get useful information we should also know how to get the correct diffraction pattern that is also very important.

Another most important aspect of an electron microscope is that from the same region of the sample we can get diffraction as well as imaging that is why we are able to do, able to get all these information about the orientation relationship and characterization of defects everything possible because we are able to image the defect as well as the same region we get that relevant diffraction pattern. So, if you have obtained some diffraction pattern the first which we have to do it is we have to analyze them that is we have to index them and after indexing this has to be used for analysis and interpretation of the results on that basis we can get information about the distribution of microstructures and characterization of defects these aspects could be continued.

As I had mentioned earlier we can use the microscope both in imaging and diffraction mode, but even in the diffraction mode I mentioned that we can use it in a parallel diffraction this is what we call it as a selected area diffraction mode and another is like convergent beam electron diffraction the convergent beam electron diffraction we have discussed earlier and this we can used to get information about not only the crystal structures and accurate lattice parameter of the samples, but we can also get information about the space group and point group symmetry. The parallel diffraction is what which is normally used in an conventional electron microscope to get information about how the phases are distributed. These aspects we have discussed already, but just for the sake of completeness to I will just recall this aspects a little bit before we go further to understand how to index the diffraction pattern.

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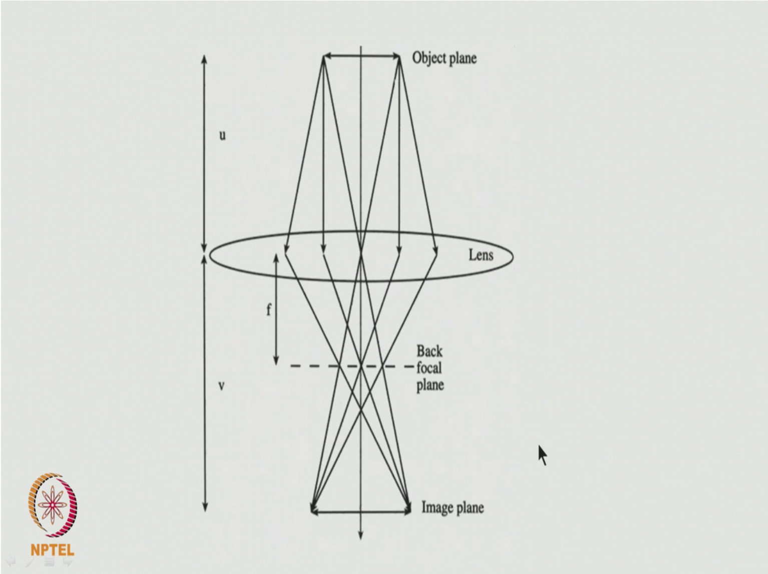

The main property of an objective lenses essentially is that if the sample is excess line sample when rays pass through that sample you we use a monochromatic electron beam in an electron microscope. So, these beams are scattered in various directions from every point on that sample surface and in some directions they all the phases add together and that gives raise to constructive interference and that is where we get the diffraction pattern. What happens when we introduce a lens? The lens is used to get a magnified view of the object that is one and another is that all the beams which are parallel to the optic axis or close to optic axis and parallel to each other scattered from different regions of the sample they are all focused to one particular point at the back focal plane.

So, at the back focal plane of the objective lens we get essentially the diffraction pattern and in the image plane we get the magnified image of that sample by putting apertures either in the object plane or in that image plane we can decide what is the area from which we wanted to get the diffraction pattern; that means, let us take that simple case we put an aperture here. So, that from this area of the microstructure we can get a diffraction pattern and also the image only from that region that is why I mentioned that in an electron microscope we can get both the diffraction and on a microstructure from the same area of the sample.

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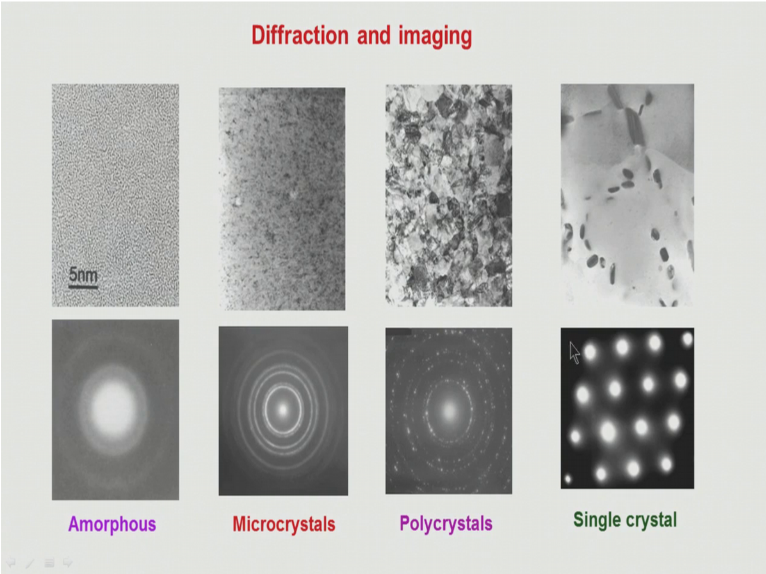

Now the microscope when we operated at different length scale we know the wavelength of the radiation which we use in an electron microscope is lambda is have the order of 0.025 Armstrong or 200 KV radiation.

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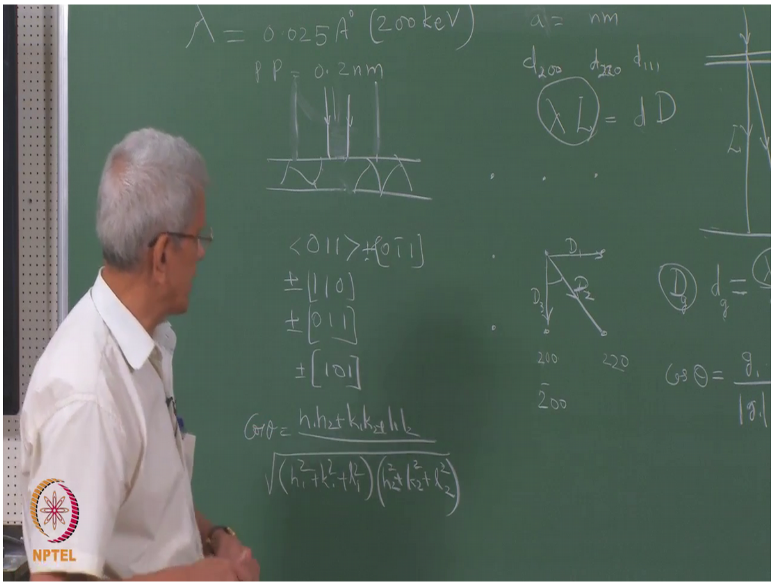

So, this is the limit of the solution because of the various lens aberrations we normally get it in a conventional microscope the resolution point to point resolution essentially is of the order of around 0.2 nanometer. And since it is an electron beam we can focus this beam when it falls on a sample using this various lenses to very fine beam or we can spread it out to a very large area these are all the advantages which we have in the lens.

