Properties of Materials (Nature and Properties of Materials: III)
Professor. Ashish Garg
Department of Material Science & Engineering,
Indian Institute of Technology, Kanpur
Lecture 26
Dislocation and Slip 2

So, welcome again to the new lecture of the course, Properties of Materials. So let us just a brief recap what we did in last lecture.

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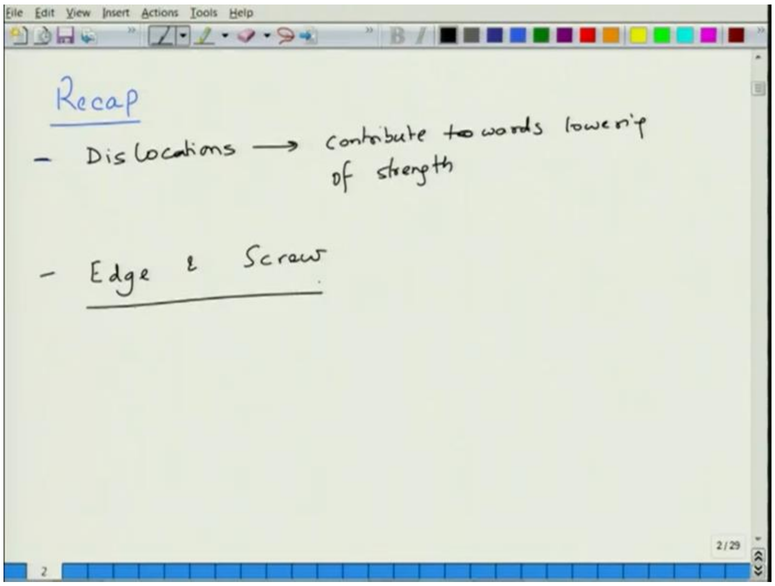

So, in the last lecture we basically introduced the topic of dislocations. So, we just mentioned that, dislocations are the ones which contribute towards, lowering of strength and then we just briefly started looking at dislocations. Dislocations are of two types, edge and screw, dislocations and we were looking at their characteristics. So just to, just for the ease of visual appreciation, I have, I am going to show you a PPT, in this lecture. So just, we will not, we already had the discussion in the last lecture. So, we will just go through briefly about it.

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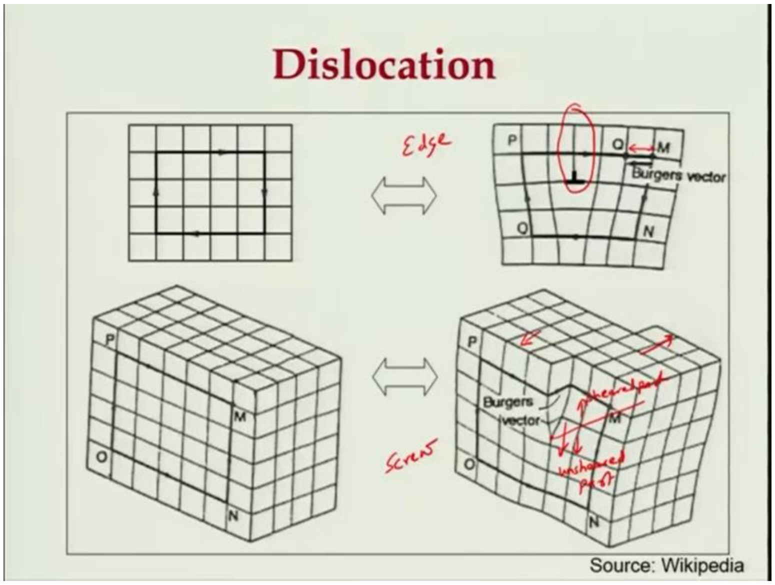

So, this is what dislocations basically are. So, dislocation if you look at the perfect crystal, this is what it is. So, if you start form P, you to M, M, N. If you start form M, you go to N, you go to O, you go to P, you go to M back again, by taking. So, number of steps up and down, number of steps left and right are similar and you reach the same location by going up and down and left and right.

But if it is a imperfect crystal, supposing you have the extra row of atoms here. So, this is extra row of atom. Then when go form M to N and N to O and O to P and then again P, if you want to go back form P to M, you have to take this extra step because the number of steps that you took form N to O, is equal to number of steps form P to Q.

So form going to Q to M, you have to take this extra step, this extra step is Burgers vector and so this is what is the edge dislocation. But you can also have a screw dislocation, in which you shear one half of crystal with another half of crystal by applying shear stress. So, when you apply shear stress on this direction, this part of the crystals shears and this line which runs through the crystal in this fashion, this line marks the separation between this is the sheared part and underneath, this is the unsheared part.

So, if you keep applying the stress, this line will move in this direction, making the whole crystal sheared after a while. So this is what a screw dislocation will do. So, this a edge dislocation and this is the screw dislocation.

