Techniques of Materials Characterization
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Lecture - 32
Basic Components of SEM (Continued)

Welcome everyone to this NPTEL online certification course on techniques of materials characterization. We are in module seven, that is week 7 and this is second lecture on the basic components of SEM, we are continuing from the last class. And in the last class we have discussed about various types of detectors I mean, we started discussing about different detectors used and what is the utility why they are used in SEM and so on.

And we discussed about the secondary electron detector, ET detector which is known and how ET detector can be helpful in detecting not only secondary electrons but also the backscattered electrons.

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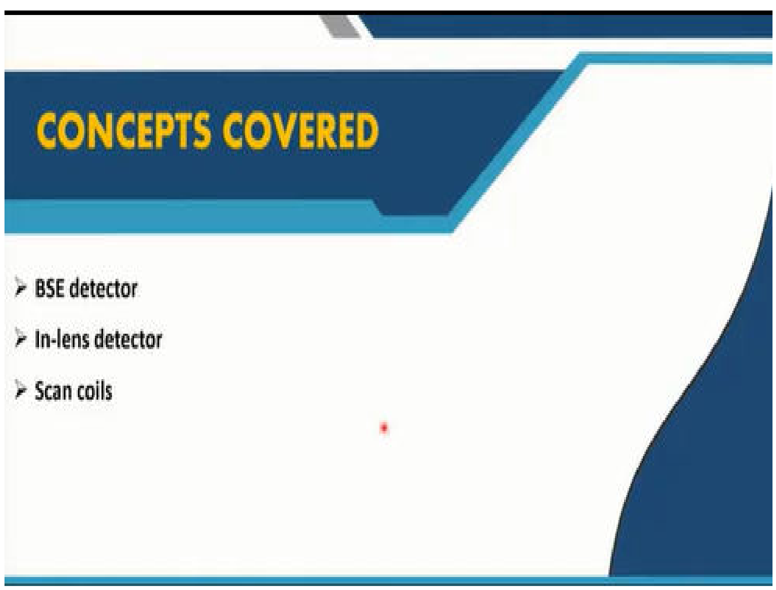

And now, we will be continuing that discussion and we will be seeing in more details about the backscattered electron detectors and then a special type of detector or special type of configuration or special type of detector configuration called the in-lens detectors and then finally we will discuss about the scan coils.

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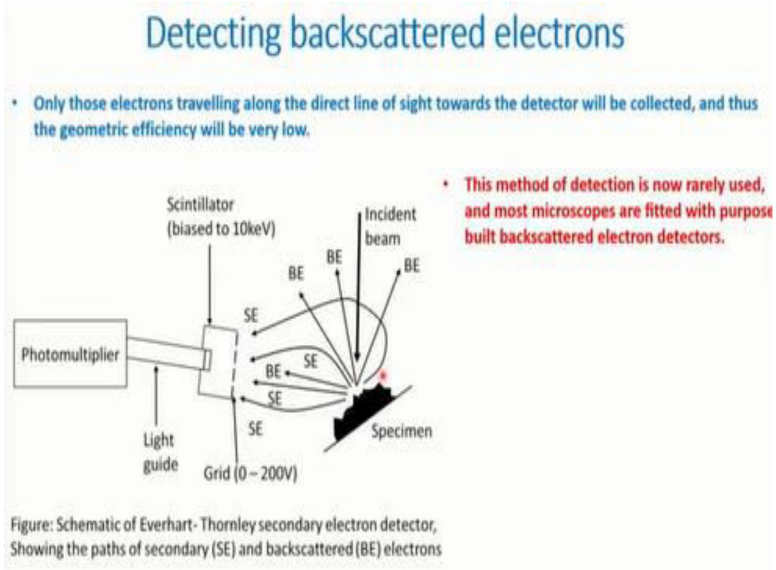

So, this is where we stopped in the last class detecting about the problems of detecting backscattered electrons with the ET detector. And we said that the collection efficiency of this ET detector is a problem. The geometric efficiency, collection efficiency is a problem because the solid angle of collection of backscattered electron is very low. Most of the backscattered electrons basically generates in and around the incident electron beam by virtue of elastic scattering and so on.