So, this advantages can be used to make the beam as small as possible and fall on a large small area get a diffraction from that area and also an image from that area or make it fall on a large area get diffraction from the various phases which are present as well as the matrix and also get that image from that area that is possible. And another important aspect is that suppose this itself contains a lot of grains nano crystalline grains then also choosing an appropriate beam size we can get information either from a single crystal or an average information from many areas of the sample from large number of grains this is an example which I had shown.

It is an amorphous sample where this is the image of sample and the this the amorphous regions gives rise to a sort of a ring pattern diffuse ring pattern by analyzing this we can get information about the radial distribution of that atoms this part of it I will not go into and quiet often the samples can be have very fine grain size and if that is that case when the grain size is very fine. And they are all oriented in random way the diffraction pattern which we get from that sample is essentially a circular ring pattern which we get it and this is the sort of pattern which we will get it if we are looking at nano crystals which are there in the range of few nanometers may be 10 to 20 nanometers or 10 to 100 nanometers. If the particles size is slightly large in the micrometer range then depending upon that aperture size use and depending upon the orientation of the various crystals if it is totally random we should get a pattern like this otherwise we will getting spots on some specific rings these rings could also be analyzed to get information about the crystal structures.

In many materials the grain size is are very large it could be of the order of may be 1 micron to 50 micron or 1 micron to 100 micron in such cases then we can get information from each of the grains by controlling the beam size we can get information that is single crystal information we can get it from this pattern this is one such pattern which is being shown corresponding to diffraction pattern which is taken from this region. We can see that thought this contains some precipitates the region which is chosen is essentially the matrix region and in this particular case it s an f c c structure we get a pattern which diffraction pattern, how analyze and index this pattern this is what it forms the subject of today’s talk.

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Suppose the sample is a deformed sample very heavily deformed then as you have studied on the course on phase transformation texture occurs and in textured samples you can see that you do not see a complete ring, but you can see that streaking of many of this diffraction spots could be observed in the diffraction pattern.

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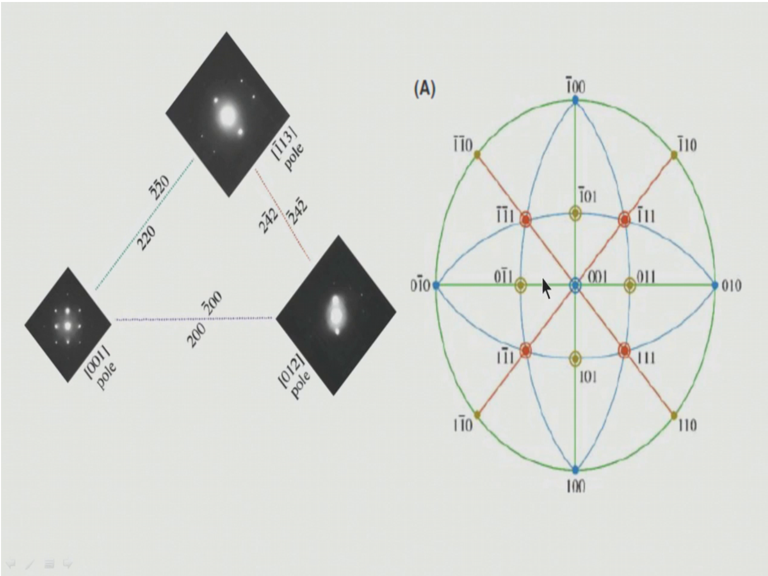

That is if we wanted to get complete information about a sample often look getting diffraction pattern or microstructure in one orientation alone is not sufficient we have to tilt that sample and try to get diffraction pattern as well as images for different orientations this has to be done in a double tilt holder in the present day microscope, but when we use such holders we assume that only in sample where it is the single grain beam is falling. So, then we are trying to get the diffraction pattern from that particular region and when we tilt the sample as we know that the reciprocal lattice and the real structures are tied together. So, as will rotate tilt the sample the reciprocal lattice also will rotate. So, we know that diffraction pattern which we obtained in an electron microscope is nothing, but a one sheet of the reciprocal lattice plane.

So, because of that since they are tied together and in a crystal the various planes and directions makes some specific angles and so when we go from here to here are tilt it or from one because here its tilted from 0 0 1 to 1 bar 1 3 or we go from here to a 0 1 2 port then the indexing of the patterns have to be consistent for that purpose we have to use a stereographic projection not only that stereographic projection can be used for indexing this is for a cubic system. So, this is a 0 0 1 stereographic projection for a cubic system this stereogram can also be used to decide in which direction we have to tilt it that is if we tilt from here to in this direction we will be reaching this zone axis because it will come somewhere 1 bar 1 3 if from here to here tilt it then this 0 1 2 zone will come. So, the stereogram can be used to consistently index the diffraction pattern this we will talk about it shortly.

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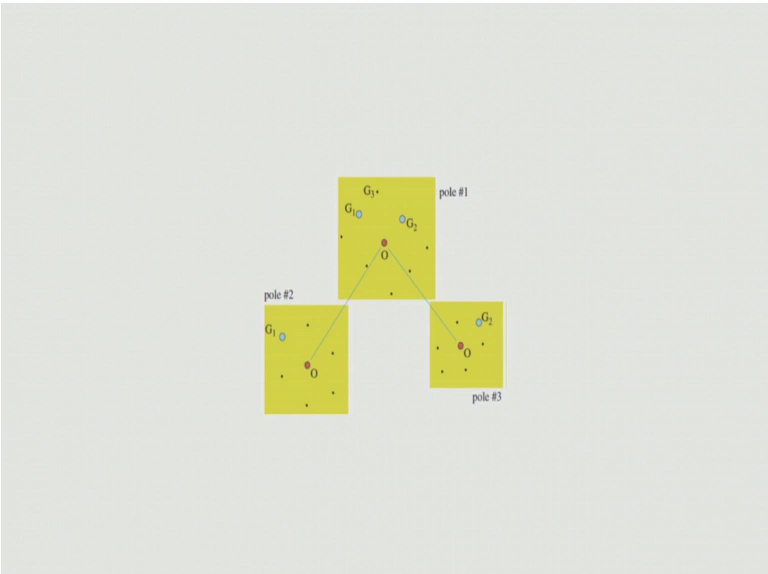

So, essentially what I had shown here is that how this tilting could be carried out I mentioned that we can use the stereogram essentially what we do in a microscope is that since the Kikuchi bands are there if we move along that is especially if the sample is slightly thick the we can get the Kikuchi pattern. And we can move along the Kikuchi bands to come to different orientations as you know that the Kikuchi bands also can be used to get perfect correct orientation of that sample.