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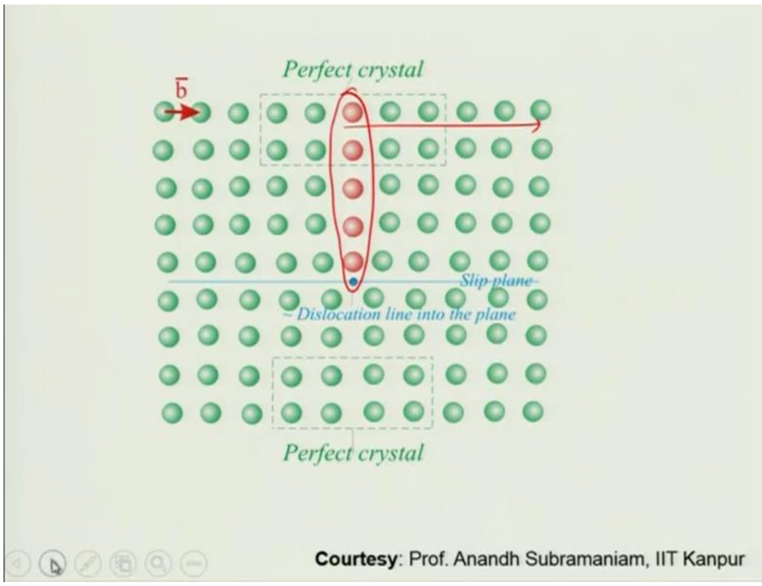

And so this is a perfect crystal and so this is what we defined, so you have this extra row of atoms in the otherwise perfect crystal you have this extra row of atoms which has been put and this extra row of atoms is going to move in this direction or in other direction and the extra step we created in Burgers vector v, b.

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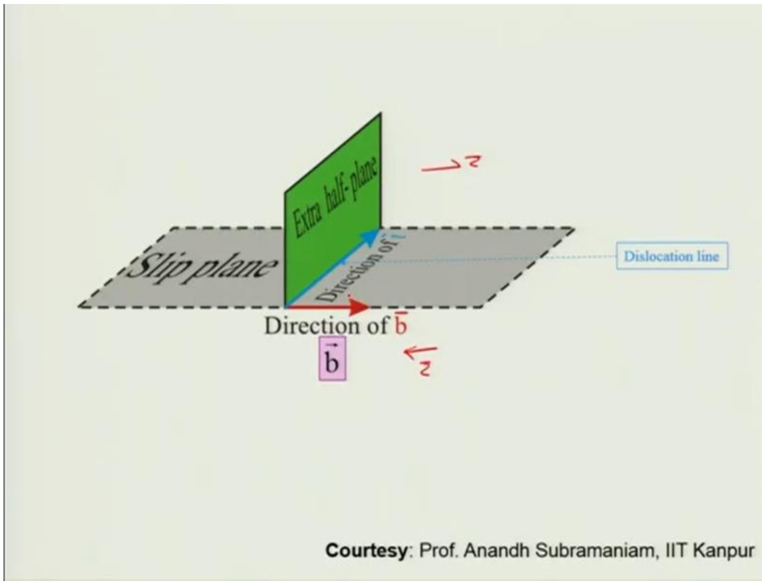

And the plane one which this extra row of, extra plane of atoms moved can be visualized in this fashion. So, you have this slip plane, in the slip plane this extra half line will move either to the left, either to left to or the right depending upon the stress. But and the line adjoining this extra half plane is slip plane is the slip line.

So, this blue one is the, the dislocation line and this dislocation line has a certain relation with Burgers vector. So, it is perpendicular to applied, so this applied stress tau. So, you can see that Burgers vector is parallel to applied stress and both Burgers vector and applied are perpendicular to dislocation line and the dislocation line moves in the direction of applied stress, this is for the edge dislocation.

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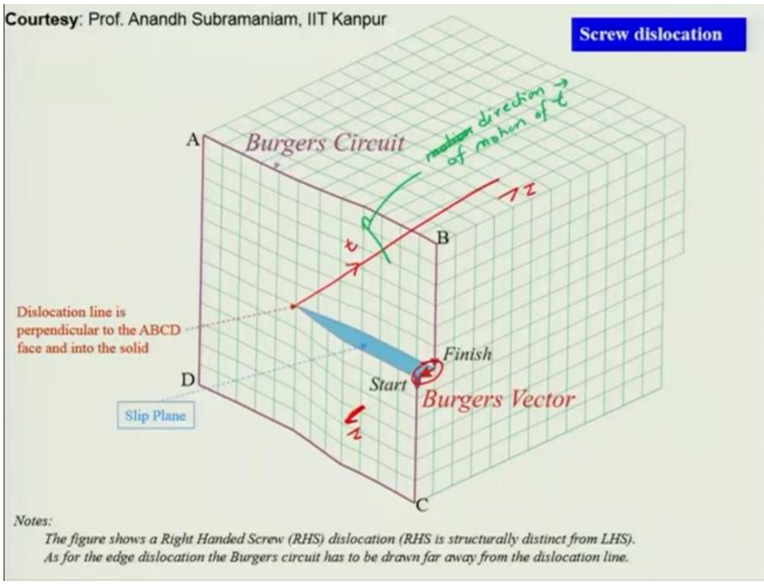

This is the screw dislocation, so by the way all this slides are been taken form Professor. Anandh Subramaniam, who have made very nice illustrations, they are available online as well. So, this is the illustration of the screw dislocation. So, this is Burgers the circuit that we draw. So, when we go form A to B, B to C and C to D, D to A.

