Electron Diffraction and Imaging
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Lecture - 25
Phase Contrast Microscopy - 01

Welcome you all to this course on Electron Diffraction and Imaging. In the next few classes, we will discuss phase contrast microscopy. So far what we have studied is essentially a conventional electron microscope, where we can get bright field and dark field images, different types of diffraction like parallel diffraction, kikuchi diffraction, convergent beam diffraction, their applications that is what we have studied.

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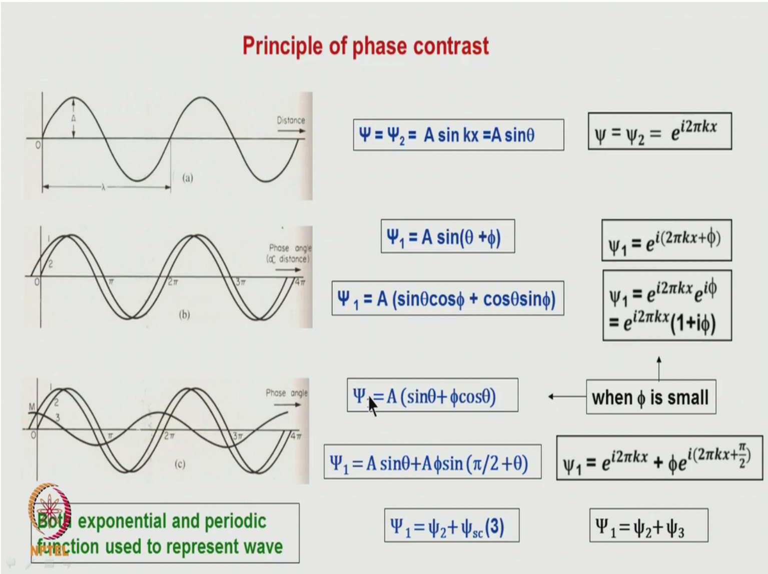

Now, we will look at what is phase contrast microscopy and what are its applications. Even in optical microscopy you have studied the various types of contrast. One of the principle contrast which is used to look at biological samples where that inherently the contrast is weak. We call it as the phase contrast microscopy. What is the principle of a phase contrast microscopy? That is the light wave which enters which is scattered from the sample which is that probe which is falling onto the sample. We can consider it as a wave. There is an electromagnetic radiation and if you consider it as a wave, there are two ways in which we can represent it.

One is the graphical representation of it as a function of time or as a function of the distance. How the amplitude of the wave changes, this we can plot it? That is one that same thing can be represented in an equation form, where psi equals a into sin k x, where k equals 1 by lambda. The same thing can be returned in the form of exponential that is e to the power of i 2 pi k x. When a wave of radiation falls onto a sample, suppose you assume that this is that sample and the radiation is falling on that sample and the radiation which comes out, ok.

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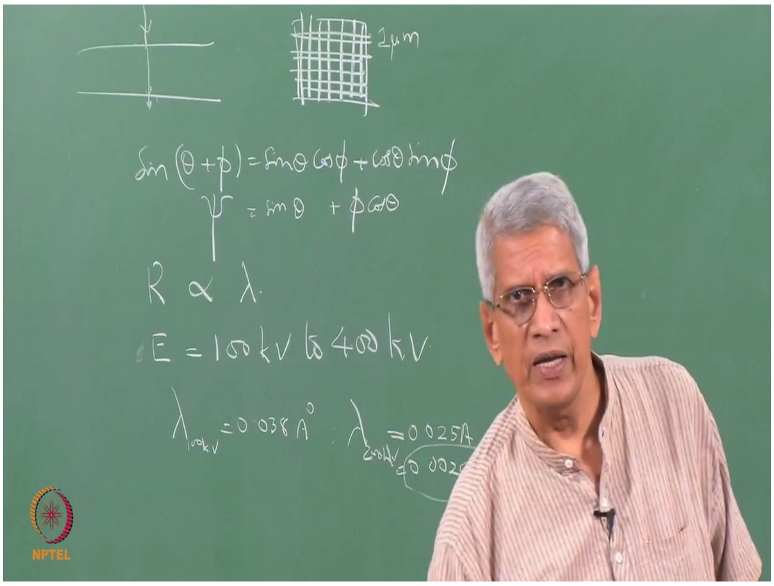

One the radiation which comes out without any interaction and some part of it which interacts it, when an interaction takes place and there is a change what is essentially happening, we assume that if absorption is not taking place, the only change which can take is that phase of the wave can be changed.

If the phase of the wave changes, then we can write that is this is corresponding, this is the initial wave which is corresponding to this particular wave and the one corresponding to a wave which is scattered and the scattered wave into since it is sin theta, this theta plus phi is the phase which has been, it could be a lag or the same thing which is being written. This expression if we now try to expand it, we can write it in this form and similarly, here also this can be sin 1 equals that is you just that trigonometric function which we use sin theta plus phi equals sin theta cos phi plus cos theta sin phi. If the phase lag, phase is very small, the change which is taking place, then this can be written as sin theta because cos phi becomes 1 and this becomes sin phi becomes phi into cos theta. This is what essentially that amplitude becomes; this is what expression which has been derived.

The same thing if you write it in the exponential form, this turns out to be 2 1 plus i phi. In this one if we look at it, essentially this can be looked at in a different way. What is this cos theta? Cos theta can be represented sin pi by 2 plus theta which we can write it; so, that means essentially the total wave which is the scattered wave can be considered as 1 sin theta which corresponds to an initial wave plus a into phi becomes that amplitude. This is of the wave which is essentially is shifted by 90 degree with respect to this initial wave.

So, then this is how this wave is going to be that is what essentially which is being written both in the exponential form or just using a periodic function sin theta, but what is essentially which we have to see is that what is the intensity. Intensity is psi psi star. When we take the intensity psi psi star, essentially what it will happen is that nothing, but when we take this, the phase will vanish and only the amplitude factor comes. So, we do not get any information about the phase as such like this, ok.

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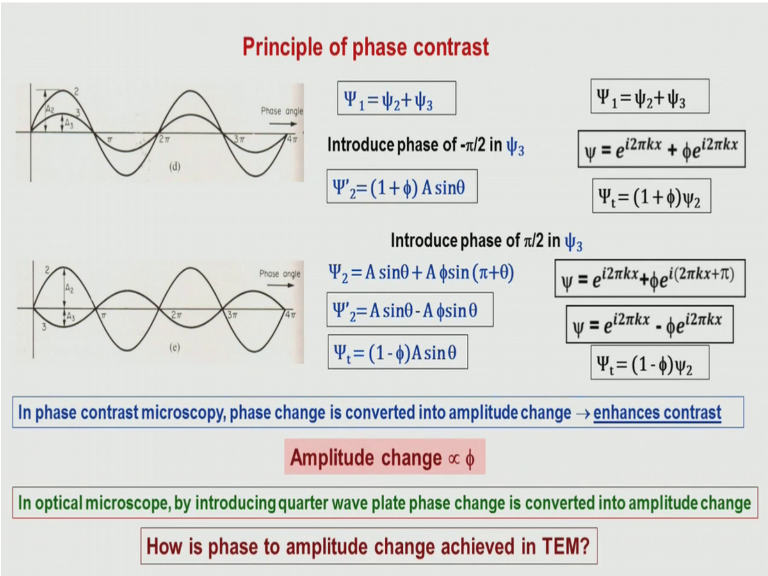

If the scattered wave if we can introduce another phase pi by 2, either it is a lag or sub, then what is essentially is going to happen is that this will give rise to what suppose we introduce a phase of minus pi by 2, this will give rise to finally the psi 2. That amplitude becomes this wave which was initially which was like this. It has been shifted that it becomes 1 plus phi into a sin phi. That means, that whatever is the phase which has been introduced due to a interaction of the beam with the sample, that has been transformed into an amplitude variation.

An amplitude variation is the one which we normally see in the image as a contrast variation. When the amplitude varies from a region to region, that is what essentially is the principle of phase contrast. If we introduce phase pi by 2, it is a lag. It is not a lag, it is going forward. Then, what is going to happen is that psi dash becomes this is what essentially it becomes. So, in both the cases, we find that the variation in phase has been changed into a. How this phase difference could be introduced? This is done in the case of an optical microscopy by introducing what is called as a quarter wave plates.

Essentially what a quarter wave plane does is, this is one which is corresponding to a scattered radiation, this is corresponding to the direct radiation and this radiation which has undergone scattering or we call it as a diffraction to this by introducing a quarter wave plate to this wave alone. We introduced another pi by 2 is the phase shift. This way we can convert the phase difference which has come in as a result of scattering into an amplitude difference. So, this amplitude change is directly proportional to phi. So, this is how it is done in the case of an optical microscope.

Now, the next question comes is that how is this phase to amplitude change achieved in t e m. That is a next question which we have to address. Before we go into this one, let us look at how an image is formed in electron microscope or in an optical microscope. It does not matter.