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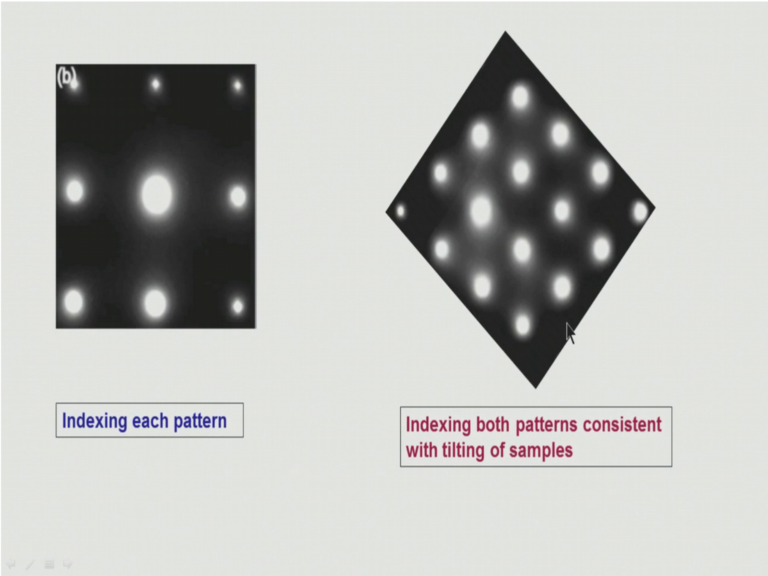

The first thing which we have to do essentially is that to get information about the microstructure.

First we should go to a symmetric diffraction pattern a symmetric pattern means that the beam is oriented along a particular zone axis direction what is a zone axis which we have described earlier, but we will come to it a little bit later and then if we come a symmetric and not only the low index zone axis then what is going to happen is that we will be getting a symmetric patterns like this we have to index this patterns take this patterns and take corresponding images then what we do it is to identify the defects you tilt that sample. So, that we reach 2 beam condition. So, that only the central spot and one of the beam spots are there that is how microscopy is being done that is being covered in a separate class.

So, in these particular class we wanted to know that having taken a symmetric pattern how this pattern should be indexed 2 things which has to be as I mentioned this pattern has to be indexed one and another is by after tilting we have reached another zone axis in which we also get a diffraction pattern since some angle of tilt has been done to given to the sample.

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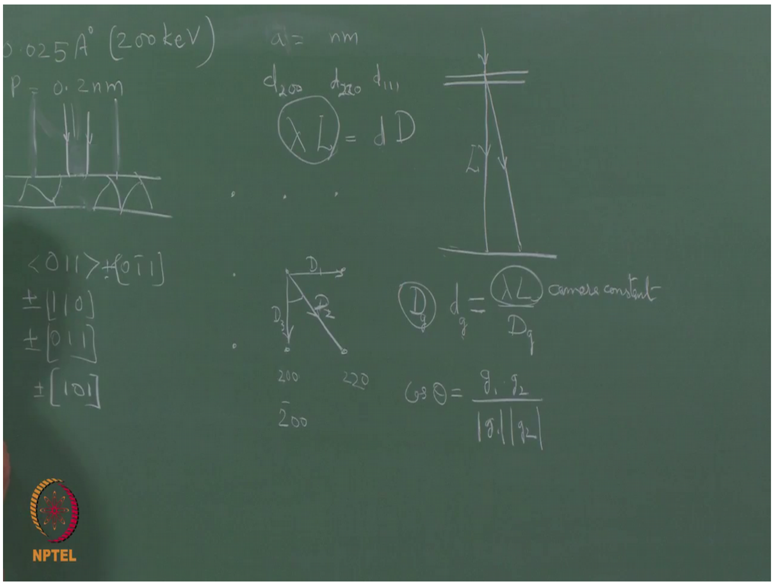

Now, what happens is that from here to this direction if we move the planes are also moving. So, we cannot index it randomly because we know that this pattern essentially corresponds to nothing, but since I know what it is I am just telling about its 0 1 1 type of a pattern zone axis pattern we know that 0 1 1, it could be a specific value, but we have to find out what that specific value of the zone axis because when I write it like this it means that it could be 1 1 0 or it could be 0 1 1 or it could be 1 0 1 or it could be 0 1 bar one like this we can have variant. So, since we have given a specific tilt we should be able to index it correctly and tell that what is the zone axis corresponding to this which is the zone axis out of all the possible combinations because this is very important in defect analysis. So, that is what I meant that that indexing has to be consistent with the tilting of the samples.

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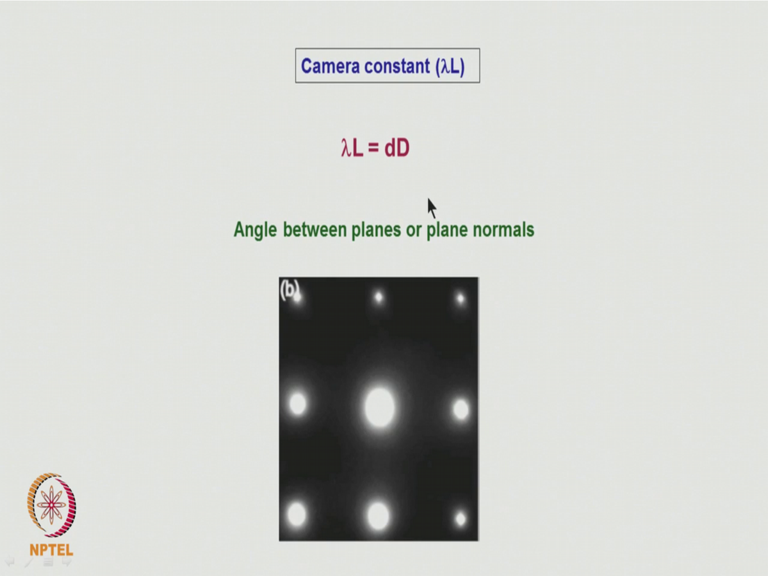

So, now let us come back to indexing as simple diffraction pattern we have got a diffraction pattern like this we wanted to index this pattern what all information which we required to index this pattern generally that electron microscope diffraction electron microscope is the not the one which is used to find out the crystal structure information as I mentioned it is to find out the structure property correlation. So, if you wanted to find out what is the crystal structure of the phases are that we could do an X-ray diffraction and get that information we assume that it is a single crystal where what is the crystal structure we have got that information and in this particular case we assume and assume that it is a cubic structure and we assume let us assume that it is an f c c structure which we have got it then if it is an f c c structure.

and if we know the lattice parameter a equals some value the lattice parameter is known in some nanometers if we know the lattice parameter then we can find out the de-spacing corresponding to various planes like this 1 1 1 that is the allowed reflections what they are corresponding to 2 0 0 2 2 0 these de-spacing could be determined this table we can have when I start diffraction I mentioned that the wavelength into L the camera length equals d into d. There is essentially if we take a diffraction pattern like this I am just drawing that same pattern which we had obtained this is the spacing of the diffraction spots in different directions they are related to the planes which are giving raise to this diffraction pattern by this formula what is lambda? Lambda is the wavelength of the radiation what is L?

