Structure of Materials
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Lecture - 25
Defects in Crystals

So, it is about time. Now that we got in to the details of dislocations and we shall start as I told with 2 extremes; the edge dislocation and the screw dislocation.

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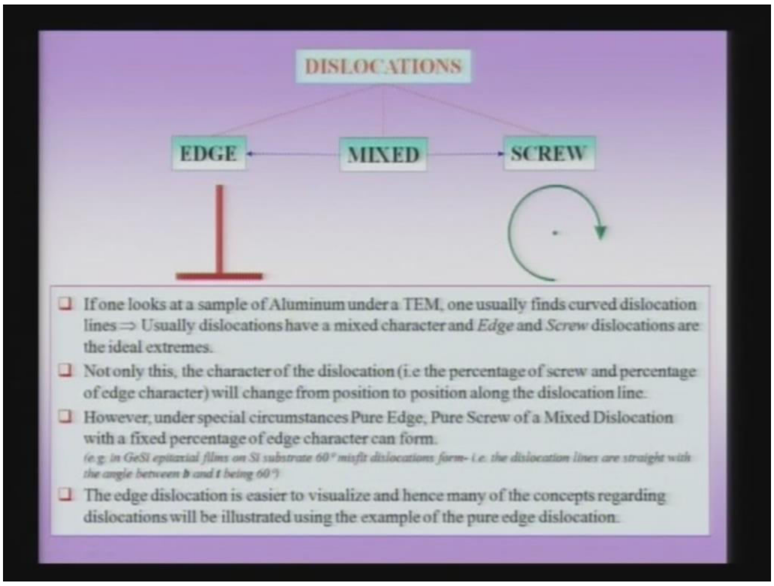

Now, it if I look at a sample of aluminium under a TEM, it pointed out typically one finds a curve dislocation point. That means there is lot of dislocations typically simple sample of aluminium, even it is a well unyielding sample. You will find lot of dislocations in a transmission electron microscope, and when you if you take a deform specimen like a deform specimen of aluminium which is been may be deformed in anyway.

Then you will find that there are lot more dislocations in the material in fact there is a structure of all these dislocations. There could be dislocation cells which form there could be reasons of high dislocation density and reasons of low dislocation density as well. But essentially all these dislocations typically will be having a curved line they will not be straight dislocations in other words as we shall see that these dislocations have a mixed character. They do not have a pure edge or a pure screw kind of a character, but they actually have a mixed character.

And in fact if you notice that the percentage of screw and percentage of edge character, and what we mean by these terms you will understand very soon by actually taking a curve dislocation change from position to position along the dislocation line. That means if I take a point on a dislocation line which I observe and transmission electron microscope it will have a certain character edge character and certain screw character.

And the dislocation itself which is mixed dislocation can be lots of decomposed in to these two parts which they edge and the screw extremes. If I take another point along the same dislocation line, these percentages would change. And therefore, the edge and screw character change along the dislocation line, however we will see that there are very special circumstances where pure edge pure screw or a mixed dislocation of a very fixed percentage can be form.

And a nice example of this would be the case of an epitaxial film of germanium silicon on which is germanium silicon solid solution on a silicon substrate And in this case you find sixty degree mixed dislocations form and these are a straight dislocations. And they are fixed character of 60 degree I said and what I mean by 60 degree also will become clear when I take up the edge and screw components of curved dislocation. And in this case of course, the angle between b and t is 60 degrees.

The edge dislocation is for easier to visualize, for easier to understand and it is also it is because that what we might call something it is associate with the half miss extra half plane or a missing half plane. And we will use the edge dislocation to understand me of the concepts regarding dislocations; of course, will also take up the screw dislocation to understand many more concepts regarding dislocations. So, we said that dislocations play a very important role in plastic deformation the actually week and the crystal.

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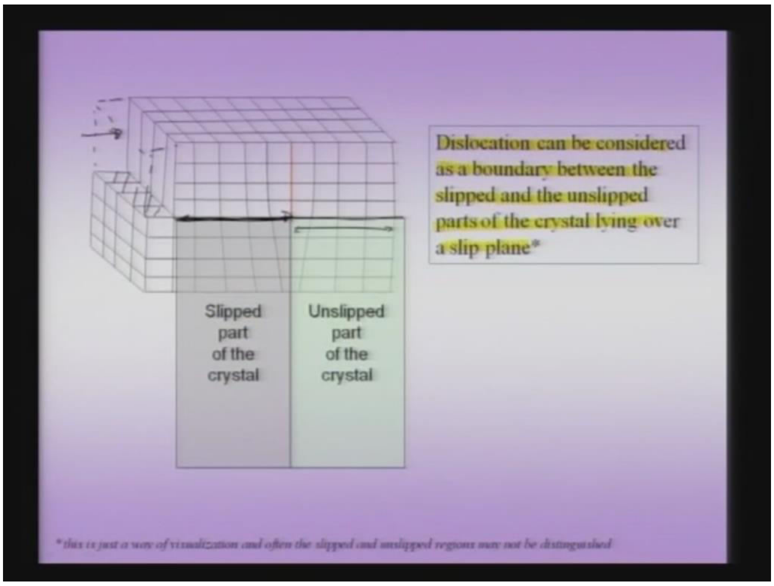

And dislocation can be actually visualized as a boundary between a slipped and unslipped part of a crystal lying over a slip plane. Now to show this; So, I have some sort of a model here, and you can see that you if I take a perfect crystal and then push in this part of the crystal. That means I am pushing a making a operation where I am pushing in this part of the crystal, and when I do this pushing, and here I will notice that there is an extra plane which is sitting outside here originally. The original crystal extended till here and this is now one. This extra plane as gone in to the crystal and in this case the extra plane has travelled to this distance from here to here and its now sits in this place.

Now, this extra half plane is a characteristic of a pure edge dislocation, and now, the crystal can this dislocation can be thought of as the boundary between a slip part of the crystal and the unslip part of the crystal. So, this way of visualizing a dislocation and often this kind of visualization may not be possible. And all we have to visualize an edge dislocation by its near character. That means the extra half plane for an edge dislocation. So, when I push in a crystal I can push in the extra half plane. The extra half plane can travel of course, and even come out from the other side the crystal creating a step on the other side. And we actually see this kind of steps as they form using some other graphics.

But now I can visualize this region which is now the slip region. So, this is my slip plane the whole plane and so, this is now out part of my slip plane which is extending outside that the crystal. And so this slip plane which extends till here. So, this region of slip plane is the part which has been just slipped and the dislocation of a slip glided till here. This part of the slip plane is where it is not lighter. That means there is no slip in that part. So, the dislocation can be visualized as the boundary between the slip plane and the unslip part of a crystal. So, this is a way of visualizing a dislocation and in this case it has been illustrated using the edge dislocation.

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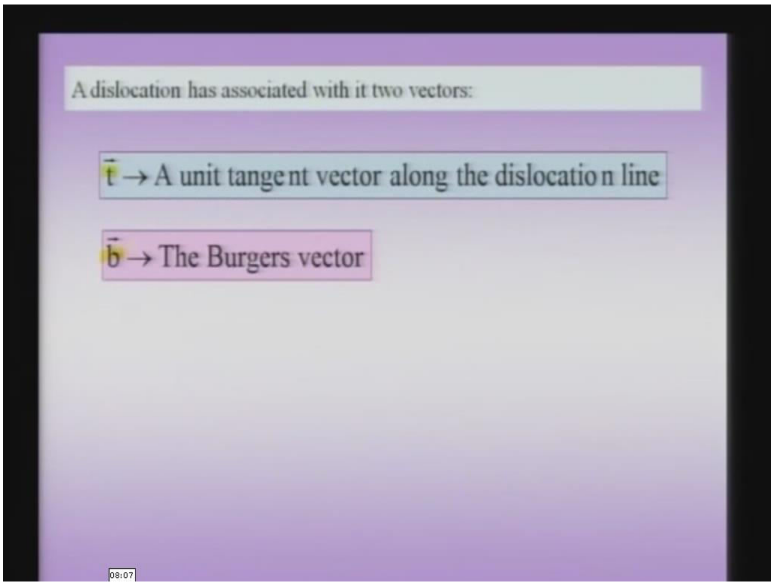

When we talk about dislocations, it has with it associated two important vectors the two important vectors are the line vector t and the Burgers vector b. The Burgers vector perhaps is nice cardinal to a dislocation. As you can think of dislocation is bond with a burgers vector and expresses it even in its death. So, entire life of a dislocation even starting before its birth to its death has this burgers vector embedded or the signature embedded in a dislocation. The t vector is a unit tangent vector along a dislocation line. And if you have a straight dislocation line the t vector is a constant and you can obviously consider unity vector also. That means which is a fundamental lattice translation vector kind of thing which is a unit vector. But also you can consider other kinds of t vectors.

But essentially it is a tangent vector to the dislocation line and for a curve dislocation from point to point. The t vector will change. But the b vector is absolutely a crystallographic constant. It will not change neither with the screw nature of the dislocation nor the edge nature or the mixed percentage of the dislocation. It remains a constant and it is determined crystal graphically. And as we shall see it is t it is the fundamental lattice translation vector for a full dislocation. So, let us start with the burgers vector of the edge dislocation, and if you already have a dislocation, then we can determine the burgers vector using what is known as the burgers circuit.