And they are of high energy of course. So, all together these ET detectors are not very effective in collecting most of the backscattered. So, this gives us a clue that if we want to have a better backscatter detector, the first thing we need to do is to place them properly. And place them in a way that the collection efficiency will be highest that means we should place them in and around this incident electron beam.

That is the first clue with the failure of or not the failure with this poor performance of the ET detector for backscattered electron. This is the first message that we get. If we want to capture more number of backscattered electrons, we have to place it somewhere within this region and that is exactly how the backscattered electron detectors have evolved over the time, over the period. Basically, the SE detectors I would say is still most popular SE detector is ET detector.

And that is also the cheapest of all the detectors you have that is the cheapest kind of SE detector and very easily available. And as I said that is a default almost by default it is present in a new SEM. If you purchase a new SEM, you will be even if you are not saying anything, you will be given an SE detector it is included in the package. Then possibly they will be asking you for custom made BSE detector or even some cases custom made SE detector which we will discuss.

And of course, you can have attachments like the EDS attachment for characteristic X ray detection and so on. You can have EBSD detector for crystallographic studies and so on. So, all of these are specialized attachment we are not going into that. But ET detector will be almost by default included in the package and then the next question will come is that do you need a backscattered electron detector.

That backscattered electron detector; will be a specialized one and a custom built one. Although ET detector can be equally applicable to detecting to backscattered electrons as well but they have this problem.

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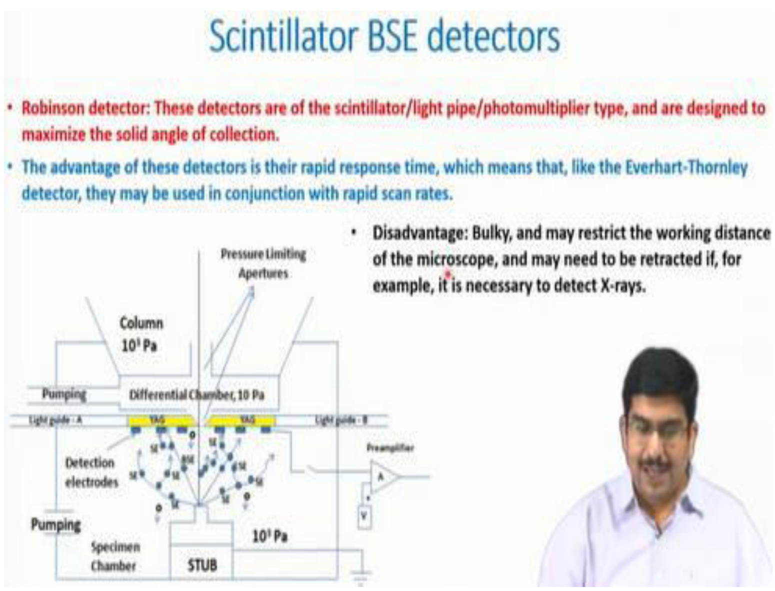

So, next we have scintillator backscattered electron detector. So, this backscattered electron detectors is no different than ET detector, configuration wise it has the same kind of scintillator, light pipe photomultiplier type. Whatever is there components are there in the your ET detector pretty much the same kind of components are present here also in this scintillator kind of backscattered electron detectors.

And remember, these are the first generation of specialized backscattered electron detectors, very old especially. So, the most popular one was called Robinson detector by the name of inventor again and Robinson detectors exactly works in the same principle as ET detector. It has a scintillator meaning it has a phosphor screen and then a high wire bias is applied. It has a light pipe photomultiplier; a bias is not that important for backscattered electron for obvious reason as I said they are already of high energy.

So, they can very easily hit and the phosphor screen and produce the signal enough light signal. So, this anode plate is not of that much of a that much needed for backscattered electrons. Another big difference between the ET detector with the Robinson detector is that here you do not need that metal cage also. Metal cage means the one which basically increases the collection efficiency of SE signal which operates with a slightly higher positive voltage in the few hundreds of volts to voltage.

To increase the collection efficiency of SE detectors that is not needed in this case. Because number one as I said that will the BSE yield itself will be high here. So, you do not need to and they are directive. So, you do not need to capture all the BSEs which are diverting from this detector. All the BSEs by default or automatically all the BSEs will be coming towards this detector.

