Fundamental of optical and scanning electron microscopy

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Module – 03
Unit-7 Instrumental details and image formation
Lecture – 18
Image formation and interpretation continued
Energy dispersive spectroscopy
Wave length dispersive spectroscopy

Hello everyone, welcome to this Material Characterization Course. In the last class, we started discussing the image formation and its interpretation in scanning electron microscopy. And then you see that certain things have come out very clear; the image formation in SEM is quite different from what you see in optical, or light optical microscopy, or even transmission electron microscopy where the ray paths connecting the location in the specimen in the corresponding the image points is not there in SEM.

In that sense, there is no true image exist in SEM, where we collect only the signals which is coming out of the specimen, and the signals are collected in the form of secondary electrons or backscattered electrons, and the detector process this electronically and then the spatial features on the specimen is converted into domain of time. Since the signals recorded in SEM as a function of time, even the very fine scale details under the SEM will have a very high frequency signals. So that is with respect to a detector frequency band which we have seen. And also the kind of detectors involved how effectively it can collect the signals and process them to produce an image. So, all these features we have just a detailed manner we have discussed in the last class, and we also introduced the origin of the contrast from the specimen. So, today, we will just continue from that point.

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Image Formation and Interpretation

Contrast

Contrast can be influenced by a complex mix of the characteristics of the beam – specimen interaction, the properties of the specimen, the nature of the signal carriers and the position, size and the response of the detector. There are three different ways the contrast can be measured:

- ***Number component*** – different number of electrons leaving the specimen at different beam locations in response to changes in the specimen characteristics at those locations
- ***Trajectory component*** – The trajectory component refers to contrast effects resulting from the paths the electrons travel after leaving the specimen
- ***Energy component*** – The energy component arises when the contrast is carried by a certain portion of the BSE energy distribution. Typically, the high-energy backscattered electrons are the most useful for imaging contrast mechanisms

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I just mentioned that the kind of parameters which is involved in the contrast, we will go through those points again. Contrast can be influenced by a complex mix of the characteristic of the beam-specimen interaction, the properties of the specimen, nature of the signal carriers and the position, size and the response of the detector. There are three different ways the contrast can be measured. One is Number Component that is, a different number of electrons leaving the specimen at the different beam locations in response to the changes in the specimen characteristics at those locations.

And Trajectory Component, the trajectory component refers to the contrast effects resulting from the paths the electrons travel after leaving the specimen, and thirdly, Energy Component which arises when the contrast is carried by a certain portion of the BSE energy distribution. Typically, the high-energy backscattered electrons are the most useful for imaging contrast mechanisms. So it is very clear whether you obtain a secondary electron signal or a backscattered electron signal, these three parameters are going to determine the property or the quality of the contrast which you can obtain from the given specimen. So now, let us get into the details.

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Image Formation and Interpretation

Atomic number contrast

(a) $(n_{BS})_1=(n_{BS})_2$ $(n_{SE})_1=(n_{SE})_2$

(b) $Z_2>Z_1$ $(n_{BS})_2=(n_{BS})_1$ $(n_{SE})_2=(n_{SE})_1$

Atomic number contrast has the following characteristics

- Because of the monotonic increase of η with atomic number Z regions of high average atomic number will appear bright relative to regions of low atomic number
- If we make use of detector that is sensitive to the number of backscattered electrons, for example, a negatively biased E-T detector, a solid state diode, then the signal from the detector will be proportional to the backscatter coefficient, neglecting any energy response characteristics of the detector

First, we will look at the atomic number contrast, this also sometimes referred as a compositional contrast or a z contrast. The schematic clearly shows that the electron beam specimen interaction and then where you have the signals coming out n number of backscattered electrons and n number of secondary electrons. Where schematic a shows n BS is equal to n BS 2 and n SE 1 is equal to n SE 2. So, according to the contrast definition, the very basic definition, these two objects will not exhibit a contrast, that is what the basic definition itself says you should have a very significant different signal collecting from the surroundings and the object. So, you will not produce a contrast but when you have the situations like depicted in the schematic b, where you see that the atomic number is different from these two objects that means, there is a sharp interface between the object 1 and object 2, then you started showing the contrast or the specimen will exhibit a significant image contrast.

So, let us look at the general remarks; atomic number contrast as the following characteristics. Because of the monotonic increase of eta that is a backscatter coefficient with the atomic number Z regions of high average atomic number will appear bright relative to regions of low atomic number. If we make use of detector that is sensitive to the number of backscattered electrons, for example, a negatively biased E-T detector, a solid-state diode, then the signal from the detector will be proportional to the back scatter

coefficient neglecting any energy response characteristic of the detector. So, this is very particular to the backscattered electron signal and again the with respect to E-T detector.

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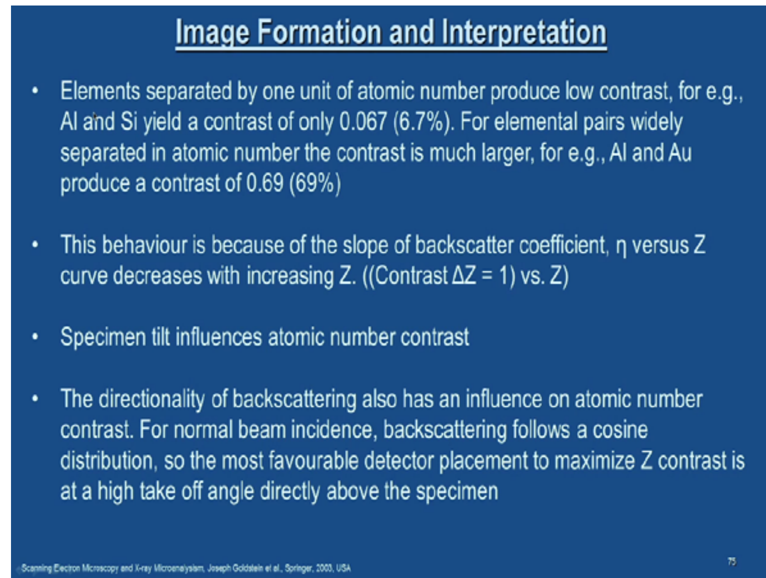

And another important point to note is element separated by one unit of atomic number produce low contrast, for example, aluminum and silicon yield a contrast of only 0.067, that is 6.7 percent.

