Defects in Crystalline Solids (Part-I)
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Lecture - 31
Cross-slip + Climb

So, we were discussing the glide of different dislocations.

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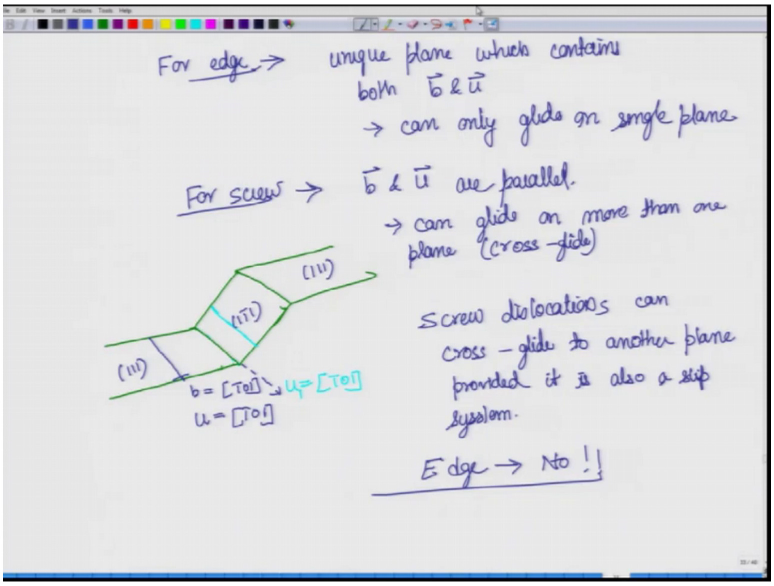

And in respect to that we said that for edge the glide plane which is defined as the plane containing b and u is unique. So, the edge dislocation cannot move out of the plane by glide. It can move out by climb, but if we are talking only about glide, it cannot it cannot move out. However, for a screw dislocation b and u are parallel. So, there may be several planes which contain b and u and are also acceptable slip plane.

Therefore, b and u, the screw dislocation, if we are talking about a pure screw dislocation; it can cross slide and we showed that example here if this is a screw dislocation. This is 1 1 1 and you can find out that 1 bar 1 1 contains the same b and u. And therefore, it can cross glide from this 1 1 1 to this bar 1 1 1. So, that is about a pure edge and pure screw. Now, the question is what about mixed dislocations.

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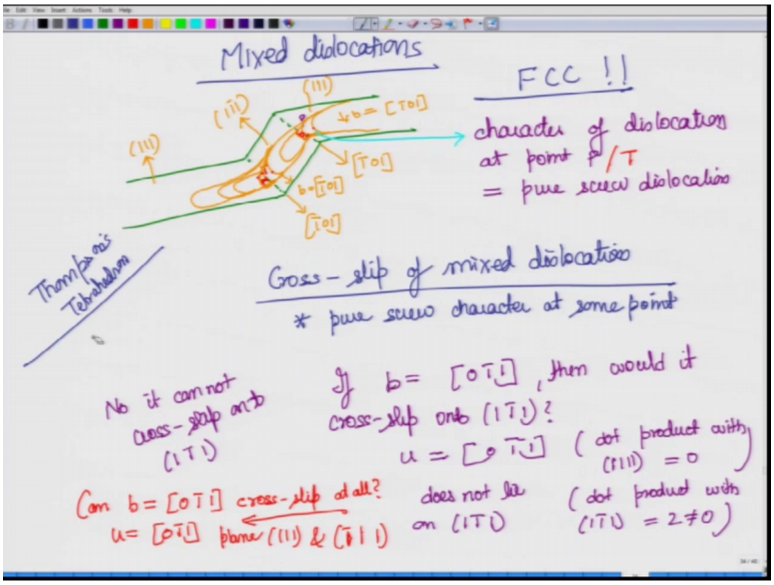

So, it may seem like since mixed on the face of it, it would look like mixed dislocations contain edge dislocation and therefore, it may not be possible for mixed dislocations to cross glide. But let us see, what really happens and as you would realize that the way I am projecting it, there must be something different from what we are expecting and it is true that actually the mixed dislocations do cross glide.

