Solid State Chemistry
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Lecture – 44
Electron Microscopy

Now, I will go to the 4th lecture of this 9th week of this course. And in this lecture I will be talking about Electron Microscopy. I will be talking very briefly and just to give you an overview of where, microscopy stands in the range of techniques and electron microscopy is an extremely useful technique and extremely widely used. And I will just skim over a few details of electron microscopy. So, keep in mind that we have already learnt about X-ray diffraction which is one of the most important tools in determining the crystal structure.

And we have also talked about X-ray crystallography and now we are going to talk about electron microscopy. There are several other techniques that are used to characterize crystals, several other spectroscopic techniques which I will not be talking about in this course ok. But I thought I will mention the class of techniques related to electron microscopy. So, week 9 lecture 4 will be on electron microscopy.

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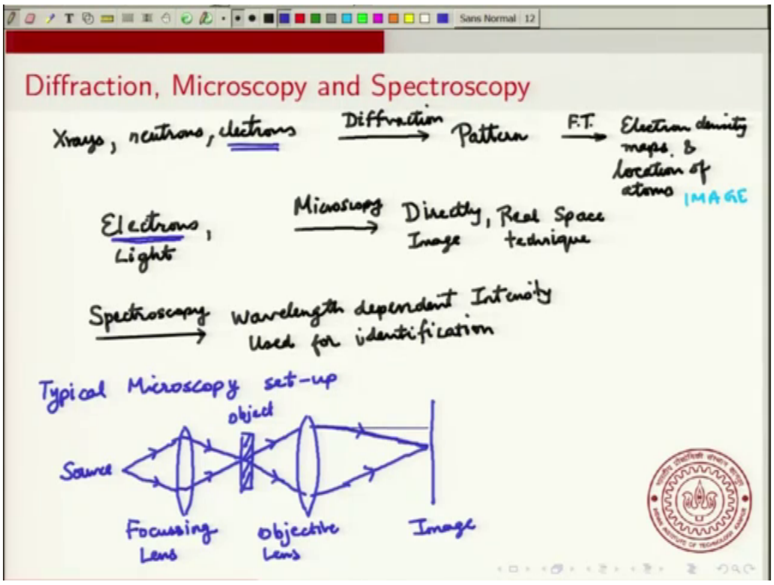

So, if you look at the whole set if you look at the range of techniques for characterizing materials they can broadly be classified into diffraction techniques, microscopy techniques and spectroscopy techniques. So, in diffraction what is done is you use either X-rays we talked about X-ray diffraction, but you can also use neutrons to do diffractions or you can also use electrons to do diffractions. And usually in the in diffraction what we see is a diffraction pattern we see a pattern and from this pattern gives us information about the structure ok.

About the location of the atoms and if we saw when we were doing the electron density maps, that you can do a Fourier transform of this to get the electron density maps and location of atoms ok. So, in some sense the diffraction pattern is something that is in the Fourier space and you take a Fourier transform and you get into the real space ok. So, this is diffraction, now in microscopy in microscopy what is done is you directly image it ok. So, this in some sense is your final this is the image that you get in X-ray diffraction, in microscopy you directly image; directly image ok.

And you do not have to take a pattern and do some sort of Fourier transform you directly get the image. So, in a sense it is a real space technique that directly helps you locate and if you use a very accurate microscopy you can directly locate atoms. Now what is used for microscopy? So, typically the most accurate microscopy uses electrons. So, electrons are used in microscopy ok, you can also use usual light to get an optical microscope ok. So, light is used in optical microscope ok, but electrons are used in electron microscopy ok. So, notice that electrons are used both in diffraction and in microscopy. And this called this the fact that electrons can be used both to diffract and see the diffraction pattern, but they can also be used for microscopy this turns out to be fairly useful ok.

And the other class of techniques which I would not talk much about is spectroscopy where, we basically this is look at wavelength dependence, wavelength dependent intensity. And this is typically used for identification, this is used for identification and there are several spectroscopic techniques that are used in the solid state ok. So, let us look what at a typical microscopy setup, a typical microscopy setup looks like this. And we will come back to this and we will discuss it in more detail as we look at other microscopic technique; as we look at the details of the microscopic technique. But, the typical microscopy setup and you can do this both for electron microscopy and optical microscopy.

So, you have a source and the source will emit either electrons or light that will come to will come to some focusing lens ok. This is a focusing lens and this lens will focus the light or the electrons onto an object onto the object that you have. So, you have the object here ok, notice that I should mention that if you are looking at electron microscopy and these are ray these rays are electrons then you do not actually use a lens, but you use various fields. We use various electromagnetic fields to focus the rays onto the spot on to the object.