The element pairs widely separated in atomic number the contrast is much larger, for example, aluminum and gold produce a contrast of 0.69 that is 69 percent, and this is very important point to remember. This behavior is because the slope of backscatter coefficient, eta versus Z curve decreases with increasing atomic number. Typically, the plot is against delta Z is equal to 1 versus Z, where the slope of the backscatter eta changes significantly. And another important point is the specimen tilt influences the atomic number contrast, which we have already seen in the some of the previous slides we talked about the specimen, how it is been loaded and so on. And also the directionality of the backscattering also has an influence on atomic number contrast. For a normal beam incidence, backscattering follows a cosine distribution, so the most favorable detector placement to maximize is Z contrast is at a high take off angle directly above the specimen.

You see when we looked at the instrumentation detail in a laboratory, I just clearly showed that how exactly this BSE detector is placed. It is placed just above the specimen fixed on the just below the pole piece, so that that is the position we talk about. That is where the BSE signals are very well collected. And you know that BSE electrons are very high energy electrons, their trajectories are straight lines as compared to the trajectories of low energy signals namely secondary electrons. So this I think is very clear.

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Image Formation and Interpretation

Topographic contrast

- The backscatter coefficient increases as a monotonic function of the specimen tilt. The more highly inclined the local surface is to the incident beam, the higher is the backscatter coefficient. This effect produces a ***number component*** contribution to topographic contrast in backscattered electrons
- The angular distribution of BSEs is strongly dependent on the local surface tilt. This directionality of BS from the tilted surfaces contributes a ***trajectory component*** to the BSE signal.
- The SE coefficient varies with the specimen title angle in a monotonic fashion, varying approximately as a secant function. Tilted surfaces thus yield more SEs than a surface normal to the beam. This effect introduces a ***number component*** to topographic contrast in the SE signal. The angular distribution of SE emission does not vary significantly with tilt angle, so trajectory effects are small.
- The topographic contrast that is actually observed depends on the ***exact mix of BSE and SE electrons*** detected which in turn depends on the detector used and its placement relative to the specimen

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Now, we move onto Topographic contrast. You see the origin of the topographic contrast is a very complex. And we will see some of the salient features of that. The backscatter coefficient increases as a monotonic function of the specimen tilt. The more highly inclined the local surface is to the incident beam, the higher is the backscatter coefficient. This effect produces a number component contribution to the topographic contrast in backscattered electrons. You have to understand one point here, before I read through another salient features, topographic contrast comes from the contribution of both secondary electrons as well as BSE electrons.

You can see that, when you talk about secondary electrons the number component is more important, but when you talk about BSE signals the number as well as the

trajectory components are more important in producing the topographic contrast. So, the origin of the topographic contrast is generally a complex thing, but it is always a mixture of these a secondary electron as well as the backscattered electron number as well as trajectory components finally decides the topographic contrast.

Now, we will move on to the next point. The angular distribution of backscattered electrons is strongly dependent on the local surface tilt. This directionality of the backscattered electron from the tilted surface contributes to a trajectory component to the BSE signal. The secondary electron coefficient varies with the specimen tilt angle in a monotonic fashion, varying approximately as a secant function. See in opposition to the cosine function, here it is a secant function. Tilted surface thus yield more secondary electrons than a surface normal to the beam. This effect introduces a number component to the topographic contrast in SE signal. The angular distribution of SE emission does not vary significantly with tilt angle, so the trajectory effects are small.

So, this is the reason why the number component of SE only contributes to the topographic contrast as against the BSE where the number as well as the trajectory components both contributes to the topographic contrast. Finally, the topographic contrast that is actually observed depends upon the exact mix of BSE and SE electrons detected which in turn depends on the detector used and its placement relative to the specimen. So, you have the detector final configuration where it is placed with respect to the specimen electron beam that also very crucial in detecting the signal and its contrast.

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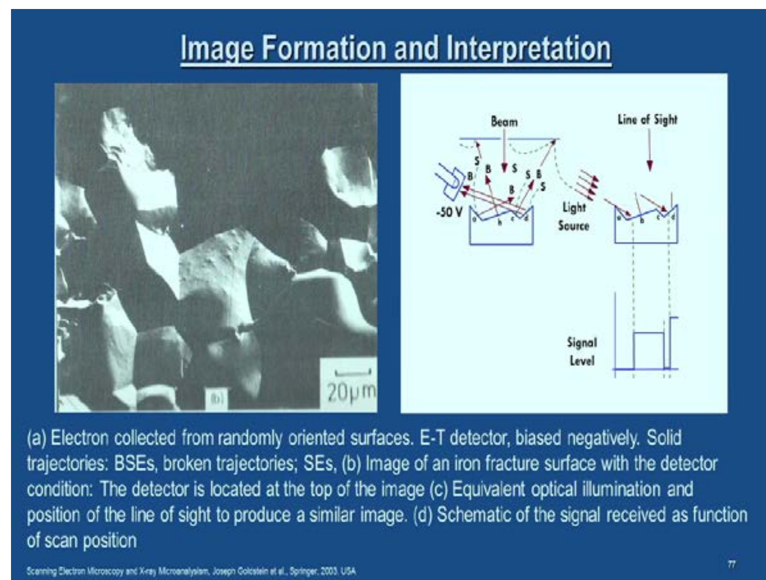

Now what I am going to show here is, look at this micrograph and the corresponding a schematic where we are going to just demonstrate how the E-T detector behaves for operating at two different potentials; one is a negatively biased potential, another is positively biased potential. The image which you are seeing is a fracture surface that is the electrons collected from the randomly oriented surface that is why you have these all the facets in the fracture surface. And we will see first look at the details here, this is the E-T detector which is negatively biased, and this is the pole piece, electron beam coming on to this fracture surface and then you get signals like BSE as well as SE these are coming out of this, and something is getting collected. Right now, we will just stick to this schematic and then we will look at this second portion of this after we finish the discussion here.

Now what I am going to show here is, look at this micrograph and the corresponding a schematic where we are going to just demonstrate how the E-T detector behaves for operating at two different potentials; one is a negatively biased potential, another is positively biased potential. The image which you are seeing is a fracture surface that is the electrons collected from the randomly oriented surface that is why you have these all the facets in the fracture surface. And we will see first look at the details here, this is the

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So what you see here is, the signals which are directly getting into the E-T detector will appear bright. So, similar situation is shown here. These facets are the signals are directly going from this to the E-T detector that means; the E-T detector is facing exactly opposite to this face so that is what it is shown here. Other facets which are randomly oriented to this detector angle they are not getting collected, you can see that they are going here and there; they are not getting into the detector. So, this facet d corresponding to the very bright region what you are seeing in the actual micrograph.