So, A to D should have been equal to B to C but there is an extra step that is created in between which is, this burgers vector. So, here the dislocation line is perpendicular to this A,B,C,D to that is, it runs crystals in this fashion. So this is your t. So here the Burgers vector is parallel to the dislocation line and the stress that you have apply is in this direction. So, this is the stress direction.

So, when you apply stress in this direction that as you apply the stress the, let me just change the color. The dislocation line is going to move to this direction. So, this is the direction motion, direction, direction of let us say motion of t. So, t moves perpendicular to the applied stress and as a result this motion is also perpendicular to the Burgers vector. So, when you keep moving it, it will become into a perfect crystal and you create a step.

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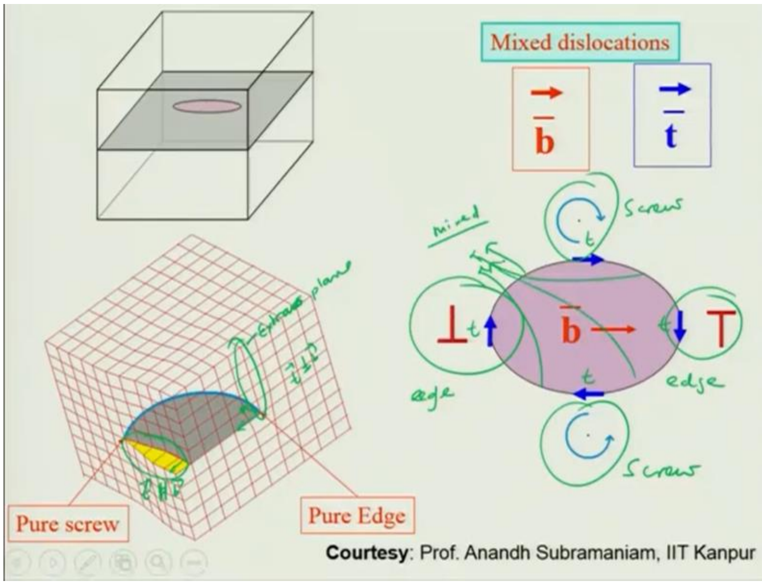

In reality what happens is that, we have a dislocation, which could be something like this in a form of loop or it could be in this in which on one side if you look at the crystal it looks like a screw dislocation. So, this is the screw component, because the burgers vector, parallel to the slip line. But here if you look at this part of the crystal, this is the edge part.

So, this is the extra row or extra plain and here you can see that the Burgers vector in this direction and t is in this direction. So, here t is perpendicular to b and here t is parallel to b. So, as a result you can see there is a loop there, you can have this in the form of loop. So, if this is the overall Burgers vector that you have, wherever you have b, parallel to t that will make a screw dislocation and wherever you have and the screw dislocation is depicted by these screws.

So, this the right hand screw, this is the left hand screw or you can say this is the clockwise, this is the anticlockwise and so this is negative generally, screw dislocation this is positive screw dislocation. So, you can see that this is edge, this is edge because b is perpendicular to t and here, so this is t, this also t. So, dislocation line is t and wherever b is parallel to t its screw. So, these two are screw and wherever they are not this would be mixed. So mixed this, that and that all of these will be mixed dislocation.

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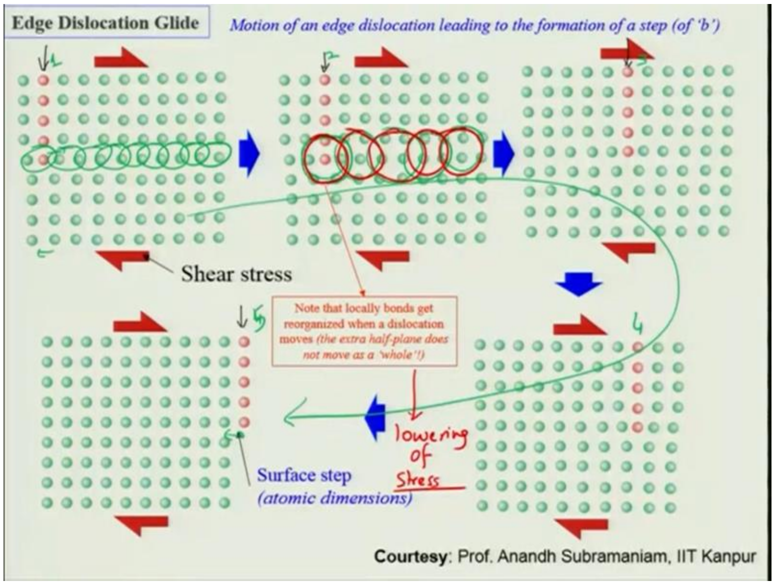

So, how does this dislocation move basically the motion of a dislocation leading to the formation of step. So, let us say you have this extra row of atoms here, you go from here to here. When you apply shear stress, so this extra row moves to the next one. So, which means this row goes in this fashion, this will come forward.