So, again here I am drawing three different planes. So, these are planes meaning here as you can see I am drawing it like continuous what is called as non-discrete plane. But in reality you must realize that these are actually formed out of atoms. So, they are all atoms sitting over here and just that these this particular plane, this particular plane are densely packed, you remember 1 1 1 which is the slip plane for FCC is supposed to be a densely packed and inter planar spacing is suppose to be higher. So, this is 1 plane, the other 1 would be much higher or which much lower than this.

But this, these plane on it itself would be very densely packed. So, do not think that this when I draw a plane it is like a plane as a floor. It is not really that; it is a imaginary plane composed out of atoms. So, now, let us move and look at dislocations ok. So, this is our mixed dislocation and let us say a burger vector is like this, which let us say for this particular case happens to be bar 1 0 1. And this is this plane is 1 1 1 or let us call it 1 bar 1 this is 1 1 1 and therefore, this is also 1 1 1. So, now, you can see that this one, the dot product of this two would be 0. Therefore, it means this burger vector is contained in this and what will be the line vector over here? The line vector here would also be bar 1 0 1.

This is the plane, this is the intersection line where the 2 planes are not meeting; but actually where the 2 planes meet. So, you can see that this particular plane, this particular direction is also perpendicular to this one means this particular direction lies also in 1 bar 1 1 and 1 1 1. And therefore, it is common to these and this also happens to our burger vector. So, now, let us look at what happens? So, at this particular point, if you look at this particular point, what is the character of dislocation at this point?

So, let us call it point P. At point P, what is the character of the dislocation? As you can realize that this particular point is if you remember from our mixed dislocation that even in a loop you will have 2 points which are pure screw and 2 points which are pure edge and this particular point as you can see its tangent is parallel to be and therefore, it will be a pure screw dislocation.

So, now that gives us a window that there is a pure screw dislocation component. Now, let us say this pure screw dislocation component reaches the intersection point that we have shown here. Now, this pure screw dislocation, this can surely cross glide. So, it will cross glide like this and once it cross glides, it will on the sides of it, it will form edge dislocations and these edge dislocations can move apart like this and it will slowly give it the shape that we had originally. And once it cross glide, then it will again form the shape like this. So, you see our dislocation which was on this plane has now moved on to this plane.

Again, if you look at this point which is let us call it this time T so, this is similar to P and this is also if you take the tangent over here, this tangent is per parallel to be the burger vector here also can realize is b equal to, the burger vector of the same dislocation does not change. So, whether it is here or here moves on to the next plane, the burger vector will remain constant. It will remain bar 1 0 1 and the line vector which is tangent at this particular point will be parallel to this line which is nothing but bar 1 0 1.

So again, these 2 are parallel this is screw dislocation. So, character of dislocation at point P, point T, they are all pure screw dislocation. And hence, when you take it further, this is screw dislocation. This is screw dislocation can, this screw dislocation can cross glide into this and once it cross glides edges; edge dislocations would start to move. So, what do we see here? Cross glide or cross which is the more appropriate term for this is cross slip; cross-slip of mixed dislocations.

And why was it made possible? It was made possible because there is pure screw character at some point. Now, let us do a little bit of brain storming and ask let me ask you if burger vector was equal to not 1 bar 1 0 1, but let say if it was 0 bar 1 1; then would it be cross-slip on to 1 bar 1 1? So, what do you think if the burger vector is this. So, right now, we had this burger vector and it was able to cross-slip on to 1 bar 1 1.