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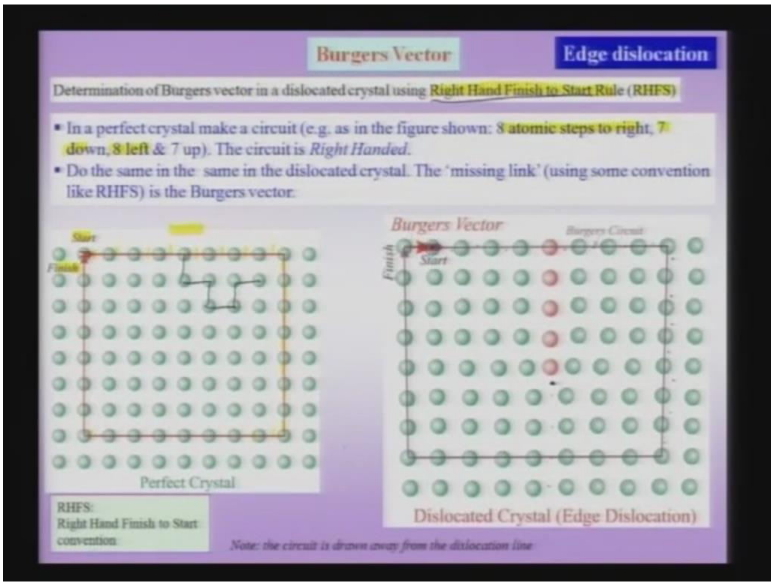

And the burgers circuit associated with a convention like the right hand finish to start rule which is return in short hand is r h f s can give us the burgers vector. So, what we are dealing with here an edge dislocation and we are trying to make a circuit known as the burgers circuit to determine the burgers vector. But please remember, even if I did not have a dislocation it for a perfect crystal crystallographic, I can tell what the burgers vector is. But if I already have a dislocation, then I can use the burgers circuit to determine the burgers vector. So, how do I come do this burgers circuit along and typically I need a convention in to define this, and the convention has to be constant across the various considerations in the problem. And in this case, we are using the right hand finish to start rule and I will explain what this rule means.

So, what I do first is, I take a perfect crystal which is a crystal on the left. You can see the crystal on the left which is a perfect crystal and I make a circuit that means a start from a point which is start and I take eight atomic steps to the right. So, it is 1 2 3 4 5 6 7 8 atomic steps to the right. This is an arbitrary number. I can choose any number of steps. It could be 8, it could be 10, it could be 40. But I just choose some number of steps to the right, then I go down 7 steps, and this again is an arbitrary number. So, 1 2 3 4 5 6 7 steps to the downwards, then I take 8 steps to the left again, and take 7 steps. So, not unexpectedly very obviously we land up exactly where we started of it. So, I land where I started of it, in other words a circuit like this closes on itself a perfect crystal as expected.

Now of course, I could have taken a more what you might call a more arbitrary kind of path taking as square path. For instance, I could have started here and I could have gone down instead of going up here. I could have gone down like this, gone like this, gone like this, gone like this, may be even gone up and so far. But it is always simpler to take a nice rectangular path; the weight has been shown here in the figure. Now, what I do the same circuit in the crystal with an edge dislocation. Now, you can see that you got an edge dislocation here, and I say pointed out the edge dislocation is associated with a half plane. So, this is my edge dislocation, it is a dislocated crystal on the right hand side.

Now, few important points about the edge dislocation, which of course, I will also explain during the using the model that the edge dislocation is not the extra half plane of atoms, it is not a 2 dimensional defect, it is not the missing half plane of atoms, so you can see that you can even consider this as the missing half. Plane of atoms; it is not the missing half plane of atoms. It is in fact exactly between the two. So, you have the edge dislocation setting right here going invert in the paper. So, this is a two dimensional section of a three dimensional crystal, which goes in to the plane of the slide. So, we will have a little more to say about the edge dislocation with the model.

And but now, let us do the burgers circuit, so the, we next, I start as usual from as a particular atom around the dislocation. And I stay for away from the dislocation line which is here. So, this is at dislocation line I say little far away from the dislocation line. And now, I construct 7 8 steps to the right. 7 steps downwards, so 1 2 3 4 5 6 7, then down 7 1 2 3 4 5 6 7. I go 8 left and come back and not as obvious you will not land up exactly where you started with and that is because, now you have an extra half plane of an atoms and that extra half plane as a counted for this mismatch. So, I have been constructed what you might call a right handed circuit. I could I equally welcome construct a left handed circuit. But I am striking now to the right hand finish to start rule.

So, I construct a right handed circuit and at the end of the circuit, I find that my finish point and the start point do not coincide with each other. And now, I use the rule which is the finish to start rule. That means, I draw a vector connecting the finish point to the start point and that vector is the burgers vector. Now, this burgers vector which is typically written in symbol as a b with a a vector cap on top or a bold b. So, is the burgers vector and the modules of the burgers vector gives the value of this vector? Now, it is clear that this is a lattice translation vector. It connects one point to the lattice to another point in the lattice. And therefore, this is an important vector which is associated with a dislocation. Now, let me summarize this slide before we take up the model and try to understand the edge dislocation. So, first I take a perfect crystal by make a circuit. The circuit could be very arbitrary.

But typically I choose a rectangular circuit and I make the circuit in a right handed fashion. That means I go clock wise in this case, then I take the same circuit and put it in a perfect crystal making sure that the defected region, that is my dislocation is included with in the circuit. And I say my circuit is far away from the core of the dislocation. And this means the region of the dislocation varies. I do not stay very close to it, and then I find that this right handed circuit leaves a small gap. I draw a vector connecting the finish point to the start point and this is what my burgers vector is. Now, let us me try to understand this edge dislocation a little more. So, I say pointed out the edge dislocation is not the extra half plane.

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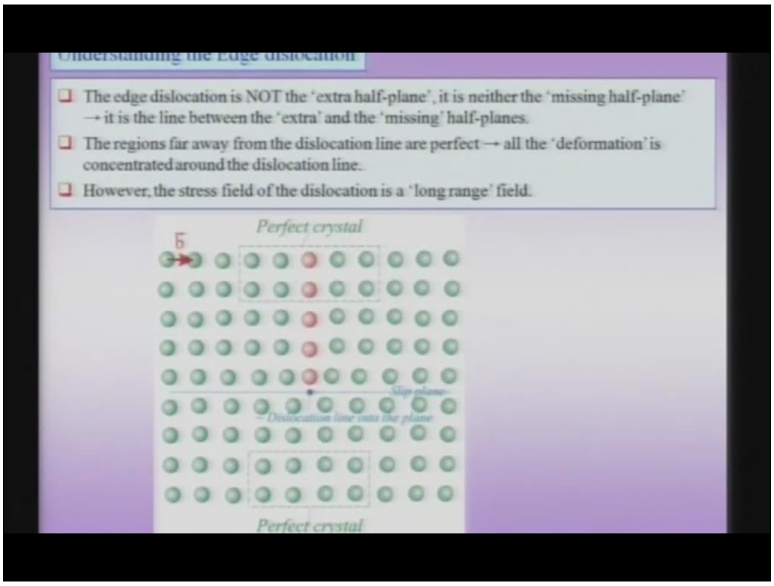

So, this extra half plane is not the edge dislocation neither is in the missing half plane, it is in fact the region that the line exactly between the missing and the extra half plane. Such as what has been marked here. Now, important point to note; if I go far away from the dislocation line, the regions of the crystal, I have here in the case. Of course, I am not going really far away, but if I really could go really far away, the regions of the crystal far away from the dislocation line either on the upper side or the lower side or perfect. So, this is the perfect region of a crystal. So, you can see you can measure the lattice parameter. They will be as close to the further. You go to the more perfect, the crystal would get and similarly, the regions far away at the bottom side of the slip plane as we call them the plane, of the where my dislocation lies is also perfect.

Now, a few points to be noted even here is the fact that you have here edge dislocation setting here you see that the displacement fields and stress fields to which will of course, come here later or long range fields in other words. Even if I go little far away, there will be small disturbances to the crystal. But as long as these instruments are small compare to the burgers vector, I treat them as zero. And therefore, I can treat that region of the crystal as a perfect crystal. So, what I will do now, I will take up the model and explain you some of these things.

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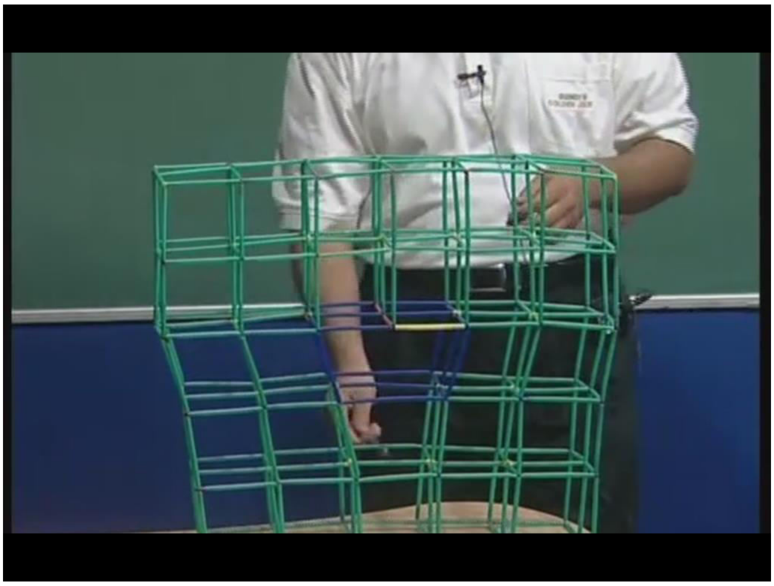

So, I have here a model now which is made of straws, and you can see that in this model there is now an extra half plane of an atom which is been introduced, and this my plane of atoms. So, it will be take up. So, this is my extra half plane which has been introduced. If you look at the crystal below, you can think of this region as a missing half plane as well and this region of the dislocation which is been marked in blue, you can see here blue is the region which is highly distorted. That means, the bonds in the region are highly distorted and the crystal is highly distorted. This is the region where in the stress fields and strain fields that very large. Now, another thing which we notice is that the region here is also region where there is some extra free volume in other words as compare to a normal lattice crystal which is far away, which is now a perfect unit cells.

