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On
Technology Enhance Learning

Course Title
Advanced Characterization Techniques

Lecture-04

by…
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Today we are going to discuss about the high-resolution electron microscopy or a chat TM in details in the last lecture. I have shown you the microscope with different parts of the microscope as well as different operations of the normal electron microscope and in this class we are going to discuss first what the basic meaning of violation in the microscope is and how such a microscopic calculation technique can be used for different purposes.

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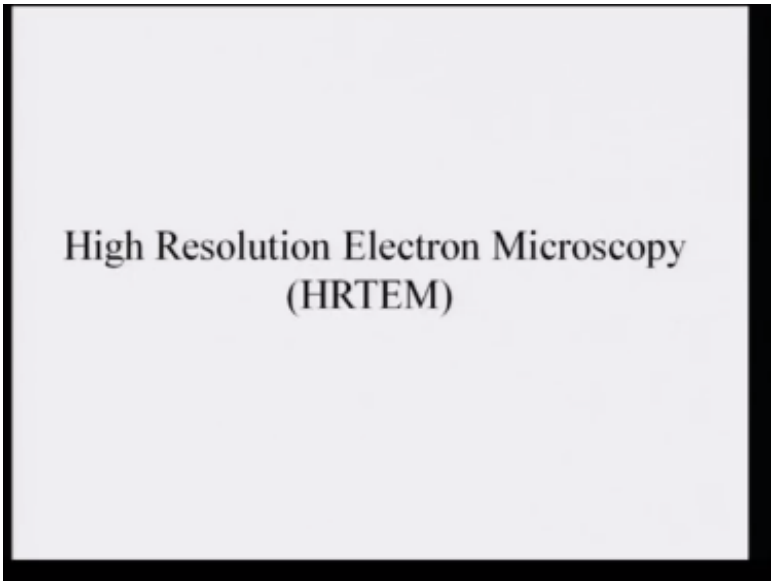

So first we will show you some of these examples, which I have not shown in the in the class one before the last one.

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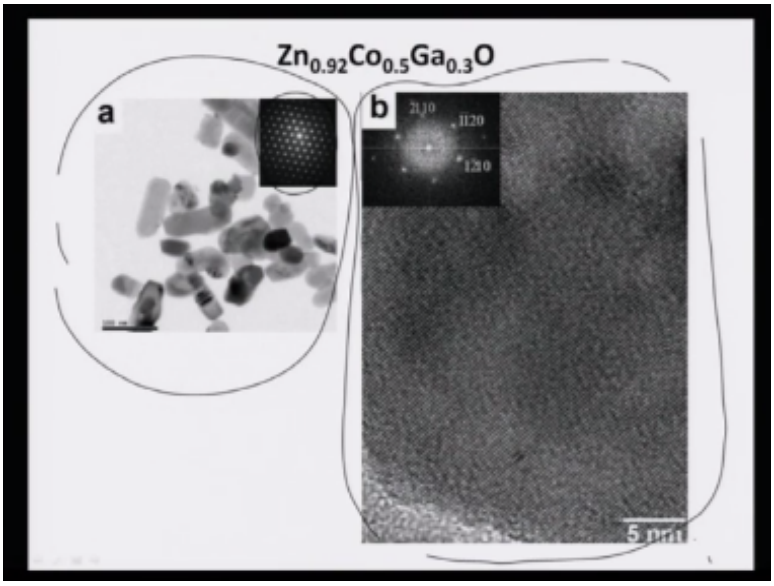

This one is basically an image taken on cobalt and gallium zinc oxide left inside of the image shows the normal rightful image of chink oxide doped with cobalt in gallium with a electron diffraction pattern taken along 0001 zone axis the right-hand side of the image is basically taken for one such crystal showing the lattice fringes that is the columns of the atoms are clearly shown in fact if we measure the distance between the two atomic layers.It should come as the D spacing of 0 0 0 1 plane of zinc gallium cobalt Zinc oxide the next one is the little.

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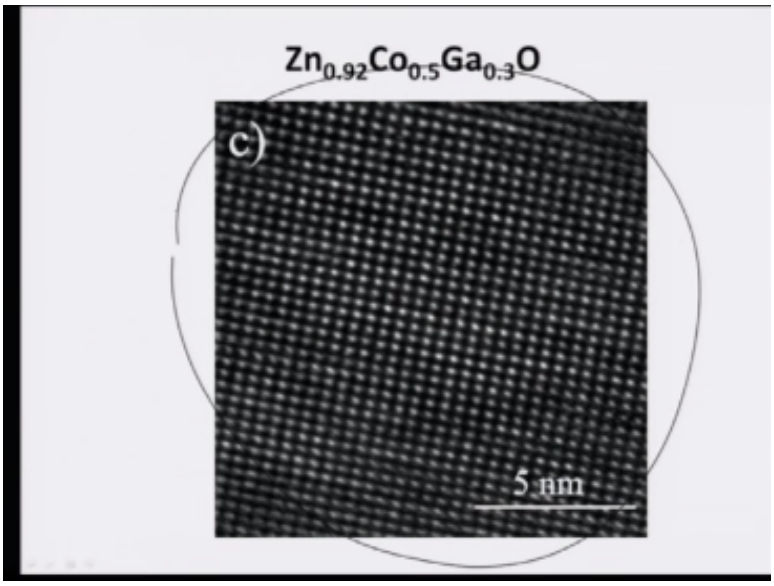

Picture of same crystal shown as bright dots the last picture you have seen the lattice fringe that is the different lines showing the columns of atoms here you can see white and the black dots as the signature of columns of atoms so but we do not know which atoms stands for what particular element but you can clearly see the atoms very nicely this images are taken in normal conventional like Lucie electron microscopes with the fake are filling machine gun control machines.

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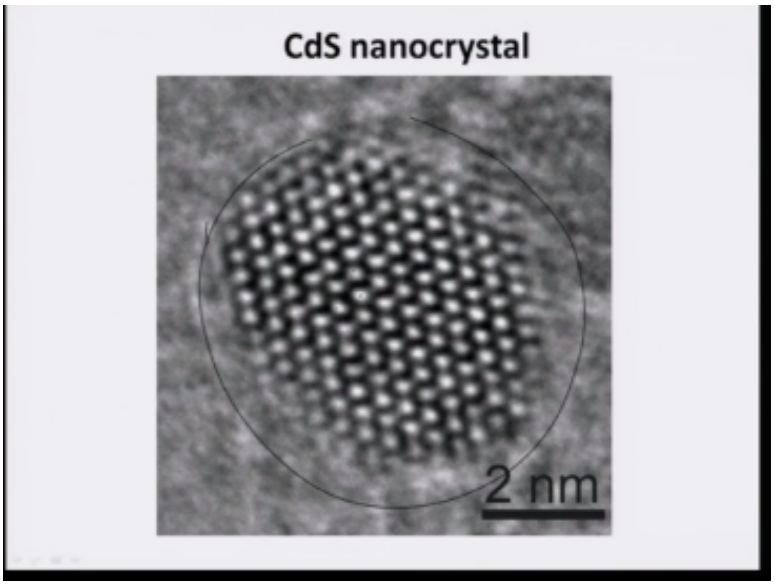

The next image is again taken from Cd s crystal the cadmium sulphide where you can see very small crystallites about approximately four to five nano meter diameter where each dots each white dots signifies a cola item similarly black dots which are not observed clearly also signifies a particular column 0 items.