And another important thing is you can see also the ridge which creates the shadow in front of this is also should seen here. So, what you can appreciate from this schematic is when you have the negatively biased E-T detector, and the electron beam falling on the fracture surface normal to this then you see as these kind of contrast only that is because the backscattered electron which is exactly getting into this E-T detector facing this facets normal to it only will contribute to the contrast, the rest of the other signal will not contribute to the contrast that is why you see the rest of the region either grayish or completely dark.

Now you look at this right hand side schematic where, you imagine that suppose if you want to look at this same fracture surface using the light. Suppose, if the light falling in this direction, the light falls on this fracture surface in this direction, then you will also get the similar micrograph in the line of light or in a light microscope, you will see that, and the schematic here which is depicting the signal level. So what you are now appreciating here is, the signal which is coming from this d is the highest that is why it is appearing bright. And the next region which is appearing gray is showing the signal level here, and rests are the region where you have the 0 signal appearing a dark.

With this description if you go through this figure caption certain things will be very

clear. So you have the electron collected from randomly oriented surface E-T detector biased negatively. Solid trajectories: BSEs, broken trajectories; SEs - image of an iron fracture surface with the detector condition. The detector is located at the top of the image and c is the equivalent optical illumination and the position of the line of sight to produce a similar image. And d is a schematic of the signal received as a function of scan position.

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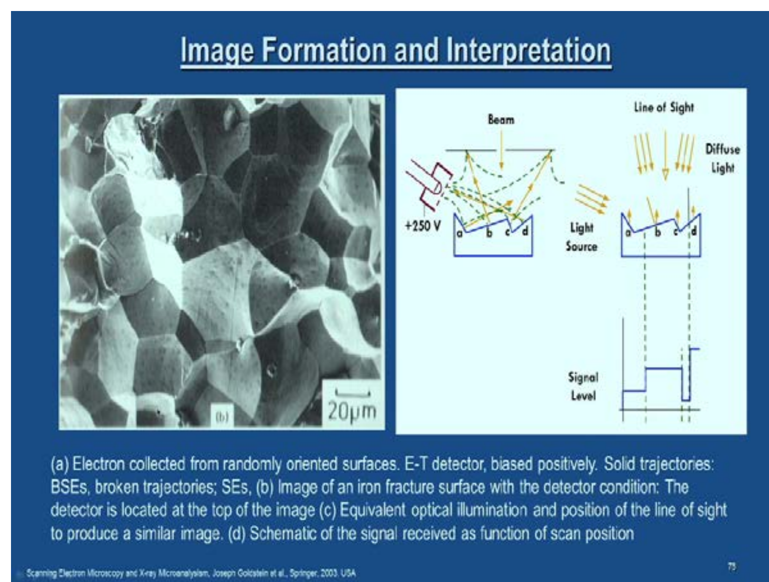

Now look at another image, where the E-T detector is positively biased. Remember when you when your detector is positively biased it is going to collect both SEs as well as BSEs. So, you can see that clearly from that specimen most of your BSEs and SEs are most of I mean SEs and BSEs are collected together in this positively biased E-T detector and the position is not changed from the previous one. But you can see that since both the contributions are there you see the fracture surface appearance much more clearly whatever was appearing quite dark there you are started appearing bright here. But still this region which appeared with the highest brightness remains the same because the detector position has not changed and you see the complete details here.

And what you are seen in the right hand side is again the light source when you I mean light optical analogy basically. So, you see that light source which comes here then also

you will see this kind of signal profile when you use the diffuse light. So, I think with this two schematic, you got a very basic idea of the contrast which is obtained on the specimens either negatively biased detector or a positively biased detector. And also you have now got some basic understanding or about the contrast mechanisms either it is a z contrast or the topographic contrast. So, with that I would like to bring the imaging and interpretation part of the SEM.

I would like to just move on to the next topic in an SEM where people look at chemical details of the specimen. You see most of these SEMs are interfaced with spectrometers like energy dispersive spectrometer a company called EDAX produces it. And then most of the chemical analysis is done using this EDS or WDS that is wavelength dispersive spectrometer though this spectrometer as such is a very specialized topic.

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And it requires quite a bit of a time to get into the details of what is the merit of each of the spectroscopic techniques and it what kind of quantitative information one can obtain from this, is requires a special it will come in a special lecture series. But for the completion, I would like to discuss these spectrometers which are commonly used in a very brief manner. So, the first one, I would like to take up is the energy dispersive x-ray spectroscopy is called EDS and the schematic I mean the photo which is shown is from

our lab which is an interface with the electron microscope.

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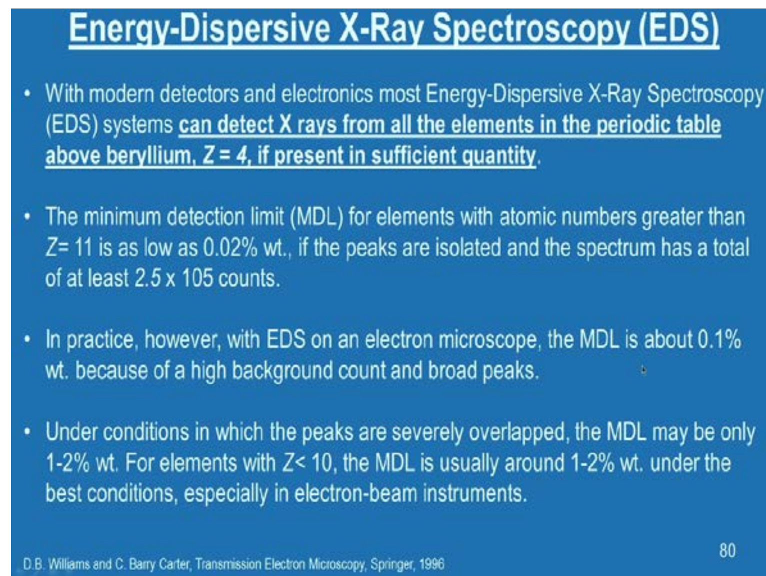

So, first look at the introductory remarks. With the modern detectors and electronics most energy dispersive X-ray spectroscopy systems can detect X-rays from all the elements in the periodical table above the beryllium that is Z is equal to 4, if present in a sufficient quantity. I also mentioned in the beginning of this the fundamentals, I just mentioned something like this about 10 percent and 8 percent or so, and depending upon the detector capability that varies of course, and this is particular area where the companies keep on making an effort to produce an efficient detectors and so on. And we will talk about those developments little later. First, we look at the basic ideas behind this spectroscopy. The minimum detection limit MDL for elements with atomic numbers greater than 11 is as low as 0.02 percent weight percent, if the peaks are isolated and the spectrum has a total of at least 2.5 times 105 counts. So, this is one rough calculation.