Now, I am asking I am just changing the burger vector; can would it cross-slip on to this particular plane? So, as you would how would you find out; so, first thing is that what will cross-slip is a screw dislocation. So, let see what will be the line vector of the screw dislocation. Line vector of the screw dislocation will also have to be 0 bar 1 1. Now, this 0 bar 1 1 must lie on 1 1 1 as well on 1 bar 1 1. So, 0 bar 1 1, if you take the dot product with 1 1 1 it is equal to 0. So, this does lie on 1 1 1, but dot product with 1 bar 1 1; what will this give? So, you see this will become 1 plus 1 into 1 plus 1 and this will minus 1 into minus 1 plus 1. So, it will become 2 so, it will not equal to 0.

Therefore, this particular direction does not lie on so, the answer is no, it cannot cross-slip into 1 bar 1 1 ok. So, next let me ask you as the continuation of this question that it cannot cross-slip on to 1 bar 1 1, but can it cross-slip at all? So, the next part of the question is can this dislocation where the burger vector is 0 bar 1 1, cross-slip at all? Ok. So, first instinct that you should get is that why should this particular dislocation be different from this dislocation; this particular dislocation which had a burger vector bar 1 0 1 is able to cross-slip. Is there anything special about it? No. Then, why should this particular dislocation not be able to cross slip?

So, the first instinctive answer should be yes, it should be able to cross-slip. But then, the question would be on to what plane? And the answer would be easy; all you have to do is again look at this u. You have to find out what is the plane that what is 1 of the other 1 1 1 plane that contains 0 bar 1 1 1. So, one of the plane we already know is 1 1 1 and what will be the other plane? So, you have to find that and it will not be very difficult to see that it would be. So, what we need to do is find a dot product where this and 1 of the 1 1 1 will give you 0 and that is what I am trying to find out and by just Firsthand rule, I am just trying to take that dot product which will give you 0. So, it is just trial and error method and I am looking at this 1 bar 1 1 dot bar 1 0 1 gives you 0.

So, here we have 0 where there is bar 1. So, here what we need to find is bar 1 in the yes, so it will be this plane ok. So, now, you can take the dot product of bar 1 1 1 and 0 bar 1 1. So, you can see this will bar 1 time 0 0 1 into minus 1 minus 1 1 into 1 plus 1. So, the dot product of this two will again give you 0. So, this will cross-slip on to bar 1 1 1.

So, like I said that the first instinctive answer you should get automatically that there is nothing special about bar 1 0 1. So, yes this should also cross-slip and what it will cross-slip onto, you will find using what is the line vector that contains sorry this line vector has to be contained in two 1 1 1 type plane and this with all this would become easier when we later on look at what is called as Thompson's Tetrahedron. So, this gives you all the possible planes say for FCC system ok, so that is something that I forgot or I assumed implicitly at it is we are talking about this cross-slip on a FCC. This is also possible in BCC, where the planes and directions would be different.

So, this remember that this is about FCC because the directions and planes as you can see are the slip systems for FCC and for FCC thankfully, we have a very useful tool which is called Thompson's Tetrahedron which will look at when we will talk more about FCC dislocation in more detail. Unfortunately, for BCC and HCP, we do not have such handy tool. But never the less once you know the once you know the concept, you know the mathematics; you would be able to find third direction and planes very easily. Now, let us discuss about BCC so, this was the in the FCC system.

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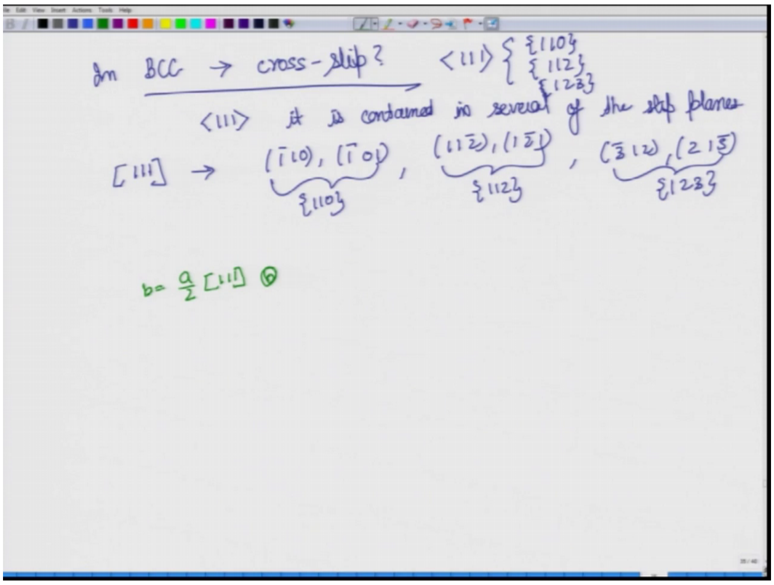

