Defects in Crystalline Solids (Part-1)
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Lecture - 27
Slip Systems + Examples

So, in the previous lecture, based on current equation for Peierl Nabarro stress, we saw that there are certain crystallographic constraints and, using those crystallographic constraint, we can, describe with particular planes, the slip will take place and, it will, it can also describe, which particular direction the slip should take place. And we found that, qualitatively what the relation says is that the planes, planes should be dense, densely packed planes, which would, in other words mean that they are the inter planar spacing is largest.

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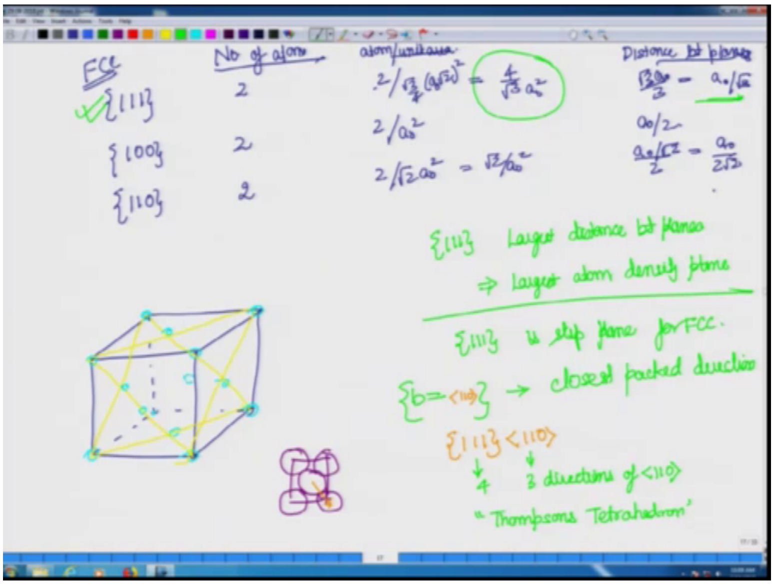

And so, we set on to look for the inter planar spacing for F C C and we looked at three, low indices planes, which are most likely to be the, low which are most likely to have highest inter planar spacing will looked at 1 1 1 1 0 0 and 1 1 0 and we found number of atoms, which is here in the simple, cubic cell and the atoms per unit area calculating the area so, the atom divided by the area.

And we also calculated what is the distance between the atomic planes? So, looking at this number, we here, we want what is the highest density. So, we found that 1 1 1 in the

F C C system has the highest number of atoms per unit area. On the other hand, for the planar spacing also it has to come, because the density overall density has to be constraint.

So, one if the plane has the highest density, the inter planar spacing will have to be largest and therefore, it turned out that the inter planar spacing, for 1 1 1 plane is the largest, which is a naught by root 3. So, now, what we want is to find out what is the burger vector? Now the, for the burger vector we saw that for the burger vector, what we need is the closest packed planed the direction. Now, which will be the closest packed direction for the F C C?

Now, if you look at this diagram or if we draw the usual diagram where we have the atoms touching in the so here, it is more like a point. So, it is described as a point here, they are drawn, that atoms are drawn more like a sphere and when we look at this, we know that the closest direction has to be like this. Now, let me use a different colour so, you can see the atoms are touching along these direction which is 1 1 0.

So, along the 1 1 0 direction, we see that atoms are touching so, this has to be the densely or the densest packed direction and therefore, b for F C C should be 1 1 0 and therefore, for F C C what we see is that the slip system consist of 1 1 1 plane and 1 1 0 direction. So, you can see that the relation for the shear stress, Peierl Nabarro stress has given us more information about the slip directions, which is the most likely slip plane and which is the most likely slip direction. Now, let us do the same excise for B C C.