So it move two position. So, this is position 1, position 2 then it moves to let us position, I do not know may be 3, it goes to position 4 which is the steps. So, it creates the characteristics step that you, it comes to position 4 and then it goes to position 5.

So it goes in this fashion, creating a surface step. So, basically what happens here is when the dislocation moves, initially it had bonds with these to atoms then it creates bond with these two atoms and it will create bond with, these, these, these, these and these. So, essentially what it does is that, it need to break bonds with, one of the atom. So, basically these atom, these bonds locally will get reorganized when the extra half plane appears to be moving. So, it is not the whole plane if actually if it is moving which is, it is just a local reorganization of few atoms.

So, this group of atoms is getting essentially reorganized as you keep applying the stress. So this, you can say this zone keeps moving forward. So, it not the whole bunch of atom which are moving it is just this bunch of, it is just this local group of atoms which are moving forward to make it, to make it look as if whole plane of atoms is moving, giving rise to the finally formation of a step, so this what you create.

So it is this, this local, local bunch of atoms which reorganize themselves when the shear stress is applied, not the whole lot of atoms and that is why you know stress is lower, this leads to, so note that locally bond get reorganized when a dislocation moves. The extra half plane does not moves a whole and this is what leads to lowering of, of stress, because you are not moving all the atoms with respect to all other atoms, you are moving just local group of few atoms to, to make this happen.

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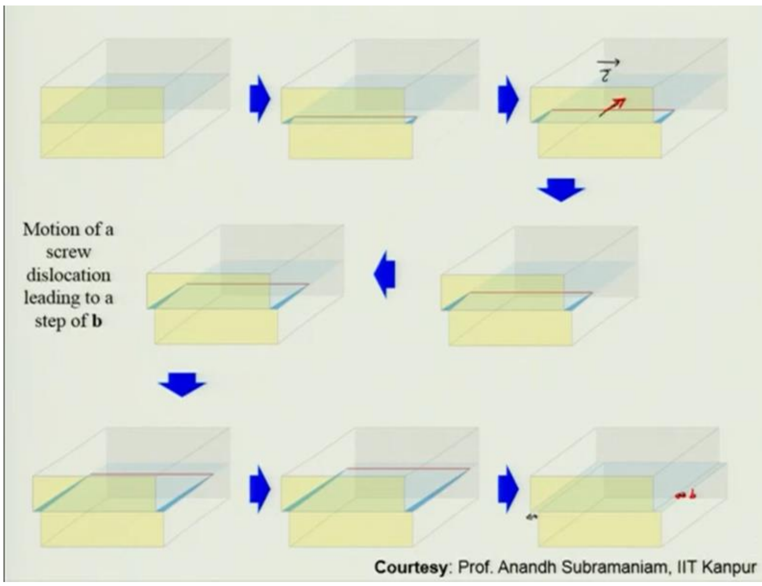

Similarly, screw dislocation if you have a screw dislocation like this, this is a prefect crystal this is the screw dislocation and as you keep applying the stress in this direction, this dislocation line moves in this direction the step gets created across the whole crystal when you come here finally, you have this extra step b.

So, this is the screw dislocation again giving rise to a, to the creation of a step. So, these dislocation together they gives rise to what we call as formation of step which is similar to what we see in slip. Formation of slip step is very similar to, the kind of steps we form in via motion in dislocations.

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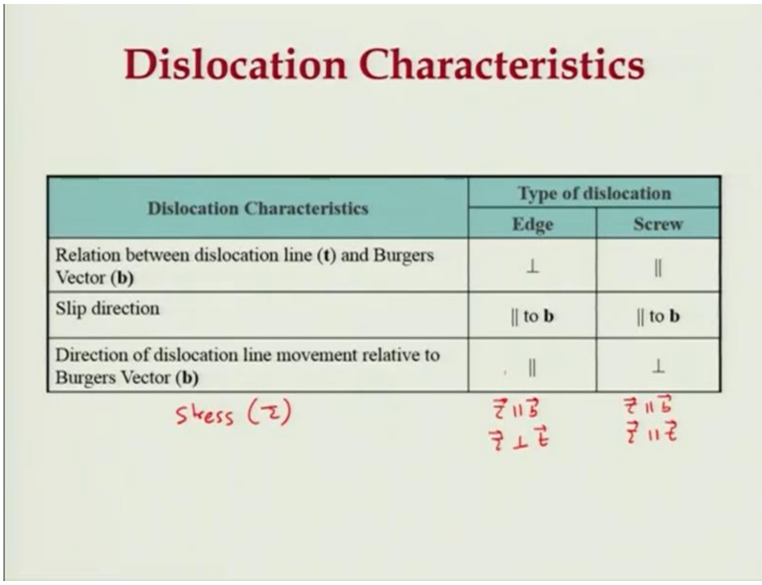

