Defects in Crystalline Solids (Part-I)
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Lecture - 25
Image Forces on Dislocations

So, let us come back to our derivation of force on to a particular dislocation.

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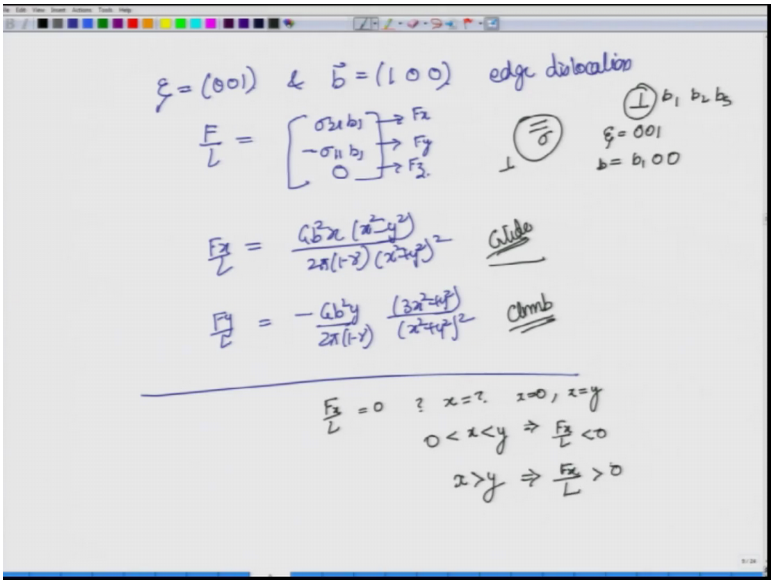

So, if we showed that if you have a edge dislocation. So, let us say this is the edge dislocation on whose Burger vector as given by b 1 b 2 b 3 and it is inside a field where sigma this is the stress field. This sigma stress field could be arising because of another dislocation or any other thing. At this particular point we saw that this is how the this how the force looks like. And without loss of generality, what we did? We have to have a line direction for this particular dislocation. So, we took the dislocation line as epsilon equal to 001, if you remember.

And the Burger vector which has to be perpendicular to it, it can be b 1 b 2 0 or without again loss of generality. We can make it that it is b 1 00. So, this is a Burger vector and when we do that this becomes the force on to this particular dislocation arising out of stress field given by sigma. These are the different components of sigma was this is what we derived last time which means that this is F x, this is F y and this is F z. F z will be 0 because we have a line dislocation, edge dislocation. There will be no forces in the z direction.

Now, here up to this point we are assuming just any stress field, but now is again we make it simple and we say that this is stress field is also because of another dislocation. Then this sigma two one is comes out from the stress field of a edge dislocation which is a lined along 001. So, we are assuming this that this first dislocation because of which this is stress field is arising is also aligned along this along the same direction as this particular dislocation on to which we want to calculate the forces and then this F x and F y come out in this from.

So, now looking at this F y is the climb force and this is the glide force. We know that we have already briefly touched upon the topic that climb will be activated when temperature rise takes place because it involves emission or absorptions of vacancies. So, let us look at the glide force right now. Now let us look at glide force the form of the glide force let us say we want to talk about what are the values at which F x by L will be equal to 0 for what values of x.

So, you can clearly see that if x is if you put x equal to 0, then this for this will go down to 0. If you put x equal to y meaning it is at a 45 degree angle, then again this term comes down to 0. Another think that you will notice is that when x is less than y is less greater than 0 meaning it is at an angle which is less than 45 degree from the horizontal, then what will happen is that here you will have x square minus y square. So, this quantity is less than y square and therefore, overall this component will be negative inclining that the force will be less than 0.

Similarly when this x becomes greater than y then y, then you would see that F x by L is greater than 0. So, some of the things that we can directly derived from this relation.

Now, if you try to plot this, how would it look like? Let us see how does this plot look like.