What about BCC? In BCC, can you see cross-slip and in fact it so happens that in BCC Cross-slip is lot more easier and in fact it is much more common than in FCC. And what is the reason? The reason is that this 1 1 1 which is the slip direction, it is contained in several; now you remember ok. So, let me remind you here again that for 1 1 that BCC we had 1 1 1 as the slip direction and although we said that 1 1 0 is the preferred slips plane, but there are also other slip planes like 1 1 2 and 1 2 3 and 1 1 1, this particular in any 1 of this. So, let say I am talking about 1 bar 1 1; any of this particular direction 1 bar 1 1 is contained in several of these planes.

So, what are these different planes? For example, if I take a simple 1 1 1, then this is contained in bar 1 1 0, it is also contained in bar 1 0 1. So, these are examples for 1 1 0 type of system. It is also contained in 1 1 bar 2; it is contained in 1 bar 2 1; these are examples of 1 1 2 planes. It is also contained in bar 3 1 2 it is also contained in 2 1 bar 3 and these are examples of 1 2 3 planes.

And this is not exhaustive we can have lot more planes over here. We are not going into details of that. It is just to show that yes, cross-slip is possible. What we needed was that this particular direction which is the slip direction, if you remember from our example for FCC that this particular slip direction should be contained in more than 1 plane and that is what we are looking through. I show you here that this one just one direction 1 1 1 can be contained in at least 6. There will be more we will look at how will exhaust that later on when we talk more about BCC.

But for now, you can see that there itself you have 6 different planes and as an example what will happen of you take something like this, let us say we talk and this cross-slip again you have to keep in mind this, this will be possible only for screw dislocation. So, it does not matter whether you are talking about FCC or BCC or HCP. Cross-slip will be only possible for screw dislocation and not for edge dislocation. So, let us say the burger vector a dislocation with burger vector 1 1 1 is present somewhere over here.

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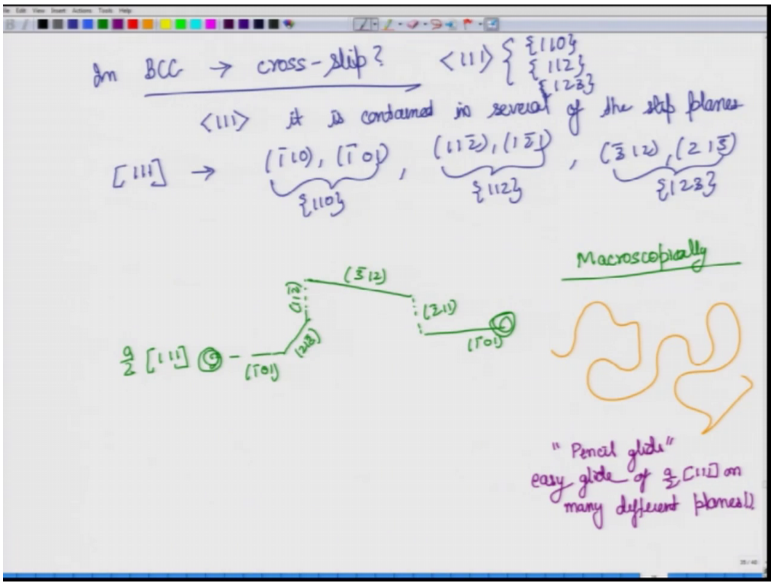

So, this is screw dislocation that I am trying to show and let me draw it a little towards the bottom side so that I can draw all the planes and what you may experience or what you may observe is that it is slipping or gliding on one particular plane let say bar 1 0 1, we know that it contains 1 1 1 and then suddenly because of some obstacle, it may move on to another one. So, let say this is 2 1 3 bar, then again it will move 1 to so here.