Somewhere, for away here in this perfect unit cell you know the kind of which are present. And you know the fraction of those voids like for instance, you can see crystal. You could have an octahydrate tetra hydrate voids. So, you know all about them. But now, if you look at this region, there is an extra free volume associated with this dislocation. And this very important thing and will come back to this. What is the effect of this extra free volume? Now, we can actually draw even for instance vector like this, which we can call the burgers vector. But typically this has to be drawn far away from the dislocation line. Now, the dislocation line itself is the line which is here, which has between the missing and the extra half plane of atoms.

Now, what happens if I look at this crystal from sideways? Side ways we notice nearly looks for effect. So looking from this direction, I cannot see the dislocation. So, the dislocation is best viewed from this direction, and this case, the dislocation line is starting from the front phase of the crystal. And of course, I only took 2 unit cells here. Typically to drawn a straight dislocation line would run and at the backside of the dislocation. So, it would the terminal first one terminal point of the dislocation on the free surface with the front free surface. The other would be the back free surface. And therefore, this is my dislocation edge. Dislocation in a single crystal. Now, an important thing of course, it is very easy to understand an edge dislocation.

Because, it has associated with an extra half plane of atoms, now, this plane on which this dislocation line lays is called a slip plane. Now, the vector t vector is nothing but a line vector which goes into the plane, because which is the vector which describes the line of the dislocation. Because this is now a straight dislocation in this crystal my t vector is not changing from position to position. But if it works out dislocation line, then not only the t vector would change, but also the character of dislocation change. As we shall shortly see now the burgers vector is. Now, this vector connecting this atomic position to the next atomic position, and this is my b vector as you can see the t vector for an edge dislocation which is this vector is perpendicular to the b vector.

So my t vector is in this direction the b vector is in this direction and the t and b vectors are perpendicular to each other. So, this is an important point to be noted and the t vector and the b vector together defined my slip plane. So, the plane common to both the t vector and the b vector for an edge dislocation is my slip plane. Now, why do I call at the slip plane that takes us back to the experiment or the model in which we are pushed an atomic plane? Push the side of a crystal so that we pushed in an atomic plane so that is what or a half atomic plane. So, this same thing can be supposed I push this part of the crystal and then therefore, I create a step on the surface and then this plane moves on here.

So, this plane which is now the middle plane, the plane is siding here would be my slip plane. And as we shall see by taking examples from phase and to be crystals etc., typically this would be a close back plane in these kinds of close back crystals. So, what are the things associated with dislocation? Now let me revise. So, this edge dislocation is associated with an extra half plane of course, this extra half plane will not reveal half. It could end somewhere in the crystal. Only thing it should not go all the way to the crystal, then it would be a make it a perfect crystal. So, it has to end somewhere within the crystal and therefore, it can be called though. We use what half we mean. It does not go through all the way through. So, that is the first thing. Second thing it is associated with the line vector which is between the missing and the extra half planes. It associated the burgers vector which is a lattice translation vector connecting two lattice points.

The t vector and the b vector together define the slip plane along which this dislocation line can move. So, if I have to share this crystal for instance, I take this crystal and I apply a share on the top like this. And of course, I will pull the bottom side to apply a share like this. Then, what would happen to this crystal is that, this dislocation will move on the slip plane. So, how in which direction would the dislocation line move. So, this dislocation line direction, this dislocation line would move in the direction of the burgers vector. So, this is an important characteristic of the edge dislocation. So, the b vector, the t vector defining the slip plane and the dislocation line in the presence of share will move along the direction of the burgers vector. What would happen if of course, if free surf it approaches a free surface? The free the extra half plane would come out and create a step on the free surface as we shall see with some graphic video graphics.

Later on the other point, we noted using this model which is very clear that this region which we shall use the word core. And of course, technically the core is the region where the linear elasticity theory breaks down. That means the deformations are slower large that you cannot use the linear elasticity anymore. And this region is associated with some free volume is known as the core of the dislocation. And typically the core of the dislocation is a region which can be thought of as something between about few burgers vector. In some cases, it would be a burgers vector. It could be about 5 burgers vector. But, some region between of the order of few burgers vector and this free volume as we shall see later it’s very important in certain phenomenon which we shall consider.

So, this is a model of an edge dislocation, and we should take up some graphic models. It will become clear that how this model is useful and understanding the edge dislocation. So going back to the 2 dimensional graphic models, so the 2 dimensional sections, where this slip plane meets the front face are shown are here in the blue line. So, that is my slip plane, the plane the extra half plane is also here the burgers vector has been drawn. The t vector is a vector which is in to the plane of the board. So, it is in to this blue line here. So, it cannot be shown in this diagram. So, it is in to the plane of the and is un changing because is now a straight edge dislocation.

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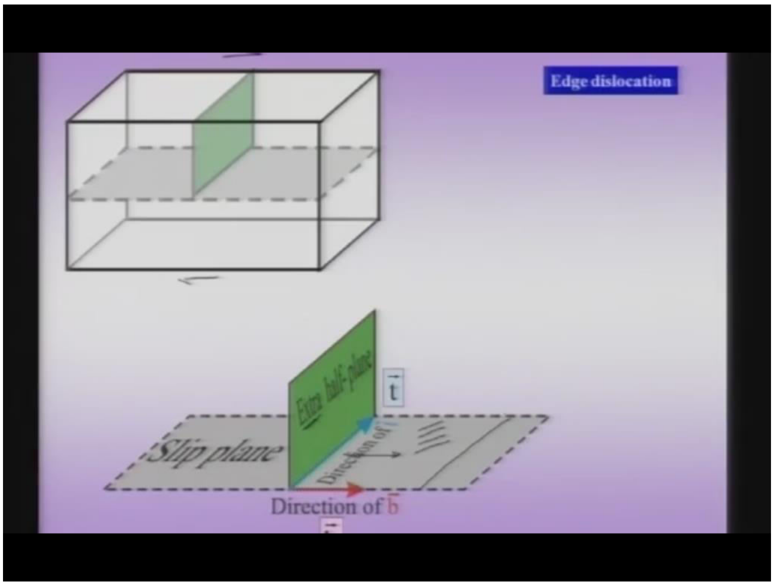

Now this is an alternate way of visualizing the same. So, this is my extra half plane for the burgers edge dislocation vectors. The green plane which has been shown here this is my extra half plane. This is my slip plane. Now the t vector goes inward of course, this is not a unity vector. I could always draw unity vector which is now shown in the blue colour vector and the b vector again this is not a crystographically shown. Therefore, remember this is stress schematic and this red vector is the burgers vector. And now the t vector and the b vector define the slip plane. Why the extra half plane contains my t vector? And now if I share my crystal, suppose I apply sharing force on this crystal now, this extra half plane would move parallel to b and it is certain time it this the dislocation line could land up here.

And finally, of course, leave the crystal. So, since this edge dislocation is associated the slip extra half plane; it is easy to visualize and edge dislocation. And many of the characteristics of this edge dislocation can we understood based on this kind of a construction.

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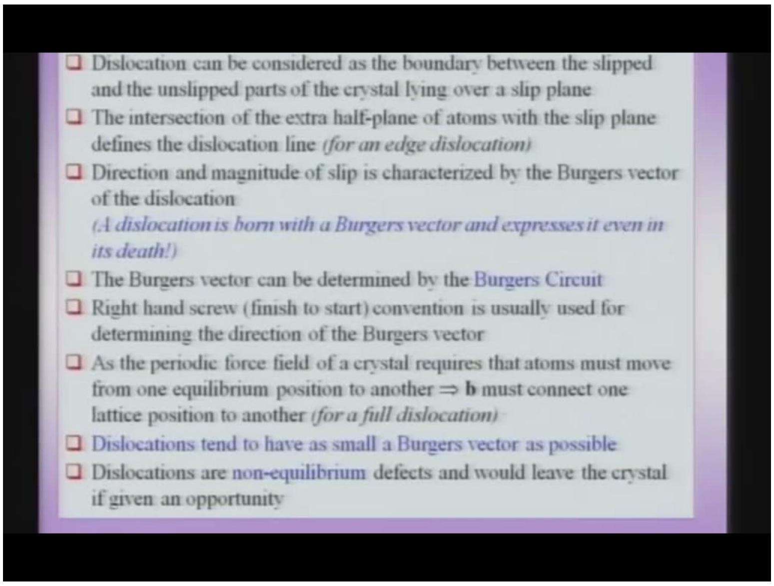

So let us summarize some more important things. We consider so far with regard to dislocation stage especially a dislocation can be thought of as the boundary between the slipped and the unslipped parts of a crystal line over the slip plane. So, again as I told you this is just a way of visualizing the edge dislocation and often it may differ dislocation exists in a crystal. it may you cannot tell which is the slip part or which is the unslip part. So, this is the question for the student's sir dislocation. That is mean dislocation line is imagine the concept it is not actually physically presents in the crystal.

Now, the first question we have to ask is that why is this dislocation a line why is it not a region as I pointed out whenever we discussing the classification of defects based on dimensionality, that we will make some idealizations. If you look at actually the displacement field of a dislocation which we will take up soon or the strain stress field, it is a long range field. The disturbance is not localized to that line which is felt by atoms which are even quite large quite far away quite. If you even atomic spacing's for away from the line of the dislocation, But never the less this is just a visualization that that is instead of now me understanding a dislocation as the displacement field of the entire atoms around it.

I localize all my visualization to a line which I call the dislocation, and later on perhaps will deal little bit about the concept of an image force. There we will see that, how we now not just worry about the line. But we can worry about the entire configuration of atoms around this line. So, definitely it is a hypothetical line. But since it is a line it is a clear cut line which can be imaged in a transmission electron microscope. It is as real as any other. So, the intersection of the extra half plane of atoms slip plane defines a dislocation line for this is for the edge dislocation. The direction and magnitude of slip is characterized by the burgers vector of the dislocation. So, the burgers vector is perhaps a very important thing whenever we talk about dislocation its energy its stress fields.