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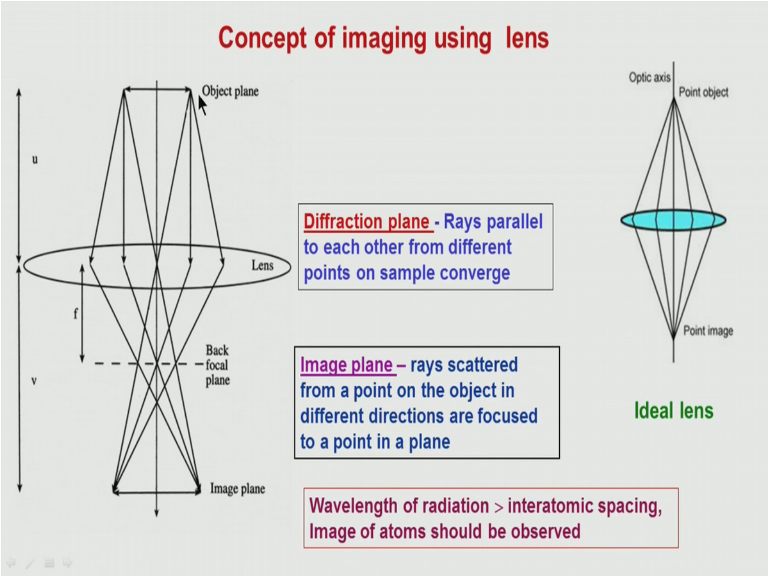

Whichever is the microscope is what we have is an object in which light is scattered from every point in different directions. These rays which are scattered in different directions, they are focused. There are two planes which we can define for a lens. One is called as a back focal plane; another we define as that image plane. What is the diffraction plane?

The rays which are scattered from different regions of the sample, but in the same direction; here we have taken two extrements which is scattered in this direction and the ray which is scattered in this direction, it is focused at this point and the direct transmitted ray which does not undergone from these region, they are focused at this point. The ray which are scattered in this direction, they are focused at this point. So, the back focal plane is the one in which the rays which are parallel to each other and close to the optic axis, they are brought back to a focus.

What is the image plane? Image plane is the one in which the ray which are starting from different points on that sample, you see that from this point this ray is scattered in this direction, scattered in this direction, in this direction. All these rays are brought to a focus at a particular point along the optic axis, perpendicular to optic axis in a plane. This plane we call it as the image plane. So, depending upon the magnification of the lens, we can get a magnified view of the object and depending upon the resolution, we will be able to resolve the features of the object. So, what is the resolution?

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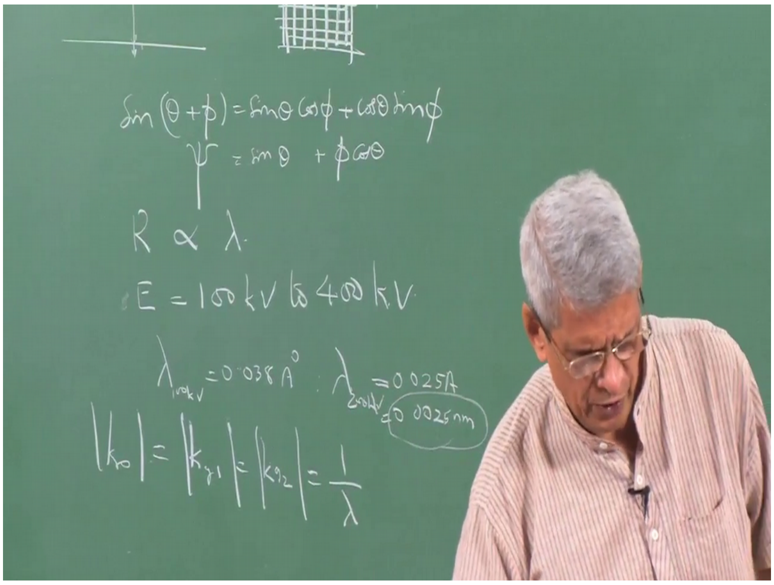

The Rayleigh criterion says that the resolution essentially proportional to lambda. Lambda is where the wavelength of the radiation which we are using it.

In the case of an electron microscope when the electrons are accelerated to very high energy, where it is of the order of voltages which are applied are 100 k v to 400 k v, then the wavelength if we consider lambda, it is 100 k v. It is about something like 0.038 Armstrong and it is 200 k v lambda equals 0.025 Armstrong or this is equal to 0.0025 nanometer. So, that means in principle the limit of resolution is essentially corresponding to the wavelength of the radiation separation between atoms in all real samples is much larger than this value, correct. So, because of this if the lenses do not introduce any of the aberration that means for a point object, we are able to form a point image where assume that it is an ideal lens. It has no aberrations or we assume that all the aberrations are been corrected and it is made into a perfect lens.

In such a case for a point object, we will be able to make a point image and the resolution is essentially is given by the wavelength of this radiation. That means in principle, the atom should be resolved. You can see it especially you have seen in the case of an optical microscope in the case of an optical microscope are when the object is grating or it is like if we take a cloth which has lots of lines are there, network of array grid if we take it since the wavelength of the radiation is if the grid separation is of the order of about may be 1 micron and since we know the wavelength of the radiation is about 500 nanometers, then we will be able to see the image which is of the grid could be formed.

Similarly in this case where in the case of a crystalline material where the atoms separation is of the order of about 1 to 2 Armstrong, in such cases since the wavelength is very small, we should be able to form in principle for a perfect lens high resolution image or an atomic image. We should be able to form. This is what it becomes obvious from this transparency.

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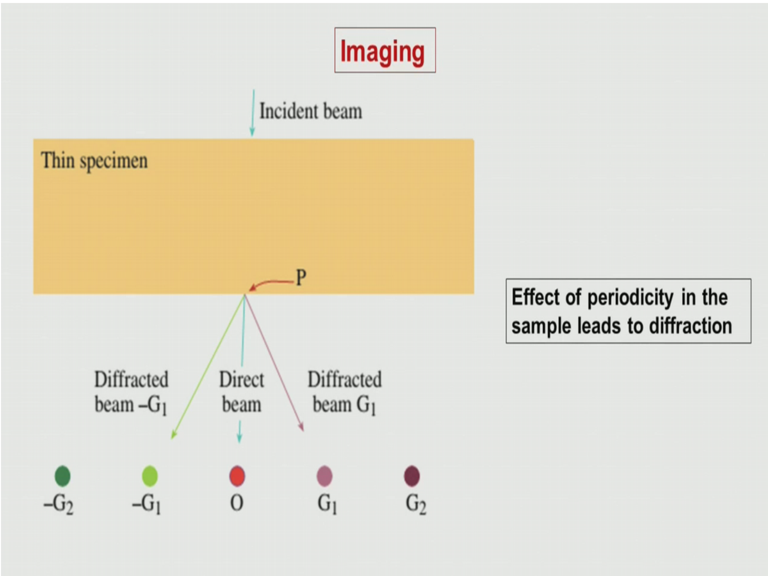

Now, let us just go into little bit more detail how do we form an image to derive some mathematical expressions which we can use it. When we have thin specimen which is there, where the incident electron beam is there, this is the direct beam and this gives rise to direct spot and the diffracted spots give rise to spots which are indexed as G1 G2 and these diffraction spots are arising because of the periodicity in the sample.

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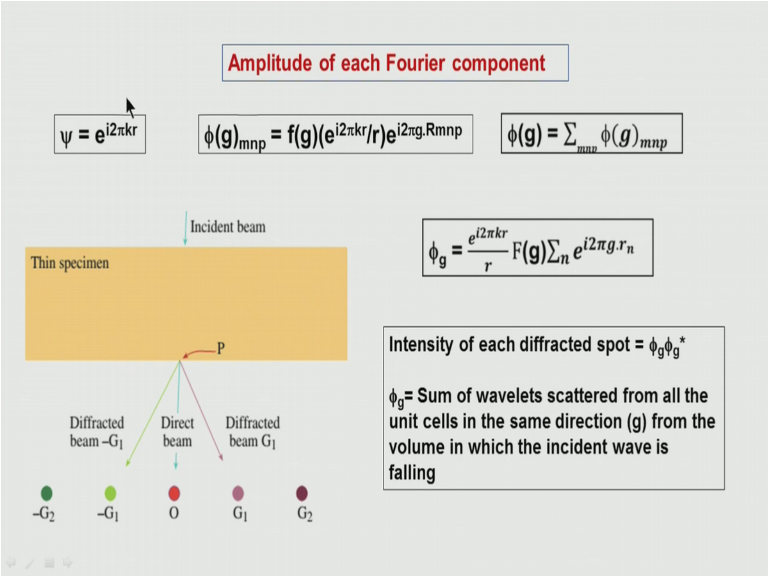

Let us look at what will be the amplitude of each of these diffraction spots. The incident wave we represent it is plane wave and it is given by the expression psi equals e to the power of i 2 pi k r corresponding to this particular position. What is the contribution to the amplitude from an atom at a position? R m n p is given by this expression, where f g is corresponding to the atomic scattering factor. This is especially this term comes because from a point source when it is scattering into a spherical one, the amplitude at any distance will be e to the power of i 2 pi k r y by r. You know that then e to the power 2 pi g dot r m n p is what it is going to determine the phase factor, ok.

If from all the atoms which are there which are being r, the incident beam is illuminating some volume of that sample. If we take the contribution from all of them together, psi m n p that this is going to give the amplitude of the each of these spots. What is essentially important here is that this factor is going to change depending upon in which direction the atomic scattering is taking place, correct.