So, this is let us say this is 1 1 bar 2 and as you can take a cross product to cross check that this indeed contains that 1 1 1 we need contain on to this plane and then, again it may decide to change direction. Because of some obstacle or change in the stress local stress field and it may move like this and then, again it may move like this and then, again it may move come back to our original bar 1 0 1. So, the screw dislocation which is started from here is still on the bar 1 0 plane, but it has taken a zigzag path.

Macroscopically, how it look like? It would look like someone has just scribbled a pen, pencil. So, it will look like something like this. It is very similar to a pencil scribble and hence, unique name has been given or particular name has been given to it; it is called “Pencil glide”. Because when you look macroscopically because you can cross-slip into so many planes, it would look like that it is continuously changing direction and there is if someone has scribbled with the pencil. So, the name Pencil glide which means easy glide of a by 2 1 1 1 on almost not almost any plane, but ons many different planes, I should say. So, this is the characteristics for BCC cross-slip and so far we have talked only about glide. Now, it is time to move on to discuss a little bit about climb.

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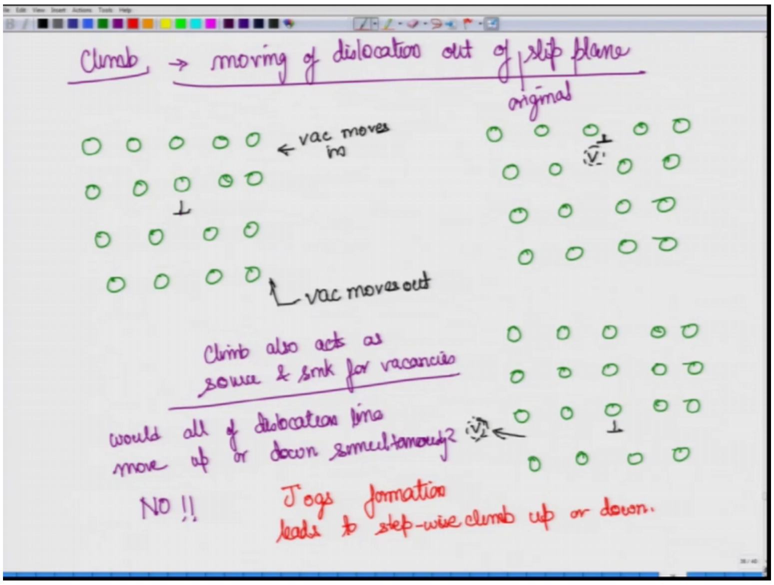

And you remember what is climb? Climb is moving of dislocation out of the slip plane. In fact, I should say out of original slip plane because it will still land up in some other slip plane which will be parallel or it can be again one of the other possible slip planes. But when once it is when it is moving that time it is not on any particular slip plane. So, it moves out of the slip plane and then, it is it automatically is in still would lie in one of the slip planes. So, the appropriate word would be moving of the dislocation out of original slip plane.

So, it may be it was on some slip plane 1 and then, it climbs and moves on to another slip plane. So, let us look at the phenomenon that is involved when climb takes place and we mentioned earlier also that it is because of the involvement of point defects that climb takes place and that is why it is thermally activated process.

So, let us say this is. So, where is the dislocation? This is the this represent the dislocation that extra half plane all the way like this and this is the slip plane on this particular crystal system that I have shown here. Now, let us say that a vacancy moves into this. So, what will happen to this? So, vacancy moves in which means I am in this particular case let us say the vacancy is such that it moves on to here and in fact, it is more likely to be here because there is larger space and therefore, it you can say resistance or the energy of activation required for the movement migration of the vacancy would be lower and so vacancy would be attracted to the core.