In practice however, with EDS on an electron microscope, the MDL is about 0.1 weight percent, because of a high background count and a broad peaks. Under conditions in which the peaks are severely overlapped, the MDL may be only 1 to 2 weight percent. For elements with the less than 10 - atomic number 10, the MDL is usually around 1 to 2 weight percent under the best conditions especially in electron beam instruments.

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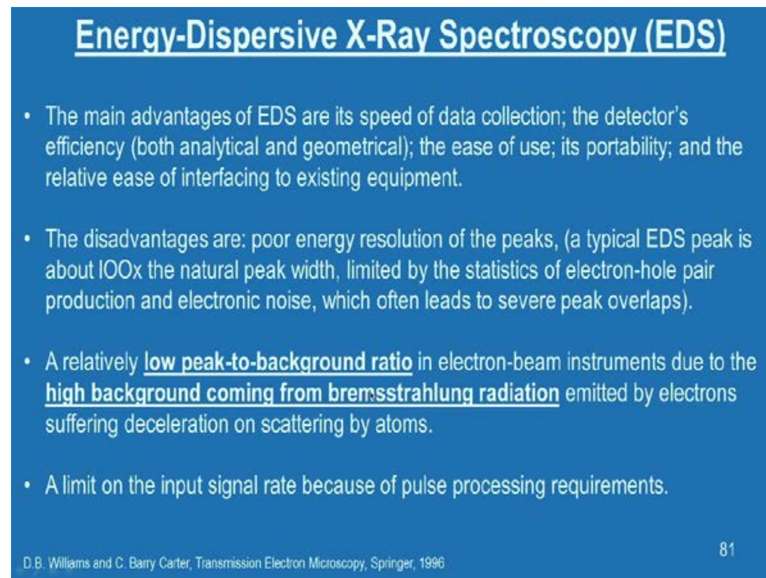

The main advantages of EDS are its speed of data collection, the detectors efficiency both analytical and geometrical; the ease of use; its portability; and the relative ease of interfacing to existing equipment. The disadvantages are poor energy resolution of the peaks, a typical EDS peak is about 100 x the natural peak width, limited by the statistics of electron-hole pair production and electronic noise, which often leads to severe peak overlaps.

A relatively low peak-to-background ratio in electron-beam instruments due to the high background coming from the bremsstrahlung radiation emitted by electrons suffering decelerations on scattering by atoms. So, these are the some of the details we will look at it when we get into the diffraction discussion later. A limit on the input signal rate because of the pulse processing requirements, this is again another disadvantage.

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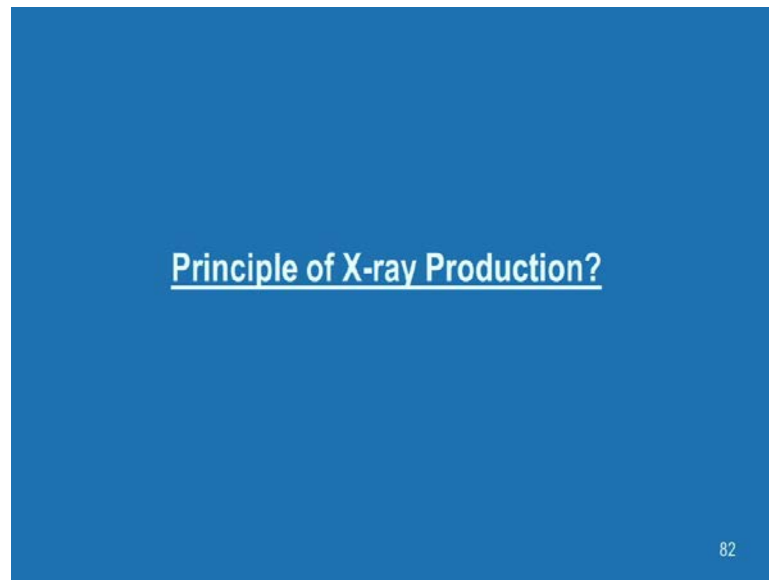

And let us look at how the X-rays are produced in this equipment.

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The Ionization Process

Vacuum
Incoming electrons (e.g., 100 keV)
Conduction Band
Valence band
Atomic energy levels
E_{L_3} L_3
E_{L_2} L_2
E_{L_1} L_1
E_K K
Characteristic X-rays
Energy-loss electrons
Nucleus

- An inner (K) shell electron is ejected from the atom by a high-energy electron.
- When the hole in the K shell is filled by an electron from the L shell, characteristic K_α X-ray emission occurs.
- The beam electron loses energy but continues on through the specimen

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D.B. Williams and C. Barry Carter, Transmission Electron Microscopy, Springer, 1996

Look at this schematic where you are seeing that atomic energy level in the one axis and here you see that all the electron levels energy levels like K, L, M and so on and then you have this valence band and conduction band. And let us assume that, this incoming

electrons having the energy of 100 kilo electron volt.

So, let us look at this schematic, what is happening, you have the incoming electrons and which is coming and knocking out an electron. So, in that process the energy is getting lost. And then there is a transition from the upper shell to the lower shell; in this case, it is L 3 to K. And during that process, you have the characteristic rays X-rays coming out, so that is how you have to visualize this whole ionization process. So, an inner K shell electron is ejected from the atom by high-energy electron. When the hole in the K shell is filled by an electron from the L shell, characteristic K alpha X-ray emission occurs. The beam electron looses energy but continues on through this specimen.

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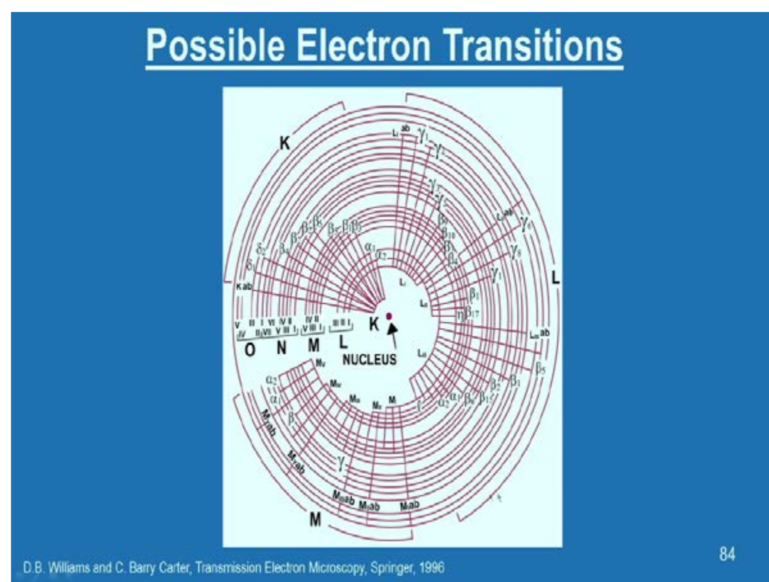

And this you all might have already have some idea, all possible transitions from different electron shells like you know have the orbits you can say L, M, N, O all this. So, depending upon the transitions, the energy levels also varies, and this is just for a completion I just brought this schematic.