Dislocation Characteristics	Type of dislocation	
	Edge	Screw
Relation between dislocation line (**t**) and Burgers Vector (**b**)	⊥	||
Slip direction	|| to **b**	|| to **b**
Direction of dislocation line movement relative to Burgers Vector (**b**)	||	⊥

So, just to summarize not the dislocation characteristics. For edge dislocation Burgers vector is perpendicular to dislocation line, the slip direction is parallel to Burgers vector and the direction of dislocation line motion with respect to Burgers vector. So, the dislocation line moves parallel to the Burgers vector.

For screw dislocation the Burgers vector is parallel to line, the slip direction is parallel to Burgers, the slip direction is parallel to Burgers vector in both the cases. Whereas the dislocation line moves perpendicular to the, Burgers vector in case of screw dislocations. These are some fundamental differences, that you can and you can also write like this stress.

So, stress. So, in case of edge dislocation, tau is parallel to b and here also tau is parallel to b. But here tau is perpendicular to t, here tau is parallel to t. So, you can write relations as well. So, these are all related, depended upon each other if you get out, if you work out some of them, you will work out naturally the other ones.

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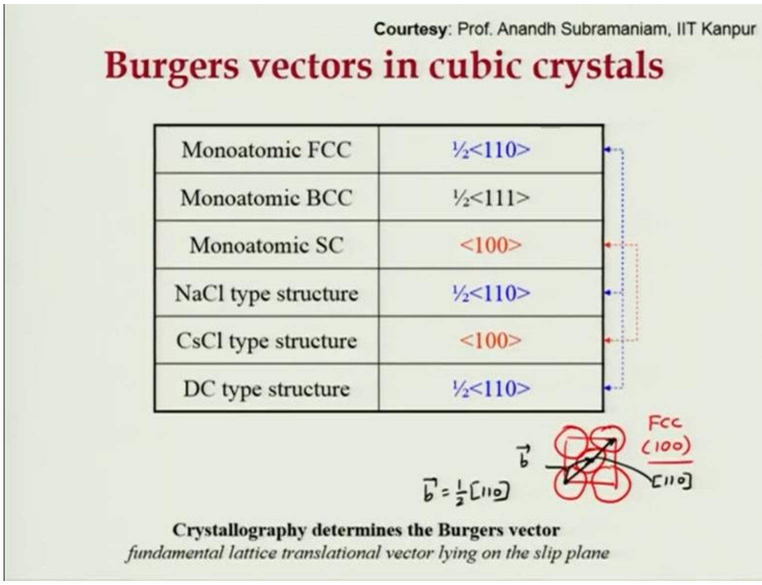

And then if you look at Burgers vector in. So, Burgers vector is basically along the sleep direction. So, slip direction is the direction which is closed packed direction. So, burgers vectors in cubic crystals are defined. For example if you take Monotonic FCC, the 110 direction is the closed packed direction. So, if you look at FCC the face of FCC is this, so this is FCC and this is the 110 direction. So, this is 100 plane of FCC. This is the 110 direction. So, the Burgers vector is form these atom to this atom. So, this is the b. So, b is half 110.

Similarly, in case of BCC, so let me just go to the, in case of BCC, this is half 11, in case of monotonic simple cubic it is 100 and the moment when you have this ionic solids it changes to half 110 and 100 because you need to an atom from, you need to move, let us say if you A atom you, can only move to A atom, you cannot from A to B, A to B is not a Burgers vector A to A is the Burgers vector, shortest distance that you require to move from A to A position is a Burgers vector. So, let me just go through little bit.

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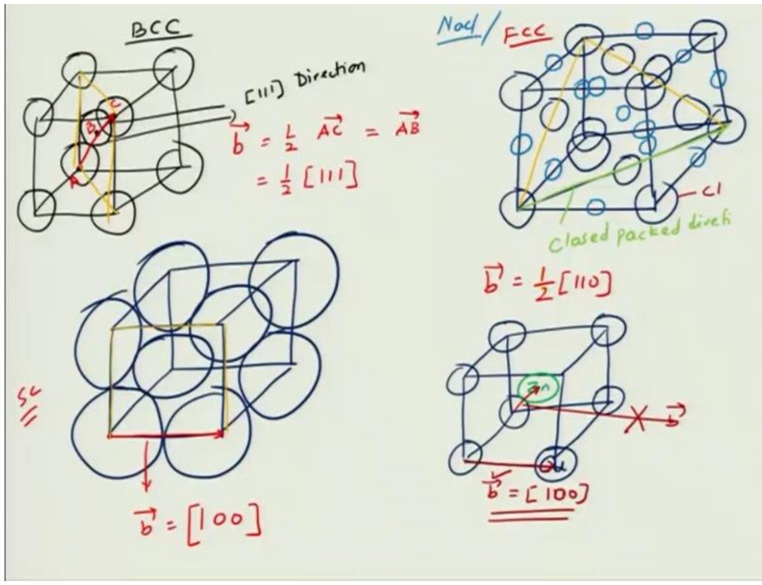