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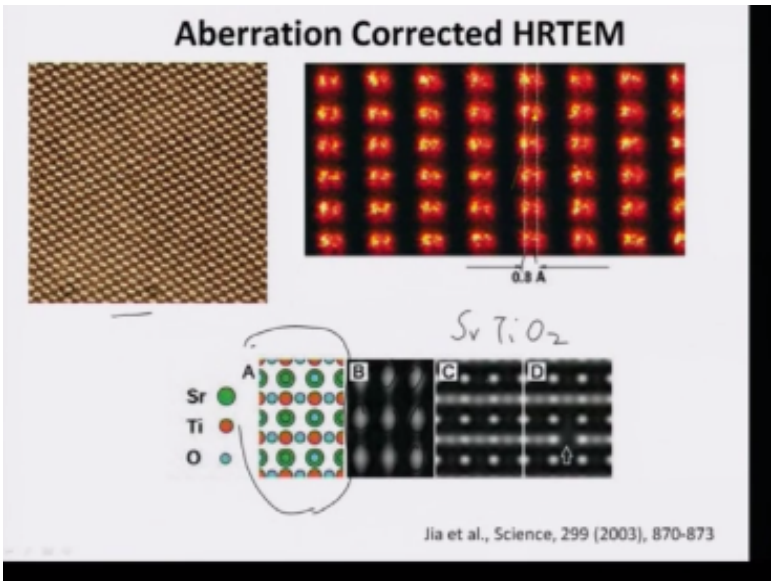

The high loosen microscopy has evolved quite a lot as we stand today we can actually have very high power aberration character adenosine microscope in which we can even see different atomic arrangements. Which are not possible even figures back let picture source the silicon crystals you can even see clearly silicon dumbbells we know that silicon dumbbells forms inside the crystals a silicon atomic gambles can be easily deciphered from this picture right inside source even.

The information limits a resolution level rather of point eight am strong the distance between the Centers of the two atoms in a dumbbell structure the bottom picture shows the strontium titanate Sr , Ti, O 2 where the this A shows the atomic positions along certain crystallographic directions b so z conventional Lucie electron microscopic image where you cannot even see different atomic species properly because of the resolution problems on the other hand.

The sea source the different at work pieces even one can see stones IAM which are the big atoms like this white color the titanium okay, 30 name is basically sitting like this that one can even see the oxygen atoms their residual contrast kind of auction item can be seen because these are all a person character in micros cumin is cos detector is used we will all discuss this thing in detail in subsequent lecture if one is very careful even one can see the vacancy.

In the atomic in the oxygen atom positions so therefore this is the state of part today of piles of microscopy so if you want to understand the health of microscope in detail we need to look at from a very simple picture of an imaging system but. I would like to tell you something more of a higher loosen Pecos copy in the sense that among all the structural characterization techniques

highly selective microscopy tells you the atomic structure along a particular incident beam incident electron beam directions.

To the atom resolution level which is not possible in any of these calculation techniques not only that as we know that if we can take this atomic scale images along different electron beam incident directions then we can build up a three-dimensional structure and that thin dimension structure is what is exactly we develop from the exit diffraction or neutron diffraction studies, so in the viewpoint we can say that it is possible to obtain the structural informations from different directions of these incident left on beam.

In electron microscope as well as also it is possible to build up a three-dimensional structure to the atomic resolution level so normally electron microscope a combination electron microscopes which you use nowadays has a solution level of 1.2 to 1.6 Armstrong's but to the health of a person electron microscope we can reach resolution limit of 0 point 6 even better than that punching am sterna even better than that so therefore it is possible.

To obtain the structural information to that level to the reducing levels of less than 1 Armstrong is what is makes hydrogen electron microscope is so powerful technique obviously as I have shown you pictures where you can see even atoms actually we do not see the atoms you see the potential of an atom when electron interacts with the material and it forms a particular image and we see basically potential of the atom in the imaging plane.

We do not see the atoms but many people write in the textbook and even the in the lectures that with quote unquote we see atoms well fine ,so this all very good features while some microscopy that you can see atoms virtually we can build up the dorsum structure we can get even composition information at the atomic energy level and we can do many other things, but it has his own problems like any other techniques the potential of this technique is severely affected by the fact that we need to interpret.

The images so quantity interpretation of the images makes this technique rather. I know difficult one for many users and it has been found that to quantitatively interpret in image we need to have app already idea of the structure of the material and therefore hallucination to microscopy is to some extent dependent on the many other techniques from where you can get a parody structure of the material which is very valid.

In case of complex structure like was a crystals are in income commensurate material structures where we do not have any idea where the exactly Adams seat so therefore describing the highly selective microscopic images quantitatively from those kind of crystals are those kinds of materials is a big challenge for us although advent of computers have made a life easy, but it is not very simple still so far to run the simulations in the computer one needs to have lot of a priori knowledge about the structure of the material computer.

The material many other things which needs to be obtained from different other characterization techniques so by knowing all these aspects let us now look at what is actually highly electron microscopy from the very basic point of view and how we can understand it from the image imaging tool open electron microscopes.

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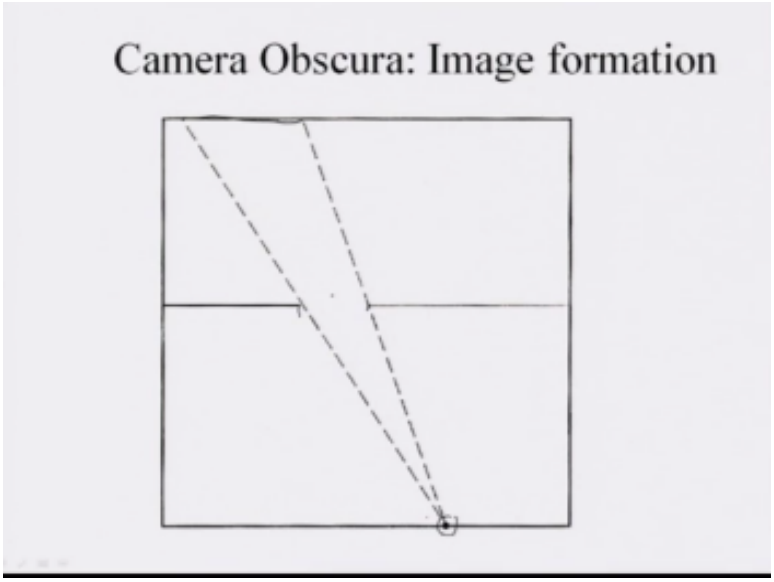

Let us start with a very simple thing that is the camera or other camera obscura in camera we know it is basically a black box and in which we have a pinhole and the light passes through this Pinole and from the image so therefore if we have an image in the image plane like this and we have a window or a small hole at work pin hole through which the light passes through and we form an image there this is what is basically a camera looks like the obscura camera means the old camera what are the camera has many other lenses.