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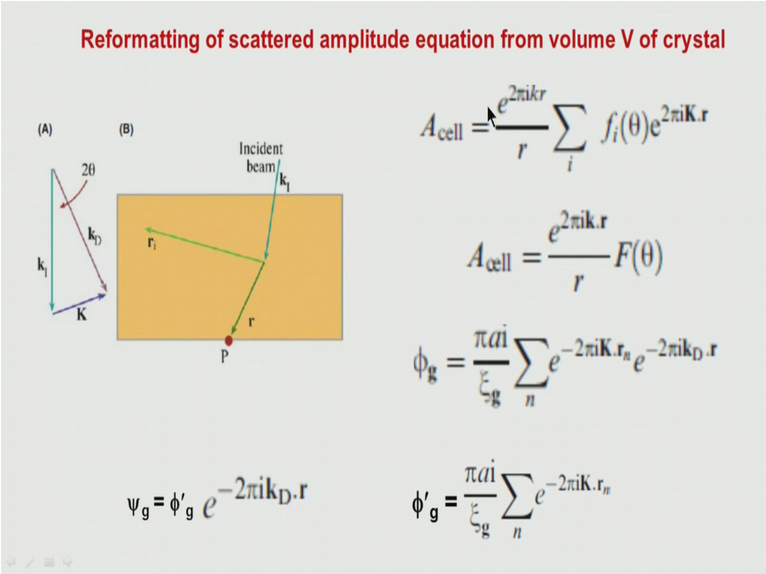

This can be rewritten in a different form which is what essentially is being done where we can introduce the temp psi g which is that extinction distance which we will forget it for a moment.

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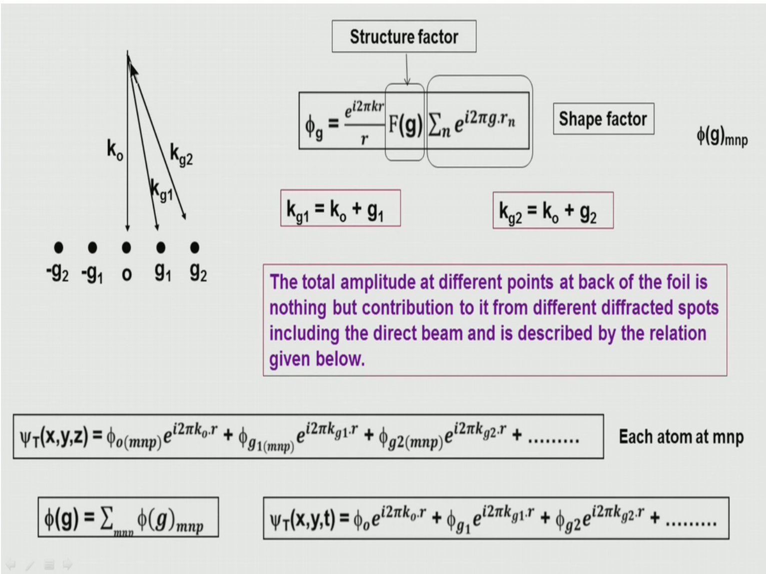

Now, what I have done is that in this transparency if you look at it, we can represent k vectors corresponding to different scattered direction; in this particular way, k0 k1 g1 k1 g2 which is corresponding to the diffraction spot g2. What is the magnitude of all this? K0 equals k g q magnitude of them that is the vector equals 1 by lambda which we know, but in a vector notation if we try to write it this k g 1 will be k 0 plus gone. K 2 will be k 0 plus g2.

So, these are all if at any point on that image plane what is going to be the total amplitude of the wave, there it is corresponding to the one which is coming from the transmitted region and the one coming from each of that spot. These amplitudes have to be added together here. What is being taken is that this itself can be written as corresponding to from particular atom to various contribution. If we take it, then the psi total will be corresponding to the path of the amplitude phi 0 m n p into the term that is term here at a distance r. It is going to be there.

Here this vector has to change because this will become k 0 plus g because this is 2. So, this is the way it will be. So, if we take some of each of this, this gives rise to a at each point from an atom at m n p. What is going to be the contribution, which is going to be there in that image that amplitude, amplitude of that image?

The same thing we can write it at what is going to be the amplitude at every point from taking each of this diffracted beam. That is what we are essentially doing it is that we are taking each of the diffracted beam has an amplitude corresponding to it at any particular point. That is what we are trying to do is essentially this is transmitted beam 0 and this is the diffracted beam.

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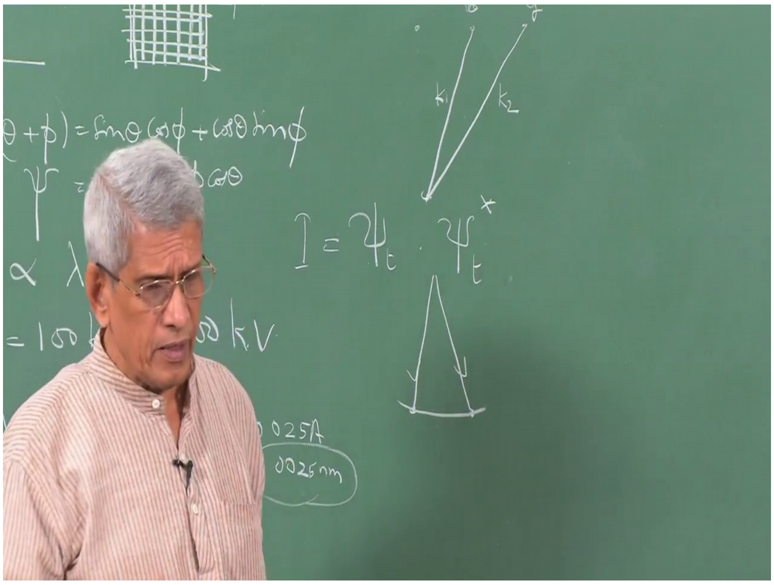

Suppose at any particular point this is the vector k, this is another vector k1. You can assume k2. So, these two vectors at these points when they come and join together, the total amplitude at this particular point will be corresponding to one which is coming from here and another from here. That is what essentially it is being this is for only two beams. If we take all the beams together, this is what it has to be added together. This is the sort of an expression happens in this if we substitute k0, this is what essentially it will become.

Now, immediately you can make out if you see this expression is that the periodicity of the lattice appears in these factors. Essentially what we have done is that the wave which is a direct wave and the wave which has been scattered, we have just added together, ok. That is essentially what is being done.

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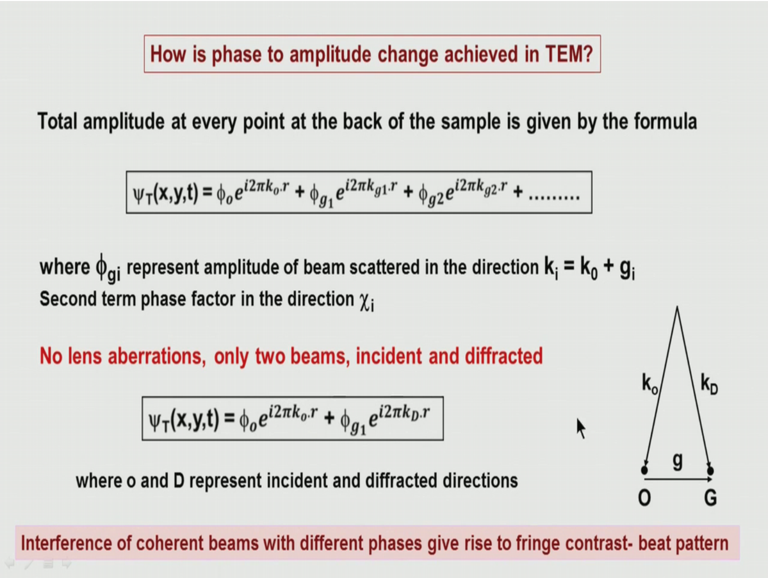

So, in that case where we consider only two waves that is which is called as a two beam condition that is though in the diffraction spot, many spots will be appearing. We are only considering one diffracted, one incident beam and one diffracted beam. Then, this is how there expression will turn out to be the interference of these two waves will give rise to some fringe pattern or beam pattern which will be generated. This is what we are looking at.

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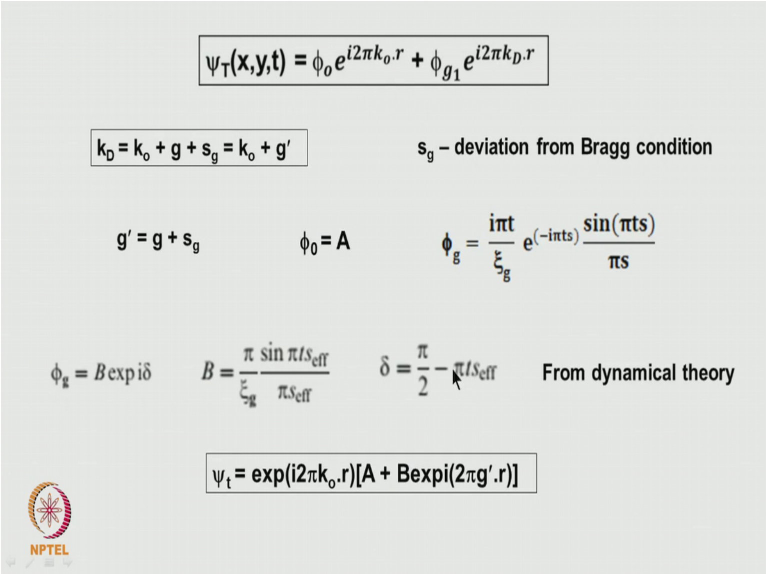

In this case, what we have considered the assumption which we have made is that the lens has not introduced any aberration in the beam. So, then we can write this k d, this diffracted beam equals k0 plus g plus s g is the deviation from the Bragg condition. Now, this turns out to be if we do these substitutions, this amplitude phi 0, we can write it as a that phi g from the dynamical theory. This is the sort of an expression which has been derived. Then, we can write this as phi g can be written as b into this one. The b is going to be pi by pi t by psi g into this term i into this one.

