

**Techniques in Materials Characterization**  
**Prof. Shibayan Roy**  
**Department of Material Science Center**  
**Indian Institute of Technology - Kharagpur**

**Module No # 14**

**Lecture No # 60**

**Electron Backscatter Diffraction(EBSD)**

Welcome everyone to this NPTEL online certification course techniques of material characterization. So this is the last class module 12 and we have so far discussed everything which was there in the syllabus we discussed about the optical microscopy we discussed about electron microscopic we discussed in electron microscopy. We discussed about scanning electron microscopy we discussed about transmission electro microscopy.

And then we moved on to diffraction-based techniques again there we discussed about diffraction. We discussed about X-ray diffraction and that module the whole lectures we had before these. There we have discussing about how to utilize extra technique extra diffraction technique for material characterization. Various effect of strain effect of crystallize size and so on amorphous material crystalline material all of these.

So we are done with all this 59 or all this lecture until up to now we are almost done so I thought that we are almost taken this last lecture I will introduce you to a special technique special why it is special we will discuss about that. But to me it is very special because this is one technique that we use my research group we use and I also used it over my research carrier very extensively. So this technique is called electron backscatter diffraction EBSD.

**(Refer Slide Time: 02:00)**

## CONCEPTS COVERED

- **EBSD and its working principle**
- **Orientation**
- **Kikuchi pattern**
- **Indexing and orientation determination**
- **Use of EBSD**

So we will be just discussing about this special technique today and we will be discussing about EBSD and its working principles. And in order to understand the EBSD results or how EBSD works and what data you get out of EBSD how you can analyze the EBSD data. So to do all of these things you have to have a some idea about orientation, what is called orientation? Or more general term you have heard about this crystallographic texture.

If you are material scientist, we aware of this term texture so what is texture or orientation and then we have to understand Kikuchi pattern because that is what is the main signal in case of an EBSD technique. And then indexing and orientation determination in an EBSD and finally we will take some specific examples about EBSD what EBSD can do and so on and so forth.

**(Refer Slide Time: 02:50)**

## Why EBSD?

- Simplicity: employed as an additional characterization technique to a scanning electron microscope (SEM)
- Ease of sample preparation from the bulk, the high speed of data acquisition, and the access to complementary information about the microstructure
- From the same specimen area, crystallography, orientation and morphology of the microstructure are characterized
- It has been applied to many industries such as, Metals processing, Aerospace industry, Nuclear industry, Automotive industry, Microelectronics, Earth sciences etc.
- Many materials have been investigated by using EBSD, such as Metals, Alloys, Intermetallics, Ceramics, Thin films, Geological minerals, Semiconductors, Superconductors

### Range of Information from EBSD

- ✓ Crystal orientation
- ✓ Misorientation
- ✓ Grain size
- ✓ Global texture
- ✓ Local texture
- ✓ Recrystallised /deformed fractions
- ✓ Substructure analysis
- ✓ Strain analysis
- ✓ Grain boundary characterisation
- ✓ CSL boundary distribution
- ✓ Slip system activity
- ✓ Phase identification
- ✓ Phase distribution



So why EBSD first and foremost is simplicity it is very simple technique it is high end characterization technique and over my entire my research carrier. I have realized that this technique if it is used by someone who has a very good knowledge about characterization technique and material science. They can do wonders with this so this can be very well complete with let us say other high end characterization techniques like electron diffraction or transmission electron microscopy or extra diffraction and so on.

So it is very powerful technique and high end powerful characterization technique but it is a very simple techniques as well. So it can be used or it can be filtered in an electron scanning microscopy most often that is how you use to see it though it can be EBSD can also be used in like similar technique can be there in transmission mode. But mostly we will be discussing today EBSD which we used in a scanning electron microscope.

So it comes as an additional detector and almost every scanning electron microscopy were procured these with a little extra money you can also get this electron backscatter diffraction. The sample preparation is very easy that is another very attractive point from the bulk material you can prepare sample quite easily. It is not as extensive sample preparation possibly not as easier as it is in X-ray diffraction.

But definitely it is much simpler than preparing a transmission TM sample high speed of data acquisition very high amount of data you can collect within from a reasonable area.

Statistically significant area to be very precise in scientific you can get a data on a statistically reliable scale that is one of the major drawback of transmission electron microscopy there. That data that you capture is very nicely specially resolved but not statistically reliable.

On the other hand if you capture data orientation data diffraction based data if you capture it from X-ray technique you can have a very good statistical large area very good statistics you can have but you will be losing that special resolution. That means the connection with the microstructure this is not so easily done in X-ray technique. So EBSD somewhere in between (( )) (05:17) also the different range of information that you can get from EBSD from the same specimen in area, you can get information about crystallography, orientation, microstructure and phase everything.