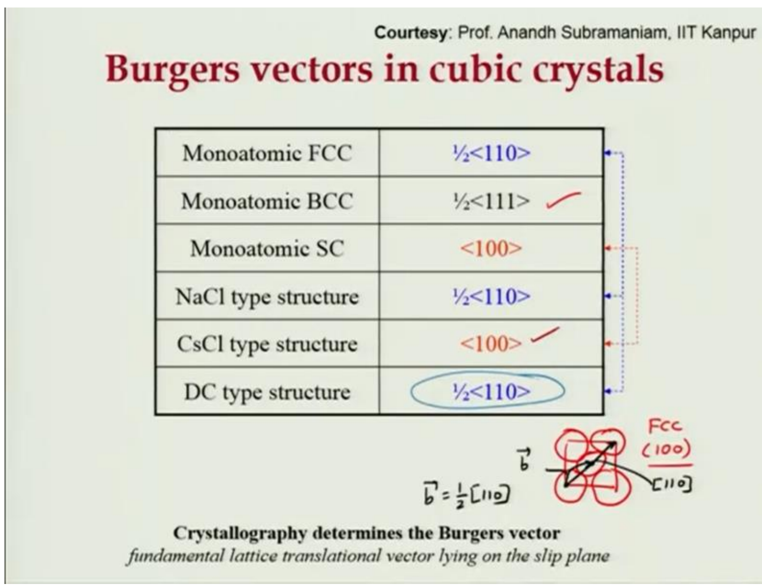

In the next one, so this is for the example BCC and you have one extra atom in the center. So, assuming that all of them touch each other, the closed packed direction is the direction which is this direction. So, closed packed direction touches this, this, this and this. So this is your, you can say 1 1 1 direction for BCC.

Let me use a different colour may be. So, this is the closed pack direction, from A it goes to central atom B, it goes to corner atom C. So half of, so Burgers vector will be half of AC and this is half of 1 1 1. This is Burgers vector in BCC that is what we said. So, it goes form one atom to the next nearest neighbor.

So, A to B or you can say is equivalent AB. If you take FCC or let us take simple cubic first. So, this is simple cubic. Let us say this is the atom these are all touch each other. So, when they are touching each other, than the closest direction is the cubic direction which is form here to here. So, this is what is the b and this will be equal to 1 0 0.

If you look FCC, you have one here. I cannot draw the, it is difficult to draw structure with touching atoms. So, let us not make the touching atoms, there is one here, one here, one here, one here, one there and one here, all these atoms within a plane touch each other. So, let us say the closed pack direction is, this is the closed packed direction.

This is the closed packed direction. This will be on one of the plane let us say. So, you can also see the, visualize the planes. So, this would be on this plane, this will be the sleep plane. The plane in which the dislocation will move. In this case the plane will be, of course this plane, in this case the plane will be this plane 1 1 1 type of plane. So, this direction will be half of, so this direction will be half of 1 1 0 that is, Burgers vector of FCC.

This is simple cubic. Now if you take a cesium chloride, for example crystal, if you take a cesium chloride crystal or copper zinc system, in copper zinc let us say if you have this king of copper zinc where this is copper and then you have zinc somewhere in between. So this is zinc, so this is zinc and these are all copper.

Now if you want to determine the Burgers vector, the Burgers vector will be. So, this would not be Burgers vector you can go form copper to zinc but you are not going form. So, this is not b. b will be this this. So, this will be b. So, although it looks like BCC it is simple cubic lattice. So, to go from one copper to copper, to go form one zinc to zinc you have to move in 1 0 0 direction.

So, that is why in the previous slide we said for the cesium chloride kind of structure it is 1 0 0. For sodium chloride it is FCC structure again to go from, to go from, if this is sodium chloride this will be chlorine atom and sodiums will be sitting. So if sodium chloride, sodiums will be sitting here and again to go form one chlorine to another chlorine you just need to follow the same direction.

So, this is for both FCC as well as NaCl and diamond cubic will have direction again, diamond cubic is again FCC kind of structure. So, again need to follow 1 1 0 type of, half 1 1 0 type of vector. So, these are the direction you need to follow for Burgers vectors in crystals. So, this gives you a fairly idea about what dislocations characteristics are in crystals. So, let us just, so we have basically discussed what dislocations are and if you wanted to follow more details then you need to go the course structure of materials to know more.

