Electron Diffraction and Imaging
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Lecture - 28
STEM

Welcome you all to this course on Electron diffraction and imaging. In the next few classes we will talk about some of the new techniques which has evolved in electron microscopy. In fact, a lot of new techniques of evolve. But some of them are being used most extensively in the present times and I will be a talking about some of these techniques. Before we go in to; what all the new techniques to understand, what all types of techniques which we can, and the first thing which you should know is what is the way in which the probe interact with matter.

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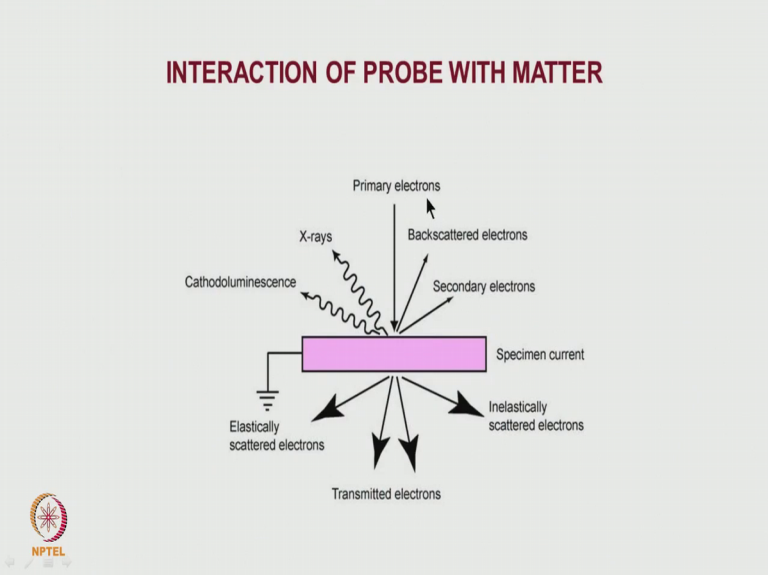

This I had mentioned earlier, but just for the sake of completeness, I am repeating which is again here. Suppose primary beam the incident beam is essentially the electrons. When the electron falls on to the sampled there are various ways in which the electronic can interact with the material.

One the electron can be scattered back which are call this elastically scattered by their called as backscattered electrons. When secondary electrons could be emitted from the sample surface where the electron beam is falling. Then characteristic x rays could come

out from the sample surface, all these signals which are coming out of an electron pimp falling onto the sample, it is used in ACM scanning electron microscope to get image of the sample surface as well as chemical composition of that element. And in addition to it is some of the backscattered electrons they give raise to diffraction, this could be used as the technical DBST to get information about the crystallographic information about the orientation of the various grains, all these things we this we might have studied in the course on scanning electron microscope.

If the sample is really thin, then what is going to happen is that most of the primary electrons we will pass through the sampled, and most of them we will come out without losing any energy; that means, that whatever the interaction which takes place with the matter is essentially an elastic scattering, these electrons which are coming almost in the incident direction these are all the transmitted electrons, these are all the owns which are used to get used to form bright field or dark filed images which you have talked about the in the earlier classes, then conventional diffraction pattern we can obtained from that sampled, in addition teeth some of the electrons are in elastically scattered, what is inelastic scattering? It is nothing but the electron loses part of it is energy that is, when the primary electron beam interacts with an atom.

Instead of elastic scattering, the part of it is energy could be in used to knock out an electron from a core level, when an electron from a core level is not doubt. And then the electron which comes out has lost some definite amount of energy, measuring this energy we can get information about the type of element which is present and in the chemi chemical state in which their element is present all this information which could be obtained. And this in elastically scattered electrons is used to get information about this sample composition this is called this electron energy loss spectroscopy. And In fact, this is also used to generate a microscope called the energy filter transmission electron microscope, which we will be talking about it a little bit later ok.

in addition to this the electrons could be elastically scattered, this elastically scattered electron could be scattered. Normally as we have discussed earlier during conventional diffraction is a process of elastic scattering of a coherent beam. But in that case the brag angled is less than 1 degree. Here when the angle of scattering becomes more than 3 degree or 5 to 9 degrees, in those regions it is essentially and incoherent beam, but it is elastically scattered. This also gives rise to some information, this is called this type of

scattering is called the Rutherford scattering. And this is used to get information about the distribution of elements on the sample surface at atomic resolution ok.

We will be talking about this technique as well today these. So, what we will be talking then, So far what we considered is that primary beam is essentially a stationary beam. Suppose the primary beam can be made to move scan on that sample surface. So, we have a sampled ok.

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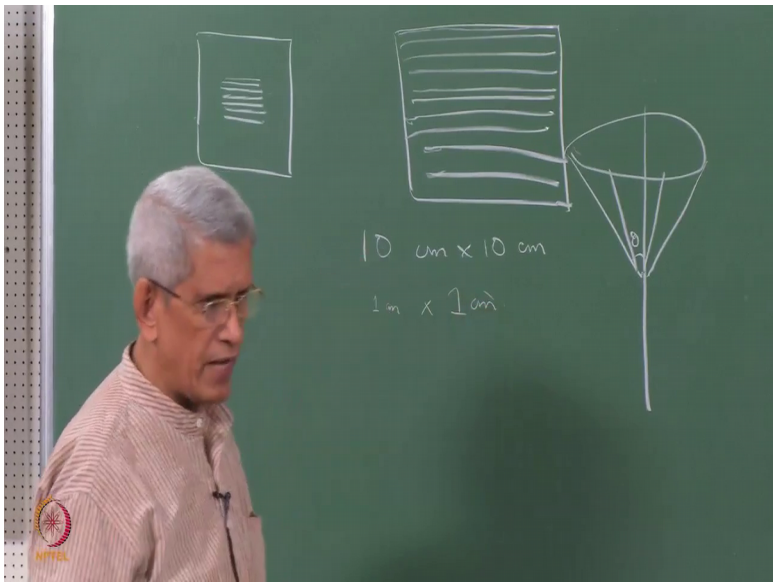

The primary beam is scan beam scanned like this over a small region of their sample surface. Every region are every point when the electron passes through the sampled and comes out of it, all this signals are obtained. So In fact, we can find out distribution of various elements, 11 columns, where the electron beam is passing through the columns on that sample. This is what is called as a this when we operate it in a reflection mode which we call it as a scanning electron microscope, when we operate it in a transmission mode we call it as a scanning transmission electron microscopy.