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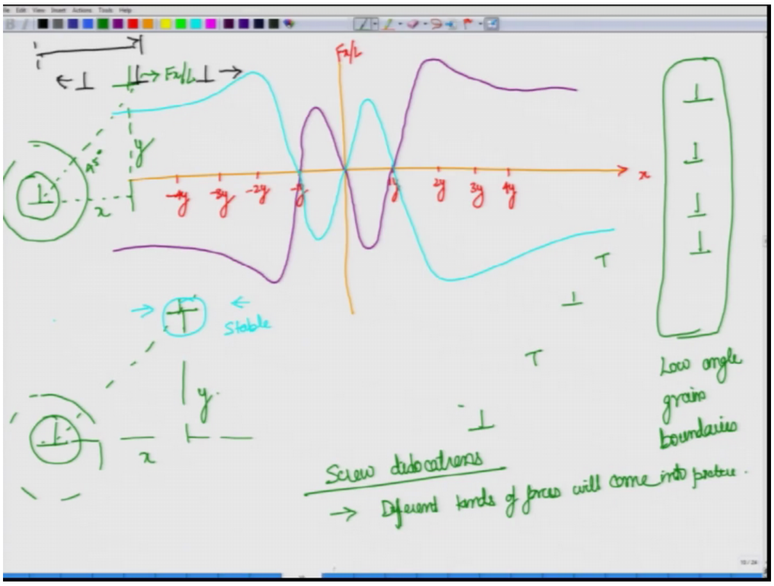

So, what we will do is well on the y axis well have the F x by L. So, on the y axis we have f x by l, but on the x axis what we will do is we will keep x in terms of y meaning it is. But we will plot it in terms of how many y because we have seen it differ even if you remember from the stress field, it changes at 45 degrees. And therefore, it is much more easier and more meaningful to understand with respect to y. So, we will say x in terms of y 1 y 2 y 3 y 4 y and so on.

Similarly, we can have minus 1 y minus 2 y minus 3 y and minus 4 y and what we have all the shows that F x by L will be equal to 0 when x is equal to 0 F x by L will be equal to 0 when x is equal to y. And it will be negative in between this region and beyond this it will be positive. And when you plot it, you would find that this comes out like this. And from this and from the equation you would be able to see that there is a inverse symmetry over here. So, you would when you plot it like this on the other side, so, this is how it will look like.

What are the things that we can? So, let me first again show what is our configuration here, our configuration is something like this. So, this is the dislocation which is creating a stress field and this is the dislocation on to which we are trying to calculate the force.

So, it is onto this dislocation we are calculating F x by L and when we say x equal to y where we mean with respect to this dislocation. So, this is the x, this is the y. So, when x is equal to y it means it is at 45 degrees. When x is less than y, it is less than 45 degrees and when it is greater x is greater than y it means, it is less more than angle is more than 45 degrees.

So, you can say approximately somewhere here you have the 45 degrees line and this is the dislocation on to which we are calculating the force and this is how the F x by L as a function of x looks like. So, when we have x which is equal to 0 somewhere over here we see that F x by L is 0 and if we keep increasing x until the point that we reach, this point where x is equal to y it is exactly at 45 degrees, then again it becomes 0. However, when it is less than y which is somewhere over here. So, we our dislocation would be x is here somewhere like this and y is equal to this. Therefore, somewhere over here we have this and in this particular condition what we have is F x by L is less than less than 0. So, it is negative.

And if we keep moving it like this, so what we are doing is? We are moving this dislocation along x direction and at up to this point it is negative, at this point it is 0 and beyond it is positive. So, what does that mean? That if it is less than negative it or less than 0 meaning negative meaning -if you have dislocations somewhere over here.

So, let me draw it with another colour it is it tends to move the forces in negative directions. So, tends to move like this. If it is that exactly at this position, then there is no force. If it is somewhere over here, it tends to move like this.

So, what is the meaning of this? It means that this particular dislocation, if it is in this range somewhere here to here which is up to y; it tends to align. So, it tends to form a stable configuration like this. If it is beyond this, then the forces are positive meaning it move it tries to move it in the positive x direction and therefore, it moves away from this particular line and it will go away into this direction.

Similarly, we put it like this on the other side up to this particular position. It will come it will tend to come back to this region and at this particular point; it will tend to move away meaning this particular point is also unstable. Meaning it does not as soon as it moves away from here, it will either move here or it will move over here.