So therefore if,I describe if I have to describe this camera image formation in terms of you know mathematical aspects so we can always assume that this image to be one-dimensional and the functions are very simple so let us do that if we assume that image has object as can be given by a function like FX how my object is given by function.

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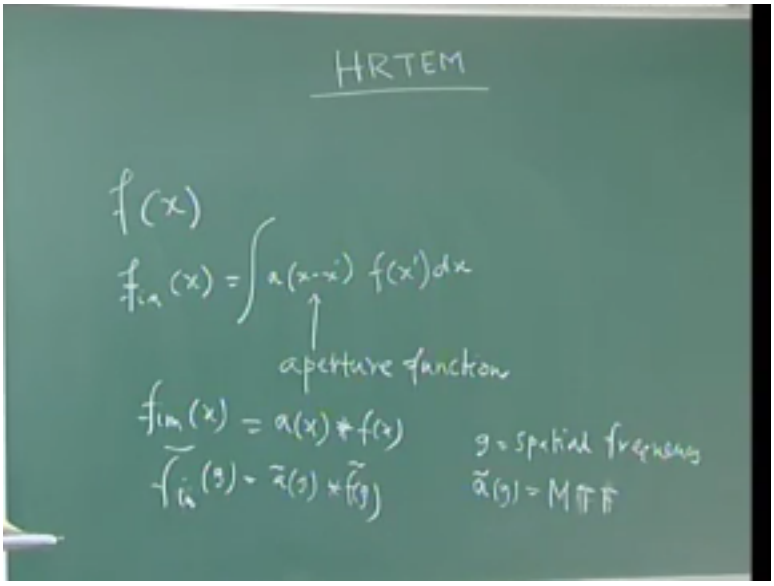

Like FX and this object is basically getting focused on the image plane while these rays are passing to the pinhole so therefore object the relay race are passing through a small aperture and if we assume this aperture to be a the window through which the light is passing through then we can interpret it the image basically the contribution of the point X in the image plane by this

function called F image (X) which is nothing but the a (X -X)x F(X) ‘dx integral okay, so we are a (X - X ‘) is nothing but the aperture function.

So that means if I want to get the image information are the informations in the image plane we need to use the aperture function aperture actually modifies the image during formation .Now this is very a simple equation a very simple equation which is used in the imaging technique which can be available any books you can actually take calculation of this 2x and this equation can be written like this a (x) = x + (FX) giving rags to the image function so this function integration.

Of the aperture function and the and this object can be simplified like this the calculation product of ax + FX and obviously any image whenever we form we need to have to get the diffraction information one needs to do the Fourier transformation so in the Fourier space this expression can be written like this F x (g) a (g) the spectral frequency so AG in convolution of AG and FG so we know that convolution of the any function once we transfer into footage space remains the conversion of the Fourier components where g is basically now the special frequency.

So G is nothing but a special frequency because in the furious pace everything is described in terms of frequency or inverse of λ and a (g) or rather let us write like this to depict it the Fourier space a (g) is given known as our Fourier transform of a(x) can be given as known as modulation transfer function are known as also the modulation transfer function of the imaging device so this is a very important aspect of any imaging device because they whatever is getting image from the object plane.

To the image plane is getting modified by this aperture function so any simple camera if we see the image even though we are assuming that the whatever is there in the object is getting directly projected into the image plane is not true so this is what actually dictates many things a resolution of them of the imaging instruments and information limit of the imaging instruments and many other aspects so every imaging device is that is why I said is characterized by this function called modulation transfer function are simply called transfer function.

In the books it describes basically magnitudes of the this spectral frequency or g which is getting transferred to this device from the image object planes to the image plane so how much of this magnitude of the values of the spectral frequency which are present in the object is getting

transferred to the image plane why this device is what tells you the transfer function so we will discuss more about this transfer function in the subsequent slides so let me just tell you something about also resolution. Which can be easily derived from this picture but once you go to the next slide.

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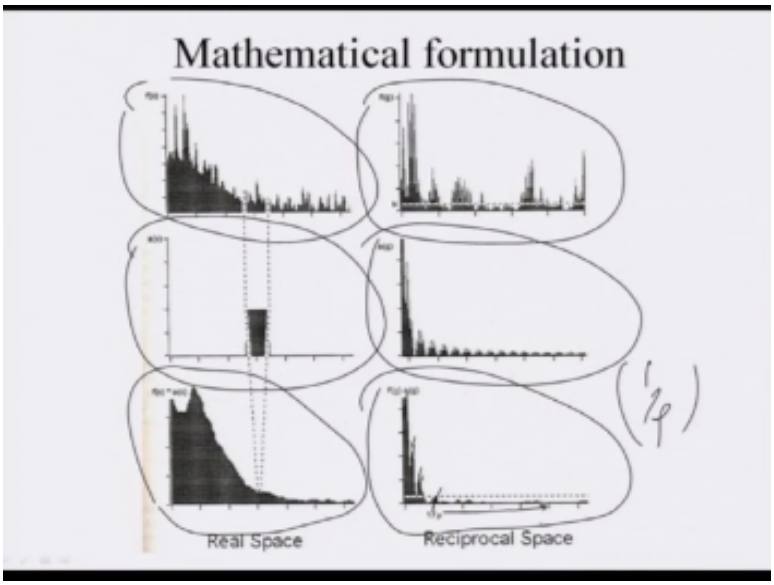

It will be clear so let us suppose the mathematically this is my the image the object function FX as a function of X in one dimensional so you can see lot of lot of spikes and lot of which liar things and if we just take this Fourier transformation of this if g it becomes a very discreet speaks in this period space because this has transferred from the image space mysterious space, so therefore everything is a function of frequency and we can always say the aperture function is like this as shown.

In this picture so aperture function is 1 in the aperture and 0 everywhere else because this is a small hole through which light is passing through so therefore any places outside the small hole like is unable to pass through therefore we can assume this would be one and the aperture do in other places and if. I just fully transform this again gives me lot of speaks ok now if I take the

convolution of F (x) and a(x) it becomes a function like this with the frequency with a Pascal distribution so which is summation nothing but is in this and this and most importantly.

If I take conversion of F (g) and a (g) it gives me one two three pics here which are basically can be called as the signal in a in a basically amazing device so therefore whatever they are in the in the object space is can only be converted into the image space once you have very nice signal coming out of there this is what actually seen are observed mathematically. When we transfer any points in the object planes to the image plane through and the aperture function or through any imaging device our way and TM or consisting of many imaging plates or imaging lenses.

