Defects in Crystalline Solids (Part-II)

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Lecture – 04
Dislocation Locks in FCC

So, today we will look at Dislocation Locks in FCC. Let us understand what do we mean by this dislocation locks. So, this kind of animation in the power point presentation will help you understand it and then we will look at how to determine which particular dislocations would form a lock.

So, first of all this dislocation lock this is called Cottrell lock. For example, if you take two planes, you know that in FCC there all the 111 planes are the glide planes and form the part of the slip system. So, let us say we take 111 and 11 bar 1, ok. So, in the cell that is drawn on the bottom left I have marked a tetrahedron which displays all the four possible 111 planes.

So, first the 111 plane has been highlighted, now I will mark the 11 bar 1 plane. So, these two are the planes that we are talking about and remember that the edges these edges all these represent the burger vector. So, the these are the three possible ones and these three are the possible ones for 111 and from this what we see is that, there will always be one common burger vector whenever we have two planes that we are talking about.

Now, let us say we have we take two dislocations which have burger vector like this. So, one there is a dislocation on the 111 plane and it has a burger vector shown by this purple vector and on the 11 bar 1 the dislocation burger vector is shown by the yellow vector over here. Now, let us say that they happened to combine and form one dislocation. Will look at whether this is possible or not energetically and what it that means, but for now let us say these two combined and form one dislocation.

So, what will be the burger vector? This blue vector will represent the burger vector of the resultant dislocation and this blue vector here if you look at it carefully you would see that it is parallel to the red one which means that this is nothing, but actually over

here. So, this is your burger vector and this burger vector is now lying actually as a edge of third and the fourth plane. So, this is neither on the 111 nor on the 11 bar bar 1 plane.

Not only that if you in the as I will show you when we do the working on it that the plane for this dislocation the glide plane would be this one which will be of the type 001. Now, this is a burger this is a dislocation with a burger vector something that we are familiar with an FCC, but unfortunately it lies on a plane which is not 111, it is 001. So, what will happen? This dislocation will not be able to move. So, the two dislocations that come came together they combined and they formed a dislocation whose burger vector is lies on a plane which cannot on which it cannot glide, therefore, it becomes a lock.

Now, why do we call it a lock? So, this particular image will help you understand. So, let us say this is one plane, this is another plane and therefore, the there is a this dislocation that is coming it is going all the way up to here, this is the dislocation that is coming and it is coming all the way up to here. Now, once they are here their burger vector is such that it cannot glide on either of these two planes. So, this cannot move. Now, let us say that more dislocations come from somewhere. Let us say there is another dislocation that comes from here and it wants to go over here, what will happen once the lock is formed after the lock is formed it will just get obstructed over here.

Similarly, there is let us say another dislocation which is come on this particular plane. So, it is moving like this, this one is moving like this and therefore, it will come and get locked over here. Eventually there will be a pile up of dislocations over here like this and therefore, this means that although that dislocations are moving are coming up to this point, but they are not able to move any further and this leads to you can say some amount of strengthening in the material and that is why this locks are so important.

Now, let us look at how to identify these dislocations which will combine to form a dislocation lock. Now, before I move on to that first thing to understand is that you will see that this is the burger vector of the dislocation on this plane, this is the burger vector of the dislocation on this plane and there is a common, there it must be along this common line only then they will be able to. So, this is the common line. So, the line vector would be would be the common vector between 111 plane and the 11 bar 1 plane.

So, now, let me show you how to. So, like I said first consider and do the homework on your own to find out what will be the burger vectors. In fact, the best homework would be that you try it out for two other set of planes 111 planes.

So, let us say here I will do it for you. So, that you understand how it is to be done. So, this is the 111 and the three burger vectors which are on the 111 planes can be written like this. You can check that the dot product of this and this would be 0 which would mean that these burger vector lie on this 111 plane. Now, coming back to my 11 bar 1 plane so, I have given the name b 1, b 2, b 3 and here I will give them names b 4, b 5, b 6, ok.

So, the first thing that you will notice is that b 1 and b 4 are same and just the negative of each other that we already know from the diagram that I showed you the power point presentation that I showed you couple of minutes earlier, that there will always be one vector common to two planes. So, this is those two vectors which are common. Another thing that you must keep in mind is that these burger vectors and their negatives are also the possible burger vectors.