L is the camera length what is camera length camera length is nothing, but if we have a sample here and the beam is falling onto it this is the direct beam and if the diffracted beam is coming like this in this particular direction if we image them in this particular plane what is the distance from the sample to the imaging plane that distance is called as the L. Because this will decide what is going to be the magnification in the diffraction spot this can be related to the de-spacing in of the real lattice or de-spacing in a direct space as well as the corresponding reciprocal lattice vector. So, using this formula in a microscope when we operate it we have this values are there the camera length we can choose and change it the way we want normally it is used between 50 centimeters to hundred centimeters that is what we normally use it depending upon that that size of this pattern will change or the magnification will change.

That means that what we measure that is in this pattern we are trying measure d 1 and d 2 suppose we wanted to measure this various distances like then this you take to be d 3 in the diffraction pattern which we have taken we measure it since we know the energy of the radiation we know what this value is. So, this camera constant is known. So, what we measure essentially is this d. So, if we measure this d then this d that is small d which is because I will put it as d DG, this is correspond this is DG; that means, that once we have measured this value we know and this lambda into L is called as the camera constant. So, knowing the camera constant and measuring the distance of the diffraction spot from the central spot using this formula we can get information about the spacing between the planes which are responsible for the diffraction.

If it is an f c c crystal and a using diffraction we have got prior information then we can compare these distances and find out what could be the reflections which these could correspond to. So, that way now we have got some information about what is that spot which is corresponds to what is the diffraction spot. Then there will be some errors which will be associated with it then to verify it w make sure that suppose we assume that this correspond to some particular one corresponding to 2 0 0 type and this distance corresponds to 2 2 0 type of planes which could be responsible for it then we have to find out whether it is 2 0 0 or it could be as well as 2 bar 0 0 which are the planes which giving rise to which this spot could be indexed to get information we measure the angle between these 2 spots. If we measure this angle between these 2 vectors then we know that the cos theta between 2 planes or 2 vectors equals this is g 1 dot g 2 divided by modulus of g 1 into modulus of g 2 using this formula.

This in the case of a cubic system it will turn out to be nothing, but cos theta will turn out to be h 1 h 2 plus K 1 K 2 plus L 1 L 2 divided by root of h 1 square plus K 1 square plus L 1 square h 2 square plus K 2 square plus L 2 square. So, this way we can get this angle also depending upon what that angle get in this specific case if we consider this angle we know that between these 2 planes will turn out to be 45 degree.

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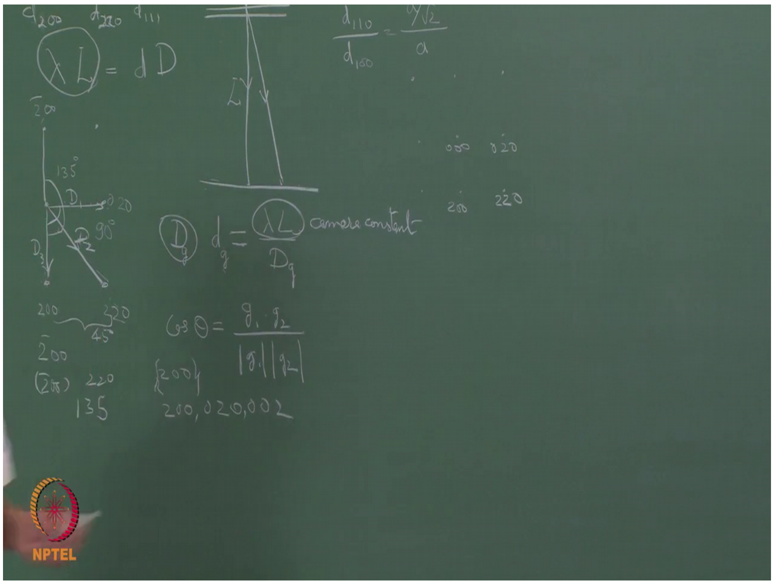

And if it is between 2 bar 0 0 and 2 2 0 the angle will turn out to be 135 degrees.

So, if this angle is 45 we can index this to be 2 0 0 and this spot could be indexed to be 2 two 0 then if we take this spot 2 bar 0 0 this makes an angle of with respect to this naturally an angle of 135 degree and another information we find in this diffraction pattern in this specific pattern is that this value of d 1 and d 3 turns out be that same and the angle between these 2 in this specific case turns out to be 90 degree we know that for that family of planes 2 0 0 type if we take it for between 2 0 0 0 0 0 2 0 and 0 0 2 for all of them angle between these planes will be 90 degree.

So, that way we can index this to be either 2 0 through and in this specific case we index this to be since this is taken as 2 2 0 this is indexed to be 0 2 0 once these diffraction this is the way in which we index the diffraction pattern because the type of information which we look for is essentially to characterize the defects. We have some prior information about the crystal structure then we can go ahead and do it very easily otherwise it is a little bit more complicated that is the part which I will not talk about it. Because normally in a microscope when we use it to get information in steels or many of chemical base alloys or aluminum base alloys is essentially to information about the orientation of the grains and the type of defects which are present how precipitates are distributed that is all for this type of analysis is what is necessary in most of the conventional electron microscopy.

And this is the way in which we can analyze I will repeat again what we have to do it is that we measure the distance from the central spot various spots and then we take the using this formula find out the de-spacing corresponding to it. So, from the de-spacing and since we know the lattice parameter of the crystal already has been determined we can find we will have a table we can construct a table of values for the different de-spacing from which we can calculate what it could correspond to then we have to find out which are the ones which has specifically corresponding to that that can be found out from taking this measuring this angle the other way in which also we can do it is that we know that between d 2 0 0 and d 2 2 0 the ratio between them if we take it.

They have to come in some specific values for the various planes that way also we can find out because we have got some of information and we measure this ratio also if that ratio between this d 1 0 0 and d 1 1 0, if we take it that is d 1 1 0 by 1 0 0 in this case it will turn out to be a by root 2 and here it is a. So, it will be 1 by root 2 that is the way the separations will come and that will be around 0.707. This way using this formulas we can get this index the diffraction pattern and we know that in the case of cubic lattices angle between planes and there is when we measure angle between the planes as well as the angle between the a plane normal they are that same. So, far we talked about indexing one particular pattern.

Now, suppose we wanted a consistency is required in indexing of this pattern that is as I had mentioned earlier this pattern could be indexed after doing this analysis we indexed at 0 0 0 2 0 0 rest of the spots will come most important thing is that 2 reduce error in the measurement.