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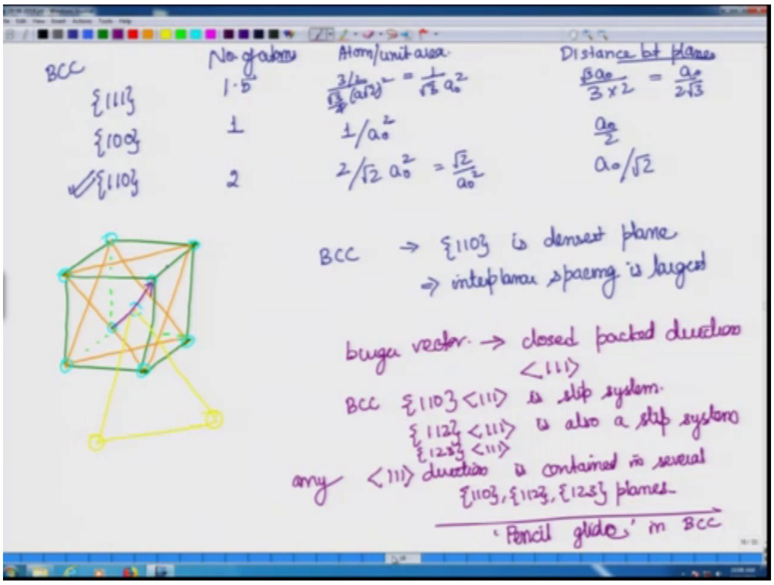

So, again will take, three particular planes, which are most likely to be the densest packed planes and now, what we need to do again like the previous time, we will draw and the unit cell B C C unit cell and we will now, assign atoms, where they belong and let me in draw this backplane. So, that I can draw the atoms in this corner and also at the center so, we have these atoms inside the B C C.

Now, here which is the plane? So, the plane 1 1 1, plane is this one and what you will see is that this particular center, atom is not really on this B C C plane even the other sorry, is not there this 1 1 1 plane, even the other 1 1 1 plane that we draw, it becomes clear that the central atom is does not line on any of these 1 1 1 plane. In fact, it lies on a altogether, third 1 1 1 plane, which is itself found by body centered atoms of three different cells.

So, here you have cell here, you have atom here, you have a body centered atom and these three together from another 1 1 1. So, here we have, one additional 1 1 1 plane, which contains atom, which is in between these 2 1 1 1 plane. So, there is, first thing to understand is that there is one extra 1 1 1 plane in this B C C and for this B C C, 1 1 1 layer.

Now, you can see that the number of atoms for this particular plane is 1.5 and therefore, atom per unit area, we will be 3 by 2 divided by the area, which is root 3 by 4 a root 2 is that sites of the triangle square and therefore, it comes out 2 1 by root 3 a naught square.

Now, let us calculate the distance between the plane, so, the total distance from this atom to this atom is a naught, is actually root 3 a naught and in that we have 3 into 2 number of planes.

So, it comes out to a naught by 2 root 3 distance between the planes. Now, let us come to 1 1 0, which is this particular plane for 1 1 0 you can you would be able to see that the number of atoms is 1, we are talking about 1 0 0, which is this 1. So, here the number of atoms is 1 and area by which we have to divide is a square. So, this is the, a square area so, this is 1 by a square and the spacing with here is from here to here, which is a naught by 2 then we have 1 1 0 atom sorry, 1 1 0 plane which is this one and here, you would be able to find that this also contains one sent body central atom.

So, here there are 2 atoms and the atoms per unit area will become 2 by root 2 a naught square, because this is the area root 2 a naught square, which is equal to root 2 by a naught square and the spacing between the planes would be a naught by root 2. So, here what do we see? Which one is the for B C C, which is the, plane, which contains the largest density of atoms and it will not be very difficult to see that it is actually 1 1 0. So, this is 1 1 0 for B C C 1 1 0 is the densest plane, which implies that interplanar spacing is largest.

So, you can see this quantity is the largest amongst all three. So, again we are able to derive what is the plane on which slip will take place based on the constraints that we obtain from the Peierl Nabarro stress. Next is the burger vector so, now, let us talk about the burger vector again, what we are looking?

It is the, as is the closed packed direction for F C C, we saw that the atoms touching the other direction in which the atom touched, where along around 1 1 0, but in B C C, there is no atom in the phase center you instead here, the atom is in the body center. And therefore, the atoms touching is in this particular direction which is 1 1 1 and therefore, here the close packed direction is 1 1 1 and what we get is that for B C C 1 1 0 and 1 1 1 is slip system.