This is what essentially written in the form of a delta. So, we if we substitute this, now what is essentially is going to happen is that this is the way the expression which will turn out to be a to a plus b into exponential i. This is what is the intensity. Intensity is that we an got an expression for psi t, ok.

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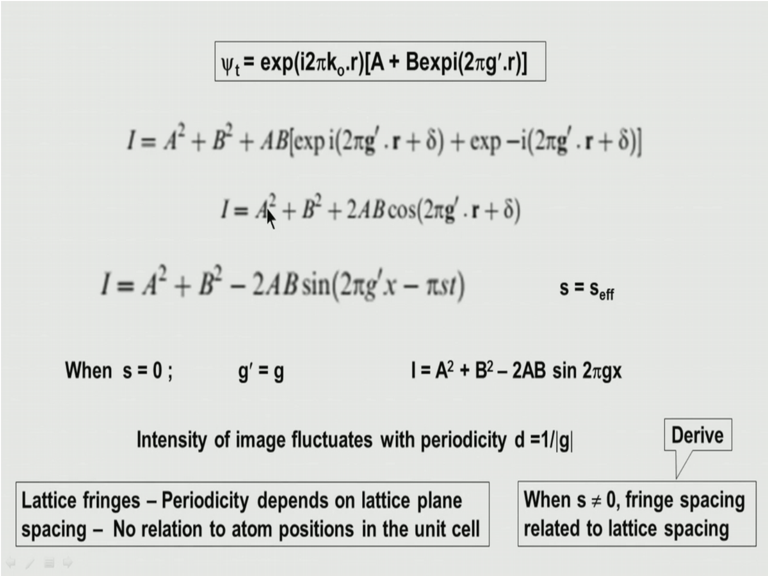

Now, we can find out psi t star because this is a complex function intensity i equals psi t into psi t star. That is what essentially which has been done and when you do the algebra, this turns out to be a fact becomes a square plus b square plus 2 a b into cos 2 pi g dash dot r plus delta. This delta what we can substitute it and then finally, this expression turns out to be minus 2 a b sin 2 pi g dash dot k.

Let us take the case s equals 0. That means that the diffracted beam satisfies the perfect Bragg condition. In that case, this is how the expression will turn out to be. Now, we can make out that the intensity is going to fluctuate as a function of g. How g is there, this is going to depend determine the periodicity in the intensity or the intensity of the image fluctuates with the periodicity that which is g. It is going to be that is equal d equals 1 by modulus of g. This is what intensity is.

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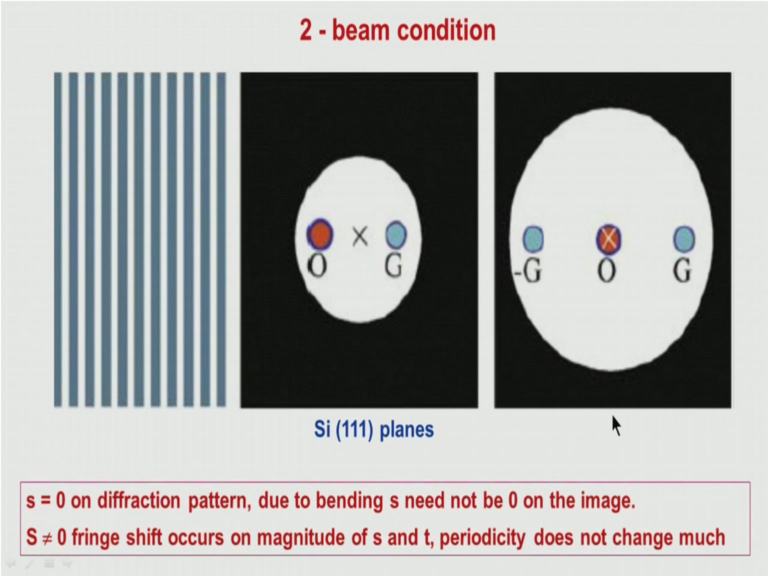

Now, we can just see how exactly it is implemented that is from this expression, what we can make out is that as function of g, the intensity is going to vary periodically. Let us look at how it is being implemented in the microscope. We have an incident spot and a diffracted spot.

If we put an aperture around it, you remember that how images are formed that ray diagram for image formation in which at the back focal plane, we put an aperture, so that the image due to both of them are allowed to interfere. When the images due to this interfere, this interference will give rise to a fringe contrast and this is how the fringe contrast turns out to be if we look at the separation between this, this separation corresponds to d, the lattice spacing depending upon the type of aperture which we can use as many beams as possible to contribute to this image.

In this particular case, since it is a two beam condition which is considered only one type of fringe takes place and another important factor which becomes is that the fringe spacing if we look at it is in the direction of g because that is varying in this. The contrast is varying in the direction of g, ok.

Suppose s is not equal to 0, but what happens is that in such a case, in this expression if you look at it this term is all also going to be there. Essentially what is going to happen is that this is not going to affect the fringe spacing, but what is essentially is going to happen is that depending upon magnitude of s and d, the fringes can shift a little bit from region to region depending upon what is the variation.

This sort of deviation can occur, that is the deviation in s can occur because even if the sample is aligned that is we have diffraction spots are there, it is Ewald's sphere passes right through the diffraction spot in spite of it the region to region defects could be there which could give rise to a local change in the deviation from the Bragg condition or the sample itself is bent a little bit because of which also s, the deviation from the Bragg angle need not be 0 everywhere on the image, but this variation is not going to make some shifts in the fringe, but it does not affect the periodicity much. That is what one should remember.

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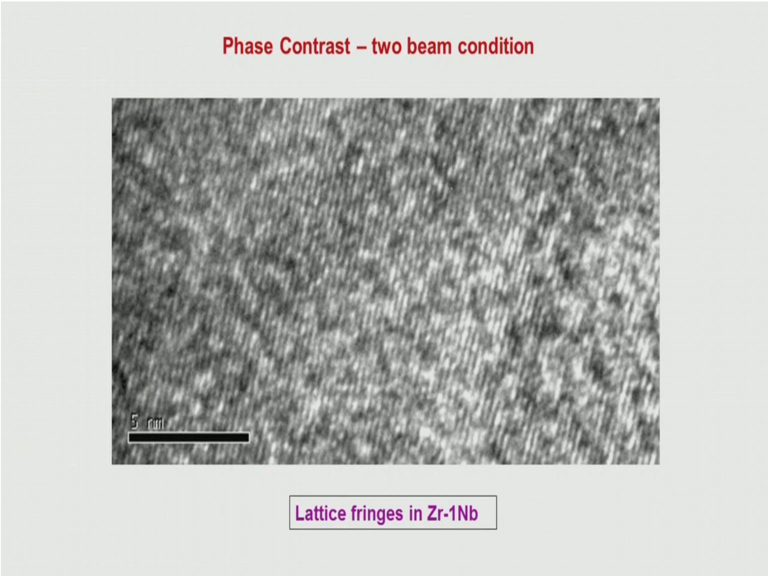

This is a typical high resolution lattice fringe image which is taken from a zirconium one niobium using a two beam condition by measuring this fringe spacing. This should correspond to the lattice spacing. So, if you know the magnification, we can find out.

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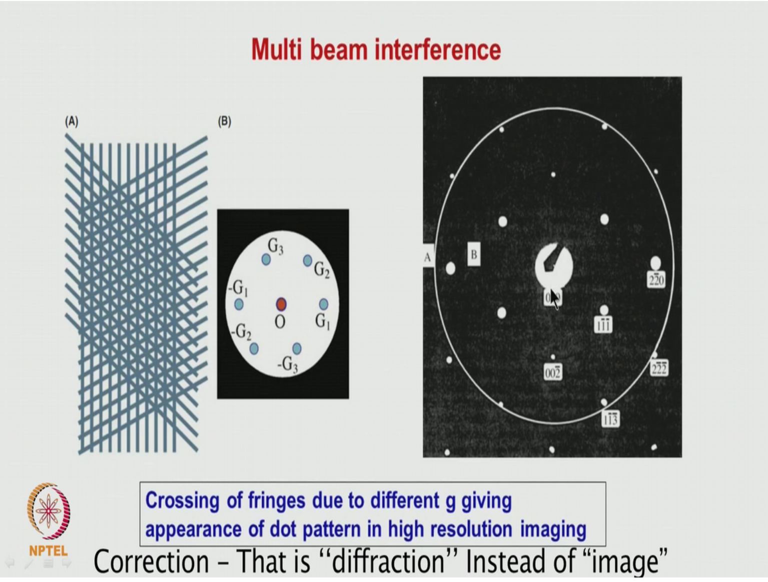

Suppose we take many spots to form the diffraction, that is the case which is being considered here due to g1 that is another g2 g3, in such a case what is corresponding to this perpendicular to this, we will be getting a fringe spacing perpendicular to this g vector. We are going to get another fringe spacing corresponding to this particular one.