If it is placed in or around the primary electron beam automatically most of the 90% of the BSEs will be detected anyway. So, you do not need to attract those BSEs here. So, these are the two major differences with a normal ET detector here, number one the metal cage the collector is not needed and second the bias voltage is also not in there. And there is a problem of applying this bias voltage is that.

Again, the same problem the bias voltage can interact with the primary beam as well and can deflect the primary beam. So, bias voltage here is not needed and not advisable as well. So, that means what we are left with is pretty much the scintillator screen straight away and the BSE electron goes hits the scintillator screen and it produces some kind of light signal and then the light signal just normally goes to photomultiplier and then the current multiplier and goes as an output signal.

So, that part is exactly the same the front part is slightly different than that ET detector here. Now generally as I said this is placed in around the electron beam. So, they in invariably have some kind of a hole here and generally they are attached with the objective lenses usually they used to be attached. It does not come as a separate component they are usually attached with the objective lens and the pole piece itself these detectors usually are fitted on.

Advantage; just like ET detector as I said rapid response time. So, this they have a very low response time and that is why they can be used for rapid scan rates. When you have very high scan rate then you can use this kind of scintillator base BSE detector. So, the entire purpose of this BSE detector is basically to collect maximum amount of BSE signals by placing it in and around this your primary electron beam that is it.

Of course, it has certain disadvantages that is why it did not it was not a continued till date. Nowadays you will not find a scintillator-based BSE detector, it is not available anywhere. So, the disadvantages are number one bulky. Of course, it is almost of the same size as this SE detector. So, putting it here within this small place between the objective lenses and the specimen is very very difficult first of all.

So, you have a severe restriction on the working distance of this microscope and what we will be discussing in the next few classes is that this working distance that means basically the distance between the objective lens and the specimen that is called the working distance. So, this distance is if you are reducing this distance, it will be good for resolution usually. So, this you cannot reduce it more than certain amount if you have a very big and bulky detector in between.

So, that is one major disadvantage with this kind of scintillator-based BSE detectors. The second problem is let us say you want to use this microscope same microscope for chemical analysis.

Now for chemical analysis as we discussed in the last module characteristic X ray signal in order to generate the characteristic X ray signal you have to use a high energy electron beam and with a much bigger beam. The size of the beam probe current everything has to be higher.

For that you have to sometimes retract this detector from this entire place because the detector has a physical limitation. It has a hole in between through which the electron beam passes through that physical limitation you have to remove and make it the electron beam make it you have to make it free. So, that the entire electron beam of much larger electron beam or large larger spots can be passed through and hit the specimen in order to generate the characteristic X ray.

So, that is very very difficult, this kind of scintillator-based BSE detectors, you cannot retract them as and when you need. Just like ET detectors this detector stays there. Once you put it here, it stays there, it works fine for BSE signals only collection efficiency increases, you do not need the bias voltage, you do not need the collector to be there all of these things is good. But these major two restrictions are there, number one working distance has to be large and second, you cannot retract them.

Because of this to this kind of scintillator-based BSE detectors are no longer use are no longer in market. Although they are cheap, because the way they works is pretty much same as ET detector with certain modifications you can very well put it here. These comes when they came these were pretty much cheap also.

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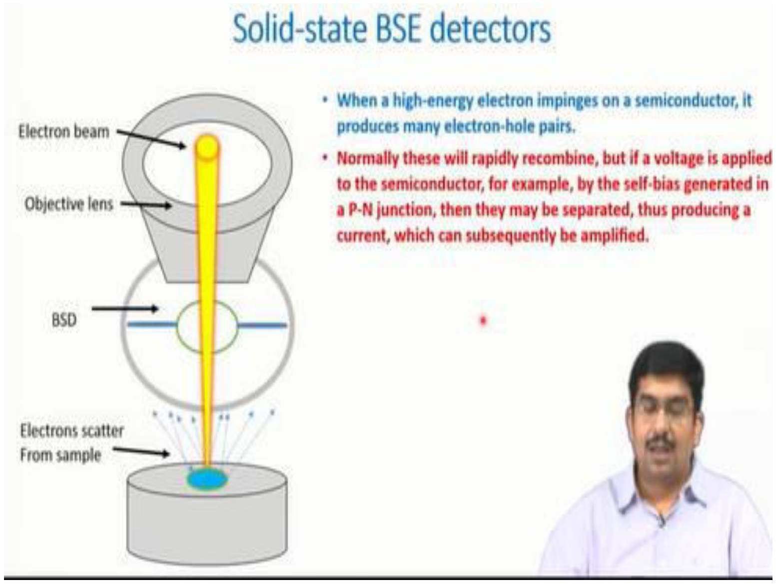