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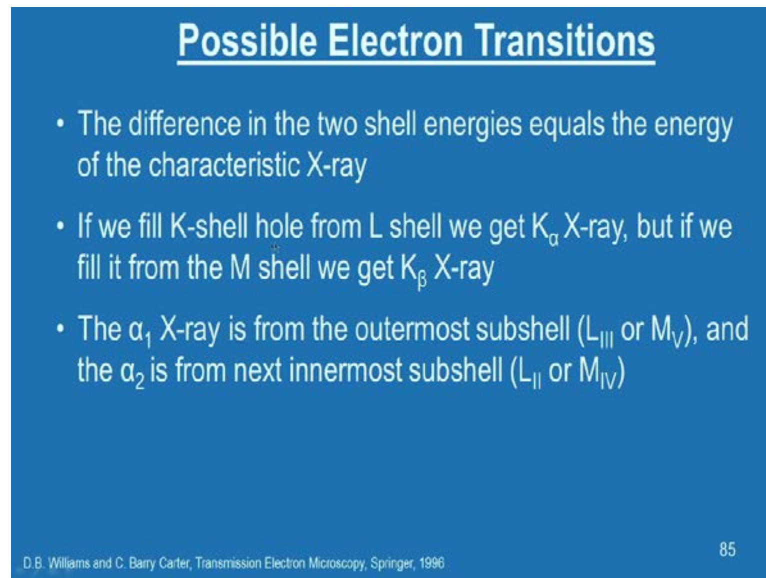

The difference in the two shell energies equals the energy of the characteristic X-ray. If we fill K-shell hole from L-shell we get K alpha X-ray, but if we fill it from the M shell we get K beta X-ray. The alpha 1 X-ray is from the outermost subshell like L 3 or M 5, and the alpha 2 is from the next innermost subshell like L 2 or M 4, so that is a convention.

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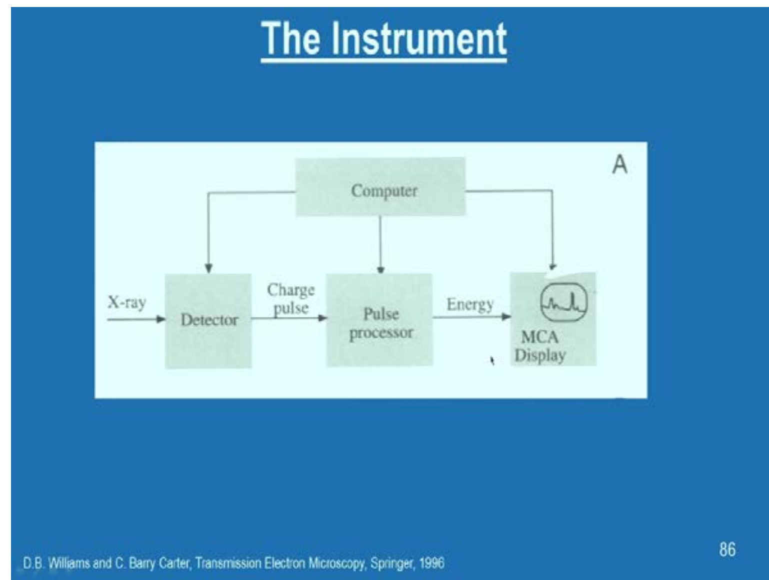

And the instrument details are like this you have X-ray come in, and you have the detector and which is having a charge pulse, and pulse processor, and then you have energy and then you have MCA display; everything is controlled by the computer. And little more details of a detector system.

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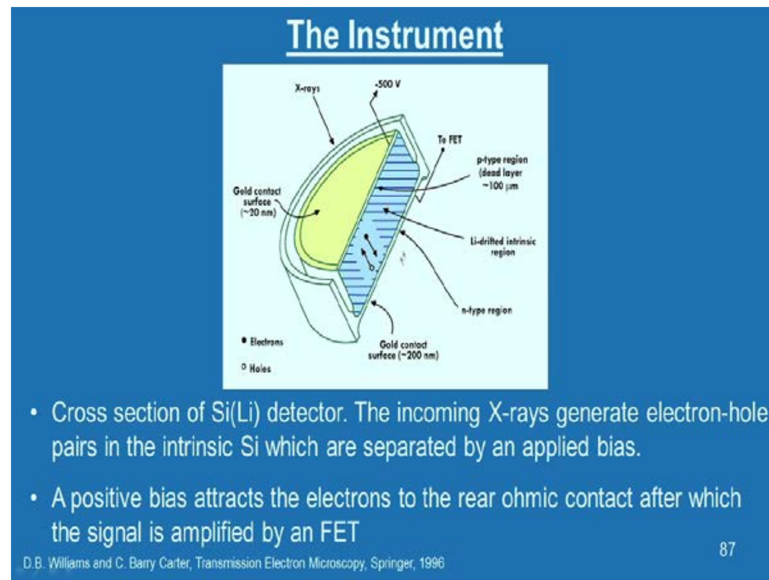

So, this is the a detector called the Si(Li) detector silicon-lithium detector. It is a cross section view what you have seen the complete details here. And the cross section of Si(Li) detector is schematically shown here. The incoming x rays generate electron hole pairs in the intrinsic silicon, which are separated by an applied bias. So, here this is what is that reaction happens. This is the lithium drifted intrinsic region where you have this p-type region as well as n-type region.

A positive bias attracts the electrons to the rear ohmic contact after which the signal is amplified by the FET.