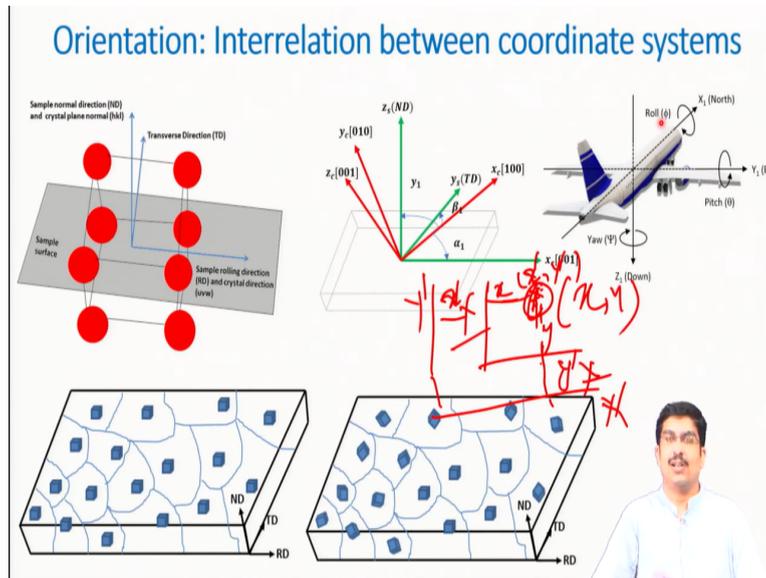
All these different types of data you can have you can also copulate with complementary information you can also copulate with complementary other characterization techniques like. You can couple it with EDS or WDS technique so you can get chemical information and you can also orientation related information and crystallographic information and you can club them to do.

So of all of these things may EBSD very attractive technique for many different fields I just name some few here but the list only increasing over the years. So metal processing Aerospace, nuclear, automotive, micro electronics, earth science ,geologist they use EBSD a lot these days. And even biological materials also slowly people are realizing of course biological materials has its own limitations and all.

But slowly some biological materials people are also using like EBSD for that and you can if you go by materials what are the kind of materials you can use by EBSD? You can have metals, alloys, intermetallic, ceramics, thin films, geological minerals, semiconductors you just name it. And that is because you can get all these different range of information out of EBSD. You can have crystal orientation, misorientation, grain size you can calculate, global texture, bulk texture you can measure.

Local micro texture you can get you can if it is deformed material how much percentage of recrystallization can happen. Dislocations of structures analysis strain analysis, grain boundary characterization, all different CSL coincidence site lattice boundary you can have about that. So all of these things you can get out of EBSD that is why it is so diverse.

**(Refer Slide Time: 07:11)**



Now as I said in order to understand EBSD you have to understand orientation what is orientation? And in simplest term orientation is basically location defining location of certain things. That means it is basically an interrelation between coordinate system so how it is so? And a simple example of that I would say most of you have possibly studied coordinate geometry I studied it.

I was very passionate in coordinate geometry in my +2 so in coordinate geometry you can have this kind of a coordinate you can define it as x all of us done that. And then if you define a point out here you can have it coordinate in terms of x and y. So x means this is what this is and this is you x and this is your y. This hits an y basically tells you the coordinate of this point that means you first define this coordinate system if it is partition coordinate system polar coordinate system whatever.

So you define this coordinate system and then in terms of this coordinate system you define this points. So this x and y basically tells the location or orientation of this particular point with respect to this coordinate system. If you change the coordinate system if you make a

coordinate system like this let us say this is I am putting it x dash y dash. Now it is orientation becomes let us say something x dash y dash where this is your x dash and this is now the new y dash.

So if your coordinate system change orientation location everything change so this interrelation is over called orientation. How it works in terms of let us say in a we will take simple example let us say any metals and alloys that is easier to understand. So how it works? There also you have this coordinate system where you have to define the processing of materials 2 different coordinate systems we define one is called the materials specimen coordinate system and one we call it crystal coordinate system.

So specimen coordinate system if you take example of something like a rolling so you have this rectangular piece where this is defining as the rolling direction and this is the normal direction and this is the transverse direction in a roll sheet. If you take a roll sheet this is how the 3 principle directions you can get. So with respect to that if you design your crystal this is different this is the poly crystalline material.

You have different grains and now what you can think of is that how this grains are all oriented with respect to this coordinates system. Rather which plane or what which directions are oriented along RD which direction oriented along ND which direction is oriented along TD? That will give you the orientation or texture that is what we got. So this is one type of material where all the grains will have similar kind of orientation and this units cells are proving that.

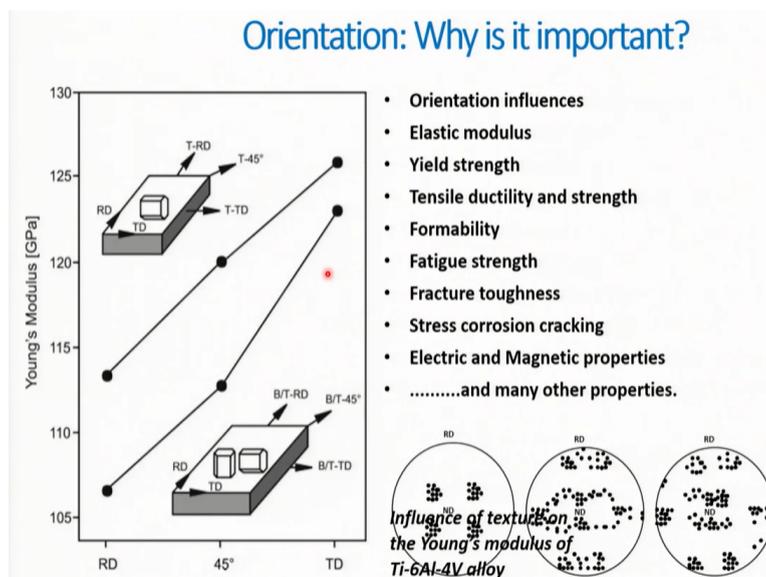
All the grains are having similar kind of orientation where as this is one material where different materials grain as different kind of orientation. So this one is textured this one is not so much textured that is what. So this is again I defined the same coordinate system in terms of rolling symmetry. And I have now check what is the crystallographic symmetry how these 2 are oriented which direction is parallel to rolling which direction is parallel to normal direction which direction is parallel.