So therefore for each of the lens theories and imaging function a transfer function so and they are all cumulatively added so therefore the total image quite a quality of image which you observe obtained after the object passes the light passes through the electron beam passes through all these lenses as basically can be obtained if we have convolution of all these the aperture functions in this Fourier space so this allows us to basically define the solution.

So a solution is basically of anomie ending instrument is defined as a cut off 01 by car door means 1 by P cut off in the sixth that means this is the one where you cut off which tells you a distance difference between the signal and the noise so if I take the ratio of signal noise there is a cut off below which nothing can be transferred by the imaging device. So any other frequencies special frequencies here above this one by P values which are marked here can no longer be transferred by the imaging device so this sets us the solution this illusion actually.

I know is basically can be easily compared with the relays definition of solution which I have discussed in the class two three class before so this is basically in a physical sense definition of resolution of any machine. Now for a transformation of this transfer function basically are this a (g) or rather whatever we have said is basically known as the implanted function which we will discuss later this is nothing but generalization of the aperture function of the camera it is basically you have seen here.

You can see this they are here also you can see that this basically sharply peaked plot of the as a function of F(g) convoluted a(g) as a function of the one by wavelength or the reciprocal space so therefore the width of this function basically can be lead.

To the relays resolution criteria now this is very simple and as I said the solution can be easily plotted like this.

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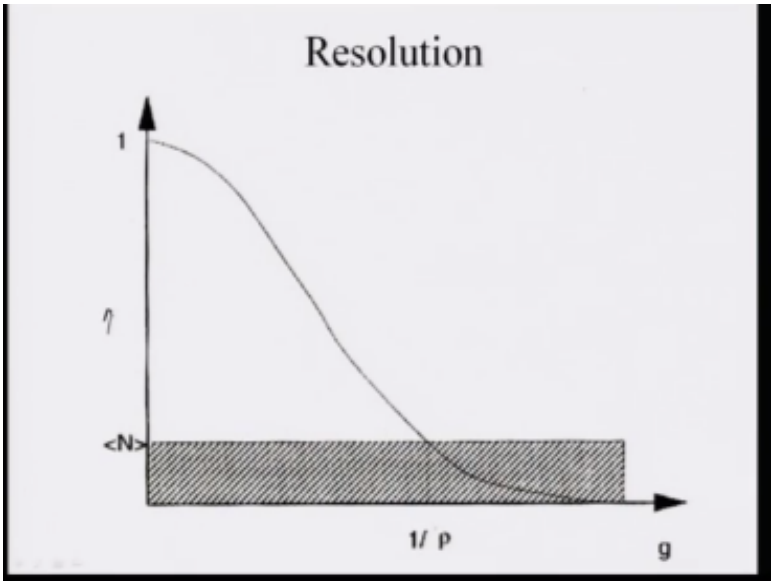

So therefore if I plot the this is a resolution in the in the x-axis are the signal actually not x-axis so if you clearly see that this is the noise level so therefore any frequency or any special frequency beyond 1 / P can no longer be transferred by that by these imaging device into the image plane so therefore we tell this is the resolution of the imaging device so all the other frequencies all the other values of g specific and sees can be easily transferred by the machine or by the dimension device is a camera or electron microscope it can be transferred into the image plane and that is why this can be defined as a resolution of the machine.

So now theoretically these are all possible practically no microscope is a perfect one or no camera is also perfect one there are a lot of defects inside it and these defects do play a chip serious do play a serious role in basically reducing the resolution level from these two even much higher so let us now discuss by knowing this you know. So these aspects very well let us now discuss about the electron microscopes this is basically very simple thought I just gave you at the beginning of this lecture.

Let us now talk about the image formation in a electron microscope we know the image formation electron microscope is a coherent process what does it mean object as all the transfer functions in the in the electron microscopes are very complex functions and their complex

functions of both are they are the complex function with an amplitude and also a phase component because they are all waves so like any other way observe the amplitude component there will be basically a phase component so as we snow that wave function.

So whenever a basically whenever if you think of an object in electron microscopes or sample electron microscopes we know that electron beams falls on the on the sample and passes through the sample also because it is a very thin one if I think of that this is a sample.

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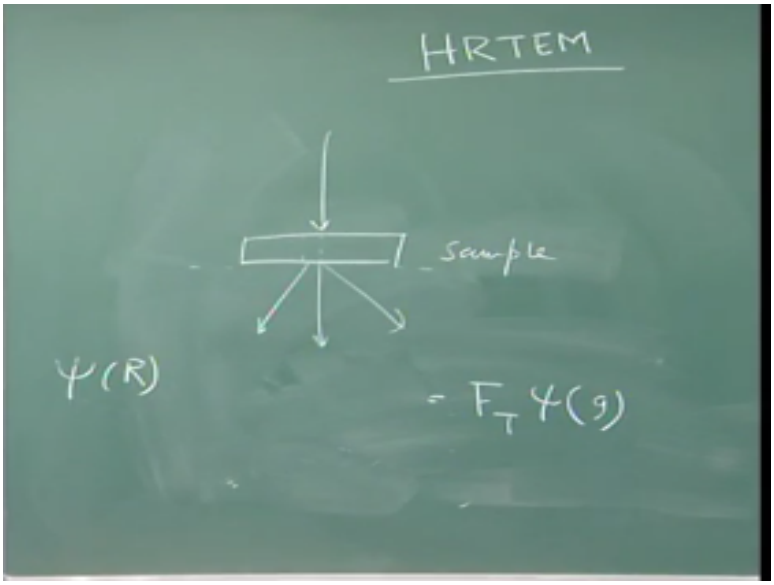

In the electron microscope and electron will Falls like this and interacts and then either get diffracted or not get diffracted through this exit plane okay so by knowing this is what happens in it mike. I discuss with you in the next class before by knowing this now if I think that wave function are electron wave function basically is at the exit plane is given by this we can always write this we are basically the (R) is the exit Ψ is the function I electron wave functions so if I have no this kind of consideration we can always think this wave function is plain as a planner you know for source are the spherical waves.

Okay these are the planner source of the finical waves here at the exit plane huge in types we can always do that and obviously then in that case if they are all plan a source of the source of light or electron at the exits plane so we can think of that the sample is acting as a grating or diffraction grating and then. I given to form offers diffraction theory front of are also the scientists who basically work tremendously on the diffraction theory after his theory the complex

magnitude of the diffracted wave is in the direction of the wherever the electron beam is going this direction can be the defect interaction can be given by certain value of the reciprocal vector.

So therefore we can always tell on the corner conifer diffraction to you that complex episode affected wave in the direction given by the any reciprocal lattice vector is can be written given by the Fourier transformation of the object function so this is the object function if I take a Fourier transformation of this object function =FT Ψ(g) is nothing but the diffracted beam .I are the what is call the diffraction refracted beam intensity are this Ψ(g) is what is the what is called the form of a diffraction theory tells us from the very basic knowledge. Now in an electron microscope so we know that objective lens.