So, this is the object and then there is some the light that comes out of the object is pass through an objective. This length is called the objective lens and eventually it gives you the there it gives you the image ok. So, this is a typical microscopy setup and this is what the usual optical microscope that you have used in your laboratories ok.

So, the point is that now even an electron microscopy has a very similar set up, you have a source for electrons and you have a various focusing set up ok. The focusing set up is it will be in the form of electromagnetic fields and then it will fall on your object on your sample. And then it will be collected and in the case of electron microscopy you can also add a diffraction layer; you can also look at the diffraction pattern ok and we look at this in more detail soon.

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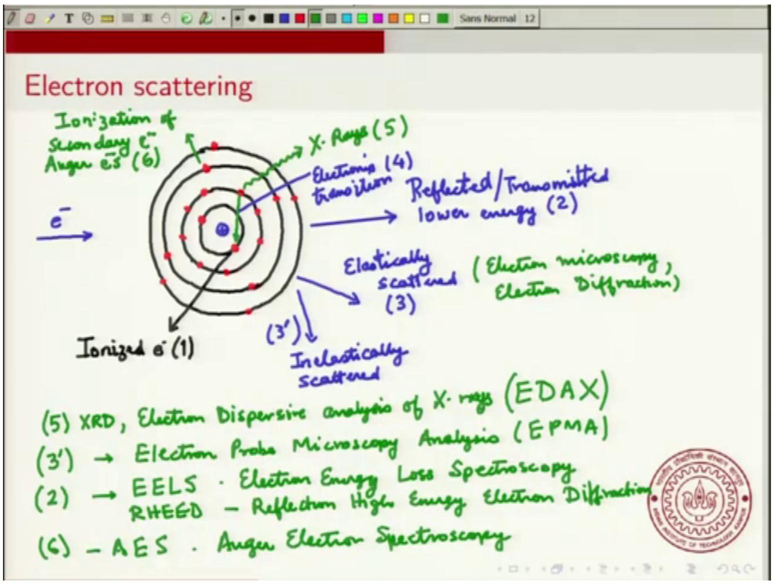

Now, let us look at the picture of electron scattering in a little more detail; this is suppose I put suppose I bombard an atom with electrons ok. So, suppose I bombard an atom with electrons. So, I have some electrons that are coming on an atom and let me show this atom, I will show the nuclear core and then I will show the various shells. This is the core shell and I will show the electrons in the red in each shell and the next shell and again some electrons and so on. You can show more shells, I am not showing all the shells I am just showing a few shells just for illustration. And I am not showing all the electrons I am just showing a few electrons again this is only for illustration.

So, let us say you have some more electrons here and let us say this is the outer shell. So, now when these electrons they come onto the atom a lot of things can happen not and when I say a lot of things can happen. So, what are the things that can happen? So, one thing that can happen is that it knocks out an electron and it and basically it knocks out an ion, knocks out an electron from the core shell. And you have this ionized electron, I will call this 1 and you have the ion electron. And when this happens then it could happen that an electron from an outer shell ok; let me show this in green this comes into the shell and it emits X-rays ok, let me call this ok.

Then you could have electrons that are simply diffracted ok. So, this is the diffracted electrons, now in the diffracted electrons there are 2 kinds. There are those that are elastically scattered; elastically scattered means the wavelength of the outcoming electron is same as that of the incident electron ok. So, this and then you have those that are in elastically scattered ok. So, these are the diffracted electrons ok, then you could have; you could have either reflected or transmitted electrons; transmitted electrons and these have might have a lower energy ok. So, I label these as 2, I label the diffracted electrons electrically deflected electrons has 3, this as 3 prime.

Now, there is an electronic transition here ok. So, this electronic transition that is taking place here ok, this is an electronic transition. Now, let me label this electronic transition as 4 and this X-ray production as 5 ok. Now what else can happen? Now, it could happen that there could be so, as this electron is being ionized ok, there it is possible that there could be what is called a secondary ion ionization secondary electrons ok. So, these are not directly knocked out by the electron, but they are secondary electron ionization.

These are also called as Auger electrons; Auger electrons and let me call this 6. So, these are some of the processes that can happen and what I want to emphasize is that each of these can be used in a characterization technique ok. So, for example, the if you look at of course, of course, we know how to use X-rays. So, 5 is used for XRD 5 can be used both in XRD, but it can also be used in a process called Electron Dispersive Analysis of X-rays or EDAX; sometimes is also called EDS ok. Now, what this technique does is basically says that by looking at the X-rays that are emitted you can get information about what the atom is.

So, if you are actually trying to if these electrons are actually bombarding on a sample then by analysing these X-rays that are produced, that are produced by dispersion you can get information about the about the composition of the sample. Now, this 3 prime which is the inelastic electron that is scattered ok. So, if you analyse this if you analyse the properties of 3 of 3 prime there is a this technique is called Electron Probe Microscopy Analysis: EPMA ok. And really it is a reflect now this is different from the usual microscopy because, you are looking at the inelastically scattered electrons ok.