So, let me write that and their negatives because many a times student forget that the negatives are also possible and so, when you are taking the combination you will also have to try it out with the negative combinations. Now, we wanted dislocation with burger vector one of these burger vector combining with dislocation with a one of these other burger vector. Now, let us say if I had combined b 1 or minus b 1 with b 5 and b 6 what would happen, let see.

So, I will do b 1 plus b 6 and you can look at a by 2 1 bar 1 0 b 6 a by 2 011. So, the common factor image same a by 2, 1 and 0 becomes 1, 1 and bar 1 becomes 0 and 1 and 0 becomes 1. Does this look familiar to you? And it must look familiar to you because it is nothing, but b 5. Now, similarly if I had done b 1 plus minus b 5 you would get, sorry there should also be a by 2 here what you will get is 011 and what is 011? This is a by 2 this is b 6, again this should not surprise you.

Now, I will just write down some other possible possibilities of b 1 minus b 1 with b 5 and b 6 and what you would realize is that all of these would be just a combination of b 5

and b 6. Why is that coming out to b? There why is b 1 and b 5 and b 6 how are they related? They are related because b 1 is nothing, but b 4. So, this once you realize this fact that b 1 is nothing, but it is b 4 then you would know that b 4, b 5, b 6 they are the three burger vectors can on the same plane. So, what they will yield is either one of those burger vectors or they will yield a burger vector which is not energetically favorable.

So, let us see the other possibility which is not energetically favorable which is b 1 plus b 5. So, what you will get when you see b 1 when you do b 1 plus b 5? You have the values you do it and what you would see is a by 2 2 bar 11 over here let us try the other combination b 1 plus minus b 6 and what you would get is a by 2 1 bar 2 bar 1.

On the left side if you look at energetically. So, over here what we have is a square by 2 a square by 2 over here what we have is 2 square plus 1 square plus 1 square. So, this turns out to be 3 by 2 a square, ok. So, just in case you have forgotten let me remind you that energy is proportional to b square. So, that is why we are taking the square of the burger vectors and on the right hand side we have this 3 by 2 a square and on the left hand side when we sum these two what we get is a square.

So, which one is greater? This is greater. It means it is not energetically favorable, ok. So, even though they are one that what we are combining are the dislocations on the same plane, b 1 is nothing, but b 4. So, it is as good as b b 4 combining with b 5 or b 4 combining with negative of b 5. So, in a one case it will either give b 6 or in the other case it will give a burger vector which is energetically not favorable.

Now, let us come to what are the other possibilities.

So, let us first look over here. So, we have already tried this combination this is of course, the same thing we have tried this, the same thing you can say about b 4 with b 2 and b 3. Now, what are the possibilities? These are the possibilities that we have you can have like this or like this. So, now, let us try these possibilities. What we get is a by 2 002. Other possibility b 2 plus negative of b 5 what you get is a by 2 bar 2 00. Other possibility is b 2 plus b 6 what you get is a by 2 bar 112 and still another possibility it is b 2 plus minus b 6 and what you get is a by 2 bar 1 bar 1 0.

Now, for the left hand side if you are now talking about energetics for the left hand side for all of these what is the energy. This is all a square by 2 plus a square by 2 which means this on the left hand side we have energy proportional to a square. Now, let us compare what we get on the right hand side.

So, here we have a square by 4 into 2 square. So, a square by 4 into 4 is equal to a square over here again a square by 4 in to 4 is equal to a square. Over here what we get is a square by 2 into a square by 4 2 square plus 1 square plus 1. So, it is 6. So, is equal to 3 by 2 a square. Over here it is a square by 4 into 2. So, it is equal to a square by 2. So, this energy the left hand side energy and right hand side energy are equal, so energetically not favorable. As soon as it can combine it can as well as disassociate. So, it can associate and disassociate without any loss or any cost of energy.