From there of course, the new set of BSE detectors we move on to there. And remember all of this different generation of detectors are basically tackling or basically trying to solve the problems of the earlier generation. So, earlier generation whatever two major problems as I said bulky and retractable. So, this solid-state BSE detector has both of this advantage. It was able to solve these two basic problems of BSE detectors.

Now how it works? Basically, this detector is a semiconductor, it is based on a semiconductor material and it is a very thin one. So, this semiconductor material when these electrons very high energy BSE electrons when they hit the; semiconductor material, it produces many electron hole pairs. Now I am not going what is electron hole pair and how it is generated and so on, people must be having an idea about that I assume.

So, when this electron hole pairs are generated, electron basically goes and hit and knocks out some certain electron and those places its hole is basically an absence of electron and vacant electron state and so on. So, those electron hole pair somehow is generated. Now normally what happens this electron hole pairs will recombine in a normal condition but now if we apply a certain amount of voltage to this semiconductor.

Then what will happen? The electrons holes we can treat them as positively charged as an absence of electron they are positively charged; electrons of course are negatively charged. So, what will happen? If we apply; now of voltage in such kind of a semiconductor, we will get a current out of it. Electrons will move towards the positive bias; holes will move towards negative bias and we will get a net flow of electrons opposite direction we will have a net flow of current.

So, where it starts? It is basically the same, BSE electrons hitting the semiconductor, in the process the semiconductor is giving a current so there is nothing in the middle. So, what was increasing the size of these scintillator base devices was basically the photomultiplier, the current multiplier and so on light tube and all of these things. Everything is now cut in this semiconductor based solid state BSE detectors; that is why BSE detectors of this kind are very very thin.

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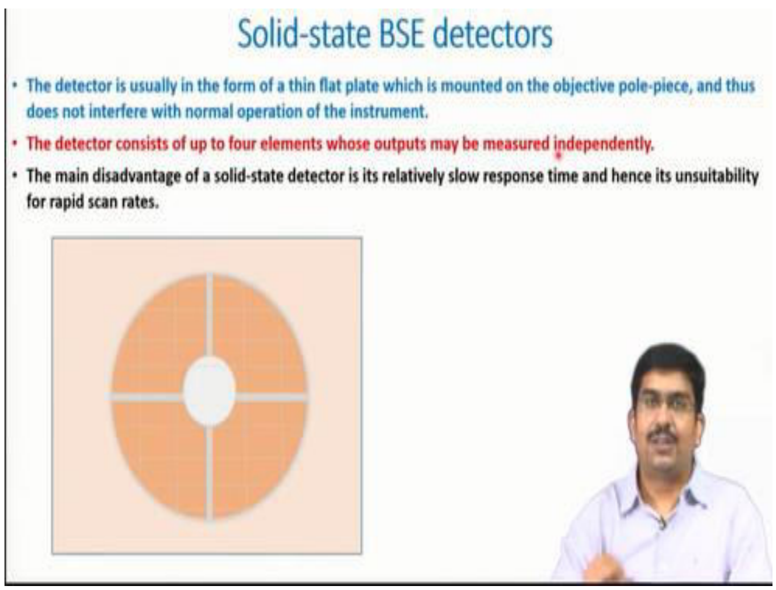

So, if you see here, the detectors are usually in the form of a very thin plate and that plates are mounted on the objective pole piece. And these plates are also usually have a hole in the middle through which the optic axis passes and through which the electrons basically passes through. So, this is how their backscattered electrons solid state backscattered electrons look like. They can be very easily fitted to the pole piece of objective lenses.

The kind of microscopes I have seen, either you have a retractable one usually you have something like a screw mechanism from outside through which you can either push this one in. And then retract when you do not need the BSE detector or even simpler sometimes, they are kept in the specimen chamber itself. You take it out and you put it on the objective pole piece this stays there with a magnetic or with a fitting mechanism, pressure fitting mechanism just stays with the objective pole piece itself.