You will always find this burgers vector appearing at anything associated the dislocation and as we shall see that. It will characterize slip or site with the dislocation. So, this is something which I told, I mention before that a dislocation is born or in fact even exist before its birth with a burgers vector and expresses it even in its death. So, this point has to be noted and therefore, we cannot forget the burgers vector when we talking about a dislocation. The burgers vector as we saw can be determined using the burgers circuit. And we typically use the right hand finish to start convention for determining the burgers vector. So, this aspect we have seen already. Now, the periodic force field of a crystal requires atom to move from one equilibrium position to the other. It implies automatically that the burgers vector must connect one lattice position to the other.

Of course, we are talking about for this for a full dislocation. And later on, we will be talking about something known as the partial dislocation also. And later on, we will also see that since the energy of a dislocation goes as square of the burger models of the burgers vector. The dislocations tend to have as small as a burgers vector as possible. So, this something which obviously there is few you have a small as lattice translation vector. You could have larger translation lattice, translation vectors. But you the dislocation will always choose the smallest lattice translation vector, and another important point which perhaps will return to later is a fact that dislocations are non equilibrium defects and would leave the crystal if given an opportunity.

So, if you take a, if you take a sample of aluminium on a cold socket, then typically the dislocation density can go up to a 10 per 12 meter per meter cube. Then, if I unseal this crystal, I leave it at somewhat high temperature. So, that there is sufficient thermal activation, then the dislocation density would reduce. And of course, there could be mechanisms like crystallization and recovery with which are operating. But the end of it you will land up with a lower dislocation density which could be of the order of 10 powers 4. So, dislocation tends to leave the crystals. And it is of course, in the scale we are seen there or leaving because of thermal activation. Now, let us next consider the more complicated or let us say the more difficult visualize form of a dislocation which is the screw dislocation.

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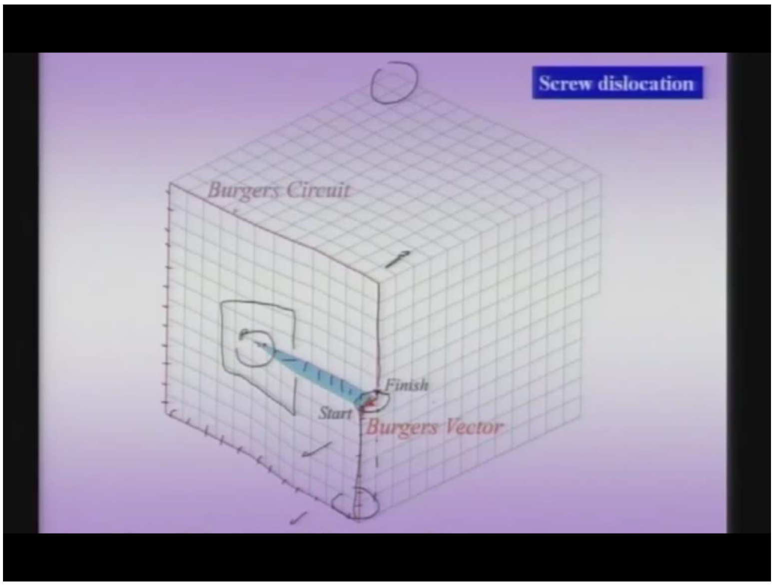

Now the reason these are called screw dislocations is can be seen from this figure that if I look at now. Now this is my perfect crystal in which a screw dislocation, I will be introduced this at that therefore, a crystal with the screw dislocation. If I look at now atomic planes you see that atomic planes of course, for away from this point or perfect. But, if I go here, and I start from this point and I make a loop around this, I would notice that I go inward. This is something like a screw. So, I if I keep on traversing, I will keep going around inward, I travel along these kinds of paths. So, again I have of course, I have models to explain how a screw dislocation works. But, from this figure, it is clear that like before, what I could do is that I could make a cut on the crystal and take a perfect crystal, make a cut.

So, this is my plane which I make a cut. I do not cut the crystal fully. I cut it only to a somewhere in between to this point say p. And then, I take the upper part of the crystal and share it with respect to the lower part. That means, I push one part beside, push another part and I make sure of course, that these atomic position and up on top of the other atomic positions. Therefore, now what I have got now is a screw dislocation. So, if you look at a region for away from this dislocation line, it is perfect if you look at another region above which is perfect. But the region here is which is close to where that cut ends is a region of high disturbance. Now, again I can make a burger circuit in this structure in which case what I do I start.

I make a circuit in the perfect crystal and reproduce the same circuit in the defected crystal. That means in the presence of a dislocation, so for in sense of case I made a circuit which is a right handed circuit. I start from this point here, start say 1 2 3 4 5 6. I go down, then I go 1 2 3 4 5 6 7 8 9 10 11 12, then I go 6 back 10. Then of course, I came back but, 1 2 3 4 5 6 7 8 9 10 11 12, and then I do the same thing to the right hand side come back and not unexpectedly. I do not land up in the same place and using the finish to start rule in the using a right handed circuit. This is now my burgers vector. So, how did I? So, let me repeat the process. How did I make my dislocation? I took a perfect crystal. I cut along this blue kind of a plane. So, they seem that the whole plane goes inward. I cut this blue plane. Then share one part of the crystal with respect to the other and of course, join this to the next plane of atom.

So, originally this row of atoms here where stuck to this row of atoms here. But now I move and join them to the next parallel row of atoms. And therefore, I get an after joining now. I get a shared crystal and this is now my dislocation line. So, for away from the dislocation line everything is perfect. But here there are large share crystals close to again what I can call the core of the dislocation. Now, let me explain the same using a model that this these concepts become clear. But now in this defected crystal, I can make a burgers circuit that as before. And now using the right hand finish to start I can determine the burgers vector and important point we notice straight away is that the dislocation line which is now of course going inward in to the crystal from this point onwards is now parallel to the burgers vector. In other words in this case a line vector which is a t vector is parallel to the burgers vector.

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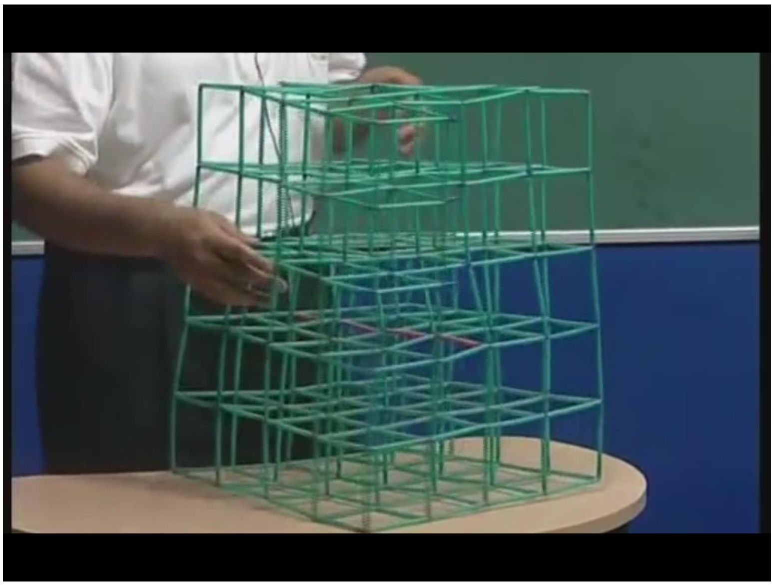

So, let me use the model to explain the concept of a screw dislocation. So, here have a screw dislocation and the way of course, it is been constructed this has as I mention before and here the red line is the line of the screw dislocation. So, let me keep the crystal like this for you to understand this. So, this part of the crystal for instance originally this plane of atoms which is coming from here originally would have been stuck to this point. So, this point originally would have been stuck to this point. This point would have been stuck to this point; this point would have been stuck to this point. So, what I did I take a share here? I made a cut in this crystal here moved this plane of atoms from here to this next end joined.

So, you can see if I look at this region of crystal which is for away. It is perfect if you look at this region of crystal. It is perfect. Unit cells are perfect. But here somewhere here is region which is highly distorted the bonds are highly distorted. Originally these atoms would want to join for this atom. This bond would I like to join with this atom for the sense would I join here is bond onwards here. As now joined shifted, therefore there is a distortion, so there is a high distortion of bonds around this place which is costing energy to the crystal. Now my dislocation line is this red line. So, I can shift a little bit and show you also. This is my red line here which is the dislocation line. And this is my burgers vector which is been, which is also here. So, this point joining this point can be thought of as the burgers vector. And therefore, this burgers vector is parallel to this dislocation line.

So, if I look at my crystal again, you can see that these planes are bend they are shared. So, this is the sharing direction of course. Is this that means I have taken this and push my crystal in this direction towards me. That means the sharing operation is going like this that is before joining, I make a cut that is go this cut is suppose hypothetical. I am doing a mental construct to get this dislocation; the mental construct goes as follows I make a cut in this crystal here. I share the crystal and join what about originally this bond must have gone. Here we put it here and therefore, I get planes which are now bend around this place and if I now travel along a particular plane, I would notice that I go like this, I go like this and I come back, I go do not come back here. But I come back one step backwards.

So, I go here for an instance in a perfect crystal. Of course, I go like this, like this, like this, like this, like this, I come back to the same place. But, here if I go like this, like this, like this, and I go like this and I shift myself. I land up here one shifted this is what this is my burgers vector. So, in fact if you are watching this video, then you should actually spent a lot of time looking at this model and perhaps try to make these kind of models yourself. Because these are just made of a straw and simple connectors because a screw dislocation is much more difficult to visualize as compare to normal edge dislocation which is of share to the extra half plane. And clearly, here there is no extra half plane and as we shall see later even the stress fields are quite different are very different between an edge dislocation and a screw dislocation.