There is another fringe spacing when these fringes they are overlapping on each other, it will give the appearance as if dotty contrast, but we should remember that this is not an atomic contrast. This is only just a spacing between the lattice planes is what is being given, nothing else beyond that. In this particular case, we are just showing a case where in silicon this is the sort of an aperture which is used to form the image.

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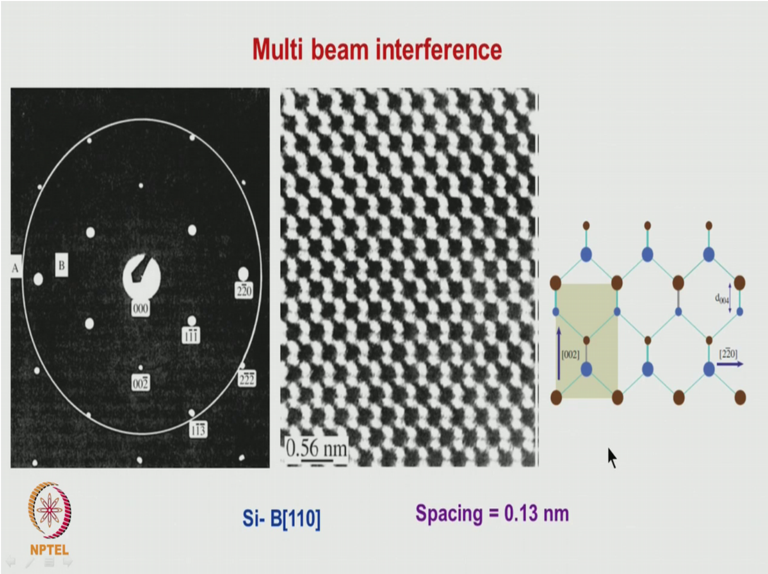

We look at the picture. How it looks like this is that aperture and if you look here, this is the high resolution picture which has that is the lattice fringe criss crossing of lattice fringes in various directions; this rise to contrast which looks like an atomic contrast, ok.

If we look at the separation between these two, this essentially corresponds to the spacing is 0.13 nano meter in silicon and the beam direction is 1 1 0. We have used only 2 0 0 reflections, 2 2 0 reflection, 1 1 1 type reflection, 1 1 3 bar reflection. These are all the reflections which has been used to give rise to the overlapping of the interference of the fringes, giving rise to this sort of a contrast. In this if we look at it, the separation between them corresponds to actually d 0 0 4.

That is what essentially the plane d 0 0 4 planes, but if you look at the diffraction spots which has been used to cross interference, we have not used d 0 0 4. Only d 0 0 2, then how does this d 0 0 4 appears. This sort of a as if from this one point which becomes very clear is that what we are essentially seeing it here truly does not represent the lattice fringes. This arises because a fringes corresponding to 1 1 bar 3 and corresponding to another 1 1 bar 3, these ones if we join them together if they interfere, that will correspond to 0 0 4.

That is how we are getting in. Actually if we look at it, we have not used diffractions pattern corresponding to 0 0 4, but then we should not get fringes corresponding to that.

This is one thing which we should keep it in mind in all these images and another is that it is only gives the diffraction plane spacing because if we wanted to know the atomic structure, we should know which positions are being occupied by atoms on different planes that information does not come from this interference fringe contrast, ok.

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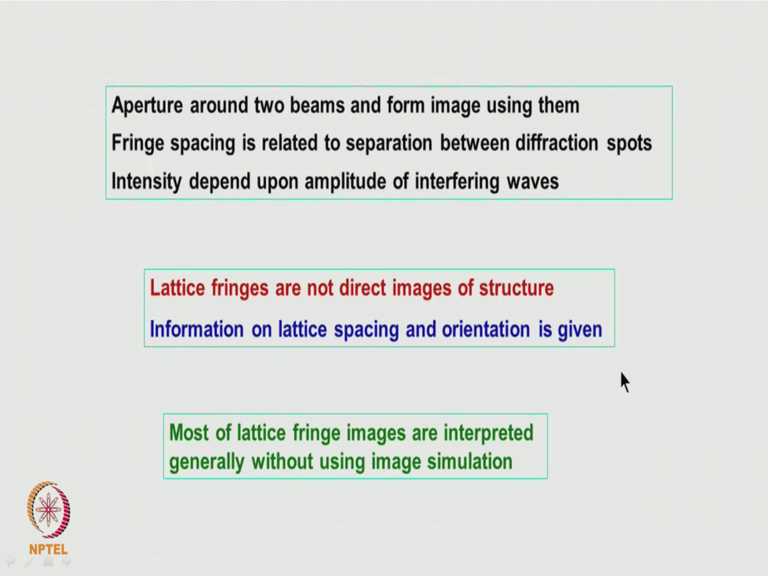

Here I had just shown some examples of high resolution images which has been taken on different samples.

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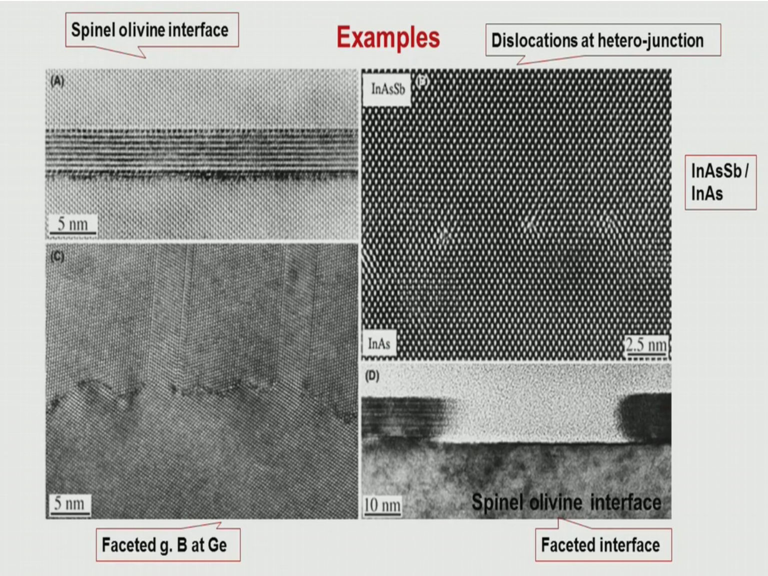

Look at that interface between two phases. One there are grain boundaries which could be faceted grain boundaries and these are all some twin related structures because these two regions are twin related. In this one, indium arsenic antimony here if we look at it, the contrast looks almost the same, but there is a distortion of the contrast which we can see; as we mentioned the fringe that is the slight shift which has happened.

As we mentioned earlier, this region corresponds to where some dislocations are present, interfacial dislocations are present and when the interfacial dislocations are present, the atoms are displaced a little bit. So, this gives rise to a variation in s which gives rise to small shift in the fringe spacing here. So, what all the conclusions which we could make out from what we have covered?

So far one aperture we place it around few beams and form image using them. The fringe spacing is another is related to a separation between the diffraction spots. That is what the expression clearly shows intensity, but what we have seen it is that we get separations which are not revealed by this separation between the diffraction spots. This could also be explained because this could arise due to interference between some other spots which could generate this sort of a fringe contrast. Intensity depends upon the amplitude of the interfering waves.

So, from this what all information which we can have, lattice fringes are not direct images of the structure information on the lattice spacing and orientation is we can get it. So, to get actual information, we should do a simulation of the images, but most of the time you will see in the literature this information which is available from the lattice fringe. Images are interpreted using simulation. This is only a very qualitative way in which one can interpret it. One has to be very careful because sometimes it can lead misleading interpretation of the results, ok.

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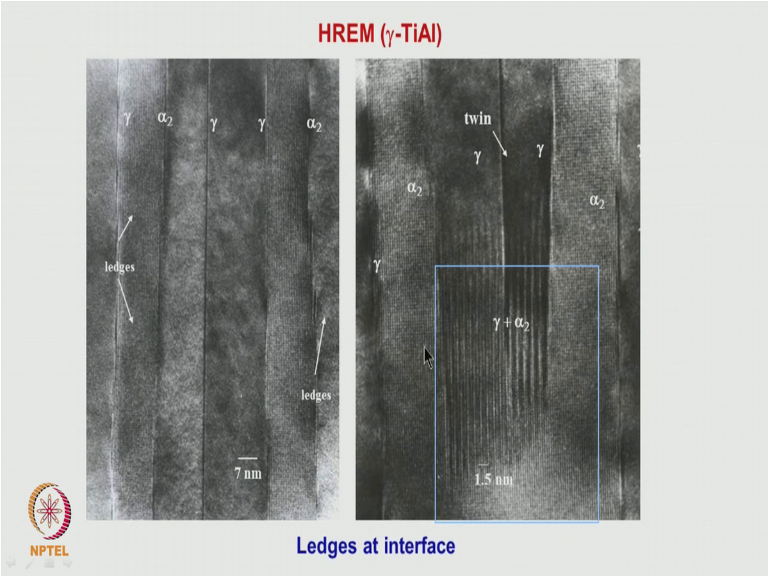

So, it is always better to do image simulation to get correct interpretation of the structure. This has some other few pictures which are taken from one is from a high resolution electron microscopy pictures which are taken from a gamma titanium alloy, where after heat treatment has separated into two phases gamma t and alpha to phase which is h c p.