So, these are the two kinds of retracting mechanism at least I have seen. This depends on different companies and different manufacturers. But more or less these BSE detectors are they are able to solve to both the problems of scintillator base detectors. Number one, they are not bulky, they are very thin plates. And second thing yet with a very high detection ability, the amount of current or the response that the current signal that generate are very very accurate.

Very high-quality signal that generate and that is why this BSE detectors are much superior than the scintillator base detector and of course, they can be retracted as well. Usually, there is another advantage of this solid-state detector which we will discuss and we will appreciate more about this advantage of BSE detector. When we discuss about the image formation that is this detector can be physically divided into four different elements.

Generally, that is how the specialized solid state BSE directors are made. So, it contains physically four different elements this like this and they are usually like you can think north, south, east, west kind of things names are there or A, B, C, D or something like that. But this in the software what I mean is that in the physically in the software when you see the detector and function you will see this element separately. And these four elements are physically separated.

So, they basically works like each one works like a detector. So, you have a collection of four different detectors here. In one single BSE plate or BSE detector plate you have four different detectors in this. So, that kind of a configuration can be made and it gives immense advantage what we will be discussing. The main disadvantage of course, still now which is yet to be solved I would say is relatively slow response time for these detectors these solid-state detectors.

And therefore, this is not very suitable for rapid scan rate. This kind of BSE detectors scintillator base detector compared to them this is much slower detector. Of course, progress are getting made people are working on them trying to improve this response time and slow so on. So, these days whatever we see detect a solid should be detected available, they are not that different I would say in terms of response time compared to the secondary electron detectors.

And most of the imaging purpose the kind of scan rates we use this is good enough sufficient enough.

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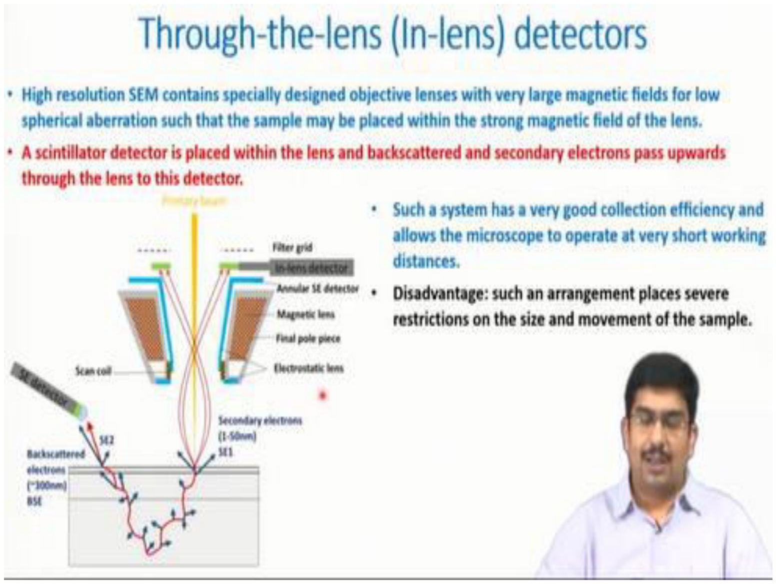

Now, in order to improve the SE signal as we already discussed that secondary electron detector, ET detectors are okay for the generating an SE signal good amount of the signal and so on. But if we want to improve a BSE signal for them, they are not at all a good one. And for that is why for BSE signal we went for this placing the detector as close as to the primary electron beams as possible.

Now the same thing we can try to do with the SE signal as well, we can put them close to the primary electron beam and we can try to improve their collection efficiency. More importantly, we can try to capture the pure SE 1 signals and a little bit of SE 2 signal. In that way what we can have is that we can reduce this spread of this beam or this SE signal. And in that way, we can restrict we can reduce the sampling volume, we can improve the resolution in SE signal itself.

If we have an SE detector, general ET detector that ET detector will have a much larger volume of this specimen that means the sampling volume for an ET detector is much larger. That is why the spatial resolution in SE signal which is captured by the ET detector is also quite low compared to that if we put some kind of a detector, SE detector in and around the backscattered, in and around the primary beam then what we will have is that we can able to capture SE 1 signal pure SE 1 signal and with a good number.