So, this is one particular finding that we can directly derive directly see once we write down the equation and we plot how the F x values are changing. The other configuration is something like this. So, let us say, we have the dislocation. So, this one which is creating stress is like this and there is a stress field because of this and the other dislocation has a minus Burger vector. And therefore, it is in opposite direction opposite side like this.

So, again this is our x, this is our y and if you put those values into the relation; what you would see is that it will show something like this. So, it will also be 0 at this particular point, but it will be negative for negative x values and positive for up to y. And so, you will see a force values changing like this. Now over here if you are somewhere over here meaning between this point to this point the forces acting onto this dislocation are in this direction. If you are away from y or higher greater than y meaning at angles less than 45 degrees, then it would mean that the force are negative meaning that trying to bring it here.

So, this in effect means that it is a stable it forms a stable configuration of a pair like this. So, this pair which is at 45 degree would tend to remain at 45 degrees. On the other hand, a pair like this where the two dislocations are of the same sign, they tend to align. So, the in the end what you will in this particular case what you will get our dislocations aligned like this, because the forces are acting in that direction.

On the other hand in this particular case what you will tend to see is dislocations. If they are opposite sign and if there are alternating, then they will form at a 45 degree angle and this will be the stable configuration.

So, we are able to get so many information just based on simple as you solve using this peach colour relation, we were able to derive the force values and then we were able to simplify it for two dislocations pair of dislocations where one of them is creating the stress, the other one on to which the dislocation is acting on to it. And by again taking how much a little bit more simplification and loss of generality without loss of generality that the line vector is along 0 0 1, the Burger vector is only along 1 b 1.

We are able to get such a simple relation from which we can directly plot this force values and we can see what will be a stable configuration when you have all dislocations of same type. And if you remember or if you have been exposed to a little bit of physical metallurgy, you would know that this kind of dislocation arrangement is also called small angle or low angle grain boundaries.

So, automatically if you allow the dislocations to move, they will align like this and form because each of them will actually give a small miss orientation between two crystals. So, a set of these would give a definite or as some significant amount of dismiss orientation between the two depending on what is the gap between the dislocations. And therefore, there it will form somewhere between 0 degree to 15 degree grain boundary. Beyond 15 degree what happens is that we do not call it a small angle grain boundary as the dislocation course start to overlap. We will come to that most likely in the second part of this course.

So, this will form a small angle or low angle grain boundary. Similarly you can also derive the relation for what will happen if you have screw dislocations. So, if you have one screw dislocations, another screw dislocation; you would say that the configuration would be similar only or the forces field force field values will be similar only that the absolute magnitude would be a little different as we know that the forces are a little different.

Actually let me correct that there will be a little different kind of forces on to this because the terms in the tensor metrics are very different for screw dislocation sorry I take that back. So, the when you are talking about screw dislocations different kinds of forces and that is something we cannot practice as one of the example problems latter on ok.

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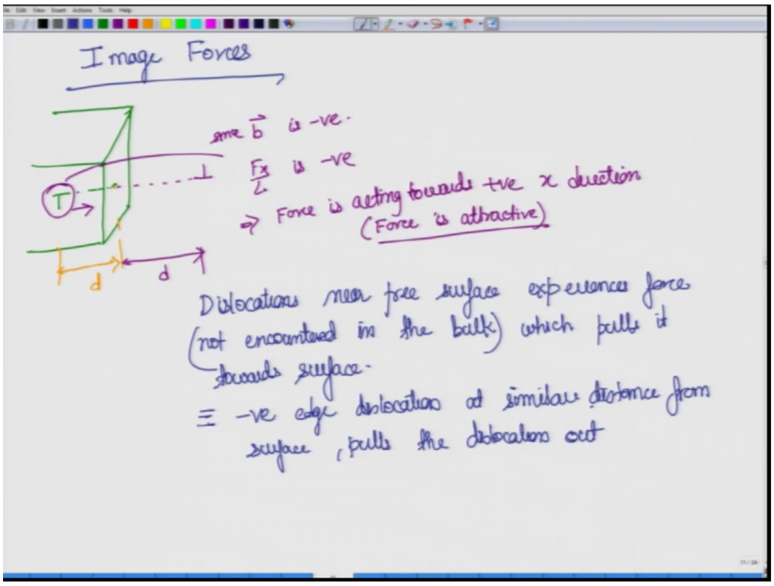