The interface between these phases, you can see the ledges which could be seen. This sort of ledges these are all the ones in a plane interface. If it has to be grown unless some ledges are there, it is very difficult for them to go which these aspects you might have studied in phase transformation and using high resolution microscopy, we can get direct evidence for it.

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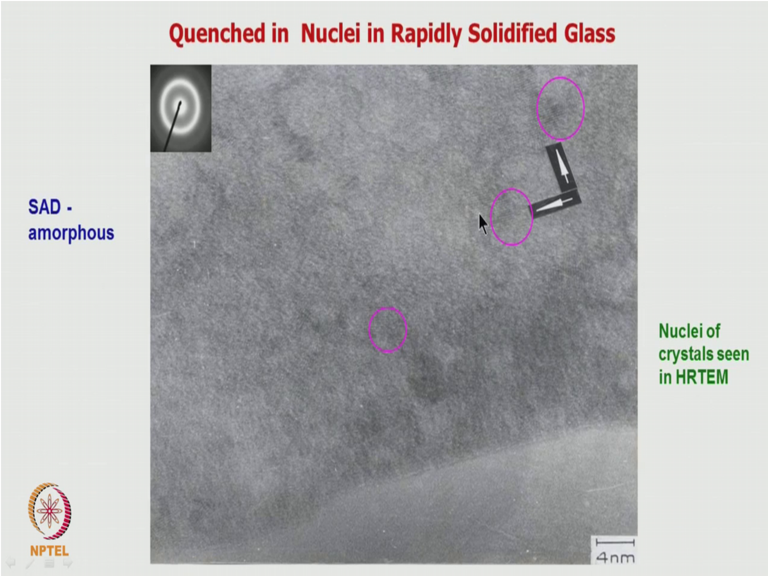

Then, here is even in a sample which is amorphous sample rapidly solidified glass, when one does high resolution image, I do not know whether you are able to see at different regions, one can see some lattice fringes could be seen. So, the regions where we are able to see lattice fringes, these are all the regions where it has transformed from amorphous to crystalline region. So, this has been used to find out the size of the nuclei and the number density of the nuclei. Like this you can this is how to use it to get as much information as possible in the study of phase transformation.

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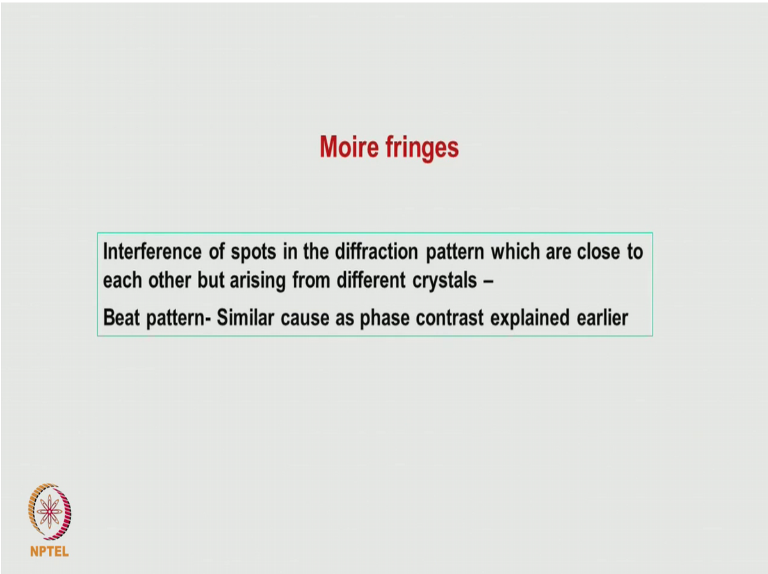

So far what we have considered is, we have considered two beam and interference of the two diffracted beams that is either could be a transmitted and diffracted or between two diffracted beams also we can use it to form images. Now, let us look at this sort of images which arises in many of the cases which is called as a moire fringe pattern. I have talked about moire fringe contrast earlier in this context.

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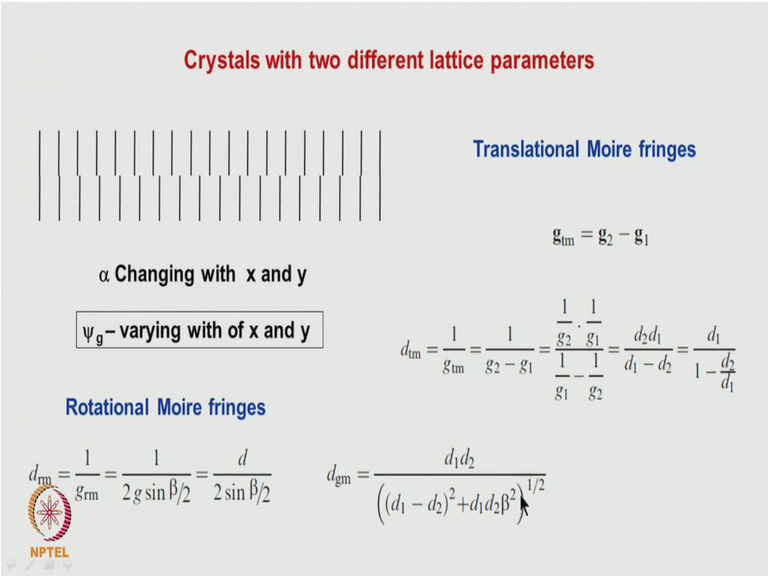

Why I wanted to introduce it is that this also arises because of interference between two diffracted spots and as I mentioned earlier it is a beat pattern here. Suppose two crystals are there one sitting on top of the other with slightly different lattice parameter, here the lattice parameter is small and in this case, the lattice parameter is slightly large. The beam direction remains that same when the beam is passing through it, the beam passes through it, we find that there be a suddenly the lattice parameter has changed. Because of this, this will give rise to some diffraction pattern.

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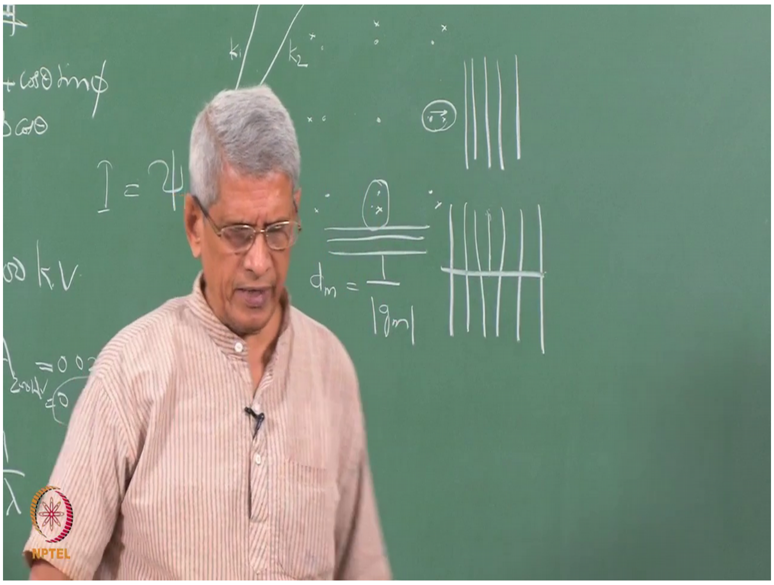

This pattern also will give rise to diffraction pattern. This will happen corresponding to like we assume that this is the one which corresponds to diffraction pattern which is arising from one which a larger one. The other one what happen is that it will give rise to a diffraction pattern. So, this is the sort of a diffraction pattern which get it corresponding to top and the bottom, ok.

If we put an aperture around say around these two spots and then, just like what we have talked about the phase contrast microscopy theory, they will give rise to a fringe pattern, the beat pattern. These are called translational moire pattern and what is going to be the spacing that is we know that the spacing between them should be equal to the moire fringe pattern equals to this should be equal to modulus of gm. That is what essentially is being given and since this is the direction from here to here, the fringe spacing should always be perpendicular to it; this way a fringe spacing will appear.

Suppose I choose this particular two spots to form the image, now what is going to happen is that the fringe spacing will appear like this perpendicular to it. That means that depending upon that type of vectors which we use; the fringe spacing is going to change. That is a beam pattern which we get. It is going to change, but as far as the crystal is concerned, they are that same orientation. That is what one should see. Similarly this is where it is one crystal and another crystal is parallel it can so happen that the crystal, one crystal could be rotated with respect to another crystal slightly. This will give rise to rotational moire fringes. There also we have this expression derived and look at it.

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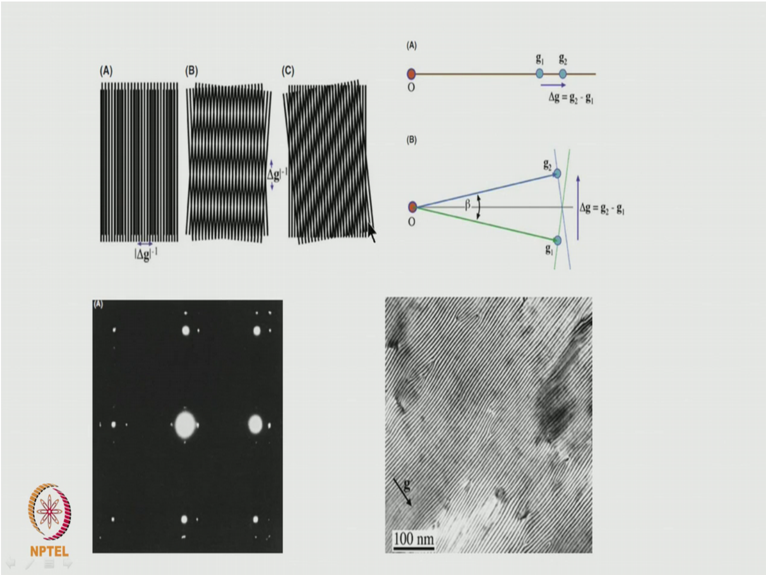

Now, we can see that this is for the translational one and the rotational one. This is a sort of a diffraction pattern which we will be seeing it that I had shown, but I will not. You can see that more spots could be coming. This is because each of the beam can act as another primary beam for a diffraction because that strong diffraction takes place that sample for electron beam and they are that gives rise to this sort of extra spots.