That also is important. We have to have a good quantity of that signal or good strength of that signal in order to be detected. Both of these we can find if we put our detector somewhere close to your SE detector, BSE anyway. So, that is there in specialized BSE or we can even use this kind of a specialized BSE detector put it here. So, this generally this kind of detectors are called in-lens detector and there is a reason for that why it is called in-lens.

That is because generally these kind of detectors are available with high resolution SEM and those SEM microscopes generally in order to reduce the spherical aberration. The lens objective lens has a very large magnetic field. Because of the large magnetic field, you know this spherical aberration in order to lower the spherical aberration you have to basically make the beam as small as possible or in other words, if you can the beam which is converging or which is diverging from the primary axis.

If you can make them converge and make them coming closer to the optic axis then you can reduce the spherical aberration at the same time you can conserve the strength of the primary beam. So, this is also so, you can very well bring an aperture there and try to cut those via electrons which are basically diverging from the optic axis. But in that process, you will be losing the beam current you can afford that in case of a transmission electron microscope.

There you really you can bring the aperture you can make it been finer and finer and then try to improve the spherical aberration, but in scanning electron microscope that is difficult to do. So, in a high-resolution scanning electron microscope you try not to depend too much and why that is so, we will come to that. Basically, when we discuss about the resolution of SEM you will realize that why we do not want to compromise too much with a beam current.

Because that also detects the resolution in case of SEM due to the scanning mode due to pixel by pixel mode, the beam current is also quite important in SEM which is not so much in case of or rather it is important in TEM but not so much as it is in case of SEM, scanning electron microscopy. So, for high resolution scanning electron microscope in order to reduce spherical aberration what we do we tend to have magnetic lenses with a very large magnetic field.

And often what happens is that magnetic field strong magnetic field of the lens extend all the way up to the specimen. So, what happens then afterwards is that these SE electrons which are generated or BSE electrons which are generated they also comes under the influence of this magnetic field from the objective lenses. And in the process, they gets focused on these lenses which are kept within the magnetic field of the objective lens.

That is why they can call in-lens detector. They are kept within the magnetic field of this objective lenses and they are able to now capture SE electrons which are now getting focused by this objective lenses as well. So, that is why this SE, pure SE electron the in-lens detectors are able to capture the pure SE 1 signals mostly and with some SE 2 signals as well. And at a much-focused way and the collection efficiency is also quite high for the in-lens detector.

So, using the advantage of using in-lens detector is then for SE signal at least improved spatial resolution without compromising on the signal strength. That is what is purely the advantage of in-lens detector over the general SE detectors. So, this kind of system has a very good collection efficiency and the microscopes can be operated at a very short working distance. So, short working distance anyway improves we will learn about that.

Short working distance anyway improves the resolution further improvement in resolution in spatial resolution you can do by using this in-lens detector. Short working distance because now you do not have any restriction here in the centre place is free. You do not have backscattered detector or any other kind of detector you are not bringing anything in between the objective lens and this specimen.

So, in-lens detector is here after within the magnetic field but after the objective lens. So, that is why working distance can be smaller and spatial resolution can be better in case of in-lens detectors. But of course, it has certain disadvantages, number one biggest disadvantages it makes the entire this configuration of lenses and other things their objective lens and all it makes it complicated.

And that kind of an arrangement of course plays some restriction on the size and movement of the sample because you cannot make the sample move out of the magnetic field of this objective lens. So, you have certain restriction in the sample movement and the area that you can scan or the area or the magnification that you can go that also lower in the lower side. The magnification physically the area in the specimen that you can you are covering they are also there are certain restrictions.

So, you cannot go too lower magnification in order to use the in-lens detector. If you go to too very low magnification that means your field of view will be so big that area of the specimen maybe out of the magnetic field of this objective lenses. So, those areas will not be covered very well by the in-lens detector. So, that is a big disadvantage for using this in lens detector. That is why generally in-lens detector when you are having in-lens detector.

Again, this is a very specialized detector and very costly as well. It costs nearly an order of magnitude higher than any of this SE detector or sometimes even the BSE detectors. And generally, when you have in-lens detector you tend to use a very and that is usually used for a high-resolution SEM where you really want to see your features in very high magnification in some almost 100k times on so on.