There is even more complex way of defining that where your specimen coordinate system can be arbitrary and what you defined here is called Euler angle you basically define 3 angles those 3 angles will tell you how you can bring this specimen coordinate system and crystal coordinate systems in coincidence. So if you have start with complete arbitrary orientation your specimen symmetry is something crystal symmetric is something how you can bring them coincidence and you will find out mathematically prove that you need 3 definite type of orientations.

With 2 different types of orientations you can bring them coincidence what is those 3 angles will define the orientation of that particular specimen this is called Euler orientation. I am going into that you can go through any texture textbook or any texture related course to understand what I am talking about. Just to tell you this is very general and one example I have shown here that this Euler angles are even used to define the location of any aircraft.

So when an aircraft is flying what with respect to the coordinate system what coordinate system how it should rotate itself it is called roll it is called pitch one is called Y. So how it should rotate with which rotate and align itself with respect to the coordinate system art coordinates. And then only it can find it position it can find which direction it should go on. So this Euler angles are very important even in aerospace this is very challenge this is how you can define in orientation.

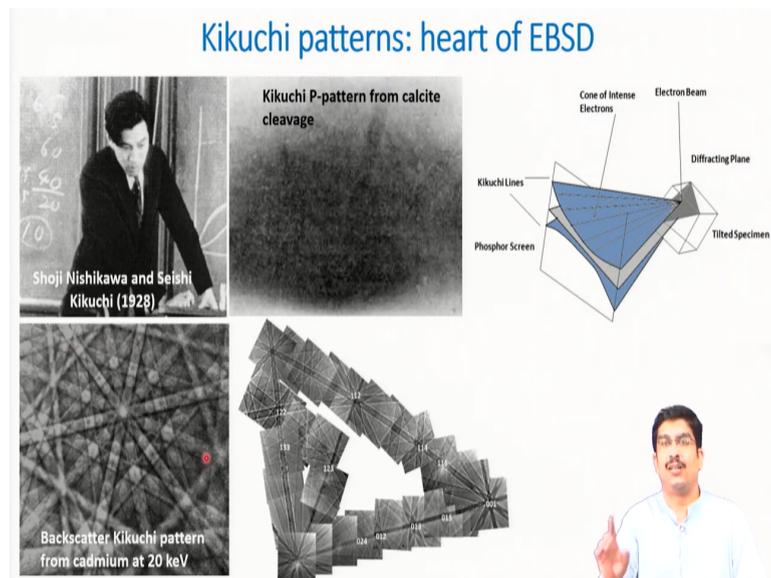
**(Refer Slide Time: 12:27)**



Orientation why it is important? Because it defines all your different properties so you can see that this Young's modulus of titanium alloy this is something to do with the titanium alloy. So this young's modulus if this titanium alloy will be changing with respect to the orientation it is something if the single crystal or titanium is oriented along RD then C axis basically this C axis if it is oriented along RD you will get something some Young's modulus.

But when that is aligned with respect to say TD you will get something L so your entire young's modulus is changing depending on the orientation. So orientation influences all of these various different properties that is what the importance of orientation.

**(Refer Slide Time: 13:17)**



Now we talk about something called Kikuchi pattern. So Kikuchi patterns is basically the heart of EBSD that is the signal as I said how it works? How the Kikuchi pattern works? The Kikuchi pattern what happens is when an electron beam hits a specimen and we understand we already discussed that in a scanning electron microscopy let us discuss only a scanning electron microscopy. So in a scanning electron microscope when the electron beam hits the specimen it generates backscatter electron.

And specialty about backscatter electron is it is an electrically scattered electron that means it has a definite wave length and if the source does not have specific fixed wave length it will be useful for diffraction experiment. We discussed about that is why only thing other than

backscattered electron will be useful for diffraction related experiment in a scanning electron microscope.

That is what another big sort of I would say specialty about EBSD because it is only technique in scanning electron microscope which will give you diffraction related experiment which will be giving you crystallographic information about the sample. All other signals will give you very others like for imaging for chemical analysis and all. But diffraction related experiment you can only use backscatter electron.

So this backscatter electron are generated from deep within the specimen and when they are coming out they can sort of. Then those backscattered electrons will be used as the source and they will be getting diffracted micrographic plane and then when this diffracted beam comes out it will form something called kossel cones like this cone they will be coming up. It is pretty similar to the extra diffraction you just remember and go through the extra diffraction this is you will be able to understand this is allow diffraction pattern the wave forms.