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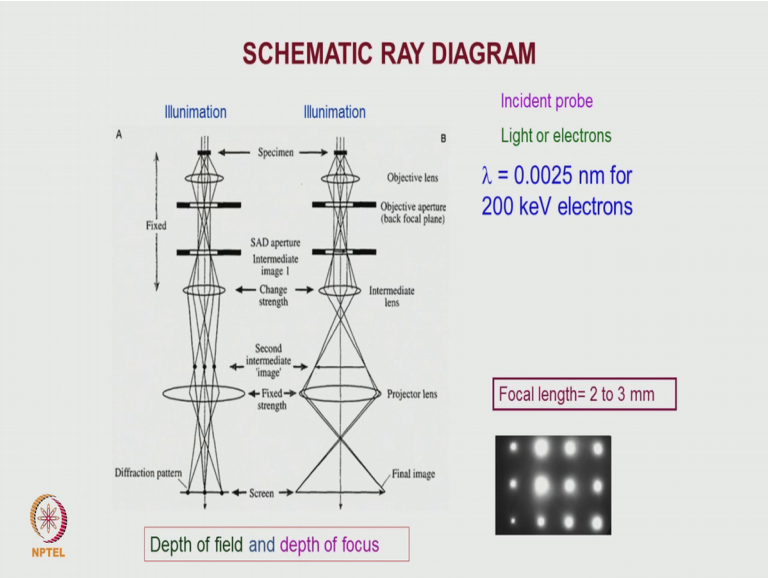

Before we go further, let us just recap what you have studied in the conventional diffraction technique before we go to scanning transmission. In a conventional diffraction technique essentially as the beam passes through the sampled, if it is a crystalline specimen in that case, the contrast is arising mainly because of diffraction because depending upon the defect which are present and how they are displaced from the original position, the intensity of the scattered radiation we will change. That will bring about a variation in intensity of both the diffracted region as well as the transmitted region. And this intensity is used to appears in the form a contrast in their image. That is how we are able to form an image ok.

If you form an image using the transmitted beam we call it as a bright field microscopy, if we use the any diffracted beam to form an image when we called as a dark field microscopy, in addition to that if the diffraction pattern from the for each other from the sampled by the electron beam is falling we can get it.

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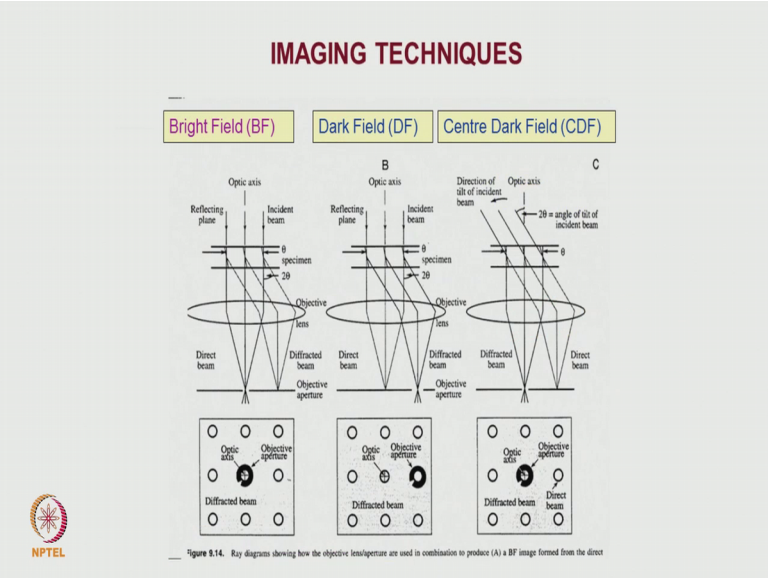

That gives information about the crystal structure, this is what we have studied earlier, but what are the advantages and disadvantages of it, we will just talk about it a little. How it is in a bright field it is done? This is what is shown schematically here. The electron beam parallel beam of electrons passes through the sampled all the transmitted beam are focused to a point at the back focal plane. And the diffracted beam are focused at to a particular point ok.

Be assume that the sample is a single crystal. If you put an aperture around it in the back focal plane so that only the transmitted beam used to form an image then we call it is a bright field image. So, essentially when we put an aperture this will be only this region will be there all the diffractions parts will be covered. The dark field image what we do is essentially we put an aperture around the diffractions part. And then we can form a dark field image, but in this sort of a dark field image the problem which essentially happens is there this beam is away from the optic axis. We know that when we use length system to magnify, any ray which is away from the optic axis the lengths aberrations becomes quite large because of which the resolution becomes very poor.

To overcome this is what we do is there if we can till that sampled so that the transmitted beam is making an angle with respect to sampled with respect to a diffracting plane and the diffracted beam is along that optic axis. This is normally called as a centered dark field technique this is the technique, which is normally employed in an electron

microscope. This technique when we use, what is the problems which are going their? Only one diffractions part which we are using it this means that the beam which is diffracted in a only a particular direction, only that we are using so, that region only will be we will be able to see in the dark field image.

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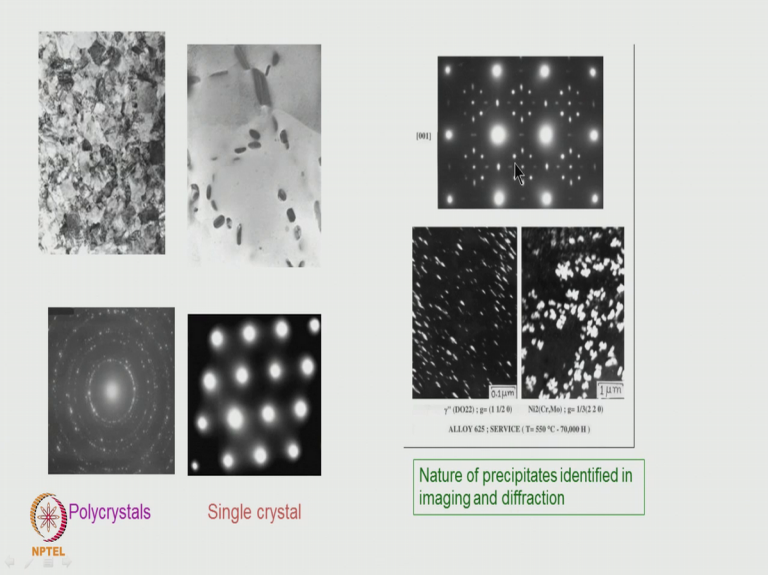

Here an example which I am showing is in a polycrystalline material which contains a large number of fine grains here diffraction pattern has been taken. One can see that this is the transmitted region transmitter spot, and the diffractors part if you look at it there are many fine spots could be seen.

But overall it appears that this is like a circular pattern. That means that, nearly all the random orientations of the grains are there. Suppose I put an aperture around this particular spot, this may correspond to possibly this particular grain from which this diffraction spot has (Refer Time: 10:10) then only that will give rise to a will be image as bright in the dark field picture. All other beams if you have to image what we have to do we have to put an aperture around here, are here, are here, are here, are here. Like this around each of this parts this diffractors parts we have to put an aperture, then only we will be able to image all other grains or if it is some precipitate which are there those precipitates can be image only that way; that means, that this takes an unusually long time. And a lot of images have to be micrographs have to be generated to get complete information about the orientation of the various grains.

This is own typical example one can think of many other examples, here it is an another example which I had given. This salts from a single crystal where one can see that using an aperture around either this reflection or this refraction reflection. We can image the type of precipitates which are there. In an another grain they may be oriented in a different way the whole diffraction pattern might have a shifted, then these spot would have shifted to some other position. And when these shifts like this that can finally give rise to a sort of a circle when all random orientations are there, this is what.