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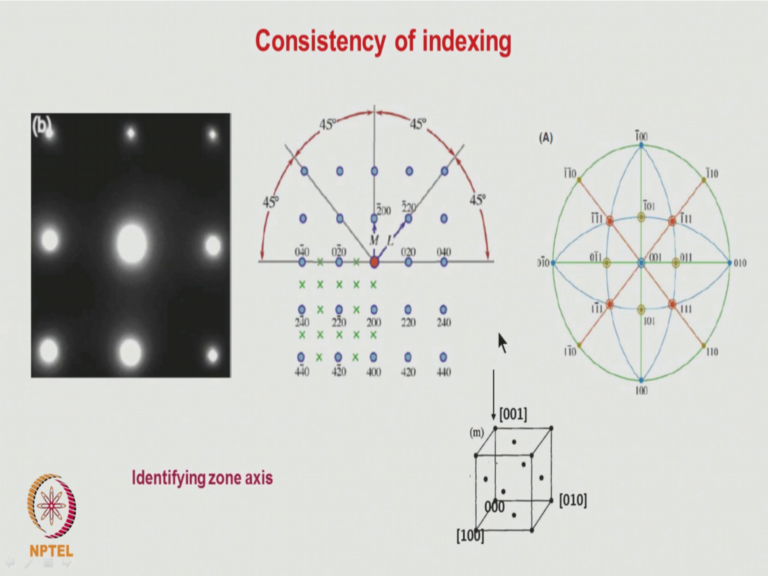

If many spots are there try to measure distance from one spot to another spot as far as possible choose many spots and measure the actual distance and divided by the number of spots which we have covered, and that way we can reduce the error in measurement of this distances d and this the way the indexing of this pattern been done to have a consistency in indexing of this pattern how we go about and do it.

We can use stereographic projection also this is the 0 0 1 stereogram project stereogram projection for a cubic system is given and in as I had mentioned in the earlier class the stereographic projection. If this is the 0 0 1 on the great circle corresponding to it which is the primitive circle in this case all the spots which are lying will be 90 degree away from it that is this is this 0 0 1 correspond to a pole corresponding to the 0 0 1 and what the great circle means is that circle which is passing through the this sphere which is 90 degree with respect to if we look here this is 1 0 0 1 1 0. Because here the stereogram tells only the angular relationship between the various planes and so that and here it will not tell about the structure factor considerations which reflections are absent or which are there that condition.

If we know the crystal structure and lattice parameter it is already available on that basis we can get that information because whether it is been 2 0 0 and 1 1 0 plane or the angular relationship does not change. So, the stereogram could be used to get that angular relationship. So, this way if we look at it with respect to this the way the stereogram is being used this is the direction because in crystallography as I had mentioned earlier. That is from top to bottom is where we index the 1 0 0 direction and left to right is 0 0 1 direction and the perpendicular to the screen is where the 0 0 is direction is used other 0 0 1 direction. That way if we do it the 1 0 0 or corresponding the 2 0 0 that will come here this is the 2 0 0 and then 90 degree away from it 0 1 0 comes at 45 degree with respect to it 1 1 0 are the essentially it has to be 2 2 0.

So, this way if we look at it this indexing which has been done also has been done consistent with the stereogram which is there and the diffraction pattern which we normally get it in a microscope these we call it as 0th order Laue zone patterns. What this essentially means has been discussed in the diffraction, but just to recollect it what I will mention essentially is that the relationship between the reciprocal lattice.

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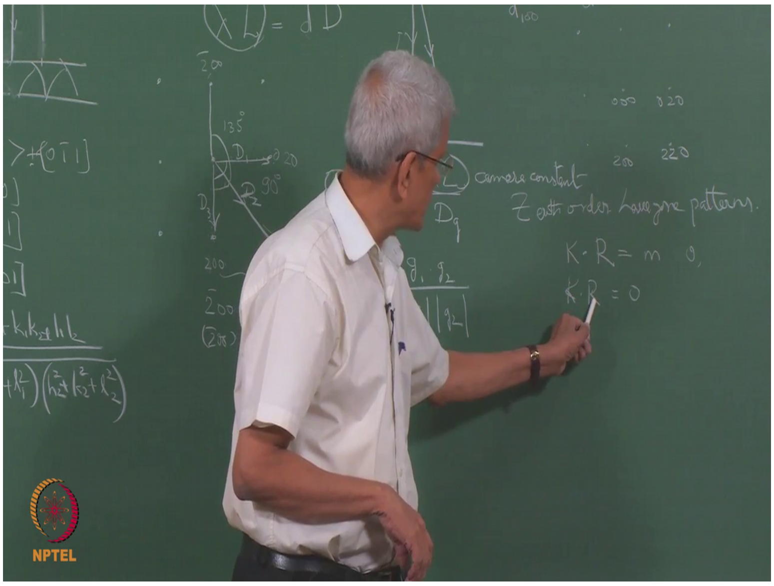

And that is one for constructive interference to take place we have taken the condition that the K dot R should be equal to m an integer where m can change from 0 to any value positive or negative when K dot R equals 0; that means, that what is R? R is a direction in the real lattice then for this particular R we can have many values of K which satisfy this condition all of them are perpendicular to it.

In a diffraction pattern also that is exactly what happens if you look here when we have index it we have indexed this patterns when we wanted to find out what is going to be the zone axis K zone axis in this particular case. Especially in the case of electron diffraction can be found out by taking the cross product of these 2 vectors if you take it that will give vector which is perpendicular to these 2 that is going to be the zone axis.

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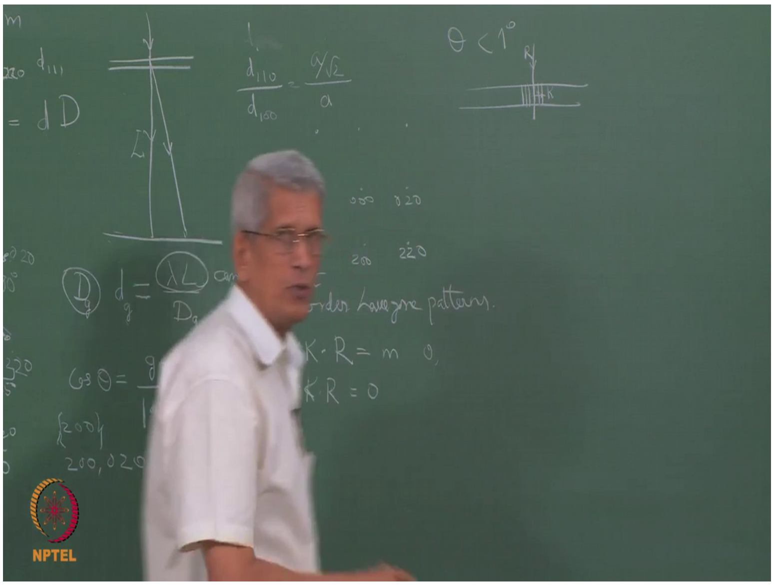

What is the reason for this because since the wavelength of the radiation is extremely small in the case of an electron diffraction the Bragg angle theta is very small less than 1 degree. And because of which what is essentially going to happen is that since the Bragg angle is the small almost when the electron beam is travelling in this particular direction in that sample almost all the planes which are very nearly parallel to the beam direction they are the ones which are going to give raise to diffraction.

The beams which are parallel to the beam direction if we look at the inter planer spacing that is going to come perpendicular to it; that means, that and in this parti direction is where the K vectors are there the diffraction vectors are going to be there in the K space; that means, that the direction or and the K is perpendicular to each other this is what is called as the 0th order Laue zone condition. So, you should remember that when we have identified these vectors.