There are several other techniques and let me just mention a few of those. So, these transmitted electrons that have lower energy 2 are used in the technique called EELS or this is called Electron Energy Loss Spectroscopy. And the reflected electrons are used in RHEED, this is Reflection High Energy Electron Diffraction. This is used to get information about the surface of the material and of course, 3 is used in electron microscopy ok. So, this is used in electron microscopy and electron diffraction ok.

So, really what we see is that when this electron hits a sample there are a lot of things that can happen and I have shown only some of the techniques. I would emphasize that there are several other techniques for example, this 6 is that leads to Auger electron spectroscopy; Auger electron spectroscopy. This is another surface sensitive technique that is used to get information about the surface ok. So, basically a lot of things can happen when an electron scatters of a material and each of those leads to a different measurement technique ok.

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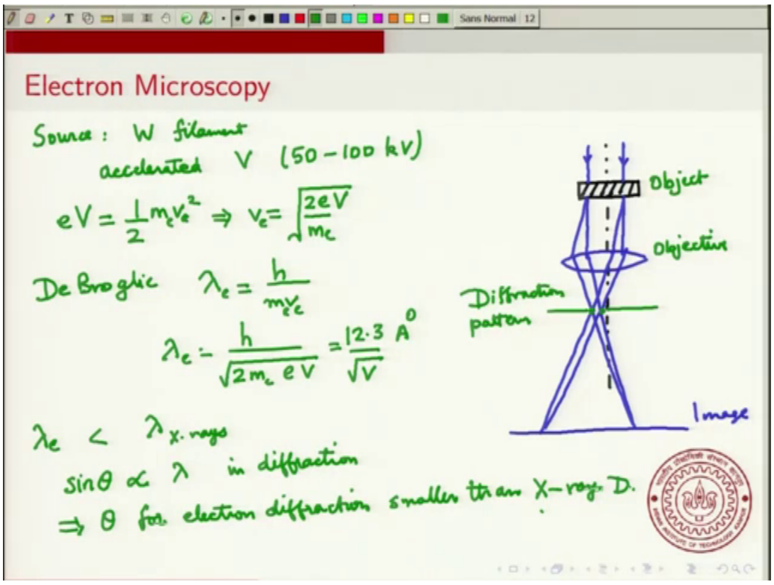

Now, let us go to electron microscopy, now I will just show schematically ok. So, we showed the general setup of microscopy ok. Now, let me help you show this in a slightly different way just to emphasize the fact that you can use; you can use the same setup both for microscopy and for diffraction. So, if you have an object and let me draw the mid plane of this set up ok. And now if you have; if you have 2 electron rays coming like this; these are your electrons that are coming through the object. And now let us say that transmitted the one that is not scattered and directly transmitted will go through ok. But, there will be one that will be deflected, there will be some waves that will be deflected and these will go through the objective ok.

And these will be focused somewhere here and these will be focused somewhere here ok. So, you will get an image you will get an image here. So now, what you can also see is that if you look right here, if you look right here you see the interference of those waves. So, you will see a diffraction pattern here. So, you can actually; you can actually see the electron diffraction pattern here and the real space image here ok. So, in this way when the single set up for electron microscopy you can get both the image and the diffraction pattern ok. Now, a few things about electron microscopy ok, the source the source for electrons is usually a tungsten filament that is heated and accelerated.

So, the electrons that are produced by heating the transistor and filament are accelerated through some voltage ok. So, if they are accelerated by voltage V then you have the condition that this V is typically about 50 to 100 kilo volts ok. And when you have this then your you can write an expression that e times V equal to half m V square. So, the electrons achieve a velocity of V of V e; V e is a velocity of the electron ok, m e is the mass of the electron ok. So, this is the accelerating voltage times the electronic charge that is equal to the kinetic energy of the electron ok. This gives you; this gives you the expression V is equal to square root of 2 e V by m e ok.

And if you use the De Broglie hypothesis so, the De Broglie hypothesis says that the wavelength of the electron lambda of this electron should be h divided by m times V e, h is Planck's constant, m e again m e is the mass of the electron times the velocity of the electron that is a momentum of the electron. If you substitute this you will get lambda electron this is given by h divided by square root of 2 m e e V ok. And you see that h is Planck's constant which is a fundamental constant mass of electron is, fixed charge of electron is fixed. So, I can write this as 12.3 angstroms.