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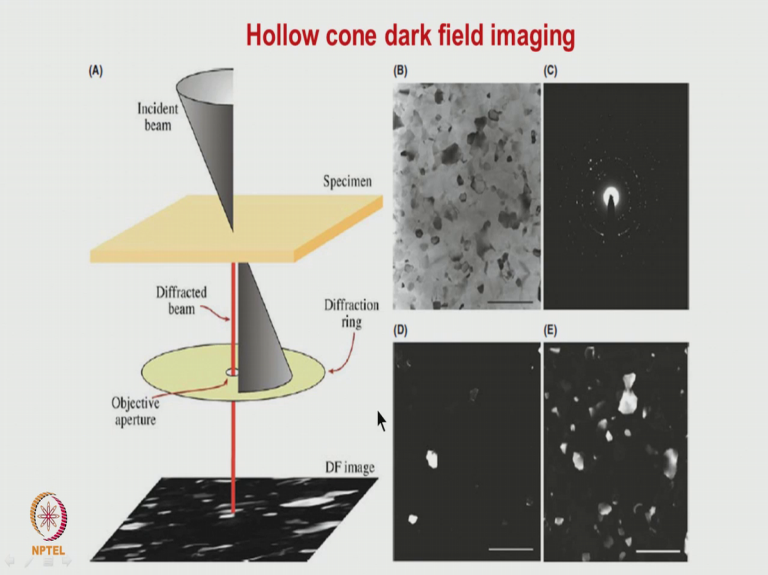

So, what is the other way in which we can increase the speed of observation or the speed of a recording of the images? This is done using a technique which is called as a hollow cone technique. If you remember here what we have done is we have taken only this diffraction pattern is essentially coming because beam is tilted like this so, this is what it is coming. Suppose many other orientations are there of the grains which are going to be there on that sample, if I rotate the beam taking it in this direction around this axis if I rotate this beam, essentially what we will happen is that the transmitted beam around a cone making an angle theta, all the possible orientations it is being rotated ok.

But the diffractors part from all those wants we will be coming along this direction, that is they are all passing through the centre, this is exactly what is being done in the case of hollow cone dark field imaging. That is for a particular black angle we want a specific diffraction is part 2 come at the center, passing that is me a passing through the optic

axis. The incident beam we just tilt it and rotate it around it then what is going to happen is that they all the transmitted spot correspondent to all of them as we scan it around there coming. So now, if you look at the diffraction pattern, if you look at the dark field image now we can see that the So many grains are getting lighted up. This is a case which I have mentioned earlier where we put an aperture on the particular spot only one or 2 grains are getting image.

In this particular case from the same bright field region when we do a hollow cone imaging So, we can controlled the scanning speed, and what is the rated which we are recording and all these things could be done So that in one micrograph we can have that images of various grains, which are oriented for the particular diffraction they could all be image simultaneous. This is one technique for which some changes are required because essentially a scanning coil these required. This could be done in a microscope which has called what is called as a scanning transmission type of an electron microscope it could be done.

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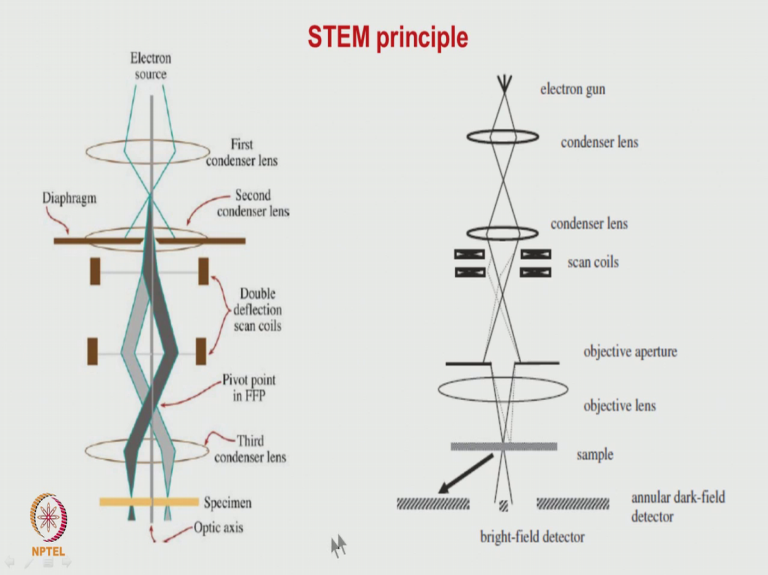

Now, let us go to what is scanning transmission electron microscope. Normally in an electron microscope what we do? The condenser lens makes a parallel beam and the parallel beam is falling on to the sample surface, correct? And when it falls on to the sample surface the diffraction is taking place, the contrast variation comes because of the different types of elements which are present, and that give rise to mass absorption

contrast. And in addition if it is a crystalline material that diffraction phenomena also we will be taking place. And the extent of scattering we will change depending upon how well the planes are oriented for scattering.

So, that is how we form an image so, but it is a stationary beam. Suppose we wanted to use it has a scanning and transmission electron microscope, what we have to do it is make that beam as fine as possible. What is essentially being done is using some diffraction coils essentially the beam is being made and fine parallel beam. And one additional lens which has been added in the condenser lens, this lens make this convergent beam. Using this scanning coils we can scan the beam across that sample surface like as I had mentioned here, you can scan that is sample surface. So, from then what we can do it is we can put a detector below that sampled we can have a detector and west as the beam passes through that sample.

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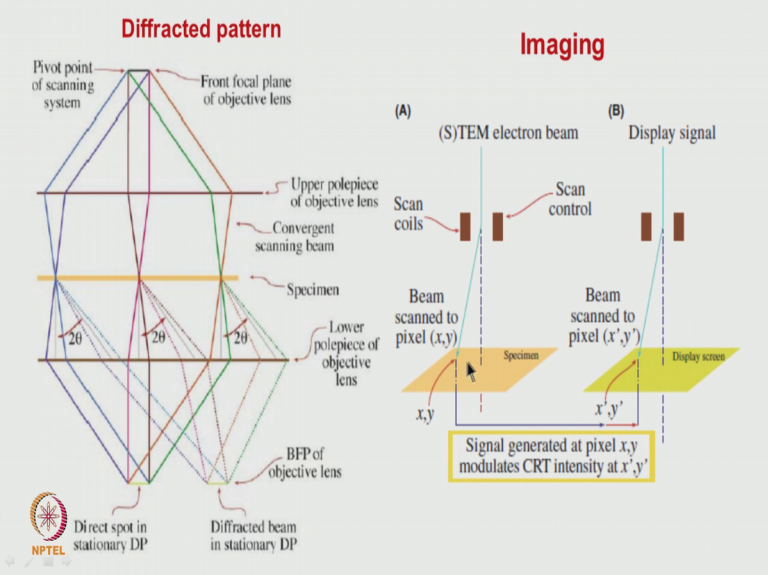

What is going to have happened? Let us look at it. At every point if the sample is a crystalline sample, the when the beam falls on to this one there is a transmitter beam it is a beam which is converged the we converged it so that we can have a very fine beam which is possible In fact, on should remember that this sort of microscopy is possible.