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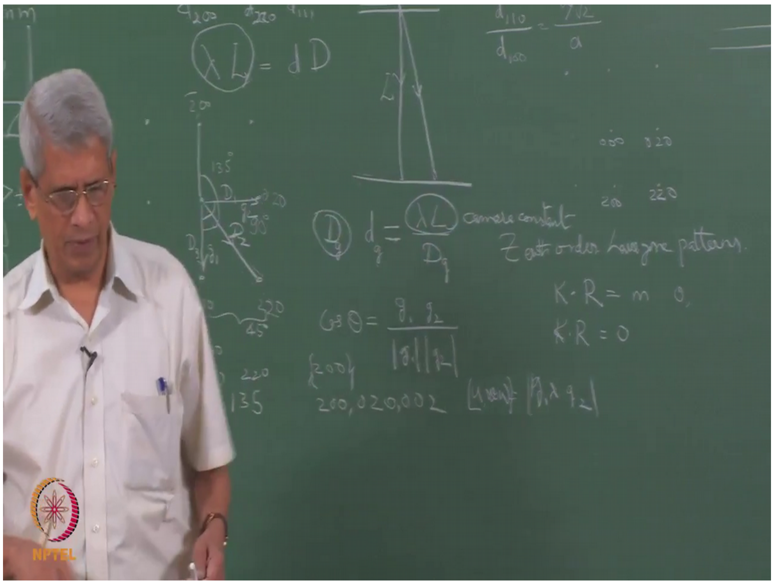

Then if this 2 vectors we call it as g 1 and g 2 then g 1 cross g 2 will give the beam direction or it will give that u v w the beam direction we could get the vector corresponding to it. So, essentially now we have covered how to get how to index a pattern and then how to find out the beam direction for that beam direction in this case turns out to be 0 0 1. Then we are trying to use the stereogram also to check consistently whether this indexing has been done correctly and find that it is so ok.

And here the same thing that is as I mentioned since the Bragg angle is extremely small for the electron diffraction if the beam is travelling in this direction this is a crystal which I had shown f c c crystal and this is 1 0 0 plane this is 0 1 0 plane and then the interpart inter planer spacing 0 1 0 is in these direction the in the same direction is where the reciprocal lattice vector also here it is going to be this direction these vectors are perpendicular to it when they are perpendicular to it that gives rise to. That means, that when the beam enters like this; this plane also can give raise to diffraction these play set of planes also can give raise to diffraction these sort of planes 1 1 0 planes can also give rise to diffraction. So, the spots corresponding to all of them we see in this diffraction spots. So, the axis the direction in which the beam is passing through this we can call it as the zone axis.

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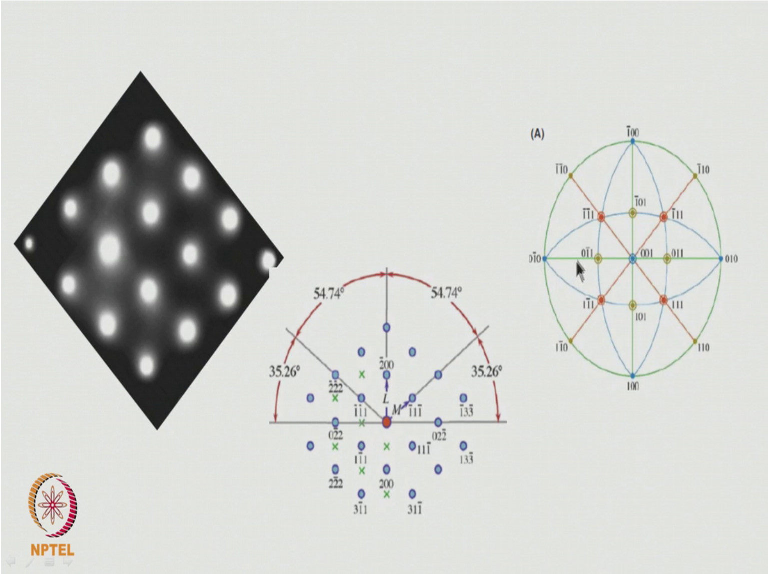

Because then I showed that if the sample is tilted because here the sample is tilted by an angle of 45 degree then we get a pattern like this; this pattern the sample could be tilted in whichever way we want it depending upon the type of tilt which we have given suppose I tilt it from here to in this direction and reach 0 1 1.

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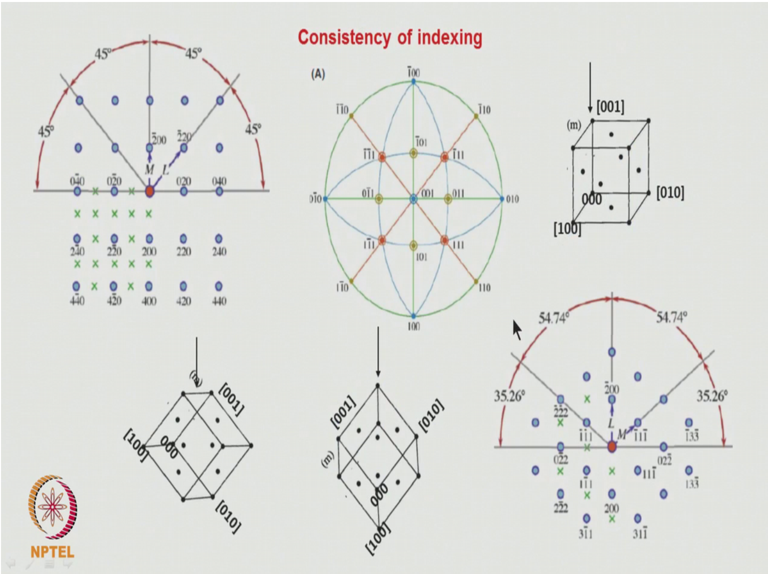

That is what it has essentially been done then this pattern can be indexed the zone axis is corresponding to 0 1 1 and then indexing of this spot can be done using this stereogram because for 0 1 1 if it is going to be the zone axis corresponding to that the all the diffraction spots should be 90 degree away from it from which the 0th order; that means, that there you should lie on a great circle corresponding to this particular pole the great circle corresponding to this pole which is 90 degree away from it is this one now we can see that 1 1 0 1 1 1 bar 0 1 bar 1 1 1 bar 1 bar 1 2 bar 0 0 these are all the poles which are lying on this, but out of which this is not allowed so, the reflections which will be 0 1 bar 1 1 0 0.

So, this will be 2 0 0 that is what it is indexed then when we tilt we can control 1 1 bar 1 and then when we rotate in the same direction 0 2 bar 2 when we rotate in these direction we will be reaching 1 bar 1 bar 1 then this comes in. So, essentially to index this spots we have used it because we have tilted from here and reached here then this is the type of spot patterns which have to come consistent with the tilt.

From these we can understand that using stereographic projection we can index the patterns correctly suppose the sample has been instead of tilted the tilting is because that if the sample is the beam direction I can tilt the sample. So, that if you tilt the sample like this; this beam direction will come and I can tilt the sample like this also then the beam direction is changing the same tilt could be given then instead of reaching it here I can reach this particular zone axis. If this particular zone axis I have reached that is why I should note down also what is the direction in which I am tilting that sample then the zone axis the pattern appears that the same. Now the indexing of we look at it this will be 2 0 0 this will become 1 1 1 this part will become 0 2 2. So, indexing of the spots will change this is very important in defect analysis.