So, if you substitute those numbers you will get this 12.3 angstroms divided by square root of V ok. So, V is expressed in volts so, these 3 express in volts and so, you get 12.3 divided by square root of V that is in angstroms. Now, you can see that if this V is 50000 volts then you can see that the wavelength will be much smaller than 1 angstrom ok. So, the wavelength lambda e is less than lambda of X-rays. So, X-rays is typically about 1 angstroms, but this is much less than 1 angstroms ok. So, and if the wavelength is less then because, you have a sine theta the scattering angle proportional to lambda in diffraction.

So, this implies that theta for electron diffraction is smaller than X-ray diffraction; X-ray diffraction ok. So, basically the scatter the angle theta is much smaller. So, the electrons are scattered to a much smaller angle than X-rays ok.

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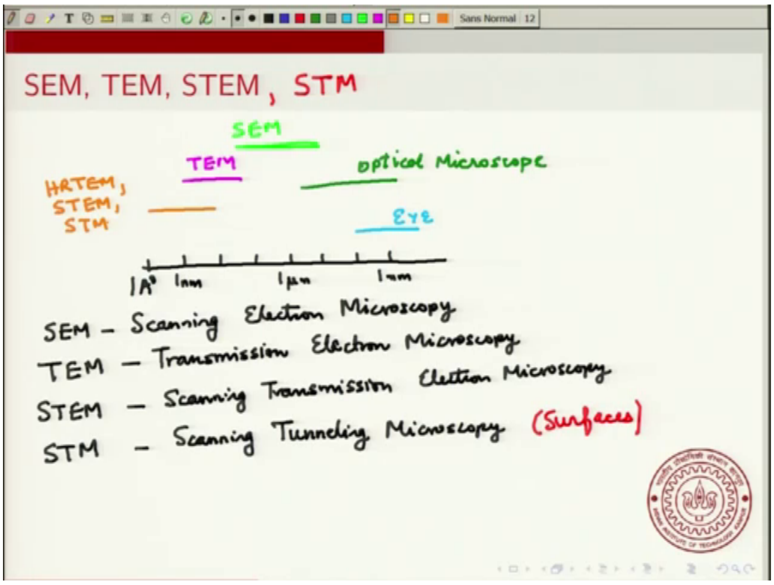

So, what are the usual microscopy techniques? So, the main microscopic techniques are Scanning Electron Microscopy: SEM, Transmission Electron Microscopy: STEM, STEM that is Scanning Transmission Electron Microscopy; this is a combination of scanning and transmission and I will add one more; I will add one more Scanning Tunnelling Microscopy: STM. So, these are the typical techniques that are used and just to give you an idea of what the sensitivity of these methods is. So, as the name says scanning is looks at the electrons that are reflected from the surface and usually it scans only a first few layers.

So, let me write these names down SEM stands for Scanning Electron Microscopy, TEM is for Transmission Electron Microscopy. And this can give you information about the interior of the sample not just the surface. STEM is scanning STEM stands for scanning Transmission Electron Microscopy. So, these are and then there is STM which is Scanning Tunnelling Microscopy, this is again only for surfaces. So, this is only for surfaces, but this is a highly sensitive technique. It can give atomic resolution ok. Now, let me let us just look at the various techniques and see how sensitive they are. So, I will just put a scale bar here, this is a logarithmic scale. So, this is 1 angstrom ok, this is 1 nano meter ok that is 10 angstroms.

Then you have 10 nano meters, 100 nano meters, 1000 nano meter is 1 micro meter and then 10 micro meter, 100 micro meter, 1000 micro meter is 1 milli meter ok. Now, if you just look at the various techniques now your naked eye your naked eye can probably see up to a 10th of a milli meter. So, this is your eye ok. Now, if you have an optical microscope like the one that you have in your high school laboratory then you can go up to maybe 1 micro meter. If you have a good quality optical microscope you can go all the way down to 1 micro meter.

This is optical microscope, on the other hand if you have a scanning electron microscope ok; the scanning electron microscope that can help you go all the way from all the way up to almost up to 10 nano meters. So, in this whole range from this is this SEM can go over this range ok. Now, if you have a TEM you can go up to much smaller lengths. So, the TEM can go down to; can go down to almost 1 nano meter ok. And if you have a HR a High Resolution transmission electron microscope or a STM or a STEM you can go all the way down to 1 angstrom. So, this is HR High Resolution Transmission Electron Microscopy scope or STEM or STM. So, these are the ones that can go all the way down to 1 angstroms ok.

Now so, you can actually see atoms in some of these experiments ok. So, I will stop this lecture here and I will conclude the discussion on electron microscopy ok. I have tried to give you a broad overview of the techniques and I have set it up in a way so, that if you want to learn more about any of these you can go and read any standard literature on these ok. So, with this we have come to the end of the lecture part of week 9. So, in the next lecture we will I will do a recap of what you learnt and then we will do some practice problems.

Thank you.