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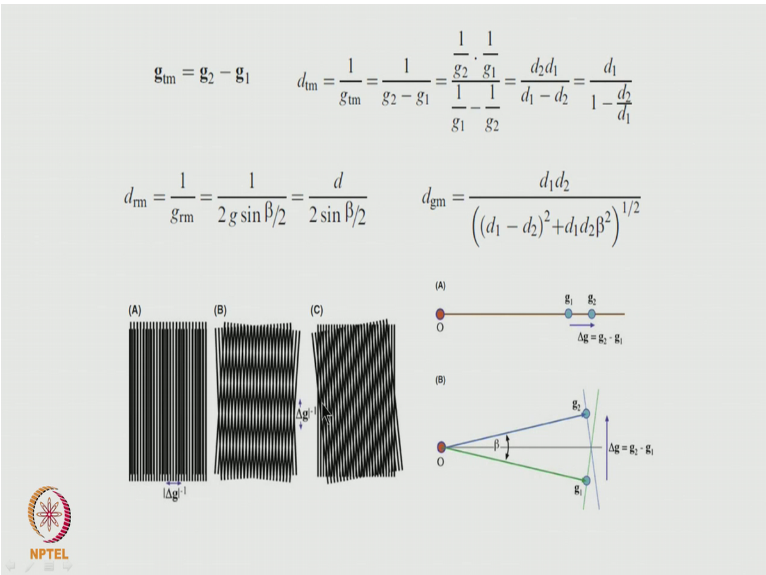

What is essentially important is that this gives rise to this sort of the fringe pattern, but if we measure, this separation between these moire fringes we can get information about difference in the lattice parameter between the various phases. That is essentially what is being given here.

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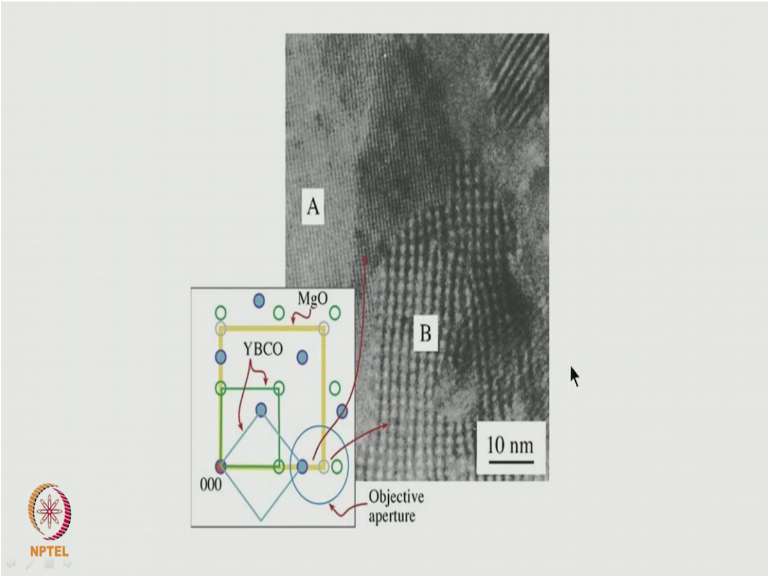

Many applications are there. One of the first application which was is that this moire fringe pattern has been used to find out how in the case of an edge dislocation when there is an extra plane is going to be there, this gives rise to that appearance which is similar to the planes. This is if you remember generally when we draw for an edge dislocation, this is how this is the slip line, and this is the extra half, extra plane which is there. The upper half above the slip line and this sort of a direct contrast of the edge dislocation image could be obtained using moire fringe contrast, ok.

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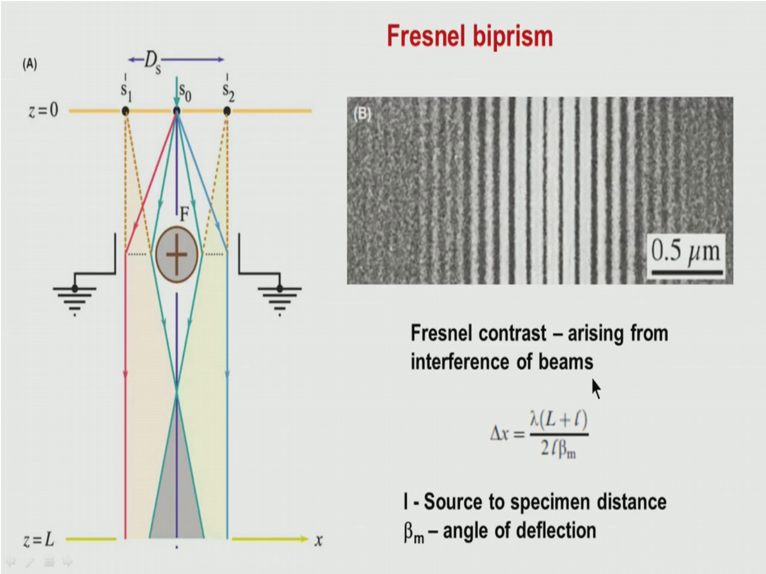

There are many other applications are there which I am not going in detail. You can see in most of the standard text books and look at it I can give you some assignments also and suggest some books which you can read it similar to this. Another type of contrast which occurs in a microscope is a phase contrast which is called as Fresnel diffraction. We know that in an optical microscopy, we have studied that when aperture is there as the size of the aperture is of the same order as the wavelength of the radiation.

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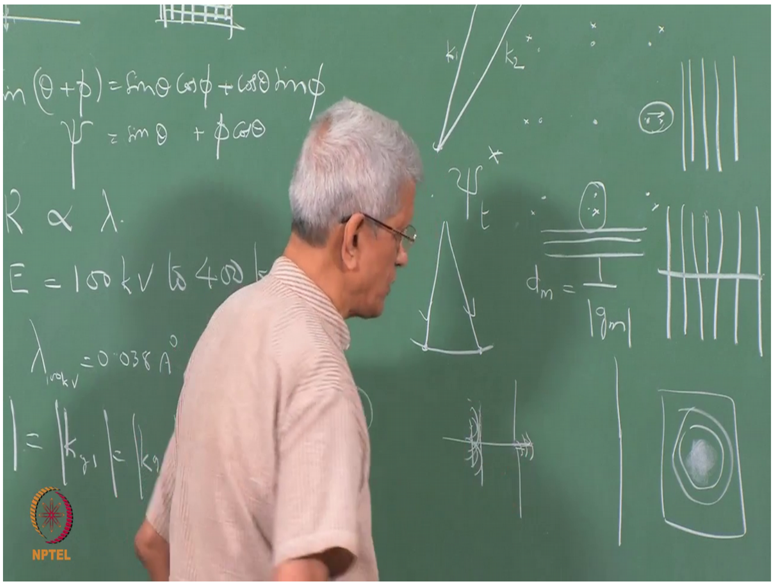

Then, when we look at that image in the image, we get one central region and this region is followed by rings. Essentially these appear because of what we called as the Huygens principle. What it says that at every point as the electromagnetic radiation propagates, each point acts as a source for a spherical radiation. The waves which are from a particular fits a plane wave if we consider from various points, we have plane waves which will be emitted like this. These waves will be interfering together where the crust reaches. This is the next one from here.

Again this will be acting emanating waves. This is the wave. The wave propagates here. What is happening is that we have the wave which is there from this region. It is going to come like this scattered radiation spherical wave and then, this direct the interference is what it will give rise to a fringe contrast. That is what the fringe contrast which we are essentially seeing it the same type of a fringe contrast can arise because in a microscope from one defect region that is from grain boundary or a magnetic domains which we go from one region to another region, sudden change of potential is going to take place. This change of potential can give rise to scattering of the electron beam in different directions and they will give rise to interference pattern.

So, here what is one simple experiment with which we can do is, if we take a small wire if a glass which is coated with metal and if we take it and apply a voltage, the beam which is coming in this direction will be attracted towards and it travel in this direction. This will be travelling towards this direction as if now it looks like this beam is coming in from this source; the beam is coming from this source. These two interfere and the interference fringe pattern will look like this particular one. This is what we call it the Fresnel fringe spacing and the separation between them depends upon the wavelength of the radiation angle through which they are scattered. Then, from this object to the screen distance as well as from the object to the source distance, these are all the factors which it depends on, ok.