So, those case kind of applications you want to have an in-lens detector. If you want to do a regular kind of SEM at a low magnification 10000, 5000, 1000 something like that in-lens detectors are not so good. Your SE detectors is good enough, BSE detectors are good enough, in-lens detectors and not so much helpful there. Otherwise in-lens detectors or configuration wise or in the way they work in-lens detectors are pretty similar to the scintillator base detectors.

Only difference is the way where they are placed that is different. Solid state based in-lens detectors are also available.

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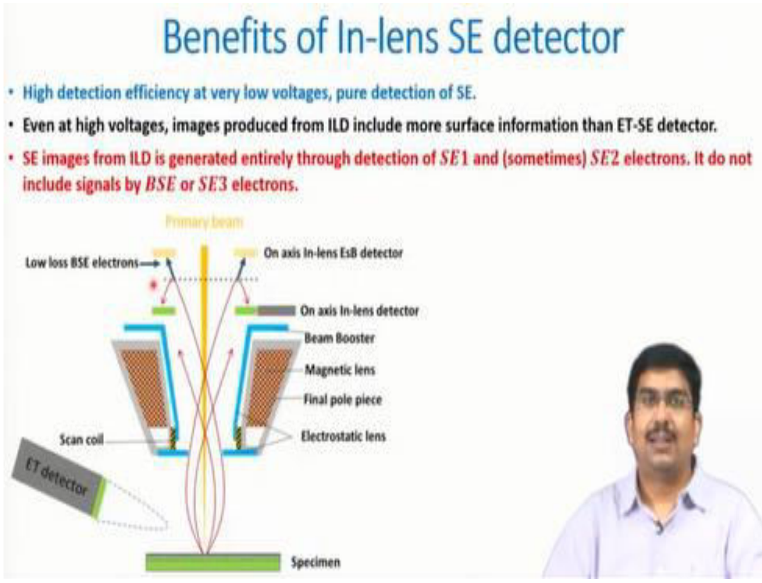

That can be used for BSE detectors and that can be sometimes used for SE detectors as well. Now, benefits of in-lens SE detector as I already said high detection efficiency and very low voltage and pure detection of SE that when pure detection of SE 1 signal with a high spatial resolution. That is the most important point for in-lens detector. And even at a very high voltage the image that is produced from in-lens detector is more surface information.

That means spatial resolution is better again. And SE images is purely detected it is a pure SE 1 signal sometimes they SE 2 signals and it does not include BSE or SE 3 signal. So, the spatial resolution as I said spatial resolution usually is very very good in this case.

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So, with that we are having a comparison between an in-lens detector image taken with an in-lens detector versus image taken with an Everhart Thornley detector. You can see that this is the ET detector and the surface features of these small particles are not at all visible here. And in the in-lens detector, you are able to see this surface clear edge you are able to see these edges, this edges effects and surface features are very very prominent here.

Look at this surface features or look at these two regions the difference in contrast between this region and this region that is only visible in in-lens detector whereas ET detector is not able to show any such contrast between the particles within the particles. So, that means the spatial resolution is much better in ET detector at the same time the signal strength also is quite high in ET detector. So, these are the advantages or the two big advantages of in-lens detectors.

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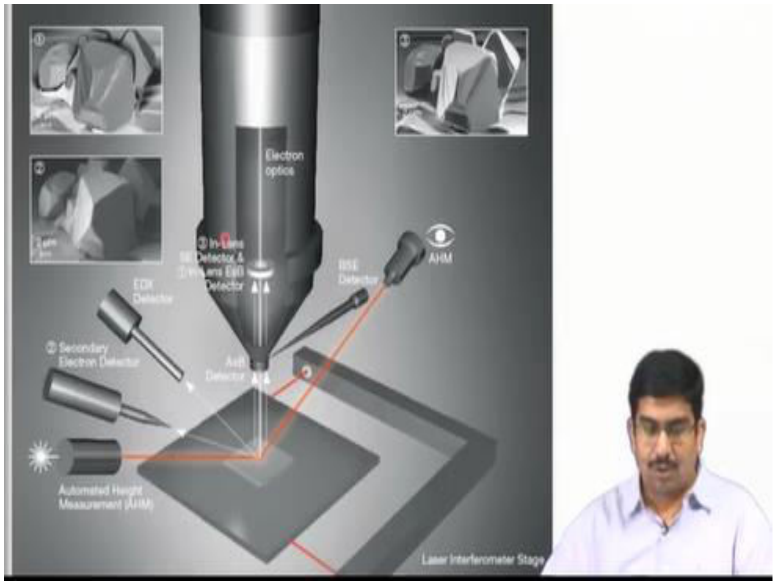