And if you keep something like a Phosphor screen in front of this like this if you keep phosphor screen here then kossel cones will be cutting through this screen and producing this kind of lines which are called Kikuchi lines or Kikuchi patterns. After the name of this person who has seen these lines all the way back to 1928. So, this is the first Kikuchi pattern that was recorded from a calcite and obviously that time that resolution and other things which is not great.

These days we get Kikuchi pattern in this way since this pattern is created in diffraction experiment it has all crystallography information like zone axis it has all symmetry related information everything. Kikuchi patterns are also generated in transmission electron microscopes. So we have seen this example I have shown this when we were discussing about TEM we have shown you how this entire stereographic angle orientation triangle generated using this Kikuchi patterns here.

So, this Kikuchi patterns generates 2 lines it is amalgamation, so anyone set of plane generates 2 lines. So, these 2 lines top and another line in the bottom and together they generate this Kikuchi band and this bands collectively all the bands will generate this kind of a Kikuchi pattern fine.

**(Refer Slide Time: 16:40)**



Now what you have to do is basically SEM this is what your electron beam is coming like this we can look at here electron beam is falling on the specimen this is your specimen. And they are generating this Kikuchi band and you have the detector over here which is the phosphor screen basically and this phosphor screen basically and this phosphor screen which is create this Kikuchi pattern.

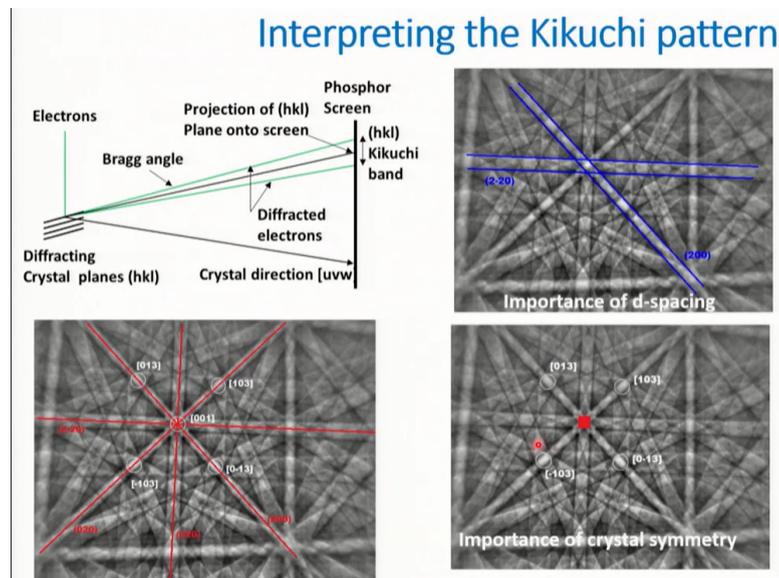
So you are basically creating this entire diffraction so there is this 3 dimensional 360 degree cone of this diffraction pattern that is happening here. This is 3 kossel cone 360 degree Kossel cone which is generated and you are just taking capturing only a part of that in a 2 dimensional detector plane. So and there it is forming this Kikuchi pattern and many a times I get questions that why it is tilting is there just go back to your SEM principle, there it is very clearly said that if you increase the tilting angle then your backscattered electron yield increases.

Or rather there what happens the interaction volume remains the same but the distance between the specimen surface and interaction volume from where this backscatter electron

generated that decreases. That means that backscattered electrons which are of low energy of course so back scattered electrons can very easily come out from this surface. And that is why electron backscattered EBSD technique is also very surface sensitive.

So this information is generated from a very small depth even though back scattered electrons are generated from a large depth inside this much larger than the secondary electrons. But still the backscattered electrons when they are coming out from the specimen in their path they will get diffracted. That is why diffraction patterns are almost generated from the surface or very small depth of the surface.

**(Refer Slide Time: 18:35)**



Now you have to interpret this Kikuchi patterns and get the crystallographic information out of it. So, in order to do that some we utilize some of these properties of this Kikuchi patterns. So basically, this Kikuchi patterns said the bands represents one set of crystallographic plane. And wherever there is a intersection of this bands basically that is the zone axis.

Remember the definition of zone axis so the intersection of this bands means the planes in the real specimen basically this is the intersection of the planes those planes at the diffracting that is what it is represented in Kikuchi pattern. So the where the planes are cutting through or intersecting each other that is represented in a Kikuchi pattern like this and this kind of intersection that is the zone access for those.

So if you define this zone access now we will be able to get this entire Kikuchi pattern you will be able to understand the entire Kikuchi band. You can understand that which of these bands is this or rather from which crystallographic plane this Kikuchi band is generated from which crystallographic plane this other Kikuchi band is generated and so on and so forth. That is what you are trying to get how you are going to get this we will discuss it is not so straightforward.

For that you have to know a lot of information about the specimen you have to know what kind of specimen, if it is if you do not like that is true for all high-end application or high-end characterization like TEM diffraction pattern analysis. If you do not know exactly what material you are going to or what you are studying what is the symmetry of this material then it will be very difficult to even understand this Kikuchi pattern and so.