And we can get good results because of field emission gun which is available nowadays as a standard one in almost all the electron microscopes. Because the field emission gun gives very good brightness and because of that over a very small region we can they

have very high intensity of the beam, coming back to the so one. So, as the beam is being scanned on that sample surface this point as the convergent beam is falling on to it, this is the transmitted beam which comes, then the diffracted beam will be coming like this.

Similarly, from this point also the transmitted beam and the different beam assuming that this is a single crystal then this is the transmitted beam, and this is different what is essentially important in all these cases when we scan the beam on the sample surface the beam has to be a the direction of the beam has to be parallel to the optic axis So there that the aberrations are minimum. And then the all the diffracted beams there is the lens what it does it that objective lens this focuses all of them to one particular point, irrespective of air the beam is heating like if you remember when a parallel beam also which we are using it which is having a large size of the beam which is falling on the sample; all the beams which as parallel to the optic axis they are focused to obtain. Similarly, in this case also all the beams which are parallel to the optic axis they are all focused to a point.

So, we get a stationary spot in the diffraction patent. This is the transmitted spot, and all the diffractors that is diffraction which is take this in a particular direction from all the region they are also focus to a specific point. We get a stationary diffraction. So, spot which we could observe. The way, in which we could do you it is that, we can collect a large number of diffraction parts when the beam is falling at every point so that from every point we get a distraction pattern corresponding to there. Or when the beam is scanning on that sample surface we can scan it over a large area and we can do a time average of it so there the diffraction pattern from the whole of the region could also be obtained.

This can be we can use a conventional CCD cameras nowadays, very good CCD cameras are there which with which have very good dynamic range so that the diffraction patterns could be recorded very easily. This is the way we can get the diffraction pattern. In fact, what we should remember is that when this sort of microscope is being used. Essentially we are scanning the beam on every region of that sampled, and as the beam is being scanned we can put detector here and the size are the detector and the angle of convergence is used in such a way that all the transmitted beam is collected here. And then we can have a detector which is away from it where all the diffracted beams are being collected.

So, from every point depending upon the characteristics of the sampled, we find that intensity of the diffracted beam where transmitted beam will be changing. So, this is being the data is being collected by this detector which has been put just below the sample. So, if we allow this information to, what we do is on a TV screen to the in a grid of the TV screen if you give this the current which has been collected. Then what is essentially is going to happen is that there will be a variation in intensity which will be taking place. And this will give rise to a contrast and their screen. So, like essentially there same scanning coil is used to control there scanning of their electron beam on the sample surface, as well as the scanning on the display screen or the TV screen which we are using it.

So, there will be a one to one correspondence between, but what is essentially how do we get that magnification here, because if small area which we are scanning it and that is being projected as a large area on the TV screen. So, the TV screen area is fixed suppose we assume that it is a 10 centimeter by a 10 centimeter is the area of the TV screen. And if you are scanning an area which is essentially about one centimeter by one centimeter on the sample surface, then the magnification turns out to be done.

So, what we are essentially doing it is the area which we are scanning in and the sample surface we can make it smaller and smaller, so that we get higher and higher magnification. Another important thing which we should understand these there, in this sort of our image formation, Once the beam has pass through the sample, we have not used any lenses to form and image, so that the lens aberrations are not the one which is going to limit the image quality or the resolution of that image.

Here what is essentially important is that the beam which is falling on to the sample that can have some aberrations which are there that will be reflected in the image. And So, what should be done is that the probe itself we have some characters are there to correct for as segment is some of the probe, with similarly the spherical aberration of the probe all these things have to be corrected so that we can get any, this is the greatest advantage because in a transmission electron microscope the as we have studied earlier, because of the lens aberration for a point object we do not get a point image, here what is happening if their the resolution essentially is determined by the spatial resolution; that means, that what is the probes says which we use that determines what is going to be the solution.

Just like in the case of an SCM. Then if we collect the information which is coming from every region into the annular, dark field detector if you use it, then what is going to happen is there we will be able to form your dark field image of the sample.

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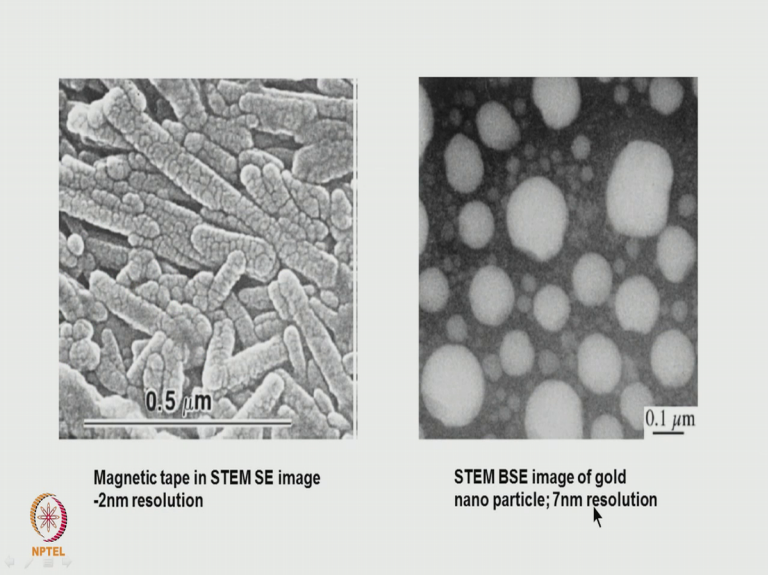

And. In fact, what I am showing it here is essentially we are talking, so far we have discussed everything with respect to a transmitted one beam; so scanning transmission a microscope. In fact, in the scanning transmission microscope there are the reflected electrons are also going to come secondary electrons are also going to come we can have a detector for both backscattered electrons as well as secondary electrons. And then we can form image like in a conventional SCM, the images of the sample could be formed. And this is one such image of a magnetic tape which has been taken in a scanning transmission mode in the secondary electron image you can see that there is a 2 nano meter resolution. Here in that it is taken of a gold nano particle with these 7 nano meter resolution.

But one can see that the contrast here if you look at it is the definitely poor compared to what you would expect the transmission mode. So, so far we have discussed about how we can form an image of a sample in a scanning transmission mode. So, in this also the principle which we are using is a diffraction which is being taken into account, but the probe is being made into that is the beam is being scanned and the size of the beam is being made as small as possible.