This over here, same thing, this is not favorable. So, this is not no it will not be formed. This one is now a special case where we have b 2 added with negative of b 6. On the left hand side if you look at the energy it is a square by 2 plus a squared by 2 which is equal to a square, on the right hand side we have energy equal to a square by 2. So, energetically it is favorable. So, yes and this is the combination that can give you the dislocation lock that we are looking for.

And, similarly if we go back and again let me bring you over here this was b 2 with b 5 b 6, similarly you can try b 3 with b 5 and b 6 and what you will see, so, now, let me pick another colour. So, b the other possibilities b 3 with b 5 and b 6.

And, what you will see is that like b 2 and b 6 give you something similarly b 3 plus b 5 will give you a by 2 110. So, this is also energetically favorable and, another thing that, you should notice that this resultant burger vector and this resultant burger vector are same. So, two possible combinations there which can give you a lock and the resultant burger vector comes out to be the same in both of them.

Now, what else can we say about this dislocation that has formed after the combination? First question that we should be asking at this stage is does this dislocation lie on either 111 or 11 bar 1 because these are the two planes that we considered performing the locks.

So, we that is why we are asking whether this dislocation the form final dislocation that has formed, does it form a does it lie on any of these burger vectors.

So, you would see that the dot product of 111 or 11 bar 1 with a by 2 110 is not 0, which means that it does not lie. No, it does not lie. In fact, what you would realize that it does not lie on any of the 111 type plane. So, that is the beauty of this final dislocation you can say or you can say this is the nature of things because of which it forms a lock.

What else can we say about this dislocation? Like I said that since they are combining at some stage it means that they are line vector must be same.

So, line vector of two starting dislocations and resultant vector must be same. Now, when you have written this it means that there is only one possibility for the line vector which would be the line vector or the common tangent or the common access between the two planes, the common trace between the planes 111 and 11 bar 1. So, this can be found out either you can do a vector multiplication which will be 111 cross 11 bar 1 or you can just look at the terms is tetrahedron and you will find that it is nothing, but 1 bar 1 0.

So, this is the dislocation line with this is for the starting dislocations they must have this line vector and the burger and the final resultant dislocation that has formed as a lock that dislocation also must have this line vector.

Now, what are the properties that we know about this? We know that the resultant burger vector is equal to a by 2 110 and that it is line vector is equal to 1 bar 1 0. If you have the line vector as well as the burger vector then we can or then you can always find what is the plane on which it lies; whether it moves or not is a second question, but the first question is what is the plane and that plane you can again find just by cross product. So, the plane again by cross product b r into cross u r and you will see that it is 001.

So, everything that I showed you in the power point you can see that we are also able to derive using the burger vectors, using the vector form of these dislocations. So, again now let us go back to our dislocation and I will show you first in the power point. So, like I said, so, these are our, so, you could have called it b 1 for this particular b. So, if

this is our 111 plane, then this becomes b 1 and 1 of these are b 2 plus b 3 and for 11 bar 1 plane this becomes b 4 and this become b 1 of these b 5 and b 6 and what you see is that b 1 and b 4 are same, right. So, this plus this will either give you this or it will give you a line vector like this which will not be which will not give yield resultant burger vector which is energetically favorable.

So, that is what b 4 combining with b 2 b 3 implies or b 1 combining with b 5 b 6 those are not going to yield anything useful. What is going to yield anything useful is b 2 plus the same side of the from here if you look at the tetrahedron if there is same side of the tetrahedron if you look at the burger vector when these two combined then you get a meaningful dislocation which is energetically favorable and this is this final resultant burger vector. So, this burger vector combines with this burger vector. And, this is the resultant burger vector and overall throughout this process the dislocation line is like this this is the green line that you see is the dislocation line.

So, this is not at any particular angles or you can say it is a mixed dislocation. So, the two mixed dislocations arrive on 111 and 11 bar 1 and at a particular point when they combine they will yield a dislocation which has a burger vector which is energetically favorable and it has a burger vector like this and in fact, this is now perpendicular to this. So, it is a edge vector. So, the resultant dislocation so, we know one more thing about this dislocation it is a edge dislocation because this is the line vector, this is the burger vector and it is perpendicular and the plane on which the line and this burger vector lie is a 001 plane.