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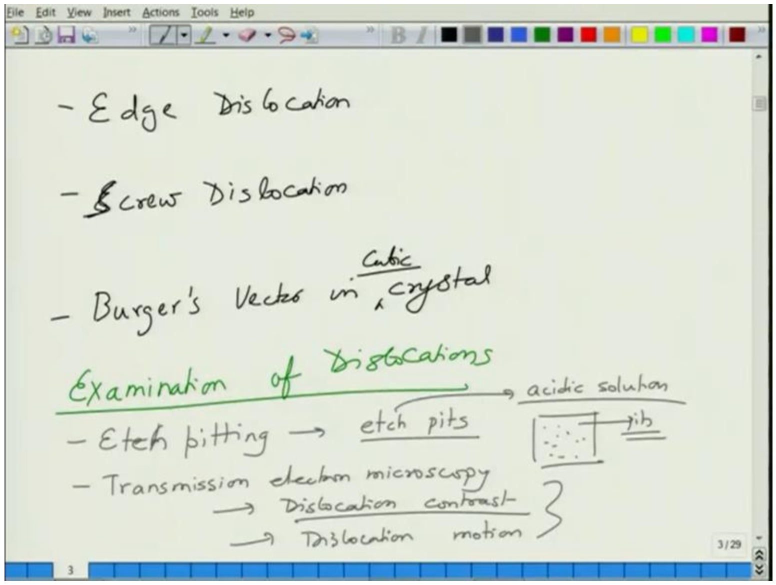

So, what we have done is basically till now we have looked at edge dislocation and screw and how to define the Burgers vector in crystals, especially cubic crystals. Now what we do is that we also see how they move in the crystals. Now how do you examine dislocation in a given materials, there are various ways of examining. So, basically dislocation can be examined by, so basically what I mean is that how do see whether you have dislocations in the crystals. You can see them by the technique called as etch pitting.

So, essentially you use a etchant and dislocation being a, being a high energy or high stress area gets etched preferentially as compared to, so basically you see etch pits. So etchant is basically a sort of a acidic solution and this acidic solution is applied to crystal in a very controlled manner and the places where you have dislocation, which terminate on the surface and they get etched more than the other regions.

So, basically you start seeing them as this kind of pits. So, these could be the dark pits which are visible in the micro scope in the crystals you can also see them using transmission electron microscope. So, basically they show what we call as dislocation contrast, so you can see them dislocation, you can also see dislocation motion in TEM.

So, these are very specialized topics, I am not going to details of these but basically this is how they are going to move. Now, how does, so having known this about the dislocations now the next question is how do you translate this information about dislocation motion into slip phenomenon. So, for that I am again take help of another PPT to just to show you the, illustrate the principle of. So, basically what I have here is.

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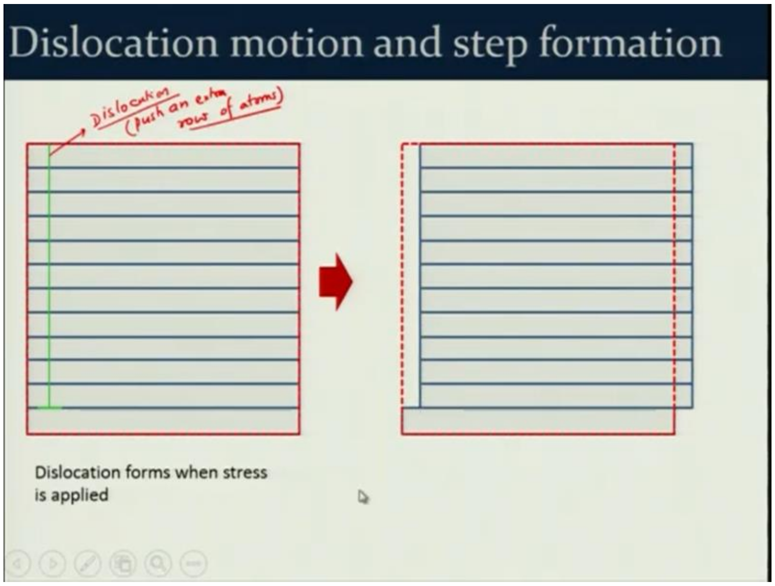

So, let us say on the left we have the perfect part of the crystal, this is the prefect crystal, in this crystal if we look at on the left I created dislocation. So this is a dislocation that we create. So, this dislocation is basically done by pushing an extra row of atoms. So, we basically we push and extra row of atoms from the neighbor.

So, push and you cannot bring atoms form anywhere. So, it has to come from somewhere, it has to come from within the crystal itself. So, push an extra row of, row of atoms. So, dislocation will form when you applies stress, when you applied stress. So, these are various, let us say stack of planes. So, what happens is that when you apply stress, this dislocation will move out and it will create a step in this direction.