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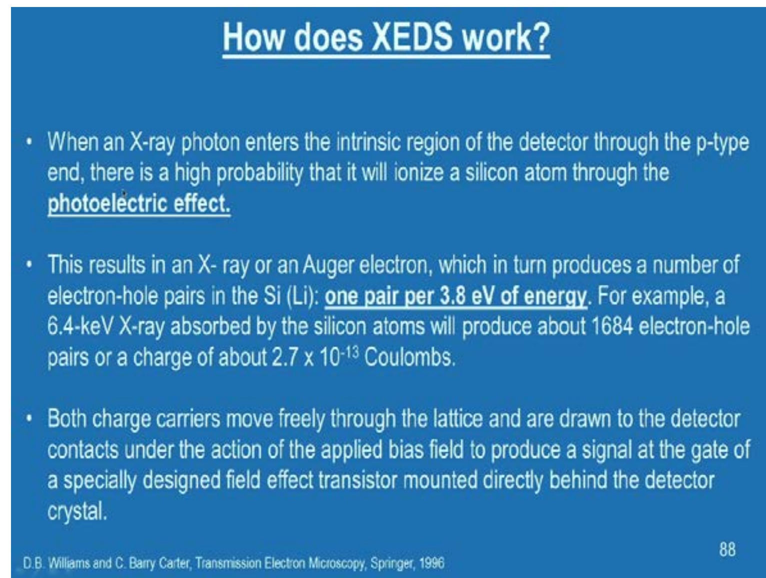

When an x ray photon enters the intrinsic region of the detector through the p type end; there is a high probability that it will ionize a silicon atom through photoelectric effect.

This results in an X-ray or an Auger electron, which in turn produces a number of electron-hole pairs in the Si(Li) detector: one pair per 3.8 electron volts of energy that is the quantification here. For example, a 6.4 kilo electron volt X-ray absorbed by the silicon atoms will produce about 1684 electron hole pairs or a charge of about 2.7 into 10 to power minus 13 coulombs. Both charge carries move freely through the lattice and are drawn to the detector contacts under the action of the applied bias field to produce a signal at the gate of a specially designed field effect transistor that is FET mounted directly behind the detectors crystal.

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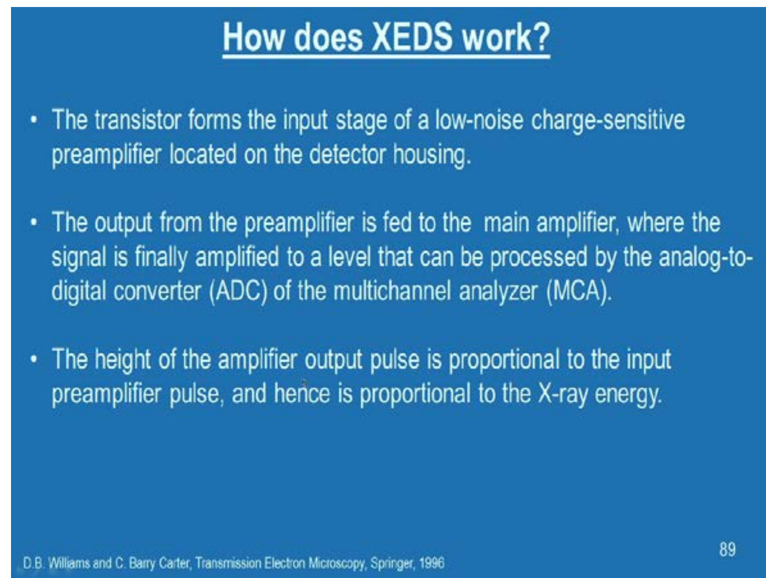

The transistor forms the input stage of a low-noise charge-sensitive preamplifier located on the detector housing. The output from the preamplifier is fed into the main amplifier, where the signal is finally, amplified to a level that can be processed by analog-to-digital converter of the multi channel analyzer. The height of the amplifier output pulse is proportional to the input preamplifier pulse, and hence is proportional to the X-ray energy.

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How does XEDS work? (summary)

- The detector generates a charge pulse proportional to the X-ray energy
- This pulse is first converted to a voltage
- Then the signal is amplified through a field effect transistor (FET), isolated from other pulses, further amplified, then identified electronically as resulting from an X-ray of specific energy
- Finally, a digitized signal is stored in channel assigned to that energy in the MCA

D.B. Williams and C. Barry Carter, Transmission Electron Microscopy, Springer, 1996

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How does X-ray EDS work? So, it is a summary. The detector generates a charge pulse proportional to the X-ray energy. This pulse is first converted to a voltage. Then the signal is amplified through a field effect transistor, isolated from the other pulses, further amplified, then identified electronically as resulting from an X-ray of specific energy.

Finally, a digitized signal is stored in a channel assigned to that energy in the MCA. So, very briefly and quickly, I have gone through this function of EDS. For a time being, this is sufficient enough for you to remember it EDS is one of the very popular interface with electron microscopes.

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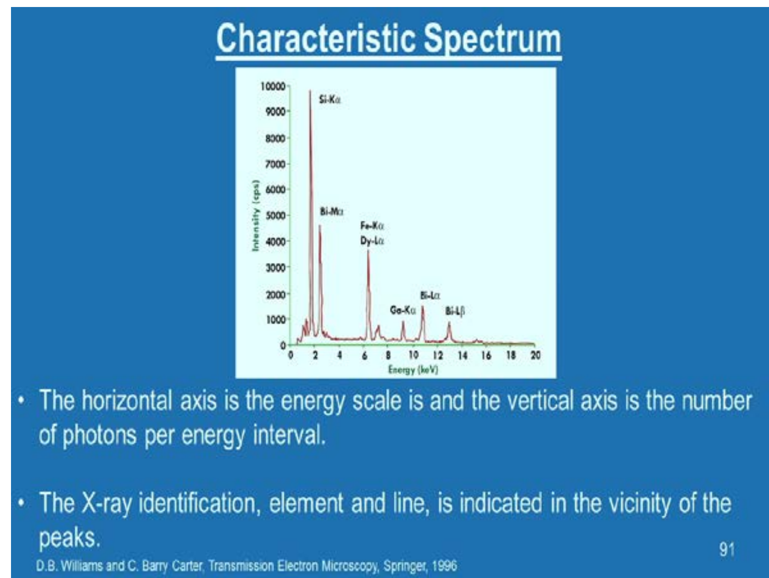

The other variant in this segment is WDS. And before we look at it, let us look at the characteristic EDS spectrum. And you have this intensity versus energy spectrum. The horizontal axis is the energy scale is and the vertical axis is the number of photons per energy interval. The X-ray identification, element and the line, is indicated in the vicinity of the peaks. So, this is the index indexing of the peaks are shown, how it is indexed.

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Why do we have to cool the detector with liquid N_2?