So, now we come to another question that we need to ask our self about this, ok. So, I will add that this is since this is perpendicular, so, you can see b r is perpendicular to u r and therefore, this is a edge dislocation. So, so many things now we know about this lock. So, this is these are the properties of the resultant dislocation which is a lock.

Now, next question that I am going to pose to you is this dislocation glissile or sessile. Glissile in technical term means a dislocation can move, it is able to glide. Glide it comes from glide and sessile means it is not in a position to glide, it is immobile. So, which one would this be? Now, we have already seen that it does not lie on any of the 111 type of plane and therefore, it cannot glide. So, it will be a sessile, it will not be glissile. So, this dislocation is sessile and hence it is a lock, ok.

So, realize that since it is sessile, meaning it cannot move, that is why it is a lock. It is not that just because it is energetically favorable, it is locked because it is energetically favorable and it is sessile it cannot move and the starting dislocation as we saw where mixed dislocation and in the end we get a edge dislocation.

Now, unless this like we said earlier unless this lock is removed dislocations on these planes on these two particular set of planes, ok, there maybe parallel there maybe lot more parallel planes. On those planes dislocations can keep moving on, but we are talking about one particular set of 111 and 11 bar 1 plane. And, the dislocations once the lock has formed dislocations on those particular planes will not be able to move forward. Unless lock is removed, dislocations on these two particular planes cannot move any further.

If at high if at higher temperature it so happens that b resultant here you provide sufficient energy that b resultant dissociates and only if you provide a sufficient energy because this was energetically favorable. So, if the sufficient energy is provided and the resultant burger vector breaks down back breaks back into b 3 plus b 5, then the dislocation can unlock. Meaning both of them will move on their own path and hands whatever dislocations that perform that were piled up they can now start to move on.

Now, whatever we obtained over here this was for the b 1 and b 4 and similarly, for the b 3 sorry this one we obtained for b 3 and b 5. Similarly, you can do for b 2 and b 6, and what you will see is that, that one part we have already seen that the burger vector is the same just in the negative direction which is just a matter of convention. So, a by 2 bar 1 bar 1, 0 and similarly the line vector is also same equal to 1 bar 1 0.

Now, let us understand this aspect with respect to the power point presentation. So, here these are the two dislocations that form this lock. The other possibility would have been so, this is the dislocation on the 111, this is the dislocation on the 11 bar 1 and therefore, you can see this again forms a dislocation like this. This is parallel to this which means it is nothing, but this one. So, two other two different sets of dislocations can combine to form a lock which has same character, same burger vectors, same line vector. So, this is what is called as Cottrell lock.

Now, the next part of this question is what if the dislocations have split into partials? Now you remember in the last previous lecture when we were talking about the dislocations in FCC, we said that this these dislocations can disassociate and these dislocations can disassociate into partials. So, right now, but when we combined we did not assume that the dislocations had dissociated. What if the dissociate; now that is what we will look into.

And, that is called what that again forms a lock and this is called a Lomer Cottrell lock. Again, what we will do is we will take 111 and 11 bar 1 and what we will do is will allow the dislocations to split and not surprisingly the dislocations, the whole dislocations which took part in forming the locks earlier the Cottrell lock are the ones which when dissociate will also form a lock. And, this one, but this lock would be formed by the partials and not by the whole dislocation.

So, again were the two condensed things, I will not going to all the dislocations I will look only out those dislocations which we have already discussed which is b 3 and b 5. Now, when this splits, what does it form? Now, let us split b 5 and remember this is on 111, this is on 11 bar 1 and the once that will combine you can again do all the different permutation and combination, and I will show you that.

And, you will find that these are the ones that when you react will form will be energetically favorable.

So, let us look at energy again we will take the square of the burger vector. So, if you take a square by 36 this is 2 square plus 1 square plus 1 square. So, a square by 36 into 6 it will become a by a square by 6. Similarly, this one will become a square by 6 and over here when you get you will see that it will become a square by 36 into 1 square plus 1 into 2. So, this is equal to a square by 18. Now, a square by 6 plus a square by 6 this is equal to a square by 3 this is certainly much bigger than a square by 18. So, what can we say energy about energetic? Yes, it is energetically favorable.