Now, this region of distortion around a dislocation line is again is so large is the elasticity the root failed drawn. And therefore, this region I would call the core of the dislocation. But now this core of the core region is not associated to the kind of free volume we are talking, we are talking in the case of edge dislocation. And typically, we will see later that is a screw dislocation would interact with other kind of defects which have again a share field associated with them. So, once again I will summarize what this use this model for screw dislocation. In a screw dislocation, if you look at now, let me show small comparison the edge dislocation in the edge dislocation, there is no there is a bending of planes.

But now the bending of planes is like this, it goes and it just comes down you can see these planes, these planes are bending like this. But there is no sharing of planes. In the case of the screw dislocation, as you can see that these planes are bending in this direction which is not which is considerably different from the case of the edge dislocation. And also the burgers vector is parallel to the dislocation line, and now suppose I share the crystal, I hallowed, I share this crystal the same way I created the dislocation, I would share I would pull this the region top and push this region we show from the side. So, with the dislocation line perpendicular to you, suppose I am sharing this crystal what would happened to this crystal is that, now this region where they the this plane ends.

So, the dislocation line starts would tare up a little more as we shall see using graphic videos which will make it absolutely clear. And this dislocation line would move towards me. In other words of course, it will move in the case of the edge dislocation. The dislocation line was moving of course, in a direction of burgers vector on the slip plane. And now this is my slip plane and now my burgers vector is in this direction and for the dislocation line its moving perpendicular to the burgers vector. So, this is an important difference between a screw dislocation and the edge dislocation. And how when this extra step you can see here has been created by this dislocation and as dislocation keep moving a step would propagate.

Downward and the finally, you will find that this whole crystal has a step here. The whole crystal downward that means this dislocation line, when I share would leave even though I am sharing in this direction, you can see I am sharing in this direction, the dislocation line would move in this direction, and finally, it would leave the crystal from this back phase and leave a complete step along the crystal. So, this is what is considerably different from an edge dislocation in this what makes visualizing a screw dislocation somewhat difficult. But using models like this perhaps we can have a better understanding of screw dislocation. Burgers vector is determined by crystographically, it does not matter if an edge dislocation.

It does not matter if have a screw dislocation. The burgers vector is a constant that does not change. What can change is the line vector. And, if it can be a straight dislocation and the line vector is a constant, it can change from point to point. But along with the change of the line vector, so is the character of the dislocation changing. Because now as when we listed, you see that the line vector is parallel to the burgers vector. In the case of the screw dislocation, in the case of the edge dislocation, the line vector is perpendicular to the burgers vector. But suppose a dislocation line or suppose I am starting with the case like this of course, we have better graphics to show you that later.

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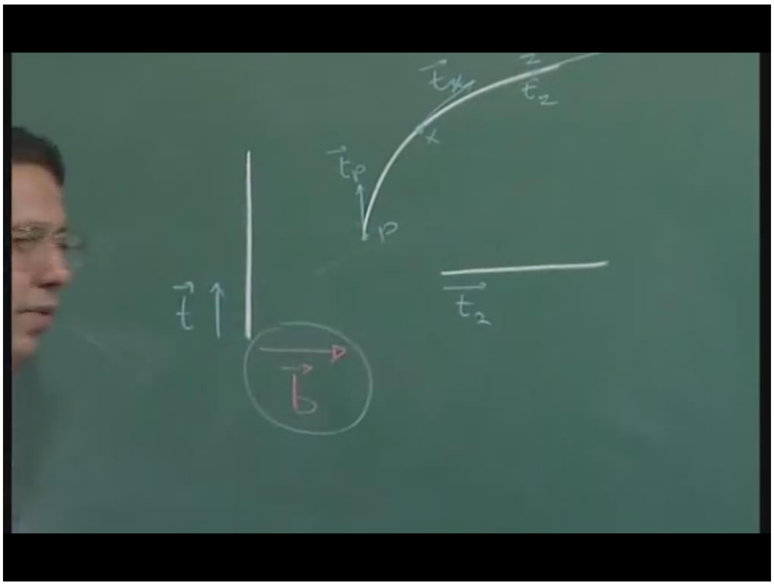

Suppose add a straight line like this, this is my dislocation line and this is my burgers vector, and this is my line vector. Therefore, this is clearly an edge dislocation. But some other part of the crystal, it would so happen that I have a line vector like this. The same crystal of course, my t vector, this is my t vector, t 2. Now this has a pure screw character. But the burgers vector remains a same. This is now my b. I don’t have to redraw my b; it is only the t vector which is changing. Of course, I could have a dislocation in which it goes like this, that means my t here is a tangent vector here. And this point b at this point it is a different direction is my t 2 or t say call. I call this t p and I will call this point say x and this is become some t x.

And some other point again in a tangent vector, this will be t g. This is my point c, so for so line vectors can change. But the burgers vector is crystographically constant is just not change another important difference. Of course, between an edge dislocation and a screw dislocation is that the kind of screw we have constructed is what I call a right handed screw. And there is just there are two kinds of screw dislocations, the right handed screw and the left handed screw. But there is only one kind of an edge dislocation which is the normal edge dislocation which we saw so structurally.

There are two different kinds of screw dislocation; the right handed screw and the left handed screw. In a right handed screw dislocation, as you make this clockwise paths you will go in to the plane of the board, why if you make the same kind of circuit, you will come out in the case of a left handed screw. So, let us summarize the geometric properties of a dislocation which we have seen.

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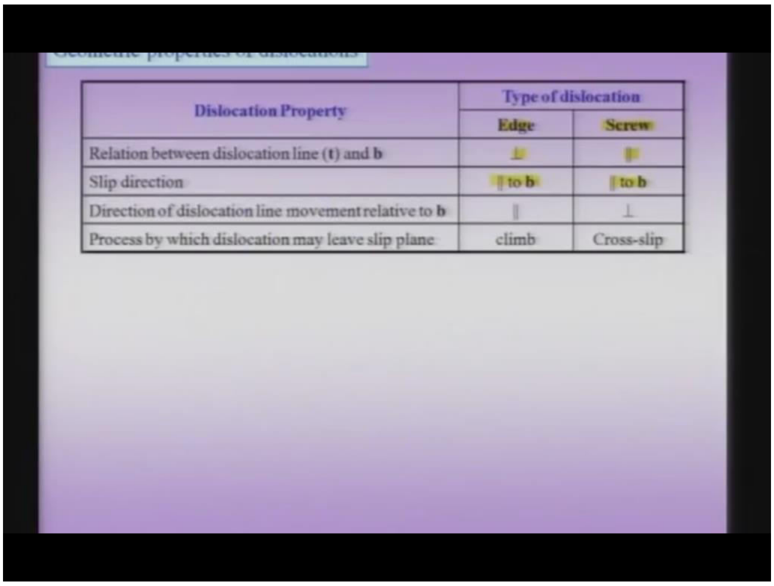

Now, so we have seen the two extreme possibilities, when it comes to dislocations; the edge and the screw we talk about the relation between T and b, the edge dislocation. In the case of an edge dislocation, the burgers vector is perpendicular to the line vector. While in the screw dislocation, they are parallel. The slip direction will always be parallel to b. It is not matter when edge dislocation or screw dislocation the slip will be determined by b. That is very clear. So, there is no doubt about that. So, the again we should not confuse the motion direction of the dislocation line to the slip direction that I some something which is not be confuse. So, suppose you look at the direction of dislocation line, moment relative to b then in the edge dislocation the b the dislocation line moves parallel to b and the screw dislocation it moves perpendicular to b.

But the motion of the dislocation line is not the slip direction, the slip direction has to be defining separately with respect to the motion of the dislocation line and the slip direction is always parallel to b. Slip step will always finally, when the dislocation leaves the crystal. It will be parallel and the step will be created which will have a magnitude b. This has been absolutely clear additional. We will not of course, this is we will note later that a dislocation of course, we are defined a slip plane can leave the slip plane. And it can do so for a screw edge dislocation by a process known as climb. And for a screw dislocation by process known as cross slip. So, this important geometric properties of dislocations have to be kept in mind at all times and this is what will determine their role when actually they determine slip that is role in plasticity.

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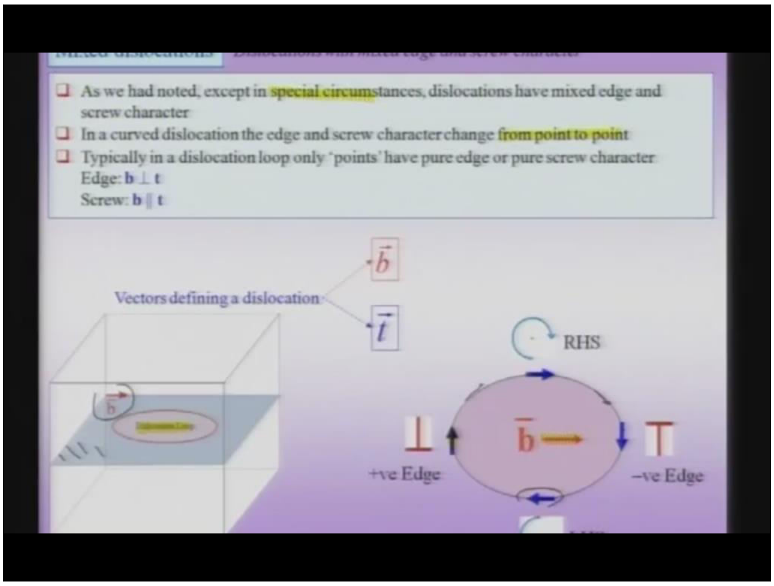

Now let us do not take a dislocation which has a mixed character that means they are neither pure edge dislocations nor they are pure screw dislocations. In fact we have noted already that only under special circumstances that dislocation would have a pure character and mostly they would have a mixed character. And typically if we have a curve dislocation line the edge screw character would change from point to point.