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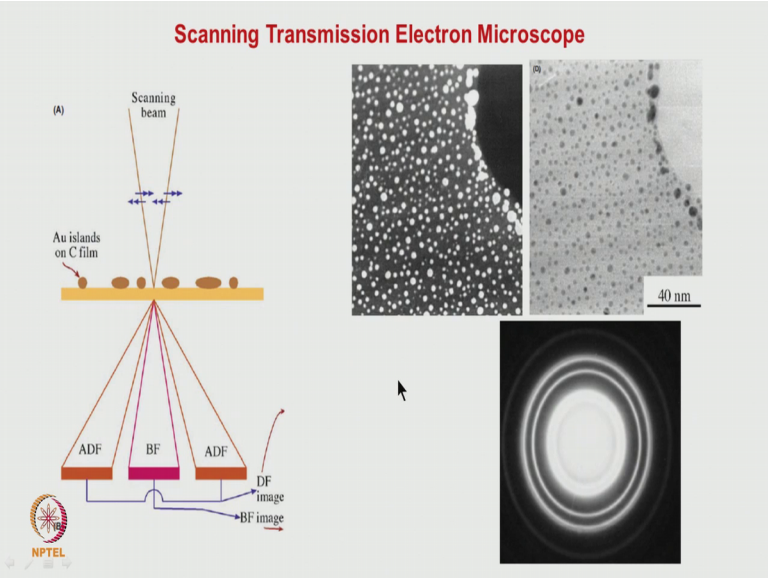

So, this is another schematic view of only the beam which is convergent beam which is falling on the sample surface, we have a detector which is their. So, essentially what we do a detector is we have a annular detector which is going to be there.

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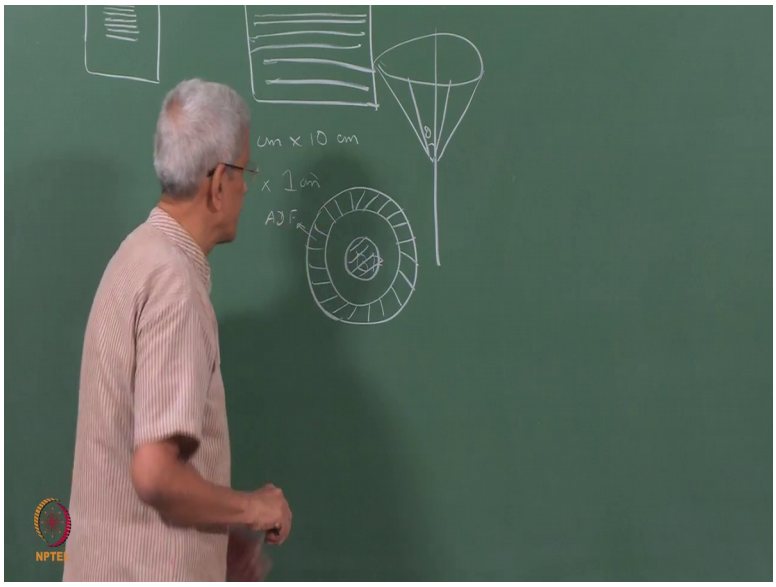

This is the dark field detector. This detector is the bright field detector, this is annular dark field detect detector.

So, the all the single which are falling on to this detector is collector to form the bright field image. So, another advantage which here this that; when we look at it the diffracted

beam which is scattered into this annular detector, all of them are collector together simultaneously and because of that compared to a conventional diffraction pattern, we could get in the dark field in much better contrast. Here we are just showing an example, ok.

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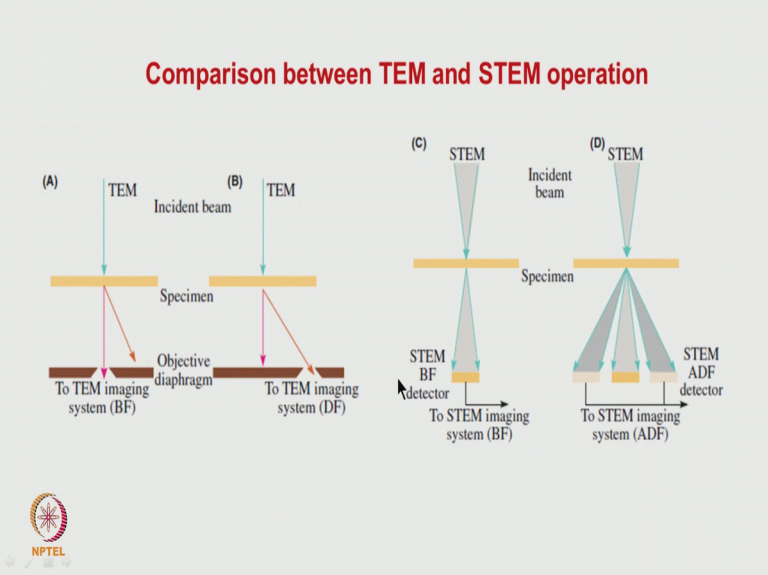

Wear gold islands and carbon film. You can see that this is the bright field picture of that sample where it is being the signal is being collected that using that bright field detector. And the on the dark field detector is used to collect, the diffraction that collect the dark field image using the beam which is diffracted on to this region.

So, because of this almost all the particles which are scattering into this particular cone which reach the dark field detector. All those particles get image simultaneously. This is a typical diffraction pattern which is taken from this sort of a particle, which is a circular ring pattern which I had mentioned earlier how it is to be taken. So, here what I am just showing it is that a comparison between TM conventional transmission electron microscope in the bright field and dark field imaging what we are doing it essentially is that in this particular case we put an aperture.

So, like in this case when we take a bright field image in a conventional transmission electron microscope, the contrast which arises is due to diffraction which has taken place from the same region in different directions. That is what it, but when we come to the dark field image we are using only a specific diffraction spot, because of which we find

that a intensity of the dark field image could be very small. Whereas, in the case of a scanning transmission operation the dark field image it collects diffraction oriented making a particular rankle particular solid angle is always collected and because of each the contrast is much better.

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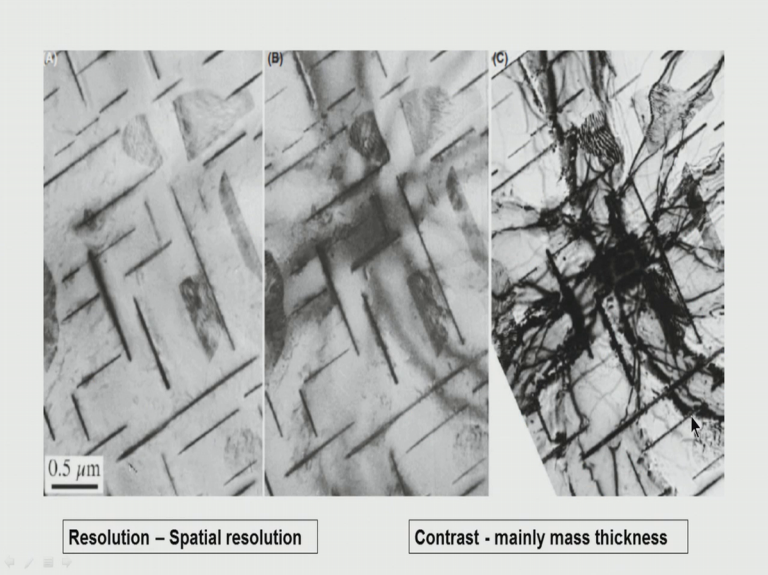

In this particular one what I am just trying to show, essentially and image which has been taken using scanning transmission electron microscope, as well as the conventional transmission electron microscopy. What one should understand that micros they present your microscopes in the same microscope we can operate it like if you remember we have talked about earlier a convergent beam reflection, in that convergent beam deflection technique we can converge the beam. And if you a scanning coil is attached if we activate that we can operate it is an scanning transmission mode, and if we a switch off the scanner scanning coils and make the stationary beam fallen that sampled and activate all of their lenses below the objective lens then we can operate it is a conventional transmission electron microscope.