In fact, we have not, looked at another plane, which is also possibility and it has been known to be also slip plane for B C C, which is 1 1 2. So, 1 1 2 1 1 1 is also, you can do the exercise for 1 1 2 and find out what will be the atoms per unit area distance between the planes and so on. And the, you would see that although it is not as high as 1 1 0 in terms of density, but it is also, it just also happens to be the slip plane for B C C system.

Now, here, what you would realize that any particular 1 1 1 direction in B C C is actually contained in several 1 1 0 planes several 1 1 2 planes and something I should mention here, at this point that there is another one here, it is 1 2 3. So, B C C is a complex in sense of mathematics, but it is it makes the dislocation movement easier, because you have not just one set of planes like in F C C here you have 1 1 0 1 1 2 1 2 3.

So, because of other factors 1 1 2 planes and 1 2 3 also become a slip plane, although 1 1 1, still remains the slip direction. And for each 1 1 1 direction, it is contained in several of 1 1 0 1 1 2 and 1 2 3 planes, which makes the slip of B C C dislocation much more agile, meaning it can move much more easily and therefore, what we observe, what is called as pencil glide? So, will come to this again later on when we talk about slip and then later on again when we talk about specifically about B C C systems.

So, this different systems and particularly the fact that 1 1 1 1 direction is present in several 1 1 0 1 1 2 and 1 2 3 planes leads to pencil glide in B C C and since, we are talking about how many planes are content. So, let me come back to this B C C system, we set that there are 1 1 1 plane and 1 1 0 direction and here, there is no ambiguity, there is only this planes and these direction which at which form the slip system. So, how many 1 1 1 direction are there? There are 4 1 1 planes and will see, this is something becomes much more clear, when we look at what is called as tetra, it comes an tetrahedron.

So, there is, there are 4 1 1 1 planes and each 1 1 1 plane contains three directions of 1 1 0, this slip system is very easy to visualize, using what is called as Thomson's tetrahedron and again will come to this, when we talk specifically about the F C C system right. Now, we are just, we came to this topic while looking at Peierl Nabarro stress and so on. So, now, we have looked at the Peierl Nabarro stress and how it is understanding leads to constraints, which gives us that which are the particular systems?

Where slip will take place and although in B C C, the predicts only 1 1 0 1 1 1, but it has been observed that slip also occurs in 1 1 2 planes and 1 2 3 planes and next, what you want to do is, we have looked at several mathematical relation. So, why not try to give do some examples so, next step is trying to solve some examples.

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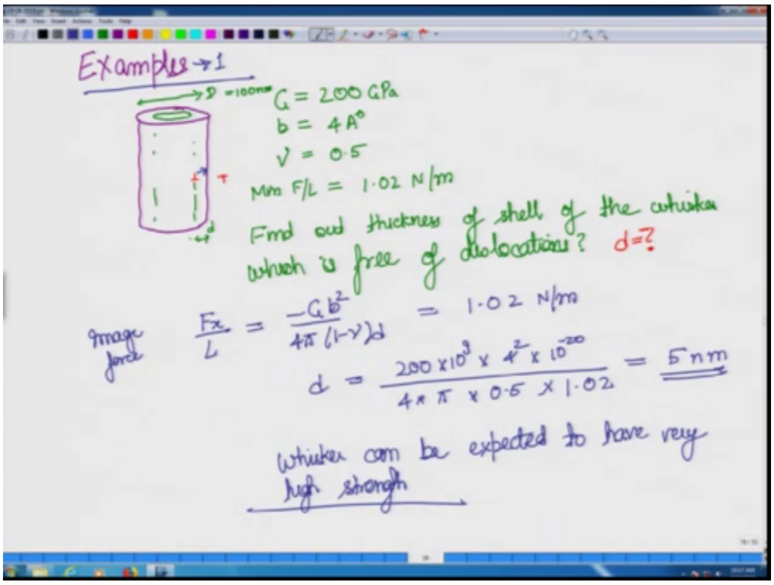

You remember, we talked about the image dislocations, so, in the image dislocation, let us say; we have taken a single whisker. Now, it is a metal whisker, where dislocations can easily move and it is given that for this material G is equal to 200 Giga Pascal. So, it is something like a iron burger vector is equal to 4 angstrom nu is equal to 0.5, which is the ideal poisons ratio and you are given that the minimum F by L required for the dislocations to move or which describes the Peierl Nabarro valley of stress is 1.02 Newton per meter.