So this another thing and if you have a curve dislocation line, as in the case of a loop which is shown on here, a dislocation loop at the bottom figure, there only points exactly only one point or couple of points where in the dislocation would have a pure edge or a pure screw character. So, let us see look at this dislocation loop now. So, this is now and as we shall note later that a dislocation line cannot end with in a crystal and one of the ways they can a is an end on themselves for me of the loop. So, this is now at the dislocation loop in the crystal and now the burgers vector is drawn here of course, this is a schematic and therefore, this burgers vector remains constant irrespective of which point in the loop of like its entirely a constant of this loop constant for this loop, this plane which have shaded here is the slip plane.

Now, let me drawn show the figure on the right, we have this burgers or these dislocation loop and now in this dislocation loop you can notice that they are points where the t vector for instance is perpendicular to the b vector. So, this point is obviously is of edge character. As I go down, you will see that the edge the dislocation line is changing its character. So, this my t vector rotates it becomes horizontal. Then it rotates even further here and then finally, becomes opposite direction and rotates. So, from point to point the long this loop the dislocation line is changing its t vector and also its character at this point. You can see the point here, you can see that that burgers vector is parallel to the t vector and this is obviously pure screw character.

Then, if you go down here, you will see that the burgers vector is becomes perpendicular to the t vector and this is again edge character and this is again going back here and comes screw character, because, here my t vector parallel to the burgers vector. So typically in a curve dislocation line any point would have a mixed character and therefore, as I go from point to point the character of the dislocation changes. A few important questions we can ask that how do we decomposes dislocation in to the edge and screw character.

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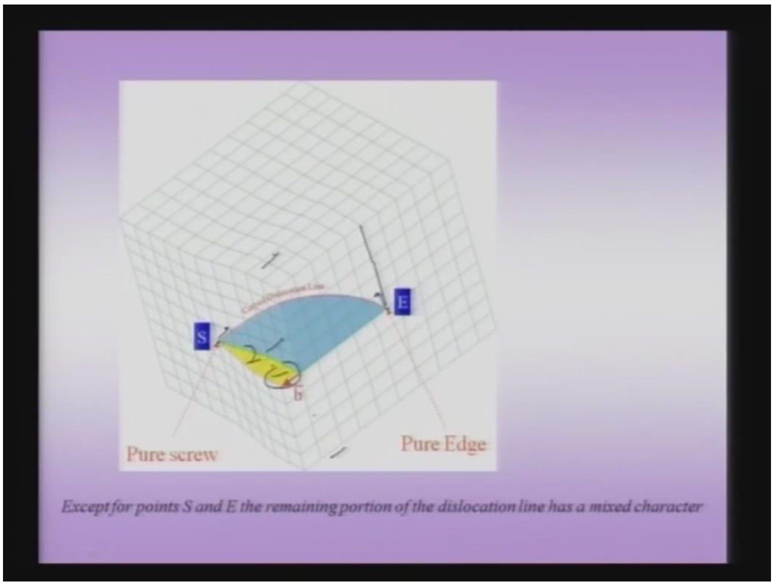

And how do I visualize, understand at each point here. So, any question?

Sir what do you mean by positive and negative edge and the screw dislocation?

Very good question! We will just come to that in a moment. So, there are some slides regarding that alone. This is now not a full curve dislocation. We got a full loop. But this is a quarter loops as you might call it and in this quarter loop, you can visualize the edge and screw components much better than in the case of the full loop. So, in this case, you can see that as before I told you the dislocation cannot end with in a crystal, it has to end on their free surface or as we shall see later, can end on note or it can it can close on itself forming a loop. In this case, the two ends of the dislocation line, it is end which is marked s which is marked e or ending on the free surface. But, important thing to notice now, this is my burgers vector b. And therefore, at this point the line vector which is the tangent to this t vector is parallel to b.

Because I am using more casual language, I am not using the anti parallel. Therefore, this is a pure screw character. This point and you can clearly see that how this slip plane is? Now which this plane is shaded in yellow is has been share to create this point. But now the dislocation line which is a curved line comes out and in this edge, in this point the b vector is perpendicular of a t vector of the t vector is inward. And in to this on this plane, same slip plane and is perpendicular to the therefore, this is a pure edge character here. And that can also be seen from this extra half plane which is presented. So, this pure edge region has this extra half plane. So, clearly you can see that this curve dislocation line has one terminal point e where in you can visualize. Extra half plane either point e which is purely, let us prove which is here fields like that means it is called the sharing pattern which is vary characteristics of screw dislocation. But if you just concentrate on this region, this corner you can see it is very. Because it is like pushing in the part, I was telling pushing in one part of the crystal with respect to the other and therefore, that edge characters reflected here the pushing in part. But if you look at here it is like you look at this region it is more like a sharing part.

I have shared this crystal and therefore, this screw part so in a sense understanding. This makes dislocation is somewhat or much more difficult then understanding this pure components. And the only way perhaps to easily understand them is to actually decompose the given dislocation, it will screw and edge component and try to understand what is their contribution to the material behaviour. So, this is a nice example where in you have a quarter loops which has which has screw and edge character its terminal points. But anywhere in between along the curve dislocation line it is got a mixed character.

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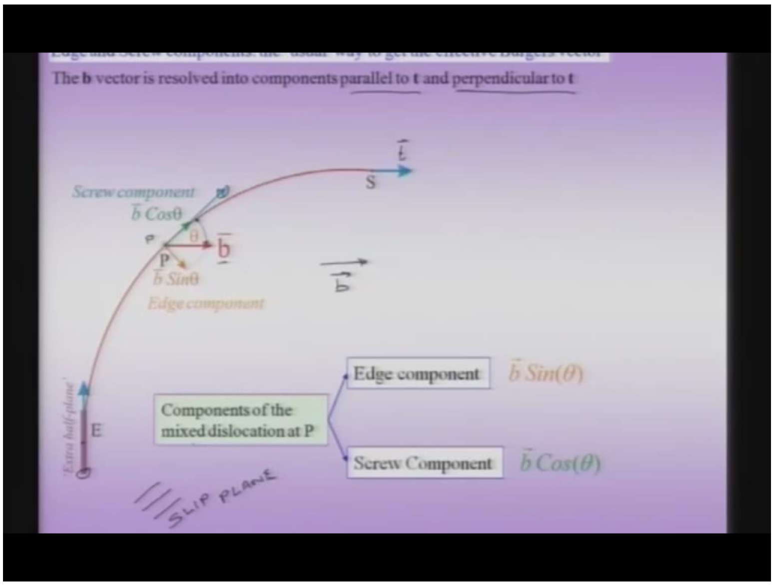

So how do I decompose now my dislocation in to edge and screw components to understand the edge and screw character. So, typically the way it is done is that and there is a word of caution here before I proceed. Further that the burgers vector is crystographically constant and here I am resolving the burgers vector nearly trying to understand its edge and screw components. It does not mean that the burgers vector has change direction. So, that point has to be noted and an alternate way to will see later to understand certain other aspects of dislocation. We can actually in fact to this the entire t vector rather than the b vector. So, I take the b vector and resolve it in to components back parallel to the t vector and perpendicular to the t vector.

So, here this is my pure edge part. This is exactly the same kind of loop I consider before a quarter loop which is one and which purely edge character and one which is purely screw character and now my burgers vector is in this direction b as shown in this figure. So, I have a b vector in this direction and this is obviously the b vector is parallel to the t vector which is blue colour. Therefore, b is parallel to t and its screw component and here this is an edge component and in this case as I as we saw for the whole plane of this slide is the slip plane. Now, so this my slip plane the whole plane of this is my and now if you look at this dislocation loop, then I know that the line vector for an edge dislocation contains my extra half plane or the extra half plane contains the line vector and which is what I have drawn here as a thick line here this is my extra half plane.

Obviously, those extra half planes are visualizable for screw dislocation or the mixed components that easily. But we will come in the next slide to understand how we can draw an effective extra half plane but, before doing. So, we will understand how to resolve this b vector. So I can take my b vector and resolve it in to a component. Now that this point for instance b, now the t vector or the line vector is the blue vector which is going like this. You can see the line vector which is shown blue colour and I can resolve my b and receiving that now my angle between the line vector and the burgers vectors theta.

So, I can resolve it in to component parallel to the line vector which is b cos theta and a component which is perpendicular to the line vector which is b sin theta. So, that perpendicular component I am showing in orange the parallel component, I am showing in green and therefore, my screw component is has strength of b cos theta and the edge component as strength of b sin theta. So, let me a revise the whole component thing again. So, I have component at the mixed dislocation at point b, it is got an edge component and a screw component. I find the edge component by first wall locating the angle between the tangent vector and point b. Which is the line vector with t burgers vector which is given by an angle theta then I resolve the b vector parallel and perpendicular to this line vector the parallel component is the screw component.

Because we know for a screw vector b is parallel to t is a screw component shown in green and it is a got a magnitude of b cos theta. While the perpendicular component has a component magnitude of b sin theta which is now my edge component. So, at every point along this dislocation line theta is going to change because the angle between the b and the t is going to change. And therefore, my contributions to my burgers vector is going to change are the components the screw and edge component are going to change along this dislocation line. Therefore, I can resolve a mixed dislocation in to parallel and perpendicular components and let understand and therefore, perhaps from it understand later on its stress fields and strain fields.