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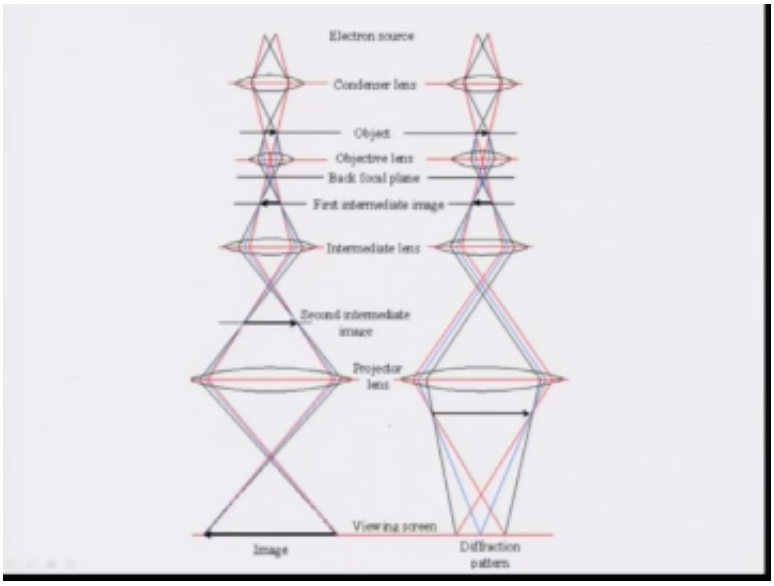

So let me just go there we know that objective lens actually placed behind the sample that is what you see here the this is the objective lens here in the microscope here also so sample is basically immerse in the audience as, I told you in the class I have not shown you in the well showing the microscopes back to the claim is basically behind the object therefore it focuses all these waves into a plane call a back focal plane okay, and that is also shown here this is the black focal plane you can see here it basically all the whatever waves coming out of the exits planes they are focused by the objective lens.

On the back lot of time and then actually the various portions of this back where this in a focused beams gives you basically diffracted spots or diffraction beams rather and when these diffraction

beams us then focused on the order from the image on the imaging plane we get a diffraction pattern therefore back focal plane of the objective lens contains the Fourier transformations of the object basically if you think of it that way in the electron microscope we can change actually that is what we said we have shown.

You we can change the settings of the electron microscope another we can change actually the poker length of these different lenses like intermediate or the first intermediate lengths to either focus this back focal plane onto the image plane or see.

To obtain these to see these diffraction patterns and obviously the intensity of these diffracting beams will be in 10 cities will be proportional to $I = (\Psi(g)^2$ Fourier transformation of this the exit pipe in the for your plane and in the object is periodic that is a crystal the diffraction pattern will be graded update is continuous effects model will be continuous this all understandable this is the basically classic sense of diffraction pattern formations in a classical TM so that is normally routinely done in the microscopes.

Whenever you inside the sample first thing we're into crystals and then put the aperture in for the slicker parallax great opportunity and get the diffraction pattern that any electron microscope users who are seriously the microscopy can immediately recognize this whenever go to the whenever he or she goes to the microscopes there is a second kind of stage of image formation this is the first kind of ice formations and in factually one can use this the diffraction buttons to do diffraction contrast imaging.

Which I will talk in within moments time so in a second seat of image formations their back focal plane can basically can be thought of acting as a set of huge in sources all the spherical waves we can always think of their acting extremely as a set of huge in sources are the sources of the electron beam as several physical waves which can be then allowed to interfere so if this diffraction spots are allowed to interfere and then with it can form the interference patterns on the image plane.

So whenever that happens we get something what is called lattice fringe images which has shown you the beginning of the lecture so this basically is called whatever by spawning this you know the by interfering this set of huge in spherical waves and then forming a lattice fringe wave lettuce range is nothing but inverse Fourier transformation which basically reconstruct the object

function sigh are in the image plane so therefore by just looking at the camera picture and comparing you with the electron microscope.

One can simply understand how these basic things actually happens in electron microscope let me show you the how the electron diffraction pattern form as, I said if I have a object here.

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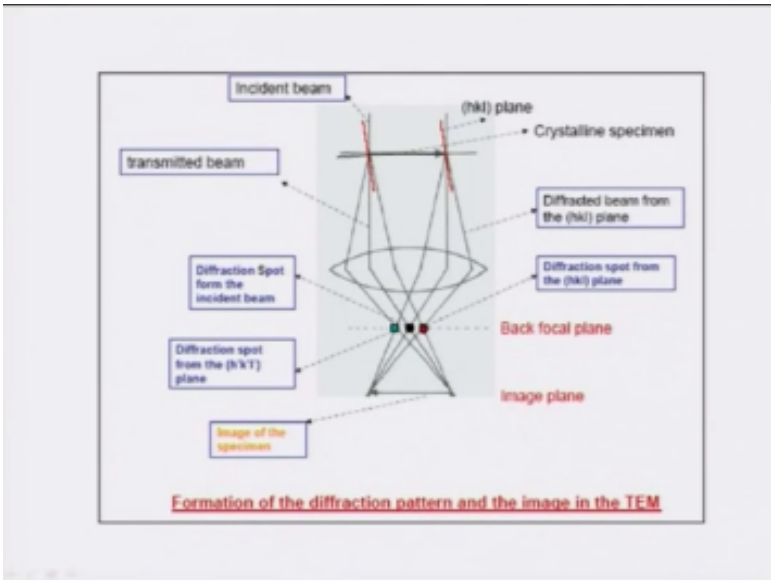

The objective lens basically focuses all these the diffracted beams into the back focal plane and that is what we get diffraction spots, when he basically image this the diffraction spots our focus is a fractious basically on the image plane now this is simple like formation of nothing but Fourier transformation of the diff the electron beams or the exit waves at the back or the exit surface of the crystal.

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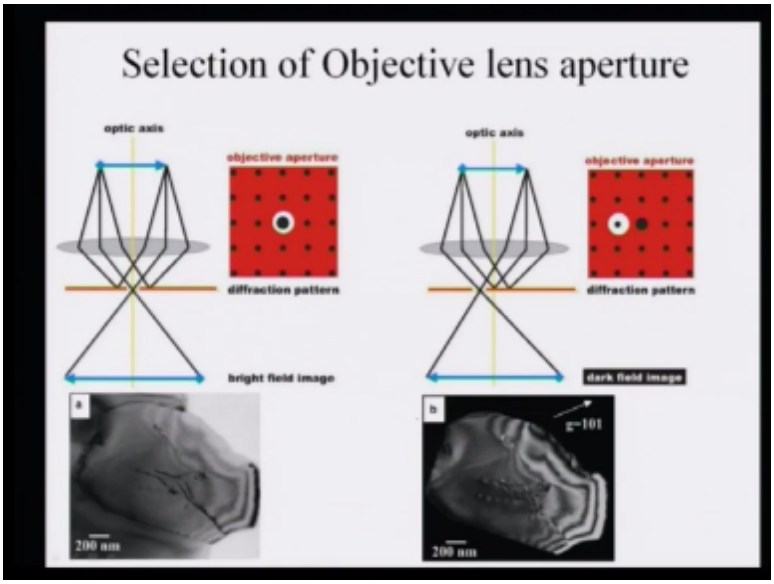

So now once we can use as I said we can use this diffraction pattern to image or get diffraction contrast which is normally done in the electron microscopes and electron microscopes, so this is my diffraction pattern on the back focal plane okay as you can see focused by the and if the objective lens this is the objective lens here and this is the diffraction pattern on the back focal plane so if i take the bright spot or the undue fracture spot or the transmitted spot or the fourth skater part whatever way you can explain then whatever we form is nothing but a battle image in the field is bright and the images looks black.