Any chemical information you must have about your starting before starting your pattern indexing point you must have some idea about your material itself. Some few things important like for example d-spacing. So basically what happens this distance between these 2 Kikuchi lines that means the thickness or width whatever you call. So width of this Kikuchi band represents the d-value or d-spacing of those planes.

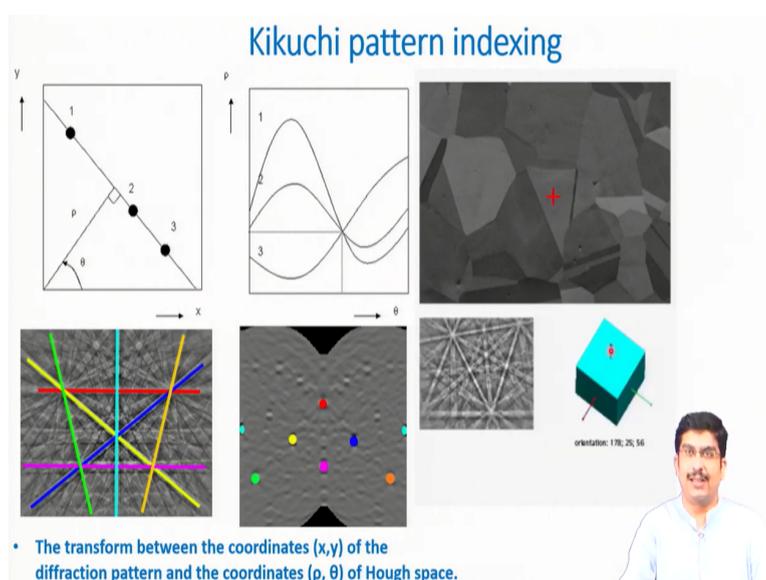
Because as I remember this I said that 2 kossel cones are generated from any one set of plane you can think of that like it is generated from this plane. It is generated from this side and that side of it front side and back side of any crystallography plane. So basically that is the width of the Kikuchi band is representing the d-spacing of those planes. So the planes which are having just like that diffraction pattern.

Remember the diffraction pattern TEM diffraction they are also that d-spacing was the distance between the central spot and the spot that is generated corresponding to any crystallographic plane. Exactly the same thing here the distance between the 2 Kikuchi bands is basically the d-spacing of that particular set of plane. So you will have in a Kikuchi band if you look at the Kikuchi band or Kikuchi pattern we will see that bands are not of the same width.

Because they are d-spacing is different crystallography plane as different types of Kikuchi or different type of d-spacing then they will have different width in the corresponding Kikuchi pattern. So that is one second thing is and then I will leave a question to you to answer this that high index plane versus low index plane which one we will have higher Kikuchi width. And from there that is another important point when we do the indexing that is another check that we can do anyway.

Also since this is the diffraction pattern equivalent to a diffraction pattern give it will have all symmetry related information that is another way of checking.

**(Refer Slide Time: 22:21)**



For Kikuchi pattern indexing basically what you wanted to do is a automatic indexing. So if you have this kind of a indexing this kind of a Kikuchi pattern you can sit with this material information and you can loop then you can try to identify. Just like a diffraction pattern solving a diffraction pattern you can try to solve it and it is possible you can do. I mean you can have library function you can have various library you can know that this is a crystallographic orientation then this kind of Kikuchi pattern I should get and so on.

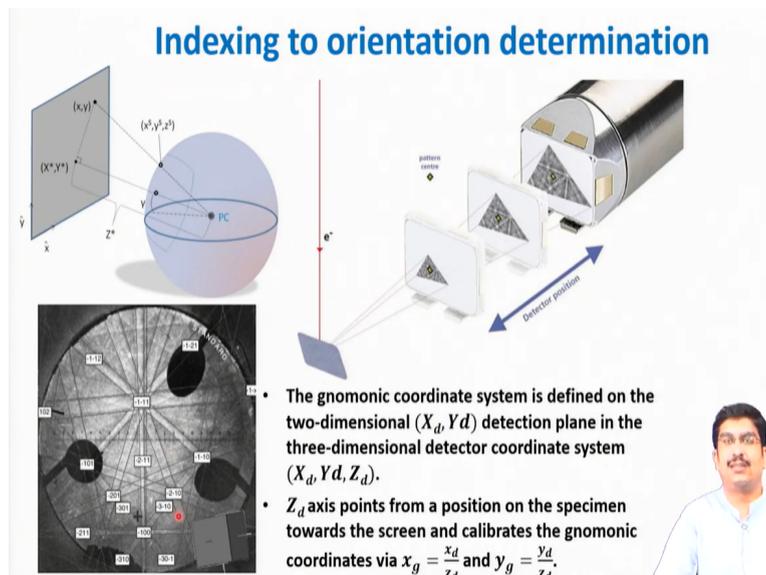
Otherwise also you can also possibly figure it out that solving this one but in a scan as I said you want to get a data from emerged statistically reliable scale. So you want to get a data from a large area which will contain many millions of pixels and each pixel here giving you

one Kikuchi pattern. So indexing those Kikuchi pattern equally is impossible that good-old-days people use to do that 1990's I was talking to somebody couple of days back he said that in 1990's when they were doing EBSD they were basically indexing these kind of Kikuchi pattern manually.