Here what I have done is that same thing what I have talked about with respect to both the patterns are being shown here you can see that this is the 0 0 1 zone axis pattern and all the spots which are coming is because that sample is oriented the crystal is oriented like this the beam is passing through this direction. If I rotate the crystal in these particular direction then what it will happen this direction is 0 1 1 that 0 1 1 direction comes. So, since this plane is essentially the beam direction these are all the diffracting planes with respect to the beam direction these planes when we rotate it only this is getting rotated. So, they still are going to be in that same position. So, the spots corresponding to them will appear at the same position that is why you can see the 2 0 0 reflection comes.

Now, 1 1 0 type of planes or 2 2 type of planes has become parallel to a beam direction. So, those spots come, but if you look at these planes 1 0 0 type of plane when we are rotated they have become inclined with respect to the beam direction. So, they do not give rise the 0th order Laue diffraction they will not appear. So, those spots have vanished. So, not only using this picture you can not only logically argued which reflections are going to come using the stereographic projection we can easily index the pattern consistently suppose the tilt has been done in such a way that it is rotated from here to here in the clockwise direction if I rotate it clockwise direction 45 degree then as it is being tilted. Now you find that the direction this comes the beam direction turns out to be nothing, but 0 1 bar 1 then the indexing of the pattern as I had mentioned earlier will change and that is the way an indexing has to be done this is how spot pattern will appear.

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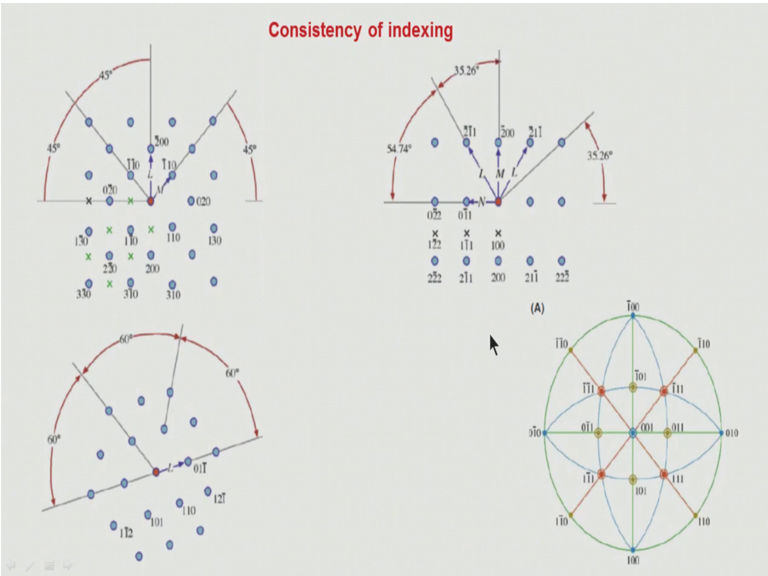

In the case of a b c c lattice this is 0 0 1 zone axis this is 0 1 1 and this is a 1 1 1 zone axis 1 1 1. So, from here to here we have tilted then the indexing is always done consistently if we use a stereogram I hope it is clear to you people. If the sample is ordered sample then we can get some super lattice reflections in between that is what it is being shown these patterns are essentially a h computer generated because that simulation of that diffraction pattern can be done when we know the lattice parameter and what is the crystal structure.

In fact, what I would advice is that for the various zone axis using stereographic position and knowing the crystal structures for example, you can take simple cubic structure or body centered structure and try to find for various low index zone axis, how the diffraction patterns will appear. And you can like in this particular case we can try to you have to index them consistently as we tilt the sample from one direction to another direction if the beam because direction of the tilt also we can get it from the same stereographic projection and corresponding to that how the spots should appear that information is also contained in the stereogram that is why using stereogram we can get we can index the spot patterns consistently.

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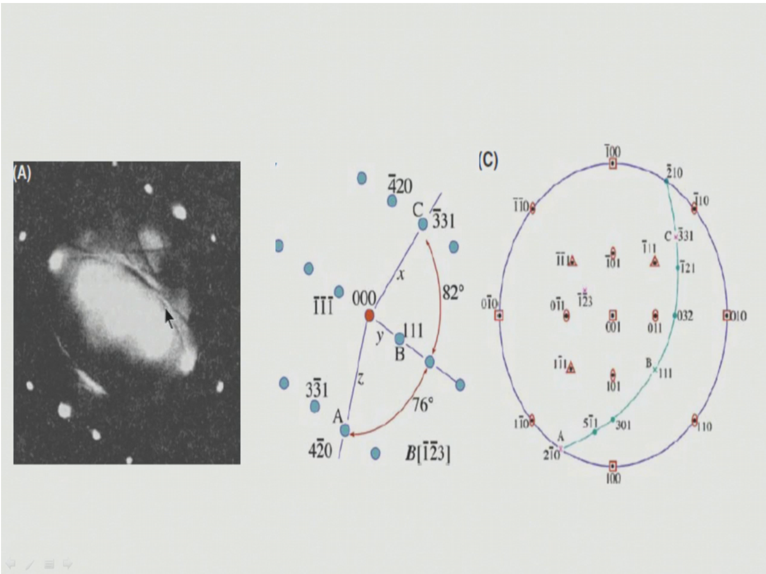

This is an another example where it is tilted to 1 1 2 zone axis direction in this with a consistent. So, when using stereogram it has been indexed no not this is corresponding to 1 2 3 not 1 1 2 this is now 1 1 bar 1 bar 2 3 and the great circle corresponding to it is this particular one this great circle on which the various reflections are lying from these reflections. Now you immediately find out using the structure factor rules which are the reflections which should appear and that way this pattern has been indexed consistently.

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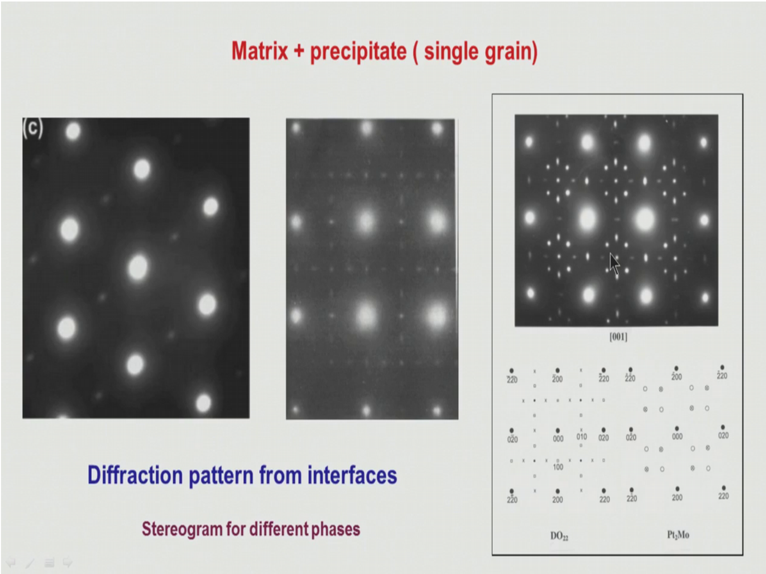

So, these patterns which we have considered. So, far are very simple patterns a single phase of a material quiet often what can happen is that even in the matrix region where we consider there are some second phases particles are distributed like this.