- Thermal energy would activate electron-hole pairs, giving a noise level that would swamp the X-ray signals we want to detect.
- The Li atoms would diffuse under the applied bias, destroying the intrinsic properties of the detector.
- The noise level in the FET would mask the signals from low-energy X-rays.

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And most important activity of keeping this EDS spectrum interface with the machine is we have to keep on cooling this detector with liquid nitrogen for some of the following reasons. The thermal energy would activate the electron-hole pairs, giving a noise level that would swamp the X-rays signals we want to detect. The silicon atoms would diffuse under the applied bias, destroying the intrinsic properties of the detector. The noise level in the FET would mask the signal from the low-energy X-rays.

So, that is why I do not know some of you would have seen a where the electron microscopes are interfaced with the EDS spectrum whether you use it or not. This (Refer Time: 31:31) has to be filled with liquid nitrogen all the time in order to prevent some of this reactions happening in the detector.

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Wavelength-Dispersive X-Ray Spectroscopy (WDS)

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Now, we will just look at again quickly the wavelength-dispersive X-ray spectrometer.

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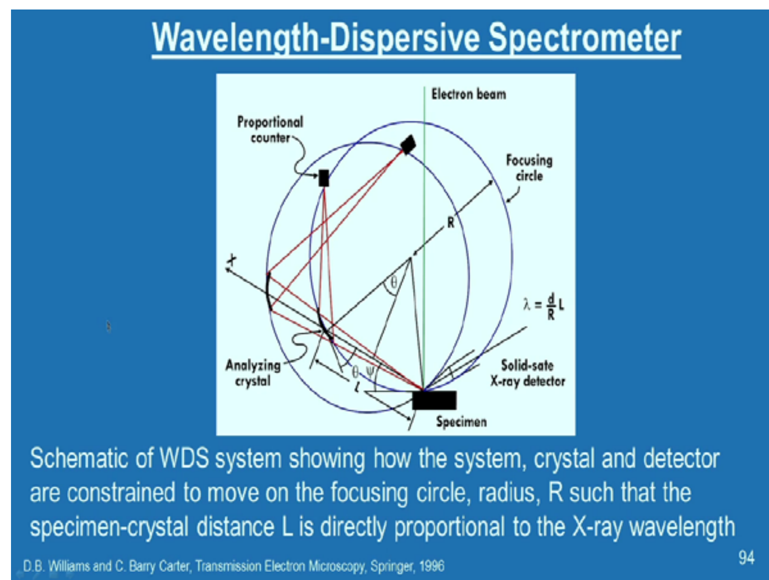

And look at the schematic this is how the system configuration is displayed. So, you have the specimen, and you have the crystal, and you have the proportional counter and everything is kept in a fixed geometry. So, you have this schematic of WDS system

showing how the system, crystal and detector are constrained to move on a focusing circle, radius, R such that the specimen-crystal distance L is directly proportional to the X-ray wavelength. So, this is the specimen crystal distance L which is proportional to the wavelength lambda is equal to d by R times L, this is the relation.

And you see that these configurations are shown in a focusing circle; a two types of configurations are shown, where you have the specimen-crystal detector are shown in two configuration, you follow this one circle. And for other configuration, I mean the changes in the theta to theta then you follow this next circle, they are kept in this manner. Why do we keep this in this position that we will see now.

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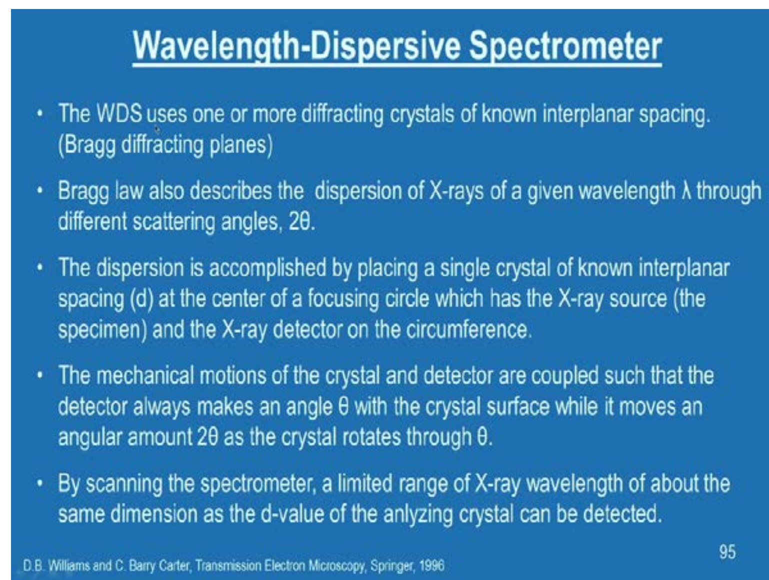

The WDS uses one or more diffracting crystals of known interplanar spacing - Bragg diffracting planes that means, when the diffraction actually happens, those planes are responsible for Bragg diffraction. Bragg law also describes the dispersion of X-rays of a given wavelength lambda through different scattering angles two theta in a normal X-ray spectrum.

The dispersion is accomplished by placing a single crystal of known interplanar spacing (d) at the center of a focusing circle which has the X-ray source (the specimen) and the

X-ray detector on the circumference. So, this is what it is you have a specimen, a crystal, detector everything is placed on the circumference where the crystal is placed in between the specimen that is X-ray source and the detector this is what is written here. The mechanical motions of the crystal and the detector are coupled such that the detector always makes an angle theta with the crystal surface while it moves an angular amount 2 theta as the crystal rotates through theta.

By scanning the spectrometer, a limited range of X-ray wavelength of about the same dimension as the d-value of the analyzing crystal can be detected. So, by moving this keeping this same theta between detector and the crystal and the specimen by moving this you will able to detect some of the characteristic X-rays which has the dimension within the range of the known interplanar spacing, so that is the idea.