And it is given that the diameter of this whisker is 100 nanometer, so, let me use uppercase d. Now, what you need to find out? The thickness of the cell of the whiskers, which is free of dislocations so, this is the question, this is what you need to find meaning; you have to find this cell.

So, this is the thickness outside, meaning you will on the surface you would look at it something like this and there is thickness outside it, where there is no dislocation and why is there on your dislocation, if you remember. So, if there is a dislocation somewhere over here, then it is always experiencing a force, which is, it which, which is as if there is a negative dislocation at a similar distance outside the surface. And it is causing attractive force on to this dislocation, to come out to the surface and therefore, when a, when this force exceeds this minimum force required for movement then this dislocation will move and it will a nil out.

So, if you, if this is the, if at this particular distance at dislocation experiences, a force which is higher than this force, then beyond this distance all the way up to the surface, you can imagine that this force would be the force acting on the dislocation would be higher then this F by L and therefore, all the dislocations outside this, particular depth would a nil out.

Assuming that first yeah, there is one more assumption that all the dislocations are located horizontally, if they are located in a direction rather, the motion path of, motion would become something like this, then claim would have to be involved or the distance would become larger. So, the in inherent assumption in this problem is that, all the dislocations are such that they can move horizontally with respect to the geometry. So, now, what we need to find is this d, what is this thickness of the cell d?

So, what we know that a force F x by L acts on to a dislocation, which is the image force. So, this is a image force I am writing in it is force, but there is no distinction in the force, it is still a force acting on the dislocation. So, F x by L is equal to minus G b square by 4 pi 1 minus nu d and this minus sign is just telling that one of the burger vectors is negative in sign, but the force is still attractive winning. The dislocation would move in this direction.

And this d is this d so, this is the distance that, it is away from the surface, this is the largest distance at which in this dislocations will be able to move. So, if it is the largest distance, this is where the force is the smallest, the image force and this is smallest force must still be equal to 1.02. So, will say that this is equal to 1.02 Newton per meter and then what we, what we need to do is d is equal to 200 into 10 to the power 9 into 4 square into 10 4 is this is 4 angstrom.

So, kind of a minus 10 into square is 10 to power minus 20 4 pi and nu is 0.5 so, 1 minus nu is 0.5 and this come to denominator so, this is 1.02. And when you do the calculation, you would find that this is equal to 5 nanometer, so, the cell of thickness 5 nanometer, which means that the overall diameter, if you look at, it is 100 diameter. So, the only the 19 nanometer diameter contains dislocations and outside it, there is 100, there is another 10, thickness of 10 nanometer including both the sides, which does not contain dislocation.

So, although this whisker is not completely dislocation free, there is a large fraction where, in terms of radius itself it is 10 percent, which becomes larger, when you consider the area and volume. So, I will very large fraction of this whisker is dislocation free so, if you look at the strength of this cell is much higher and this particular, region inside it is, you can assume that it has the similar strength as a bulk material, which is also not true, but for now, let us assume that the inside component has the same strength as the bulk material, but the outside has much higher strength.

So, even in that condition given that this is a large fraction of the whole whisker, this will have very-very high strength, not anywhere close to the theoretical strength, but still much higher than the total strength of the bulk material and this is what gives rise to such high strength of whiskers. So, here for in this example we had the 100 nanometer whisker, where only 5 nanometer of the cell outside it is dislocation free, but still it will have very high strength.

So, whisker we have not calculated as strength so, I will just write whisker can be expected to have very high strength given that a large fraction of it is dislocation free. So, this is one example which is related to the force acting on to it.