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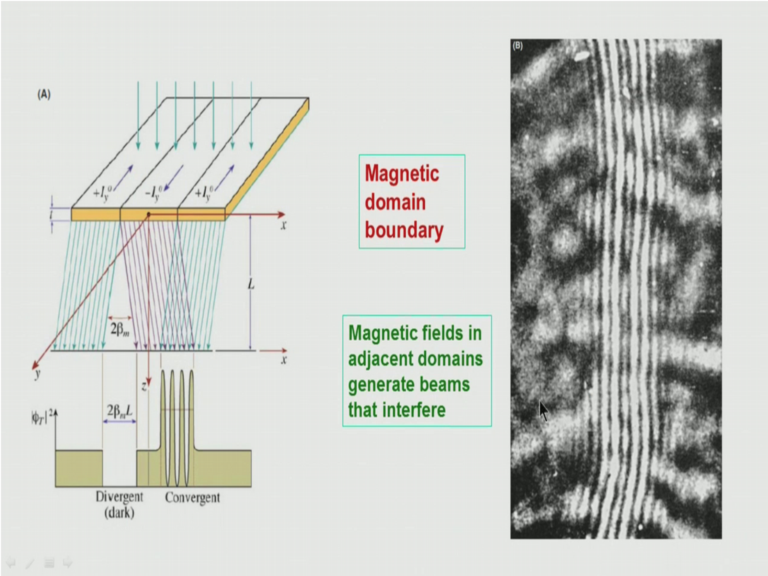

What is the application in ferromagnetic materials or magnetic materials or in ferroelectric materials? The boundaries which are there between these various domains, there are sudden change of electric or magnetic field will take place. This will scatter the beam in different directions and this will give rise to an interference which will give rise to this sort of a fringe pattern. This way we can identify the various types of boundaries which are present on the sample. Another application which we can think of is that suppose in a sample which is radiated that contains some helium gas bubble is going to be there.

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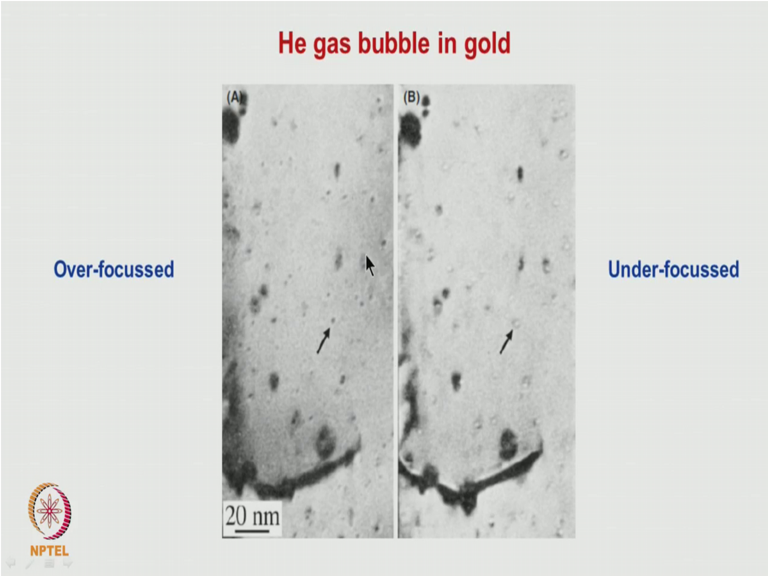

So, the helium gas bubble is nothing, but in a sample if we consider, it is something similar to a vacuum. So, the potential is 0. On the other side, there is going to be a potential where the sample is there. If we do a little bit of under focusing, then what we can see is that some Fresnel fringes will be formed around this and using these fringes, we can identify the defects that is in this particular case, the gas bubbles which are whites which are going to be there and we can count them to find out what is the white density, white size. All these information has been obtained.

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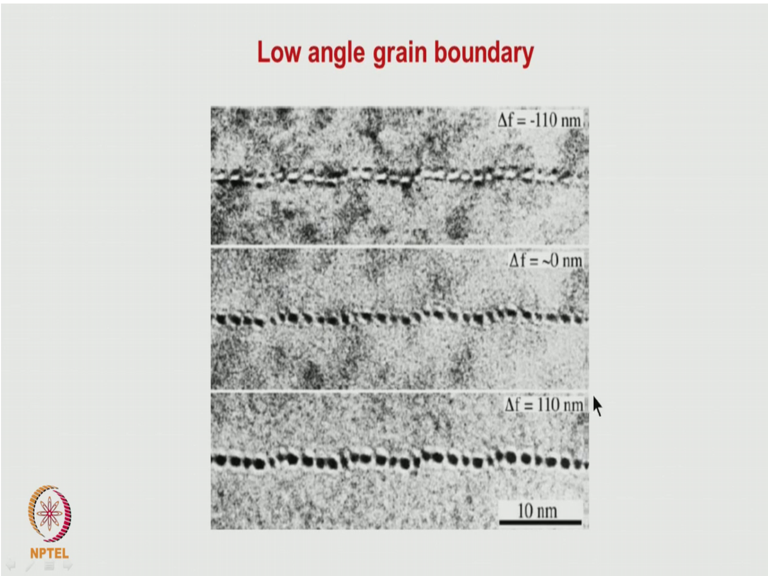

The theory of it you can see in the relevant papers which are published in the literature. Similarly, if a low angle boundary is there which periodic arrangement of dislocations which are going to be there in that boundary. Then also since there is a sudden change in potential is going to be there. This will give rise to a sort of Fresnel fringe contrast and this fringe contrast also will vary depending upon what sort of focusing which we use at zero focus condition or under focus or over focus.

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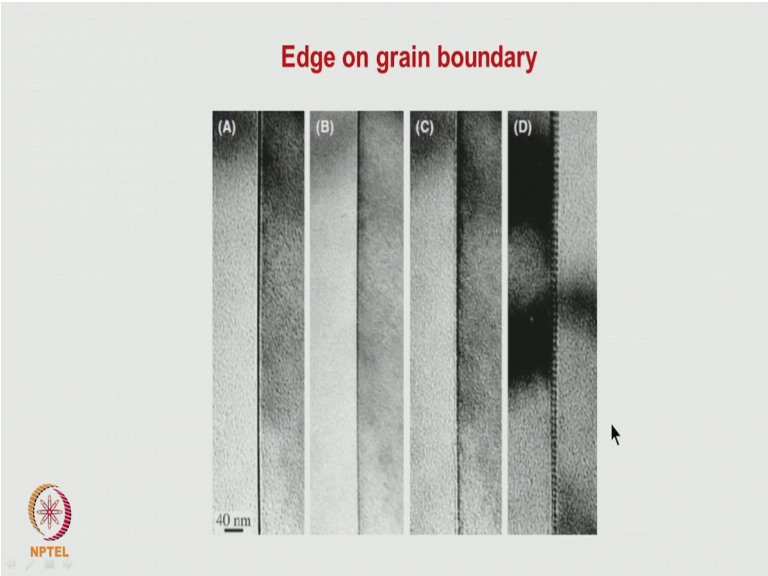

These are all the various ways in which we can do. This is another where an edge, this is the boundary, the grain boundary itself in a sample which has been edge on orientation and here we can see that depending upon the con, there is a bright line and dark line could be seen. This sort of contrast is arising again because of the Fresnel fringe contrast.

So, you can understand that this Fresnel fringe contrast could be used to get a lot of information about the different type of boundary, but to understand them completely, why they arise and what sort of boundary it is, we have to do some computer simulation which is very much necessary; that part of it is beyond the scope of this lecture, but basic image simulation which is required for high resolution, I will be talking about in the later classes, ok.

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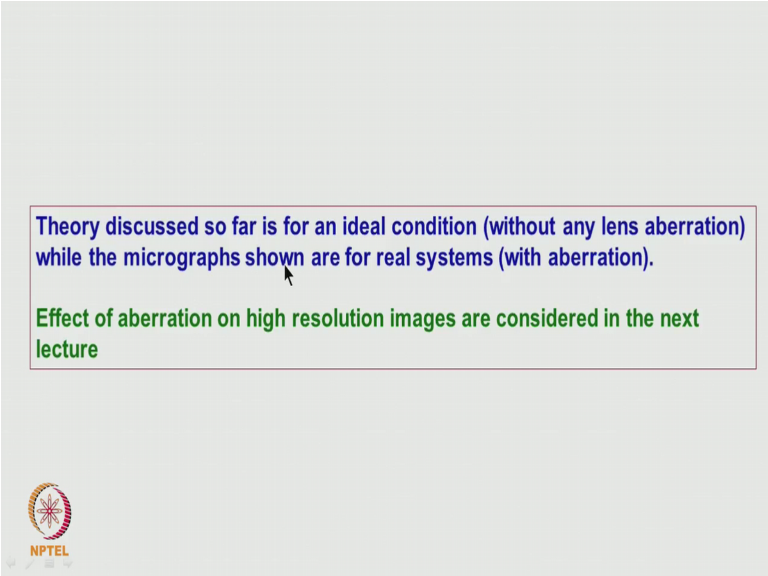

So, what we have done so far? We have discussed a phase contrast microscope image formation in an electron microscope. When the lens aberrations are 0, but real microscopes contain the lenses are not aberration free, they do contain aberration. If aberration is going to be there, how this aberration is going to affect the image contrast, how some of these aberrations which are present is used to still get high resolution images, that is what we will be discussing it in the next lecture.

So, essentially in this lecture we have considered an ideal lens where for a point object, we are able to form a point image. In such case, how we can get a simple fringe contrast which we can be obtained, how this fringe contrasts could be related to the lattice spacing.

I will stop here now.

Thank you.