Now it is completely automated and the automation one of the way you can do the automation bring this automation by doing a mathematical transformation known as off transformation. I am going basically what is Hough transformation it is operation by which this bands are transformed to a point in off space just like a Hough transformation and then indexing becomes much easier.

You can use library function so once you do that basically different grains you can go and Kikuchi pattern corresponding to that orientation of the crystal planes you will get different Kikuchi patterns.

**(Refer Slide Time: 24:01)**

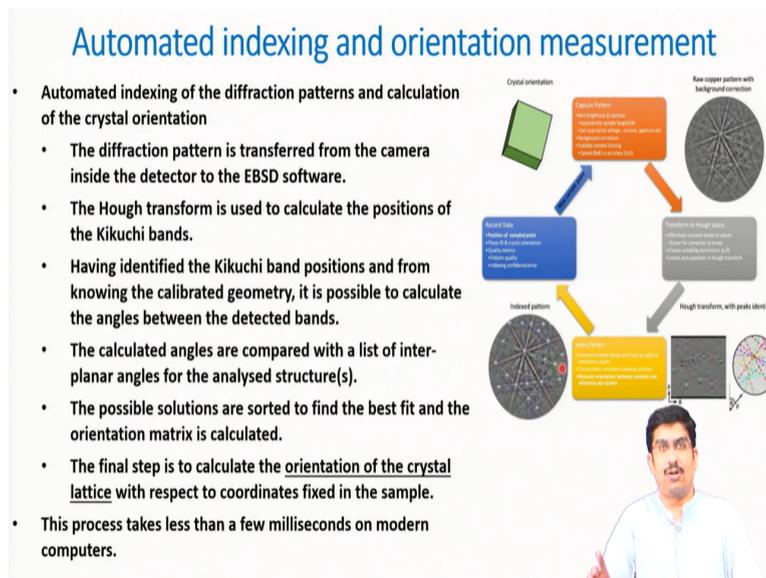


Next step is indexing to orientation determination you have index the Kikuchi pattern done now orientation determination. As I said orientation is the interrelation of coordinate system and basically here the coordinate system means this specimen coordinate system. How this specimen is oriented and how the crystal planes are oriented and then bringing them coincidence in terms of coincidence basically to determine this Euler angle.

That is what you need to do and for that you have to do lot of calibration which is something called pattern centred determination which again I am not going what is patterns in determination. But that is how you basically can understand this Kikuchi pattern happen indexing you can figure out that how this grains basically each of these grains how they are oriented with respect to the crystal to specimen coordinate system.

Now you have just defined the crystal coordinate system but after this you want to determine the relationship between crystal coordinate system and specimen coordinate system that you can do by again completely automated way and do this. And for that you have to do this calibration and all so all.

**(Refer Slide Time: 25:09)**



So this entire process as I said known as automated indexing and orientation measurement. And this process if completely computer controlled these days so you can basically get this entire process this entire Kikuchi pattern determination right from capturing Kikuchi pattern to hough transformation to indexing the pattern. And finally to generate the orientation data or Euler angle so this is 4 step.

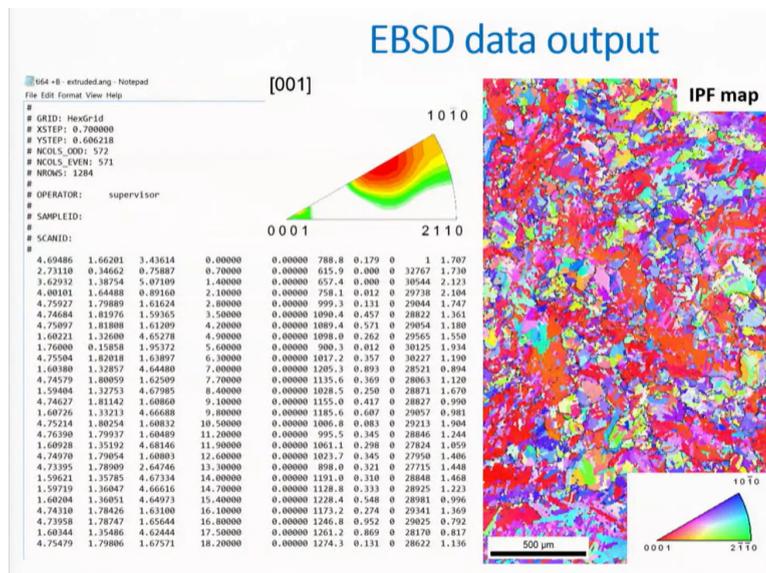
First you generate the Kikuchi pattern then you do a half transformation this part is only real this is only the hardware part where the beam is generating the Kikuchi pattern. So this is what you measure basically after that this all 3 parts is software related computed controlled

that is nothing to do with the measurement itself so you generate this Kikuchi pattern you do the hough transformation software does it for you software then look at table.

Basically you generate artificially you can generate this Kikuchi patterns and then you match them and finally you can generate this orientation information basically the 3 Euler's angle you calculate and that is done. This is how the EBSD basically works and this entire as I said entire pixel this entire process you can do it this case in milliseconds. So large area continuing millions of pixels will not take more than few hours for you.