So, for now let us move on to another aspect of interaction between the dislocations which is what is called as image forces. Now, we saw that dislocations react to the presence of the dislocations, but in a materials there is also reaction or forces acting on to dislocations because of imaginary dislocations. And these are what are called as image forces. What do we exactly mean? Let us see.

So, let us say that you have a single crystal like this. Now, let us say that there is a dislocation like this which is some distance d away from the surface. Now, for dislocations which are very close to the surface, they experience an attractive force attractive force meaning something as assuming that there is a dislocation of opposite Burger vector line somewhere over here and at a distance equal to d. So, what will be the force between these two dislocations? Again if you go back, you would see that this will be a attractive force meaning F x by L on to this dislocation is negative or particular in this particular case, it is positive meaning it is trying to pull it out. If we were to calculate on this, it will be negative.

So, since it is already a negative Burger vector F x by L is negative which would mean that it is moving in the plus x direction. So, you can actually so, yeah; so, let me correct that since b is negative F x by L is also negative implies forces acting towards positive x direction. So, the net effect is that dislocation is force or tries to move towards a surface and this is this phenomenon is called the image force.

Because you can see why it is image because there is no real dislocation over here, but the distance some force acting on to it probably some kind of ability of the material to decrease its energy by annealing out the dislocations. But whatever it is the total force acting on to this has been found that it is related to as if there was opposite sign dislocation some on the distance away from the surface as it is inside the surface.

And therefore, it is called image force. So, these there is a image dislocation with different Burger vector of course, with a negative Burger vector because that is what is causing it to be attractive force. So, the better word here is force is attractive. So, that we do not get confused on what is the Burger vector sign and where whether it will be in the positive x direction and negative x direction. All we need to know that it is a attractive and since it is the image is on the outside, so it move towards the surface. So, that will ensure that we do not get confused with signs of the Burger vector and signs of the forces.

So, in words what we can write is that dislocations near free surface experiences force which is not encountered in the bulk which pulls it towards surface. In other words are equivalent to this negative edge dislocation. So, for a positive edge dislocation and negative edge dislocation at similar distance from surface outside the surface, but pulls the dislocation out. So, this is what we imply when we say image forces and the relation for this would be very simple.

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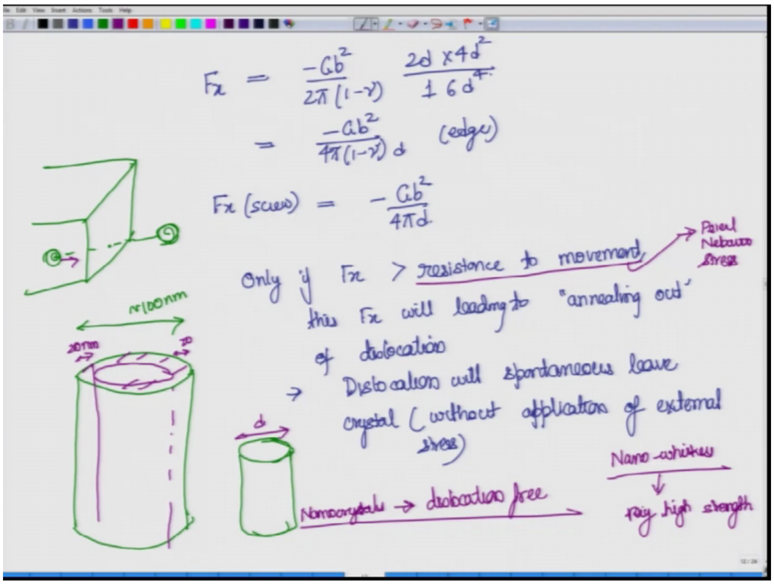

If you go back to our equation, it will be because the distance is now 2 d. Therefore, all we need to do is now the force will be described as negative 1 minus nu 2d into four d square. So, this is x square minus y square and this is x square plus y square whole square. So, this is sixteen d to the power four and therefore, it is now this is the force acting on the edge dislocation.