On the other hand if I take any of the diffracted beam hair like this and use this to form the defected the image then we what you get is a dark field image in the field of use dark image is basically bright and this is what is shown here in this way so by using in the apache obviously aperture we can either form the black virtual image or you can format actual image and this is

duty lee done in electron microscopes anyone who is doing normal serious microscopy are very well conversion with this or never.

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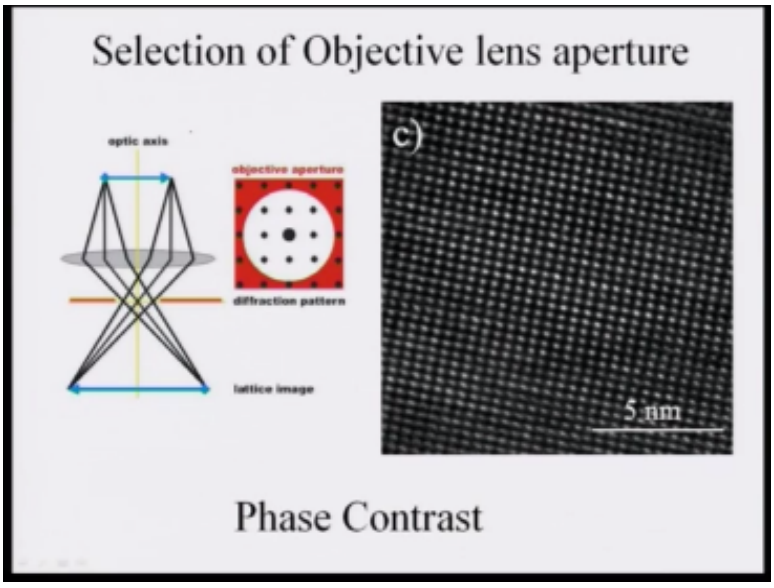

And what I am saying in the second set of imaging process just a few minutes back. I discuss is nothing but if I use all these diffracted and the transmitted beams and allow them to interfere and then I form what is known as a lattice fringe or lattice image this is what is shown here you could see that I am market larger area all I put a bigger aperture in the diffraction pattern. I selected at least you know 98 defection spot along with the transmitted spot and we can form this kind of the phase contrast images.

This is the second set of the formation which is done routinely no microscopes nowadays because of the advent of different you know high-quality microscopes this is now also can be done routinely so as you can see that that in a real practice by putting an aperture in the focal plane or objective lens it is possible to form either a phase contrast or interfere phase contrast image which is basically nothing but the interference of these diffraction and is transmitted electron beams from the back focal plane or we can select.

One of these basically transmitted beam of the refracted beam and then disallow this interference to happen and from the images but as you as I told you electron microscope like any other

objects in this world which man makes is not a perfect device so therefore anything anyway which is passing through this objective lens in electron wave your undergoes a phase shift and also amplitude reduction an amplitude reduction nothing but a damping therefore we need to consider the task for functions of a target of lens.

To really describe actual image and this is what we will do it a transfer function in objective lens our objective electron microscopic lens can be written or can be given in a very simplified way I would not discuss the digital derivation of that but transfer function can be written very easily so I if I write transfer function.

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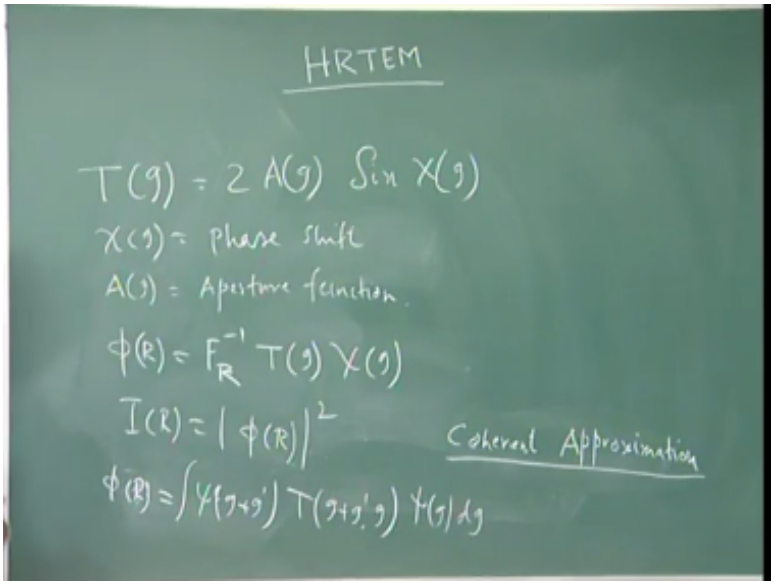

In a electron my orbital lens like this TG ,TG is nothing but 2 A(g) special frequency and Sin X(g) so this is what is basically simplified transfer function in a in a electron microscope of the orbital lens where AGS basically tells us the effect of the aperture function effect of beam selecting aperture and X(g) which is very important parameter here is basically phase shift it tells other phase shift and A(g) is that Aperture function so this is a very important functions of the objective lens in electron microscope this will tell us not only the solution.

But also the information limit which you can obtain in the highly scenario microscope that is what I am Telling so wave function at the image plane obviously can be written like every simplified wave function can be written like this is ϕ wave function in image plane is image plane is if it is (R) then can be written as inverse Fourier transformation so inverse Fourier

transformation is like thisF-1R in where transformation of the T(g) and the size and X (g) intensity obviously will be I (R) =1 ϕ (R) ^{2} of the wave function that we know so that is therefore and this is very simplified theory okay we assume.

In this theory that the crystal is a very thin so there is knowing I know interaction between these diffracted beams inside the crystals once they come out then you know the interference from the image so that is not only this is what is called as a coherent approximation so if you assume the coherent approximation then only these formulas correct otherwise the formula gets complicated and those complicated formula needs.

To be derived based on the concept of transmission cross coefficients okay how this the beams are actually interacting and because of that is across coefficients so if you know that animation cost coefficient then we can actually see this function then will be much more complex which I can actually give you so ϕ (R) =Ψ(g+g') T (g+g'g) Ψ (g) d(g) thus basically tells you the interaction between these two different special frequency G&G forget about it we are not going to use this we are going to use.