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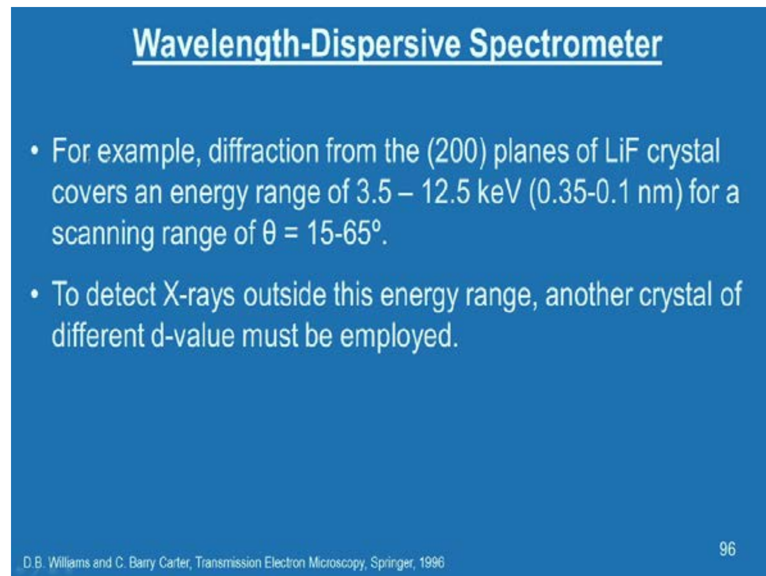

For example, the diffraction from 200 planes of lithium fluoride crystal covers an energy range of 3.5 to 12.5 kilo electron volts for a scanning range of theta is equal to 15 to 65 degrees. To detect the X-rays outside this energy range, another crystal of different d-value must be employed.

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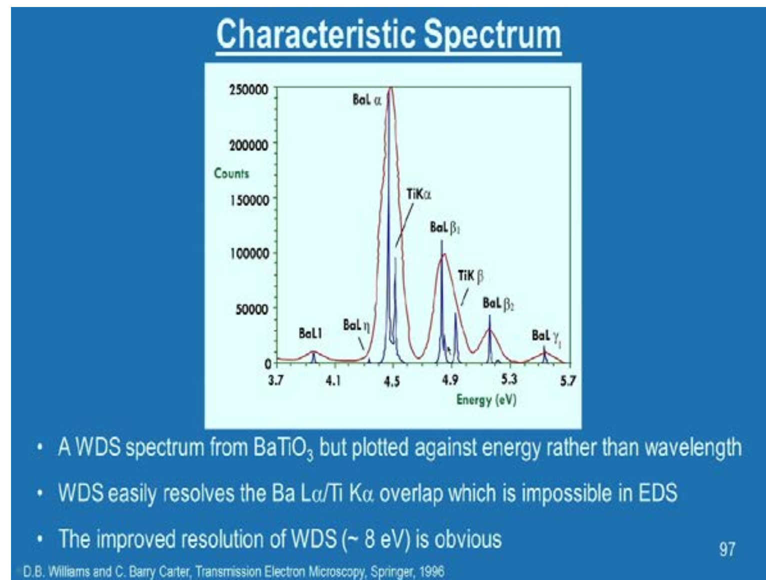

And you look at this a typical characteristic spectrum of WDS, for the purpose of comparison the EDS spectrum is super imposed into this. So, you clearly appreciate the resolution capability of WDS is superior as compared to EDS. This is the WDS spectrum of barium titanate, but plotted against energy rather than the wavelength. WDS easily resolves the barium L alpha by Ti K alpha overlap, which is impossible in EDS this is what you shown here, barium L alpha and titanium K alpha. The improved resolution WDS is quite obvious which is about in the order of 8 electron volt.

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Major drawbacks to WDS as compared to the XEDS

- The crystal has to be moved to a precise angle where is collects only a tiny fraction of the total number of X- rays coming from the specimen, whereas the detector can be placed almost anywhere in the TEM stage above the specimen and subtends a relatively large solid angle at the specimen
- The WDS collects a single wavelength at a given time while the XEDS detects X-rays of a large range of energies.
- WDS is a serial collector; XEDS is effectively a parallel collector

D.B. Williams and C. Barry Carter, Transmission Electron Microscopy, Springer, 1996

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And we look at the major drawback of WDS as compared to EDS. The crystal has to be moved to a precise angle where is collects only a tiny fraction of total number of X-rays coming from the specimen, whereas the detector can be placed almost anywhere in the TEM stage or any electron microscope stage above the specimen and subtends a relatively large solid angle at the specimen. The WDS collects a single wavelength at a given time while the XEDS detects X-rays of a large range of energies. WDS is a serial collector; XEDS is effectively a parallel collector.

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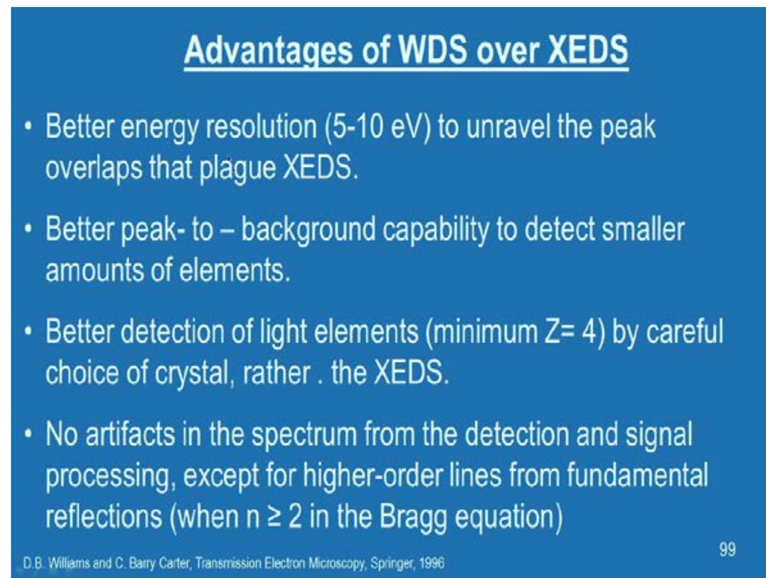

And what are the advantages. Better energy resolution 5 to 10 electron volts to unravel the peak overlaps that plague XEDS. Better peak-to-background capability to detect smaller amounts of elements. Better detection of light elements which is minimum atomic number 4 by careful choice of a crystal, rather than the EDS. No artifacts in the spectrum from the detection and signal processing, except the higher-order lines from the fundamental reflections; when the order of reflection is greater than or equal to 2 in the Bragg equation. So, these are all the very brief introduction to this spectrometers, which is commonly used or interfaced with the scanning electron microscope.

As I just mentioned, we have not gone into the details of how the quantitative information is taken from this spectrometer or how they exactly they mapping of the elements, how sensitive these detectors are we have not discussed in detail. But, however, I just for a sake of completion, I have just introduced this very briefly and fast about this two spectrometers which is very common.

The other details, we will look at in it the different lecture series. So, in the next class, we will look at the some of the special topics in SEMs. Again I will just only highlights those mechanisms; for example, special mechanisms because of the magnetic contrast as well as electric contrast, and also we will look at some of the how the backscattering

diffraction will enable to find crystallographic orientation mapping and EBSD and so on, very briefly in the next class.

Thank you.