Image of a sample from the same region is being shown which is taken in bright field both in a this is in a conventional transmission electron microscope and this is in a scanning transmission mode, what one can see very clearly is that here the bright field picture the contrast one could see very clearly, but at the same time we can see all the

ben contours all of them give rise to a contrast, which is masking the features which are to be seen like here because of the contrast we are not able to see here.

Whereas, this bend can a since we are scanning the beam on to the sample surface, and these secondary effects like ben contours contributing to scattering, they do not worker in the case of a scanning transmission electron microscope, and because of their we can see the features much more clearly free from all the ben contours and other effects. This is one important advantage in using a scanning transmission electron microscope.

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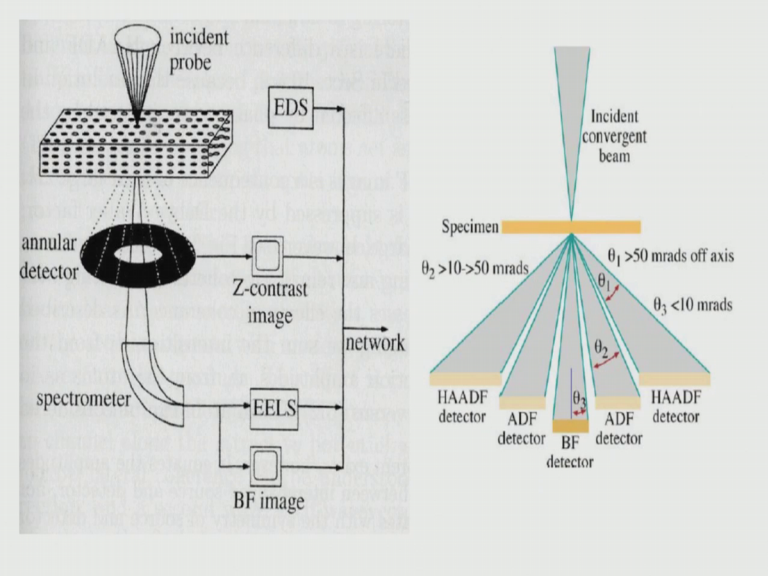

So, here what I had just showing it is that, suppose we make the beam as find as possible may be of the order of about 0.1 my nano meter, then what is it going to happen? Such a fine beam we can almost probe column of atoms on along the beam direction could be proved very easily in a scanning transmission electron microscope ok.

So, whatever is the contrast which we are getting it, bright field are the dark field contrast, we arises essentially from each region of the type of atoms which are there how much they contributed, because we have made the beam almost as fine as possible. So, essentially scattering from each of the individual atoms is going to determine; what is the sort of a contrast which we are going to get. In this particular schematic what essentially is being shown is that what is the angle of convergence or the angle of divergence; so which that we collect the signal. That is if we collect that signal over an angle which is between 10 millirads 250 millirads scattered in that direction, this generally gives rise to

a conventional dark field image. And if we collect signals over a angle which is much larger than that there is, between 10 to 15 millirads that is it is about something like maybe 3 degrees to above 3 degrees to 5 degrees ok.

This is called as high angle annular dark field imaging, or this is called as the z contrast imaging which we will come too shortly and try to understand it. And it is only a very small angle over which angle less than 10 milirads is over which the bright field detector is collecting the information.

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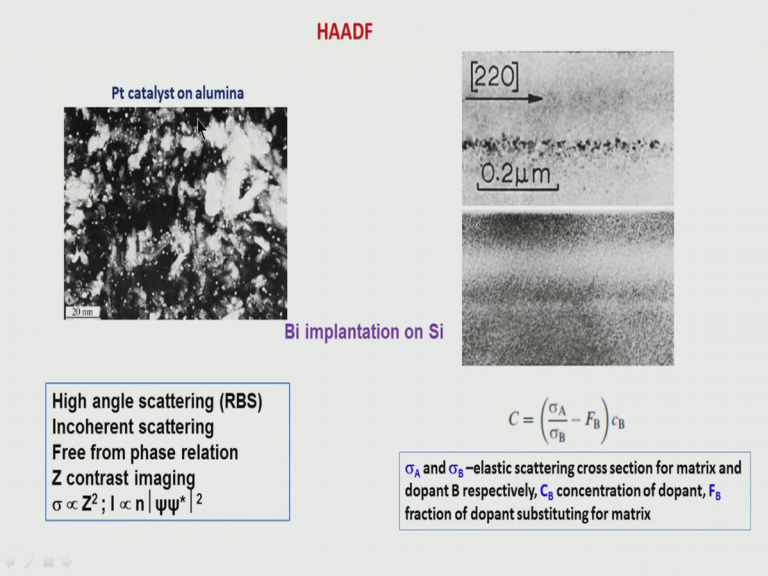

Here what is being shown is the image of a sample, which is essentially a platinum catalyst on the surface of an alumina. The platinums are verify platinum atoms which are sticking on to the surface of, here what is essentially is being done is that as I mention if you have a sample like this, ok.

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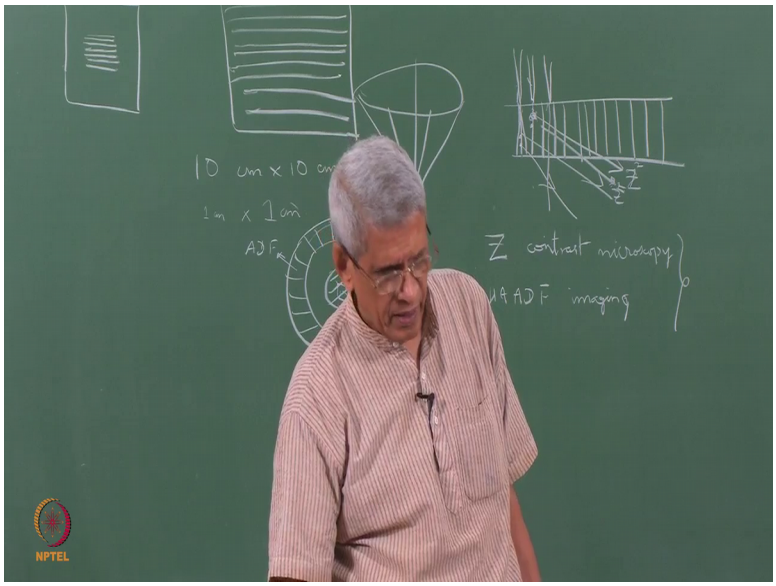

These are all the rows over which, you assume that this you can (Refer Time: 34:36) plain over which we have columns of atoms are there. If there beam them conveyed beam is falling on to this column. It will be interacting with their atom then, it is scatters into we are different directions some scattering and some are getting scattered into it.