The coherent approximation and for that the particle wave function at the image plane can be calculated using inverse of a transformation of the transfer function and these Ψ well by knowing this now actually one can seriously look at the exact nature of this phase shift are the Ψ(g) function which we are going to do in the today is lecture very seriously and that is the basically the purpose because this will tell us many important aspects of the image formation so as you see that Ψ as I said these goes into the transfer function very importantly.

This is the aperture function so a partial function can be derived as I showed you in any electro Michael any device but let us first look at one of the nature of this fashion the studies indicate that size E is basically depends on 3 factors.

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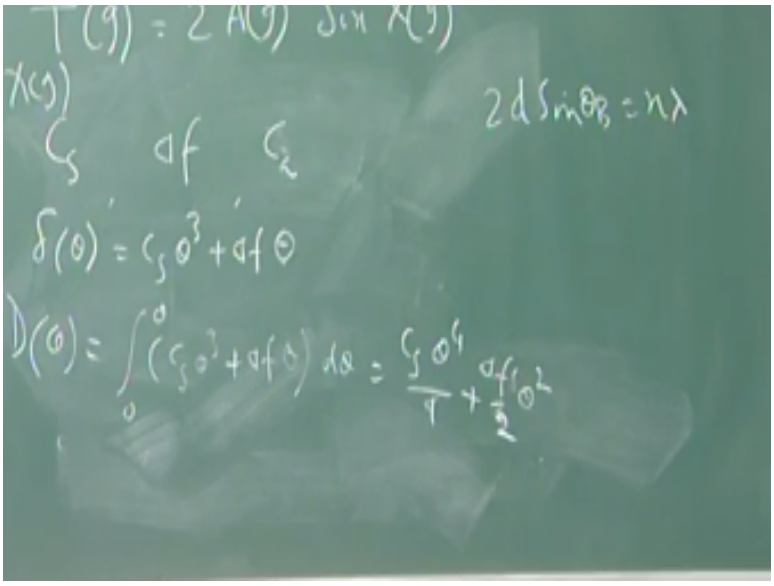

Or it actually has a combined effect of CS the spherical aberration constant of the lens as I said any lens is not a perfect length, so like a camera also you know the lenses have spherical aberrations come I mostly fake elevations common decoration also comes. Into picture because chromatic aberrations comes from the difference in energy levels of the incident electron beam but let us for the sake of understand how the simplicity.

Assume that spherical aberration is the most important defect and then second factor is the ha f or the focus and third factor is what is known as other this is a Δ f is the focus which is basically the depth the objective lens defocus and third factor is obviously the wavelength we will see that and they all see as a no G the related we will see also that so if we can consider we can find out.

A point it at the pessimist basically what does it mean the effect of this on the size he means that if I appointed in the image plane that point will be focused as a disk because of the effect of spherical aberration and the focal n are the defocus of the objective so therefore we can basically tell that that you know this the image whatever has been form on the image plane as a disk can be given by this radius Δ θ = c s θ3 q + Δ F θ this function tells us the disk which is formed so if you want these two small then you want CS and Δ F to be optimized and that is can be done by analyzing the whole problem mathematically.

Which will do the next ten minutes or so finally so we are discussing about this effect of the different parameters on sighs II so let me just describe it in detail all that as I said that sighs II this function which is going to the transfer function very as a factor depends on three aspects the

CS the secular version comes in constant d focus of the orbital ends and the astigmatism of d of little else so as team at ism can be easily corrected as you know any normal camera also estimate ism can be corrected but these two parameters CS and Δ F.

They need to be optimized to basically have the best value of transfer function so that we can obtain very good resolution the images now we shall grow through a very simple exercise to derive this the value of these sighs II let us do that and as I said that the basically the exercise is nothing but the combining this effect of CS and the defocus of the outer lens so if I do that we find that any object any point in the object normally will be focused onto the image plane like a disk because of these presence of the CS.

And the Δ F and so therefore we can write down the diameter of the disk as Δ θ = C as θ cube +Δ F x θ and so basically the race which are passing to the objective lens they at an angle θ are not focused to the same point okay ,because of the spherical aberrations and finite value of the of the Δ F that is why they are basically coming at that but we know that that not only one value of θ we need to consider but we need to consider all the values of θ, θ is nothing by the diffraction angle so therefore we need to consider all the diffraction angles in that case we need to average out the Valor the this value as a function of the diffraction angle and which can be done by simply doing.

The integration of this equation form 0 to θ cos θ pew +s Δ F θ D θ and as you can see if we once integrate this equation one can get this as a CS $\theta^4 / 4 + f \Delta f / 2 \times \theta^2$ this is what is the basically the disc average disk diameter if we integrate this we can get now we know that from black's law that we can very easily write from blacks law that 2 d sine-θ = L λ so therefore we can write down for TM basically for normal microscope you know θ is very small if θ is very small then we can write down to θ B sine θ = almost like θ = we can write down well simply that λ into Z where g is basically one by 2d .

You can see that g is 1 / 2 d which is the reciprocal space this one by d actually see the reciprocal lattice vector so if this is the case the two θ p is basically very specific value because this is the diffraction scattering angle for the diffraction to happen now we can inside this if this was called value into this function and then we can get the whole function like this the size.

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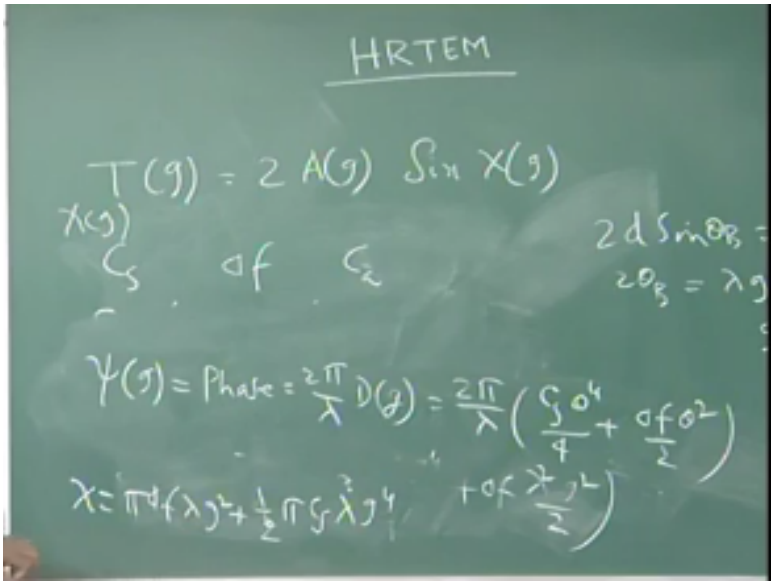

Ψ(j) s is the phase that is = d 2 λ y 2 Л by λ x d g and this is nothing but then 2 Л by λ I x CS θ to the power 4 θ to the power CS a 330 power 4 by 4 + Δ F θ square by 2 and this can be easily written in a mass simplified form like this so Δ F x Δ F by Δ F x λ square now we can convert this θ x into λ as you can see from there so therefore we can finally get this to be = twice pi by λ into CS λ 4 and g 4 by 4 + Δ F into λ G by 2 θ B that = λ square G square by 2 so that basically gives me the value of sighs II and therefore that means.