If you have to do if you think that even something when I started my journey in way back in 2006 when I started doing this EBSD this kind of data takes almost million pixel means almost days will be taken in a scan. These days you can do it with faster detector with lots of software improvement computation power improvement you can do it in few hours itself. But The basic principle remains the same this 4 steps you have to recall and remember.

**(Refer Slide Time: 27:00)**



Now this is how the EBSD data comes out this is the output I am showing you a real EBSD data output so this is how the Euler angle these 3 first 3 data this is data EBSD data if you open it in a text file this is what you are going to see. The first 3 so this each of them is basically is a pixel information in a pixel. So all of the pixels you have like it will tell you x and y definitely in a specimen with a specimen what is x what is y?

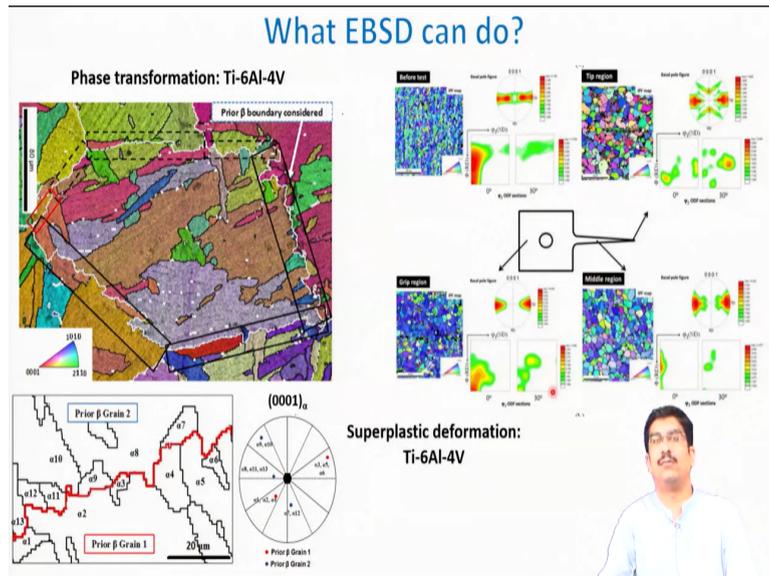
This is the location of that pixel then what it will tell you is Euler angle 3 Euler angles so these are the 3 Euler's angles for that pixel. So that pixel the crystal orientation is such that you have to rotate in these 3 along or these 3 different angles if you rotate it will come in coincidence with the specimen coordinate system. So that is what you can determine and finally this from here from this data.

Again you use software analysis software various commercial software's are available various pre-software's are available matlab programs are available also. You can develop these kind of maps or you can also develop this kind of texture information and various other things you can do with these data itself. So these data gives you as I already mentioned orientation information but as a function of micro-structural tells that is the power of EBSD.

It gives this entire map basically represents the orientation of microstructural features you can imagine that these are the grain this colour coding is basically giving you the orientation of each of these grains that is the power. That is where it is different or it is higher in characterization compared to and SEM. So SEM only give you this image it will not give you any information about orientation plus it will not give you information about phase you can also identify from the diffraction.

Since it is a diffraction technique you can identify the phase X-ray will possibly able to give you this kind of a texture information it will not be able to generate this kind of a map. And that too in a statistically labelled scale you can see that this is almost you have measured around few millimetres around 5 millimetres by something like 2 millimetres or 1.5 millimetres of area you have measured within your specimen.

**(Refer Slide Time: 29:30)**

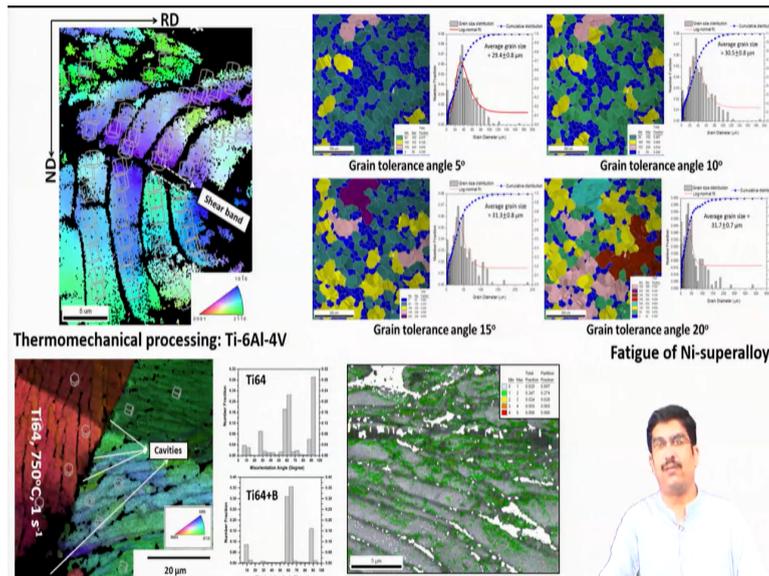


What EBSD can do I am not going in details again this is some results that I have in my research career I have used EBSD for various type of materials problem. And just a glimpse of that if you want to know please write to me I can pursue or I can suggest you the corresponding publication you can read about that. So I have used them for something phase transformation so this is one titanium alloy 2 phase titanium alloy.