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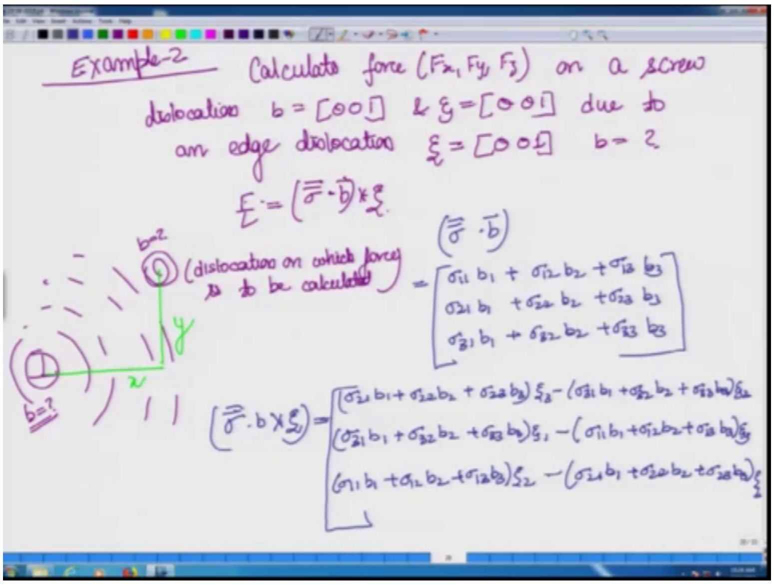

Let us solve another example, here, you are being asked to calculate force when I say force; I mean you have to calculate F x F y F z in using the peach correlation, what you get is the vector quantities, so, it will have all the three components. Now, you have to calculate it on a screw dislocation and it is given that the burger vector is so far to make your lie easy it, as given as 0 0 1 and if it is given these burger vector 0 0 1, you can also say that the, the line vector is also 0 0 1 are it is negative and where is the stress arising from d it is due to an edge dislocation.

So, in order to calculate the stress, due to this edge dislocation, we also need to know their geometry and it is given that E is equal to 0 0 1, what you will notice is that the burger vector of this edge dislocation is not given. So, it looks like something is missing so, can let us, see we can find out this missing quantity.

Now, if you remember when we were solve, we were deriving the relation for not deriving actually, when we looked at the full form of the peach correlation, which is, sigma dot cross b which F by L is equal to sigma, which is a tensor quantity dot product with burger vector and cross product with line vector.

So, we wrote down the full form of this equation and over there are, we solve some are we tried out some simple problems. Over there we were looking only at force on edge dislocation, because of an edge dislocation we have not yet considered with a screw dislocation I just set in passing that in a screw dislocation, it would be a little different.

So, this is what we will experience here. Now, here we are seeing what that we need to calculate the force on to this screw dislocation. So, this is our dislocation on which force is to be calculated and the stress is arising, because of edge dislocation. So, this is the edge dislocation, because of which there is stress field. So, this is screw dislocation is at some distance x and y from the edge dislocation, which is causing this stress field and we are given 0 0 1 line direction for both of them.

So, that is why I have drawn it like this so, this is a screw dislocation with it is direction going into the plane. Similarly, the direction of the edge dislocation, which is causing the stress field x direction is going into the plane, but what we are not given is like a send, the burger vector for this dislocation, we know the burger vector for this, because it is a screw dislocation. So, burger vector will be the same direction as the line vector or it is opposite of it, but anyhow we are given 0 0 2 and 0 0 1 so, they are both parallel and not anti parallel.

So, what do we need over here, so, let us go back and recall what was sigma dot b in the full paiget form sigma dot b if you remember, if you write all the quantities assuming no particular kind of dislocation. So, we are, we are assume that all the nine quantities in this tensor are available, then it comes out to be and the assuming that again this burger vector is also, not 0 0 1, but b 1 b 2 b 3, where all the three components exist, this comes out away.

So, this is something I have already written earlier, but for the sake of completion, I am writing it here again and it will help you visualize, what is what should be the final form of the answer and it sigma dot b, this we also showed that sigma dot b cross E is equal to there is a little bit of repetition here, but I hope this will be useful for you.

So, that you know exactly what are the a specific steps that are needed to calculate or solve these problems. So, what you need to do is first write down the general form of the equation so, this is epsilon 3 or eta 3 eta 2 eta 1 eta 3 eta 2 and this is eta 1. Now, this one is the expanded form of the sigma dot b cross e, all you need to do now, you already know what are the sigma components that are present, because this is a edge dislocation.

You also know what is the b and E which is because of this and then solve it ok. So, I will end this lecture without solving it and leaving it here and I hope you can come back and you can solve it. So, we will meet in the next class.