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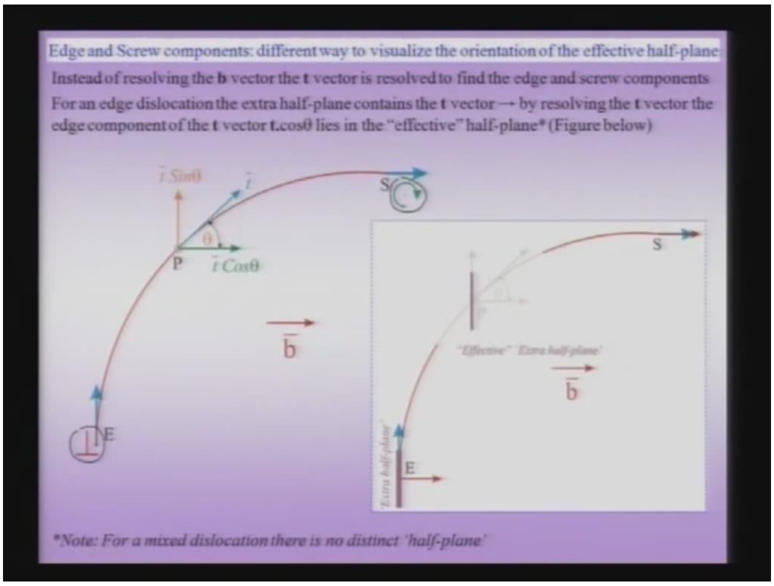

Now I can do another trick, the question I can ask further is that I have already drawn an effective then extra half plane at the point e which is a pure edge part. I have also drawn the pure screw part which is at s. How can I now try to understand where an effective half plane is? So, it is got an edge component of this lead is does not have an extra half. May be it can be visualized usually for a pure edge dislocation But can I still visualize an effective half plane and now how do I do that now what I do instead of resolving the b vector I resolve the t vector. So, I resolve my take my t vector and resolve it parallel to b and perpendicular to b. So, when I resolve it parallel to b, I get this t cos theta and perpendicular to b. I get the t sin theta and now I can draw an effective extra half plane like here which is shown in this figure, which is now parallel to the original extra half plane.

But it is got a thickness which is reduced by the factor of t cos theta or t sin theta. So we are so for consider, so let me revise what we consider so far, what we have consider is the edge dislocation. The screw dislocation and the mixed dislocation we also understood the important vectors associates with the dislocations and we understood the relationship between those two vectors the b vector the t vector and how they are different for the between the edge dislocation and screw dislocation. But we also have seen that the burgers vector is constant for the entire dislocation line.

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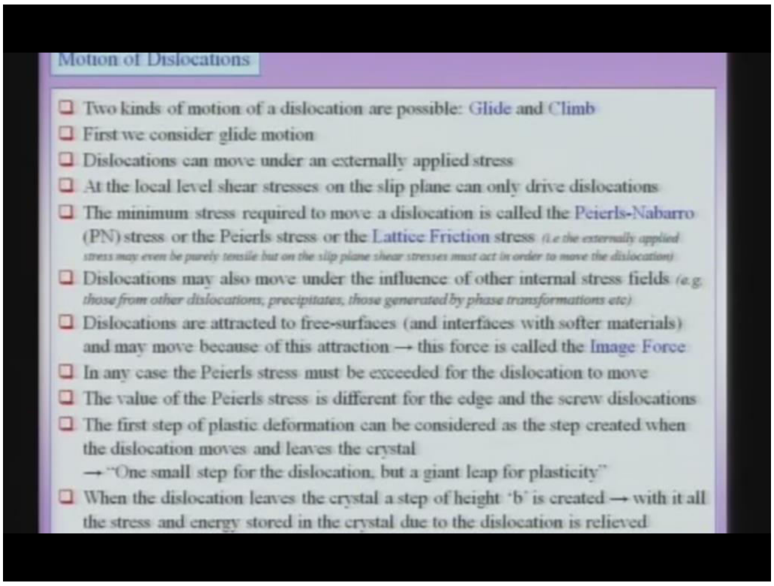

The next topic we can take up is a topic on motion of dislocations two kinds of motion of dislocation is possible and as we saw why are we considering the motion of a dislocation Because of the role of dislocation motion has an plasticity the other roles we already seen in of a dislocation But here we are concern with plasticity mainly the two important more the more dislocation motion are glide and climb and we will first focus on glide motion of the dislocation and typically at dislocation would move under the action of an externally applied stress and we have already noted at the local level share stresses are responsible to move a dislocation line that means even though macroscopically we may apply tensile on the other kind of stresses.

If we do not have share stresses of the slip plane level, that means slip plane it not face a sharing stresses then a dislocation cannot move by gliding action. Now, there is a minimum stress we need to apply to move a dislocation and this is stress is called the Peierls Nabarro stress are the are two more in a short formally Peirels stress and sometime also refer to as the lattice friction stress. So, again when I am talking about these kinds of stresses, these stresses are at the microscopic slip plane level and not the macroscopic stresses which we apply externally to the macroscopic specimen and we as already know. Even though if you might have a tensile specimen and you may be a purely applying a tens tensile load but, at the microscopic slip plane level, if you have a tension specimen for this cylindrical tensions specimen, the horizontal plane and the vertical plane do not have any share stresses.

But, every other in climb plane would face a share stress. And therefore, these share stresses can drive the motion of dislocations leading to plasticity this is what we see a strain or a plastic strain when you do a any actual tension experiment now. So, this part of this understanding is very important. Because often we have to understand the microscopic level to cause plasticity by slip or glide of the dislocation we need only share stresses dislocations may also move under the influence of other internal stresses for instance arising from other dislocation precipitates and we will also take up the case of a free surface or those stresses which is generated by phase transformations. So, there could be internal residual stresses which could be even for instance residual thermal stresses which can lead to the motion of dislocations.

So, even though we may not have an external externally applied share stress there could be other internal agents which could actually be giving a as to share stress of the on the slip plane finally leading to the motion of a dislocation. And are attracted to free surfaces and also, me interfaces that softer materials. And because of this attraction also, they may move and this force of attraction between a free surface and dislocation is called the image force. And we will try to understand later why is it call the image force and how does it affect my dislocation. Now, the minimum stresses as I pointed out that you need exceed so that its dislocation moves is called the Peierls stress and if you have a stress applied on the slip plane which is less on the Peierls stress, the dislocation would not move the value the Peierls stress is different for the edge and the screw dislocations.

This point has to be noted and in most important point, is that the merely motion of the dislocation cannot be considered as plastic deformation and of course, when we talking about gross macroscopic gross deformation. we are talking about the collective motion of a huge number of dislocations But at the microscopic level or at the atomic level the first step of plastic deformation still involves a dislocation moving on its slip plane and leaving the crystal to create a small step of burgers vector length. So, when the dislocation leaves a crystal, it creates a small step and this step can be consider as the one small step for a dislocation but, a giant leap for plasticity. Because if this step does not occur as long as dislocations keep moving within a single crystal there is going to be no plasticity.

But the step as I pointed out when we are discuss the topic on understanding dislocations, we set the single motion of dislocation has perhaps negligible contribution to overall plasticity and macroscopic share changes. And therefore, there we need to consider collective motion of a large number of dislocations along with what we may call intersections dislocations etc. But never the less this one step which the dislocation creates when it needs the crystal is a first step of plastic deformation or the first small step of plastic deformation. But then this under lying mechanism for most of plasticity which includes for in sense of rod of aluminium which I may bend to a new shape, the small step is only a b small b in height in dimensions.

But if many dislocation lead the crystal of the same plane, in this you could create a large step which could be hundreds of burgers vector in height and if you take deforms specimen of copper and then sea thunder even an optical microscope you will see lines on the surface which you call slip planes and these are coming from these large steps which have been created by many dislocations moving on the slip plane and leaving the crystal. But when this dislocation leaves the crystal, it relives the entire stresses associate with and it is now only a surface step and no longer can it be called as a dislocation.

So, the sea does to exist a dislocation it leaves a final mark as a small step of the height b of their width b on the surface. So, this is where we can consider the dislocation to have died or left the crystal. So, let me summarize the slide dislocations can move on the slip plane and this process is called as glide edge dislocations can leave a slip plane and this takes place by the portion of a process known as climb. So, edge dislocation only can climb, later on we will see the screw dislocations of an alternate path to leave the slip plane which is known as gross slip. Now, the region of dislocation has to always be a share stress on the slip plane and this can be from an externally applied shared stress or from one of the residuals stresses present within the material.

So, it could be one of these and it could also be free surface influence of free surface which is now causing the dislocation to move the minimum stress you need to see it. For a dislocation move is what is calling the Peierls stress or the internal friction stress and the reason for this very simple because we when we look at edge dislocation for instance then a picture we go we go back here it is a Meta stable equilibrium state. It means even though it cause energy for the crystal and this dislocation would like to leave the crystal, but never the less its lock up in a small energy minimum else small value a. Therefore, if I have to move this to this dislocation from this position which is marked here to the next position which is exactly identical cryptographically, that is why this is now a burgers. The slip is characterized by the burgers vector which is a lattice translation vector.

Therefore, this moment has to go up hill in stress or up in and therefore, I need to apply external stress. So, this is the stress I need to overcome so that the dislocation move a and already seen that this stress orders a magnitude smaller then sharing an entire crystal. So, finally, if I am crossing my Peierls stress, that dislocation will begin to move and finally, it can leave a crystal create a small step of burgers vector height which is which is perhaps the first step towards any kind of plastic deformation.