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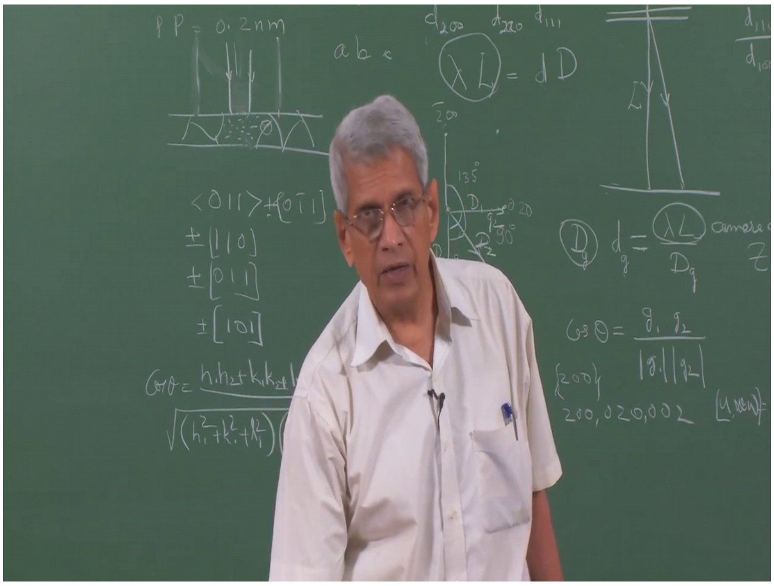

If they are distributed depending upon their orientation they can also give raise to extra reflection corresponding to them if we index these matrix as well as the second phase particle. Then we can get information about the orientation relationship between matrix which is necessary for correlating microstructure to mechanical properties.

This is a from a gamma prime phase where by indexing it we could identify it that its orientation and it is the cube to cube orientation relationship between matrix and the precipitate. But in this particular case if we look at it this is from another diffraction pattern which is little bit more complex where you can see that there are many reflections are there to identify to index this diffraction patterns the first thing which we have to do it is that we have to identify the reciprocal lattice sections because the periodicity of the lattice has to be maintained in the reciprocal lattice section as well.

So, in this if you try to look at it all this intense spots they give raise to one particular type of a periodic structure then if we look from here to this spots which are there in the this one they give raise to another periodic structure then if we see the spots which are like this L this one this one this one they give raise to and another one this gives raise to another type of a periodic structure. So, many types of periodic structures are there since this has been analyzed I am talking about it, it is not a very trivial this one this is the one which you have to learn and this will take this comes through experience by analyzing first the best thing to do is to first analyze simple patterns from the matrix that is the way you learn how to index the diffraction pattern.

Then you go into a complex patterns where the matrix plus precipitate is there here in these pattern if we look at it there are diffraction patterns due to matrix plus 3 variants of a particular phase and plus 2 variants of an another precipitate phase all embedded they are in this diffraction pattern this pattern which has been analyzed which is given here one corresponding to this one. And the another corresponding to the second phase that is both the phases are present here how it is being indexed, but the when you have the final result it looks quiet trivial, but the root which you have to take it to get it is not that trivial this which we will learn when we try to do some assignments this is from a single grain what we have considered where the matrix plus precipitate.

Suppose, we wanted to find out orientation between this grain and at this particular grain are how that interface plane or even in this second phase particle how the interfaces look like if we wanted to find out we have to get a diffraction pattern from both the regions together or from this region and this region across it different types of patterns. And then analyze them and then try to get information about their interface that part of it I will not go in this present lecture that is beyond the scope of this course and another important aspect which you have to think is that these super lattice reflections which you see they correspond to some of the ordered phases which are non cubic. So, for non cubic phases which are present for each of this phases standard stereogram are not available.

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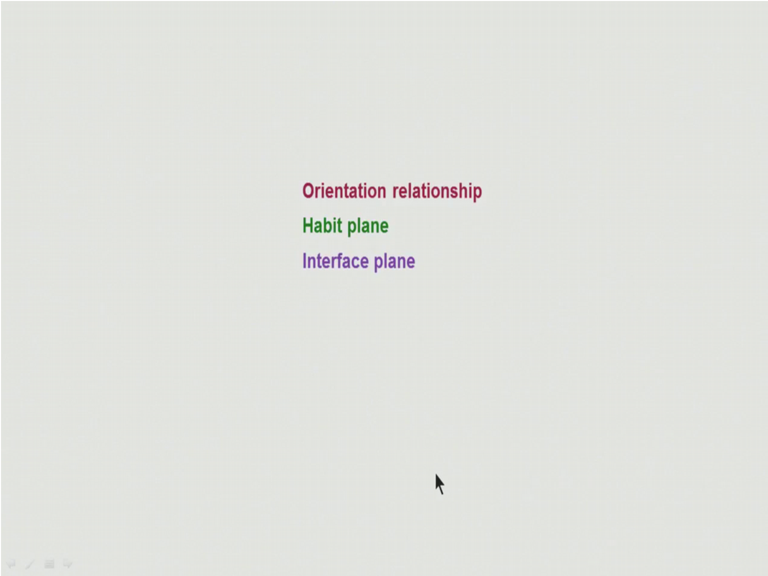

Once you know the lattice parameter A B and C as I had mentioned in the class on stereogram you can construct stereogram corresponding to various poles for those phase those stereograms could be used to index the patterns consistently. So, as I had mentioned overall once this sort of patterns have been analyzed we can use them to get information about the orientation relationship then.

Suppose, this spaces have some specific habit planes are there what is the habit plane which that second phase is lying then what is the interface plane what is the grain boundary plane like if it is a low angle or a small angle grain bound all these information could be using this diffraction pattern analyzing this diffraction patterns. What is essentially important is that first analyzing the diffraction patterns each pattern and identifying what zone axis they could correspond to and using the tilt information of the sample which is available the indexing of the pattern have to be made consistent.

So, that we know that if we tilt from one particular orientation to another orientation in a specific direction in the diffraction pattern this is the specific type of reflection which will be coming one such an indexing has been done. Then those index patterns could be used when we have got corresponding images of the microstructure to characterize various types of defects in the material in one class. It is not we cannot cover everything about indexing of the various types of diffraction pattern what I had told in this class is just a brief philosophy of how to go about and index the diffraction pattern you understand it much better when you index various types of diffraction pattern from simple crystal structures then you gain experience and also confidence how to go about consistently analyze that diffraction patterns and use it to interpret the micro-structural observations. I will stop here now.

Thank you.