Now, if we were to similar phenomena can also take place for a screw dislocation. So, instead of a edge dislocation, you could as well have a screw dislocation like this and at a similar distance from this outside it, there will be opposite screw dislocation. So, this is a artificial dislocation.

So, the real forces are acting on to this and the real forces are trying to pull it like this and this f x for screw it will not what will be different will that will be that it will have not have this one minus nu term because this one minus nu term, if we remember gets included only in the edge dislocation leading to higher energy larger force requirement for edge dislocation. For a screw dislocation this is lower energy and hence lower force requirement.

So, this is the force that dislocation is experiencing, if it is screw dislocation this is the force that the dislocation is experiencing if it is a edge dislocation. Now will that cause any change? There is of course, force I can be applying force on to something i can be applied force on to this screen, but is it really leading to some work or is it leading to any change it will only happen in this particular case when the resistance to the dislocation movement is greater or sorry this force is greater than the resistance to the dislocation movement.

So, only if F x is greater than resistance to movement this F x will lead to you can say annealing out of the dislocation. Because once it starts it means that it can it force will keep increasing further and farther. And therefore, once it starts it will move all the way up to the surface and therefore, it will get annealed out leading to annealing out of dislocation.

So, that dislocation spontaneously leave the crystal given that F x is greater than resistance dislocation will spontaneously. Why I am saying spontaneously? Because without application of any external stresses spontaneously leave crystal spontaneously meaning without application of external stress. This is a very interesting phenomena that dislocations on the surface are leaving the crystal and therefore, very near the surface there it will be dislocation free.

So, you may think that if I am talking about a bulk material how does it matter that will this will length would probably be of the order of few hundred nanometre at the most because the force would be greater than resistance only in that region. So, you will have a dislocation free only the few top hundred nanometer, but rest of the several millimetre or centimetre of the component would still have as much dislocation. But this will become interesting if you are considering nanoscale components or nanocrystals.

So, let us say our crystal size itself is few hundred nanometre. In fact, let me make it to exaggerate this concept, let me make it cylindrical. So, let say this is a nanocrystal single crystal and the diameter here is few hundred nanometer and let us say that only twenty 25 nanometer of the surface experiences force large enough that dislocations can move. Therefore, up to this some region which is let us say close to 20 nanometer on every side. So, something like this; this region is dislocation free.

Now, keep reducing the diameter of this cylinder, let us now bring it down to 40 nanometer, what happens? Rhis nanocrystal is completely free of dislocations. So, this is the interesting aspect of this image forces. If we are talking about nanocrystals, then this nanocrystals can be completely dislocation free.

So, up to a certain size up to a small certain width or the diameter up to a certain diameter, you can get dislocation free crystal s. What will this d depend on? This d will depend on that what we have described here as resistance to movement. This we will let us see on is what is called as Peierl Nabarro stress.

So, if your force that is that these dislocations are experiencing this is larger than the peierl nabarro stress which is what is actually the lattice resistance to movement, then the dislocations will be able to move. And once you know this value the Peierl Nabarro stress, you would be able to find out what is the d diameter d for which you will have a dislocation free crystal.

And therefore, you can get very high strength, you remember from the first class that we said that if there are no dislocations then you can get very large strength and that is the origin of so high such high strength in nano whiskers. You may have heard about in whiskers in fact, whiskers itself of nano size, but let us call it nano whiskers to stress the fact that they are crystallines crystallites with very small sizes. So, they are of the nano order and since their length are of the dimensions are smaller than this particular critical dimension d. They will have they will be dislocation free and therefore, these viscous will have very high strength.

So, even in metals we can get very high strength if we can get to nanosize nanowhiskers and this can be used as composites. So, next time we will come back and we will move on to more about dislocation motion, we have said that there are two motions glide and climb. So, we will look more at more at those topics in the next class. So, we come to an end to this image force.

Thank you.