If you remember the earlier, I mentioned when we talked about atomics scattering factor. In the case of an electron the interaction of primary beam with a sample, it interacts with the nucleus as well as the electron surrounding it ok.

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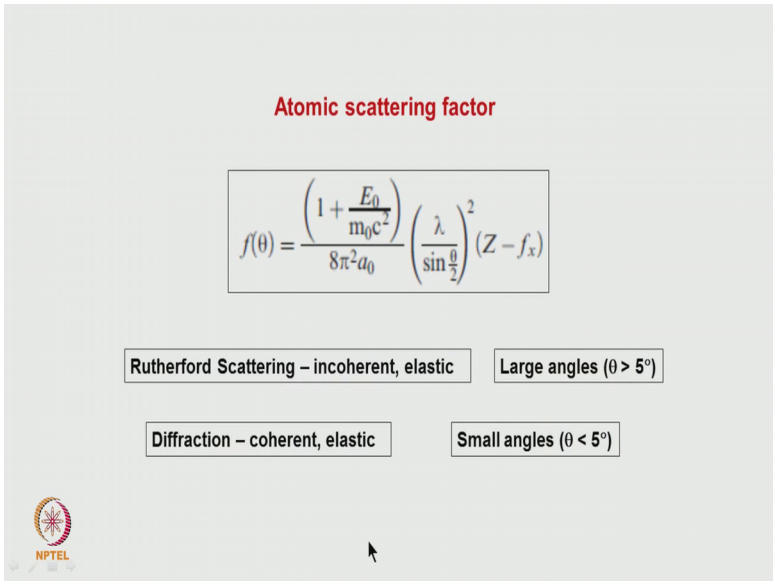

That means that if you look at the atomic scattering factor, there is a term which contains due to the nucleus scattering. This scattering we call this an in coherent scattering when that angle is very large it is incoherent, but the scattering is an elastic scattering. And here we can see that f of theta, there is the atomic scattering factor from each of the atom the contribution to the scattered beam is proportional to e set are in the intensity we will be proportional to e set square. This factor it is essentially comes from the elastic scattering which can contributes to a normal diffraction. And especially angles greater than theta this Rutherford scattering is the one which predominates and the angles which are smaller than theta where the diffraction is what is going to be predominant.

So, annular detector which we are using it, they can collect thus information which is being collected as the beam is being made very fine is depending upon the type of atoms which are going to be present. The contrast will be changing, because atomic scattering factor is changing as we have seen just now. Because of that what is going to happen is that in the image when we form different regions we will show different contrast here the platinum is high is at one compared to alumina. So, it appears as a bright particle that is what we are seeing in this is called that the sea contrast. And with this earlier this was done using annular dark field so that, but in annular dark field both this Rutherford scattering as well as the conventional diffraction both of them could play essentially what determines is the size of the probe. The earlier the probe size was rather large only with the advent of as I mentioned the field emission gun, we could get probes which are very fine and probe columns of atom ok.

So, high angle scattering that is what I had just listed here. High angle scattering is a Rutherford scattering, and this is an incoherent scattering. And this is free from their face relationship which we can not (Refer Time: 37:56) for diffraction and this also called as the reset contrast. And the atomic scattering there is a clause section for scattering if you take it this is proportional to f square. So, it is could a z square. So, the intensity if you look at it will be the number particles which are going to be there. Another example which have taken is a silicon sample on which bismuth has been implanted indeed. This is a bright field picture, in these bright field pictures we can see the defects which are being present on them, and they are getting imaged here. But in this region if you look at it, here there is a very slight variation in contrast is going to be there, but this is the dark

field which has been taken from here. Now we can make out that in this region as you will this even there is a increase in brightness is there, ok.

This is where the bismuth has finally come and settled on the samples of us. The contrast which arises can be related using this formula where sigma A sigma B minus f B into C n. Where C B is the concentration of the dopant, and F B is the fraction of dopant substituting in the matrix atom position sigma A and sigma B is that Rutherford scattering cross section for matrix atoms as well as further dopant respectively. Using this you can find out how much a contrast is going to be there. This is essentially arouser the solution picture ok.

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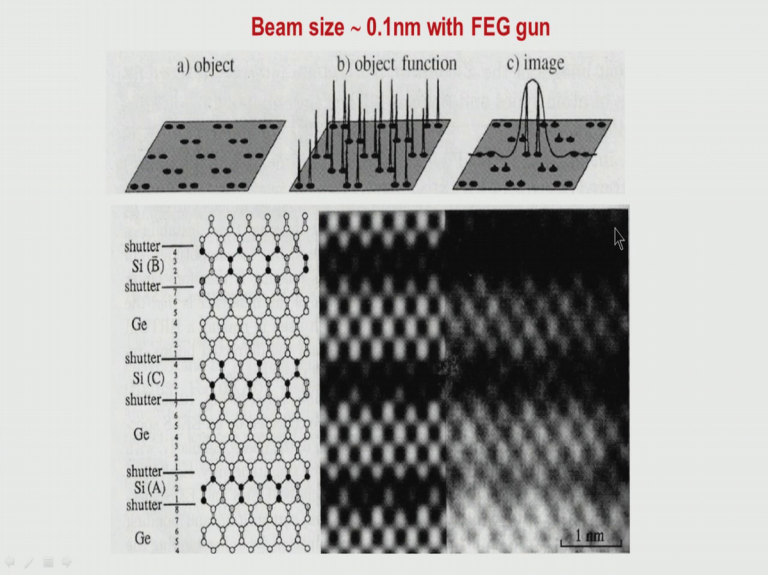

This we have already discussed. Now let us come to the case where the beam size as I mentioned can be made as fine as possible. Here what I have taken is a silicon sample, which is along 1 1 0 direction.

The advantage here is that this is a multi layer of a sample which has been chosen; the multi layer which contains germanium then silicon germanium silicon germanium silicon. We know that the gen with some specific thickness of both of them. We know that both of them are iso structural. And in this when we try to do a C contrast imaging that is here the imaging is done using what is called as high angle annular large dark field image. In this particular image if you look at it because here the contrast from conventional diffraction is also there, here that is reduced considerably. So, most of the

contrast is coming essentially from there elements which are present a different sizes at different positions ok.

So, now one can make out that germanium has gotten atomic number higher compared to that of a silicon. So, the contrast from germanium atoms the scattering should be more. So, since their beam size is very fine, as we make the beam pass through this, like this and the beam has is passing through the center the intensity will be more here. And there is passes through this depending upon the amount of scattering which is going to happen the intensity we will be less in the transmitted beam. But in the dark field if I have heavy atom is going to be there, this will give rise to the large scattered angle, the intensity of the scattered beam is essentially proportional to insert square. Whereas, from an atom which is going to be there are from this region the intensity is going to be again proportional to a z square, but suppose it is a low is a at element this will be a poor that is the neighboring region we will have a poor contrasts compared to this region where it will be high.