I basically this size basically function of pie or psycho meatiness a Л Δ F λ Л Δ λ into G square + + CS half Л x CS λ to the power C and G to the power 4 so what you can see is a very complex nature of this function side and if I take a sign of this that becomes very simple complex function and it is very difficult to even calculate this functions normal simple mathematical way we need to use certain tools to calculate that but whatever you see that the size depends on not only the Δ F λ and G okay depends on ∇ Δ I planned but also CS very strongly so that is why one needs to optimize the Δ F and C as in electron microscope very clearly and in the next and basically ideally the transfer function should be like this from zero.

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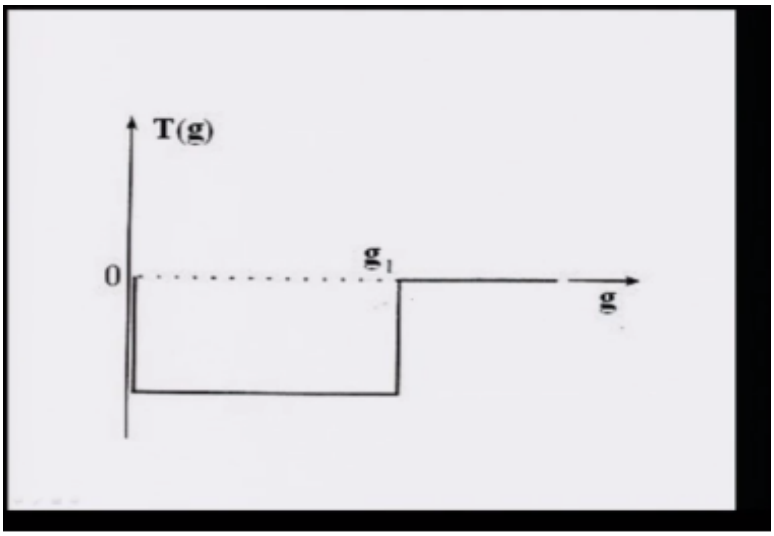

To g1 is to the Pacific value and beyond that it will be all zero this is the idol transfer function in electron microscope but this is never possible.

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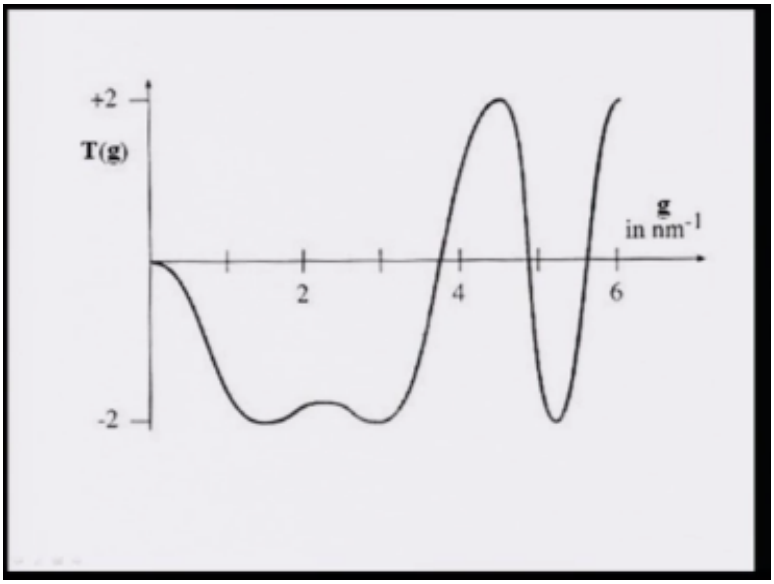

So if I plot this transfer function as a function of Z here generalized functions okay ,obviously depends on the values of Δ F the λ and CS if I consider CS to be you know one millimeter and Δ have to be 50-58 nanometers and the easy oh that is the electron beam by the radiation the voltage by health electrons accelerated is to be 200 kilo electron volts then this is the nature of TG so you can see that it is not does not look like the idle nature rather it is basically the from zero it goes down the increases there are a lot of crossovers that makes the life very difficult now. Let us look at the nature of this curve as different functions.

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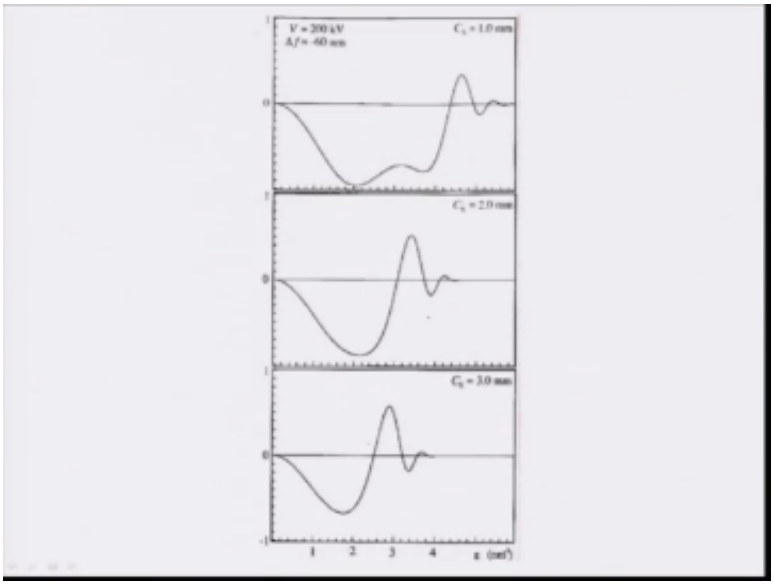

So the next one is basically as a function of CS so if you can see if we increase the CS from 12 to 23 the function h is totally changing as you can see here the for the value of 1 which is very low for CS with a particular value of the accelerating voltage and the defocus we can see that there are different costs over cause over here is basically cross over there is coming a different

values of g even one can even see the cross over is basically changing getting lee coming at a lower value of g as you increase the value of CS.

Now if we keep the CS to be one millimeter because that is why the best possible you have seen and then vary the focus for the defocus from 30 to 50 to 70 - a nanometer and one can see that how these things are changing in fact one can see as you go form- 32 - 50 basically this width changing the 21 is also changing the crossover point at which this trance function is 0 is also changing but once you go to very high refocus values we can see there is two spikes coming into picture 1 a G1 other energy too and both of them are basically not meeting these the line at 0.

So that makes the life very complicated therefore what could have seen that these two parameters the CS and the Δ F has a strong role in basically determine the transfer functions and I mean electron microscopes CS is obviously given by the orbital length configuration CS can never be you know changed so given a microscopes we can what you can change is the objective focal length or the Δ F value they refocus so in the next lecture.

We are going to see the effect of d focus and how we can use this to obtain various informations in the Aleutian term micrographs you.

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