And, the line vector we are again talking about b 3 and b 5. So, the line vector would be unique since these are lying on 111 plane and 11 bar 1 plane. So, we can find that unique line with there can only be one line between two planes and that you can find by taking the cross product which we have already done earlier when we are talking about the full dislocations and we know it is nothing, but 1 bar 10.

And, plane is also unique. So, when you are do this try to calculate the plane you will see the plane also comes out the same and it is not surprising because this burger vector which is in the same direction, it is only of a smaller magnitude if you remember from the when we combine the full dislocation over there the final dislocation was a by 2 110 here we are getting a by 6 110. So, this is same direction or the burger vector direction is same only the magnitude is even smaller. So, the line vector and the plane for the resultant burger vector come out to be the same.

Now, when you are looking at the partials you would see that in the partial there is one more possibility of combination. What is that possibility of combination?

Here if you take a by 6 112 plus a by 6 11 bar 2 then you get a by 3 110. Now, energetically let us look at it, take the square and I will not have to describe each and every step. You can find that this is a square by 6 a square by 6 and this is 2a square by 9 and this translates to a square by 3 which is you can as well as say 3a square by 9. So, this is again not drastically greater than 2a square 9 by 9, but it is still greater which means this is also energetically favorable.

So, when we are talking about the partials, when the dislocations have a split into partials there are two possible combinations by which you get a dislocation lock. In one of them the energy it is you can say the resultant burger vector is energetically much more lower and enhance more favorable compared to the other one, but it also depends on what are the two possible combination that are coming into contact.

For example, if we look at it let us say this is now let us say there was dislocation over here whose overall burger vector was like this and the partials would have formed like

this. So, now this partial would be different, this partial would be different, similarly you will have. So, depending on whether these two these two partials are coming into combination these two are coming into coming into combination you will get different possibility of whether case a of the lock will form or the case b of the lock would be formed. So, but either way in the partials there are two still possible ways out of the four total possible combinations two possible ways will give you locks.

And, you would see that the resultant burger vector here also has 110 type of vector which we would mean that if you wanted to find out the line vector then the line vector for this would still be 1 bar 1 0 and the plane on which it lies is still 001; meaning whether we are talking about dislocation locks formed by full dislocations or the two possible dislocations formed by the dislocation locks formed by the partial dislocations. In all these cases the final burger vector direction is same, only the magnitude varies a little bit. The line vector is same and the plane on which they form or also same.

Now, let me show you that if you had you wanted to talk about this dislocation with respect to Thompson's tetrahedron, then how it would look like.

$$\gamma A + A\delta \rightarrow \gamma\delta$$

Now, we have already given earlier there were four nodes A, B, C, D and the centre of those where alpha, beta, gamma, delta. So, in those terms we could have written it like this that a dislocation dissociate and forms this will form on ABD, this is the plane one, the other plane would be AC and this would have given A delta plus delta C, this would have been on ABC. Now, over here gamma A plus A delta would you would give you gamma delta.

Now, this is the reaction that we are talking about which is a dislocation lock with respect to Thompson's tetrahedron. Now, let me bring the Thompson tetrahedron that I had shown you in the previous class.

So, this is your Thompson tetrahedron and first focus on the 111 plane. So, this is the 111 plane this is the 11 bar 1 plane and like I said there is one common direction over here, but what we need to select are two other lines. So, you select one burger not line, but vector. So, the you select this burger vector and similarly, this side this side burger vector and what you will get is a burger vector like this.

So, if you are talking about these two planes; this is one, this is one burger vector, this is another burger vector and the resultant burger vector is right behind this. This is now you can clearly see does not lie on this plane or this plane and it lies on a plane like this. So, and at the same time you can form the same type of lock using this burger vector and this burger vector and it will be like this. And, like the equation I showed you using those equation it will come out to be the you can describe it using those terms that is gamma A plus A delta equal to gamma delta.

So, with that we will end this lecture we have seen enough of dislocation locks which is a unique feature in the FCC. In fact, that they will come back to another type of lock which is also in a FCC related structure and that gives again special properties to material, in fact, it is called super alloys. So, we end the talk on dislocation locks in FCC here.

Thank you.