And how the phase transformation happens from high temperature BCC phase to low temperature HCP phase how this phase transformation happens what are the mechanisms what different type of microstructure it forms so on and so forth. Those kind of structure studies you can do because it can give you information. Again as I said it can give you information about crystallography and from there you can generate something called orientation relationship everything.

You can also study deformation of materials this is one extreme example I have taken where I have used EBSD for measuring mechanisms for super plastic deformation high temperature deformation those mechanisms you can get y EBSD technique.

**(Refer Slide Time: 30:36)**



Normal thermo mechanical processing people regularly use EBSD to find out the mechanisms to find out how microstructure develop how the texture develops own? And you can use it for any other metallurgical or materials related problem like I have used for fatigue for Nickel sure alloy. There we were able to simulate kind of green growth we were able to see something called macro grains.

Or this grains or cluster of grains which are responsible for fatigue crack generation under high cycle fatigue conditions. So those kinds of studies also EBSD comes out to be very important for them.

**(Refer Slide Time: 31:18)**

### Remarks about EBSD

- EBSD is unquestionably the fastest and most reliable way to acquire data for crystalline structure and orientation in a solid crystalline phase.
- Traditionally these types of microstructural characterisation studies have been carried out using optical metallography and SEM, X-ray diffraction (XRD) and/or electron diffraction in a TEM.
- The hardware part of EBSD is well set, so as the software part: Data acquisition and data analysis has become fairly straight forward.
- Newer developments are on the buzz: Faster detectors, innovative informatics, newer analysis techniques.
- Biggest prospect: Applying this technique in various unexplored fields of research (ceramic materials, coatings and thin films to name a few).
- Know the technique, it can do much more than you think.

3D microstructure by EBSD

EBSD-EDS

Transmission Kikuchi in SEM (TKD)

So these are couple of examples finally these are my concluding remarks about EBSD first of all EBSD is unquestionably the fastest and most reliable way of acquiring data for any crystalline materials. The only problem is you have to can use it since it is a diffraction based technique you can only use it for a crystalline material. If you have an amorphous material it does not going to help.

But these days we are trying to use it for and for partially amorphous or something class ceramics where one of the material one of the phase is called the glass. One of the phase is an crystal there we are trying to get the orientation of this crystal phase using this EBSD technique. So that kind of system you can use it so of course as I said it is very fast because of this improvement in all this automation coming up in their.

And you can do it in a statistically reliable question traditionally many of this characterization with people used to do by optical microscopy SEM, TEM, X-ray and so and so forth. So all of these things you can replace all this characterization routine by one single EBSD can it is possible. You can get every kind of information from this EBSD technique hardware part of EBSD is very well set and faster detectors every other date I get to hear about some faster EBSD technique where acquisition speed is much higher.

Where the resolution of special resolution of this phosphorous or phosphorus is there screen is getting better and better and those kind of and then increase of computation power Obviously. So all of these things is a very well said software's the theory of this EBSD that is also very said and improvements are happening people are trying to do many more mathematical treatments on the EBSD data. How to get better patterns centre the calibration?

How to get hough transformation much better and so on and so forth so the software part is also very sort of well said and data acquisition data analysis has been become very fair illustrate for. So if you are working on a deformation related problem of the traditional problem where EBSD people are using 15, 20 years it is very well set. It is like a routine analysis obviously in your techniques if you want to use it in your research problems that is still a challenge that is all the fun of the research.

Newer development as I said a bus faster detector innovative informatics newer analysis and biggest prospect as to be I mean as I said this is all coming out of my experience or working with this technique for 15 year now. Applying these technique various unexplored field of research like a one example I have given you ceramic materials we are using this one in something like glass ceramics.

And coatings, thin films all this places microelectronics many people I have seen using this to know the texture of the thin films and so on. And this is what my final remark to everyone who is listening this NPTEL lecture that you know this EBSD technique it can do much more than what you think. If you are interested please you can contact us back and I have here given some of the very latest techniques that people are trying to do in the EBSD field.

For example 3D microstructures so this here this is called dual beam system so you take EBSD scan over one surface and then you remove the surface and then you can take another EBSD scan from a lower depth and so on. So go through in the Z direction and then finally develop this 3D microstructure coupling EBSD and chemical analysis almost this fairly become very routine this it is not nothing new.

Almost last 10 years people are using this and it has very common but it can give you lot more than normal EBSD information. Transmission Kikuchi in SEM so this is something called TKD transmission Kikuchi diffraction within SEM. So where you are using a transmission TEM's specimen within an SEM and you are trying to get the pattern of Kikuchi pattern out of it that is something which is really a recent one.

And people are trying it for last I would say 5, 6 years people are trying to use it and this can be a really very good technique where you can get advantage of TEM as well as. So the resolution is of that TEM level and you can get information instead of using TEM based electron diffraction you can get the EBSD. So you can scan a larger area and much faster so with this we are stopping it here thank you all for attending this course and I wish you all the success for you future end of this thank you