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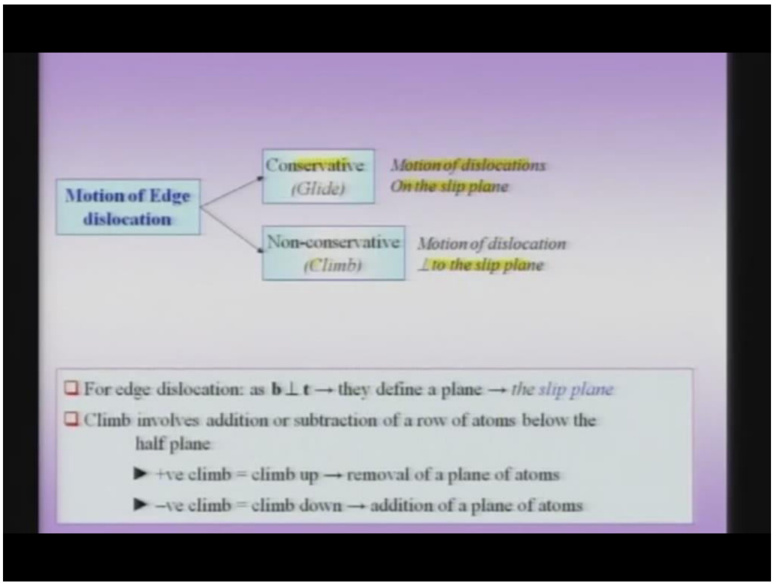

Now as I pointed out the motion of an edge dislocation can be conservative which is the motion of a dislocation slip plane is called a conservative motion. And, if the edge dislocation moves perpendicular to its slip plane the slip plane means and particular slip plane then this process is called climb and it is a non conservative process. When I mean a non conservative process, it that means it involves mass transport motion on the slip plane just involve share stresses. But motion from one slip plane to a parallel slip plane would involve mass transport and we will see how that is so.

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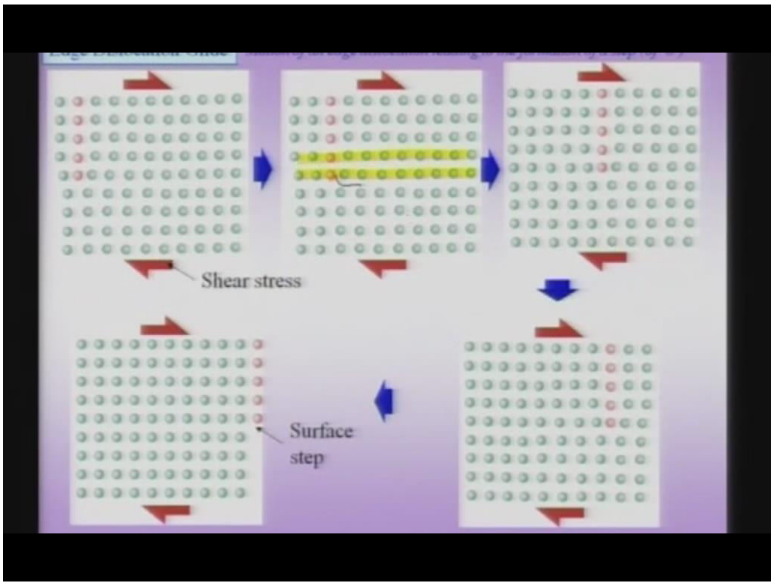

Because now the climb process, so let me see. So, suppose now I have a dislocation string in the crystal here and now this is my slip plane. Now, if this slip plane has to move to the next slip plane parallel to itself then automatically this row of atoms where the dislocation ends has to remove. We removed and of course, how this can happen is that these rows of atoms can actually move in the crystal and go and suppose there where vacancies somewhere in the crystal. Here this row of atoms could go and sit in the vacancy.

And therefore, the vacancy concentration on the crystal would be reduced. But, this row of atoms would be caught rid of and therefore, now instead of this being my slip plane, this slip plane would have move one step upward and this will be my slip plane. So, non conservative climb of edge dislocations involve motion of some mass transport and suppose, I am now talking about this slip plane going downwards, that means I am talking about negative climb, that means slip plane is coming down from this plane to the next plane which is parallel to it automatically.

That means that I need a row of atoms to common condense here and obviously that means that this row of atoms has to come from somewhere within the crystal and this would for instance these atom can defuse and come here this would actually lead to an increase in vacancy concentration in the crystal. So, positive and negative climb are possible leading to the change in slip plane of above or below for an edge dislocation and this negative climb as we saw involves addition of plane of atoms and so this is not just me a really a one atom here. But entire row of atoms going in to the plane of the slide and therefore, I need to add an entire row and this would lead to a positive or negative climb.

So, let us focus on glide first and in this case you can see that if I am applying shares stress on a crystal, you can see that my dislocation is now here sitting in this place. So, as I apply share stress we can see that the dislocation slowly moving to its right side. So, it is come to the next position it is moved a little further down here and finally, it of course, it comes little more towards as right surface and finally, it leaves a crystal creating an extra step. So, this step height of the step is of the order of b. So, this is my b this step.

So in this case there is a dislocation within the crystal. The second case also there is a dislocation in the crystal. The third case and the forth case. But here there is only a surface tab and there is no dislocation in the crystal all the stresses and energy associated the dislocation have in relieved at but, a little extra energy is involved in creation of the extra step. Because now there is an increase in surface area, but never the less the dislocation this see this to exists remain it is leaves a crystal. Now, this deformation which has been created here is permanent and this will remain in the crystal.

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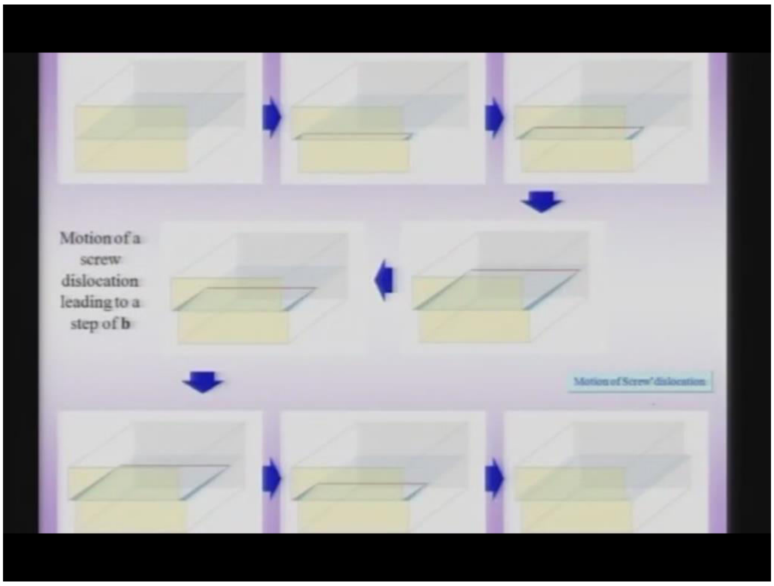

So, when I am talking about a motion of an edge dislocation of course, you can simply visualize this in even a two dimensional figure that actually this is my slip plane now and the dislocation is moving from one step to the other and therefore, finally, it leaves the crystal motion of a screw dislocation is slightly more difficult to visualize and these set of slides hope to make you understand how the dislocation moves. So, you can clearly see suppose I have a perfect crystal on the which is shown on the top figure here then I have a figure with a dislocation line which is shown in red here rite and when the dislocation line moves.

So this is my now curved planes here and the dislocation line moves inward in to the crystal. The part which is shared keeps on increasing. So, it moves here from this and then downward here. You can see that so have to here and finally, two more here. And therefore, finally, you can see that I think therefore, path is after this I think the next slide should be this one. After that this next larger share, then this one is the larger share and finally, this larger and this is the last step before which that it leaves the crystal creating a step. So, we run there bottom right hand figure you can see that dislocation is left the crystal and created a step.

Now, the step the dislocation was moving in a direction in to the crystal. So, it was at the direction of motion of dislocation while the step has been created on the right hand side. So, this something which is very important very different from the edge dislocation where in the dislocation was moving on the right hand side and the step was also created on the same side. So, here the step has been created on the right hand side and side this is like tearing a crystal and producing a step on the right hand side. So, this blue plane in this case which is the plane between the top and bottom half is now my slip plane in both cases. Of course, I am finally, getting a step of distance b. So, this is my step of burgers vector right that much is very clear.

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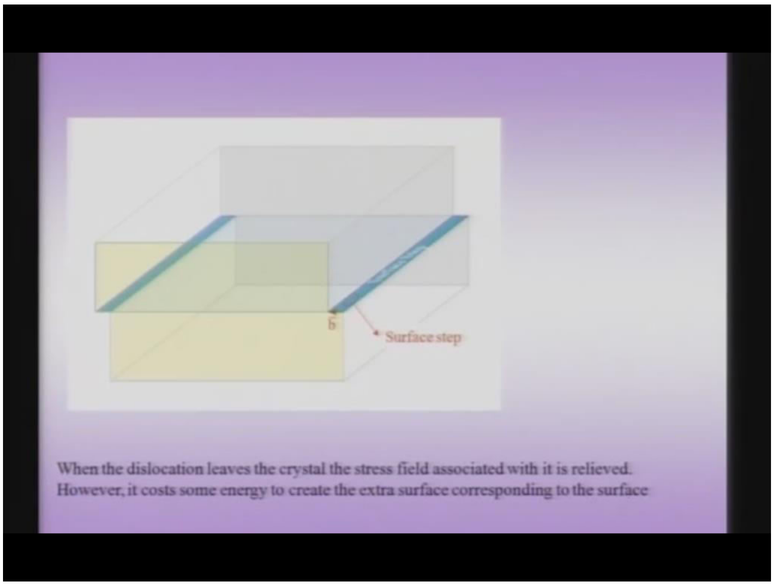

So this is my surface step which has been created by the motion of the screw dislocation. And as before all these stresses associated with the screw dislocation are relieved and, but a small energy is added to the formation of this extra step which is now I surfaced.