So, the more likely that the vacancy would move over to this place and once, the vacancy moves to this place it would mean that the atom moves out of this place and so the final configuration would look something like. So, there is the vacancy over here and in effect it has caused the dislocation plane to move 1 layer above. So, this is when vacancy moves in. Now, what is the vacancy moves out ok. So, this is in effect you can say artificial moving out of a vacancy.

So, there is no vacancy per (Refer Time: 23:31), but let us an atom moves here, it would result in a vacancy moving out from here on to the bulk side of the sample. And therefore, what you would see is something like this. So, what it had resulted in is the lowering of the extra half plane? So, there is one the plane has moved down and at the same time since an atom has reached here a vacancy would have to move out. So, in effect it has created a vacancy and in this particular case, it has absorbed a vacancy. So, you can say that client also acts as source and sink for vacancies.

So, this is why it is also called as non-conservative process, the climb. Because it is changing the concentration of vacancies and we are not talking about 1 or 2 vacancies, there will be order of change in order of magnitude for the vacancies. Anyhow, let us come back to our climb process itself. So, when we say that this dislocation line has moved from here to 1 plain above over here; do we mean that all of the dislocation line has claimed simultaneously, do we mean that in fact the right appropriate question would be would all of dislocation line move up or down simultaneously?

And the answer would be emphatic no, you would have guessed by now based on our understanding for the glide, where we saw the formation of jog that jog takes jog makes the movement of causes the movement of dislocation and not all of the dislocation line moves simultaneously. Similarly, for the climb it is not jog, but sorry in the case of glide, it was kink. In the case of claim, it is jog ok. Let me so, here it is the formation of jogs leads to step wise claim up or down. So, this is how the climb would takes place. Now, let us stand it in a little bit more detail.

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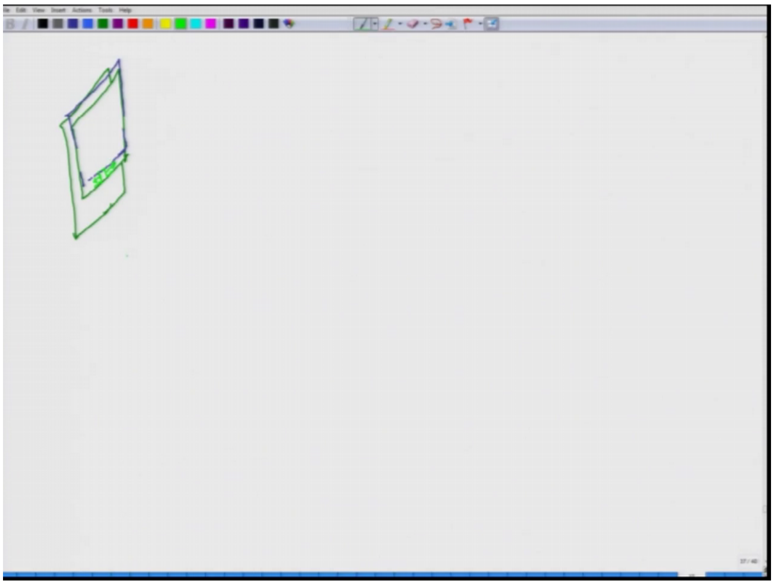

So, let us say this is; so, let us say this is extra half plane now this extra half and these are different layers. So, let us say this is an extra half plane and I am not showing the place beyond this because it will obscure the vision for this one. So, what will happen if it has to move up? So, meanings that we would like this to take place. So, this extra half plane has to move up; how would that happen? It will not move all the plane would move simultaneously up or even if you ignore the top part, if you just want to retake away 1 layer, it does not happen like that. What happen is you form a jog so, you can see a jog thing like jogging up.

So, this jog formation takes place and this jog formation once the jog has found these steps can move across and lead to the overall displacement of this extra half plane, one layer up. And will come back to this in the next lecture to describe more about climb. So, we will continue with this discussion.