Ok. In fact, from this explanation if you can make the beam very fine, we should be able to probe inform and get information about atoms along a specific column or even a single atom identification should be possible. This we will talk in the next class. Here what we can make out is that depending upon the element which are present at different regions, the C contrast the intensity of the contrast from those region is going to be large, because of that both silicon as well as the germanium, we can see that high resolution pictures which we could get it. Because we are probing row of atoms that is what essentially is being shown here this a row of atoms which are being shown, projected along that this had direction, this is how that object function means that how that this set is going to change in these regions ok.

In the image depending upon what the beam says is whether if it is able to resolve it will resolve it. In this case it is not able to serve, but still we can see that disappears as here flight increase. We can immediately make out that the regions which contain germanium the contrast is high, the regions which contains silicon if you look carefully the contrast is poor. I have just taken another example where it becomes much clear ok.

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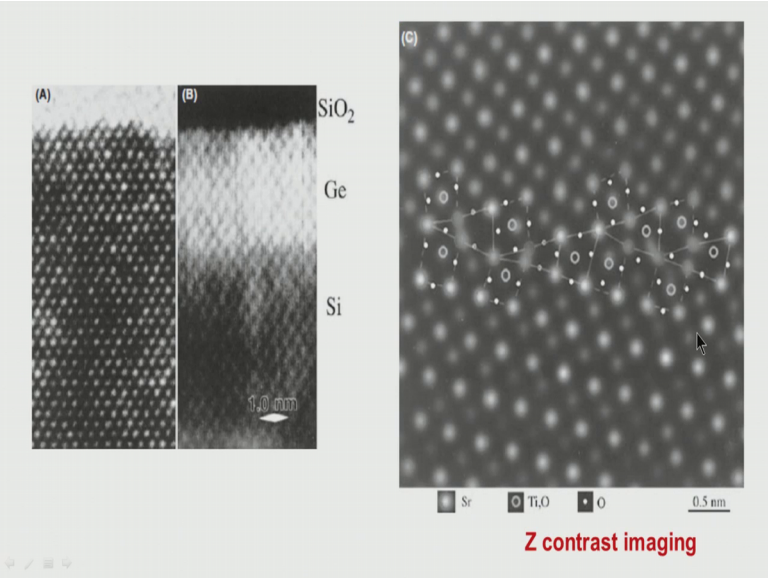

You look at this case, this is again silicon germanium sample with an a silicon oxide on the top of that sampled. This is a normal high resolution picture which has been taken. If you look at this picture we cannot make out whether which region contains silicon which region contains germanium. We have studied about how to form a high resolution picture do a high resolution transmission electron microscopy earlier. And this is from the same region we are now doing a scanning that is a C contrast microscopy.

So, since the beam size is being made as find as possible there is of the order of the atomic size, because of that we can get an atomic resolution image of the sample could be obtained. That is one thing which we should understand. That this is also from a strontium titanium we could get an (Refer Time: 44:57) resolution pictures because the earlier we studied that essentially the phase contrast be use it, to get an atomic resolution pictures.

But making the beam smaller than the inter particle inter atomic decisions, and probing on that samples of us, we can generate atomic resolution pictures could be generated. And what is the advantage? Here we are not able to differentiate between silicon and germanium, here we can make out that the silicon the contrast are the intensity of each of the dots is very poor. Whereas, the intensity is high in the region which contains germanium this way we can distinguish these 2 regions belong to different type of elements ok.

In this particular case the strontium titanium here on can immediately make out that the region which contains that strontium, these are all the regions which has gotten. This is looking at some along a boundary. And this is the region which corresponds to like here which is being shown both titanium, and the oxygen atoms are there because strontium has the high atomic number so the in brightness is high here. Here it is less, when that oxygen atom are going to be there it is very difficult to make out, but it is a very faint contrast is there.

So, this way essentially 2 atomic resolution images could be obtained using C contrast imaging. So, almost all the atoms which could be done, but this looks very simple, but what essentially is being done in the microscope is that there are some competitions also models also have to be d 1 1 has to calculate it. But it is still possible to identify the various types of elements which are present and where they are present on the atom side those information also could be used. Those informations also we could obtain in a C contrast imaging.

The C contrast imaging is called by another name, that if we said that C contrast microscopy are high angle annular dark field imaging. So, both the names are being used, but irrespective of it to get atomic resolution pictures what is essentially important is that the probe should be made into has find probe, of the order of that atomic radius. And the aberrations correction of all the aberrations and alignment of the beam along the perfectly along the optic axis, is the one which is important to get this sort of images that part of it I am not going into a details which you can see in many books, which are available in the literature. This is another example where as I mentioned the silicon in silicon antimony has been diffused into it, ok.

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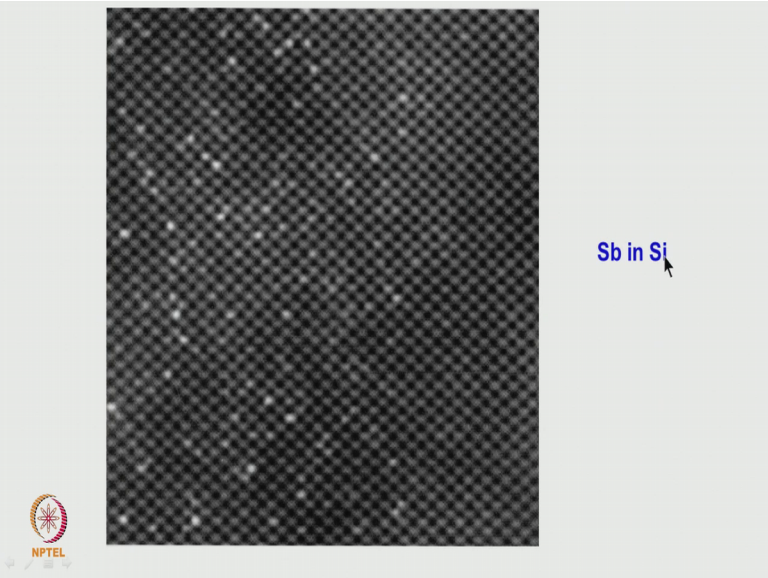

In this picture we can make out that silicon atom positions, and this bright spots which we are seeing or the positions which contain antimony atoms. So that way we can identify where the elements have gone and sitting on that sample that identification is possible.

In most of these cases the one thing which one has to always remember is that if the sample is slightly take the beam has it enters when it interacts with it the beam size will become large. So, if that should not happen. The atomic resolution pictures which we have to get it the beam has to in the sample thickness has to be as small as possible. Most of the time this images are taken from sample where the sample thickness maybe of the order of 5 nano meters 5 to 6 nano meters are less, then we can get much better picture also we can precisely find out where exactly the atoms are sitting on the sample surface.

We will stop here now. In the next class we will talk about electron energy loss spectroscopy.

Thank you.