So, now these are the different kinds of signals or different kinds of detectors as I already said. Three different detectors are very common and most commonly used in an SEM. So, you have the secondary electron detector here which is the typically the ET detector then you have the EDS detector that is characteristic X ray detector here and you have these backscattered electrons a general solid state backscattered electron detector here.

And this is in that retraction the way it is retracted by this. You have the screw-based mechanism basically and with that, you can retract this BSE detector here. And then you have this in-lens detector and as I said in-lens detector again can be SE type, BSE type whatever. But you have the configuration is such that they are placed within the objective lens within the magnetic field of the objective lens plus there are certain other kinds of detectors are there.

For example, you have a CCD device in order to physically see a camera, basically phusically camera you have in order to physically see this, whatever is happening within the specimen chamber. And also, sometimes usually have an automated height measurement system that works by the lay principle of laser and then that gives you a signal that what is the physical height between the specimen and these lenses. So, that is also is important to know.

And in this case, so if we compare this different type of images here. So, this is captured from detector one that means detector one is I think it is in BSE detector in-lens BSE detector, detector one is basically in-lens BSE detector and detector 2 is again this secondary electron detector and detector 3 is in-lens SE detector. So, if we now compare between say image 2 and image 3 that means secondary ET detector versus in-lens detector you can very easily see the difference.

These features are not at all visible in this ET detector that means the spatial resolution here is much better in the ET. The in-lens SE detector gives a much better spatial resolution than the normal secondary electron detector. Again, if you now compare between one and three that means in-lens SE and BSE detector, you are seeing certain regions here which are something like which are very bright which is not so bright it is dark here in the SE signal.

This is giving a compositional contrast. Basically, remember the BSE signal is also produced and also shows compositional contrast. So, this compositional contrast here is shown, but at the same time you can see this spatial resolution. So, BSE signal which we will discuss in later basically gives two types of contrasts both topographic contrast as well as compositional contrast. And both of these two contrasts are shown here which is different from this pure SE signal.

Wish we could have signal or we could have an same image from this channel normal backscattered detector and then by comparing that backscattered detector image with this in-lens backscattered detector image we will be able to see the difference. The advantage of basically using the in-lens BSE detector is that again just like SE signals it also captures pure BSE signal. That that means the collection efficiency of in-lens BSE detector is much higher than the general backscatter detector which is placed here.

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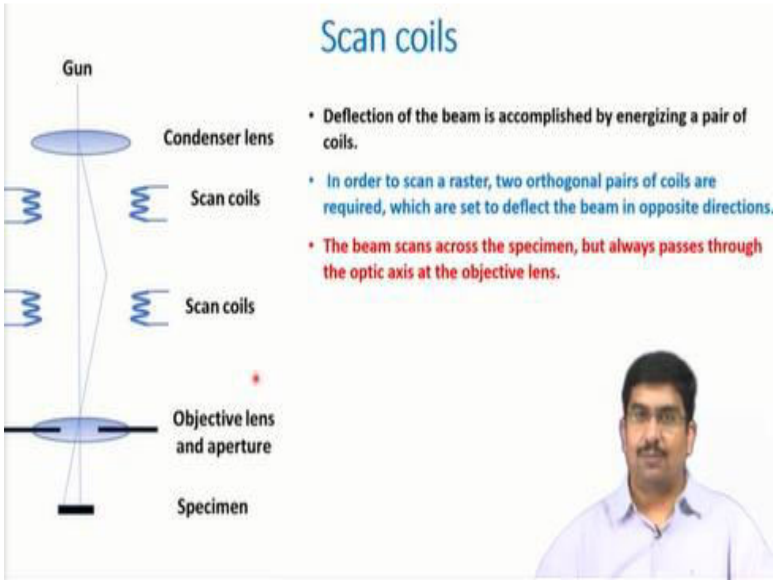

So, with this we are moving to scan coils but I think we will discuss this in the next class. Thank you.