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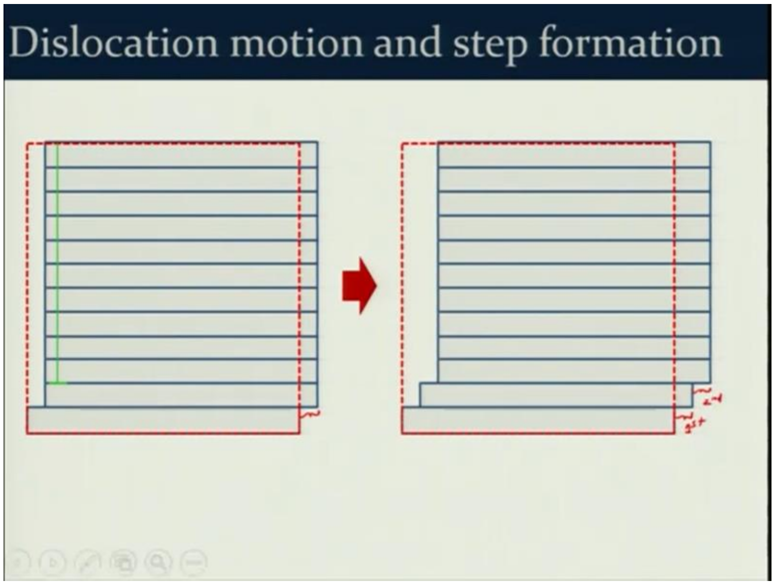

When you apply further stress you create another dislocation in this manner. So, this is another dislocation that is created, this will push the next plane to move out of the crystal in this fashion. So, you created first step here. So the first step is here, now this is the second step. This is the first one, this is the second step that you create.

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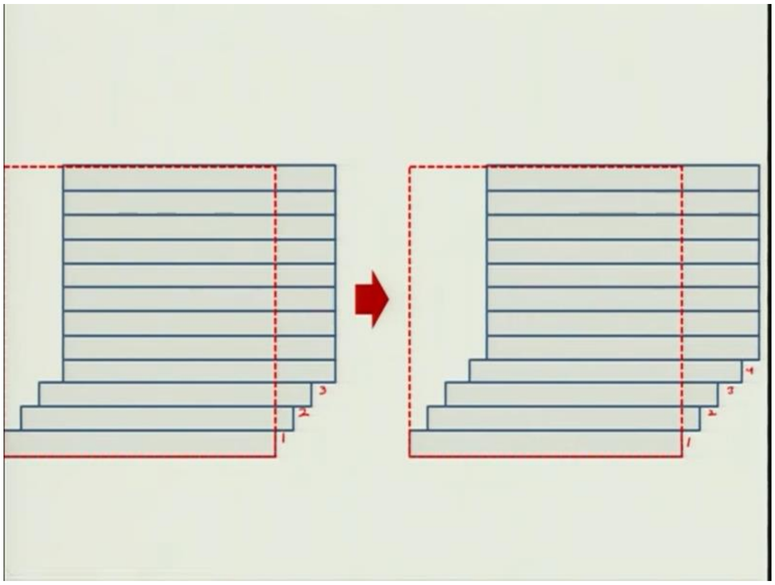

So, if you keep doing that, so you had the first one, you had the second one, then you create third one, then you go 1,2,3,4. So, you keep creating the steps and when you look at it on a microscopic scale.

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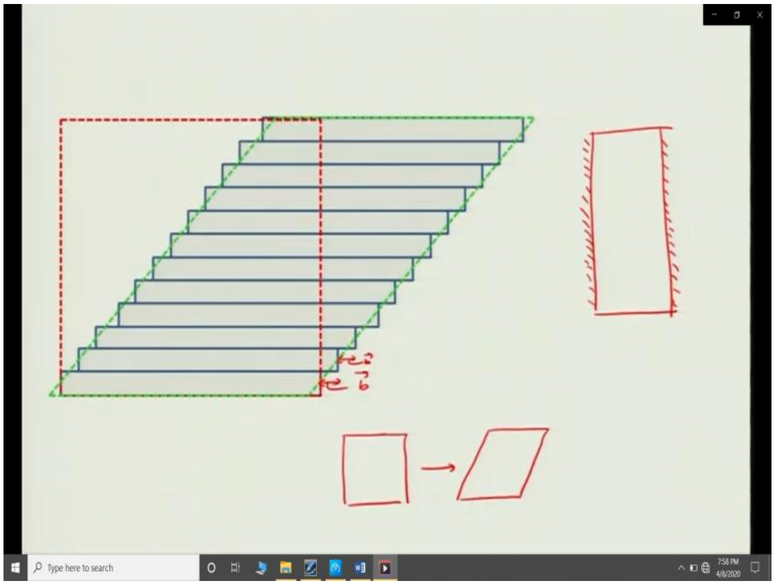

This is how it will look. This was the red dots or the red dashes show the original crystal with was a square crystal and by the motion of dislocation in the successive planes, it has given rise to a sort of parallelogram. So, the crystal has become from a rectangular crystal to, it has come to a different shape in this form and this is what basically is the deformation you have gone from this shape to this shape and this is what has happened with the and each of this step by the way is equal to nothing but Burgers vector.

So, this is Burgers vector. So, multiple Burgers vector you create on the surface and that is why when you looked at the slipped crystal the slipped crystals will look something like this. If you look at them under the microscope, they will show you these steps from the surface. So, this is how it will create the steps on the surface and to look like a deformed body.

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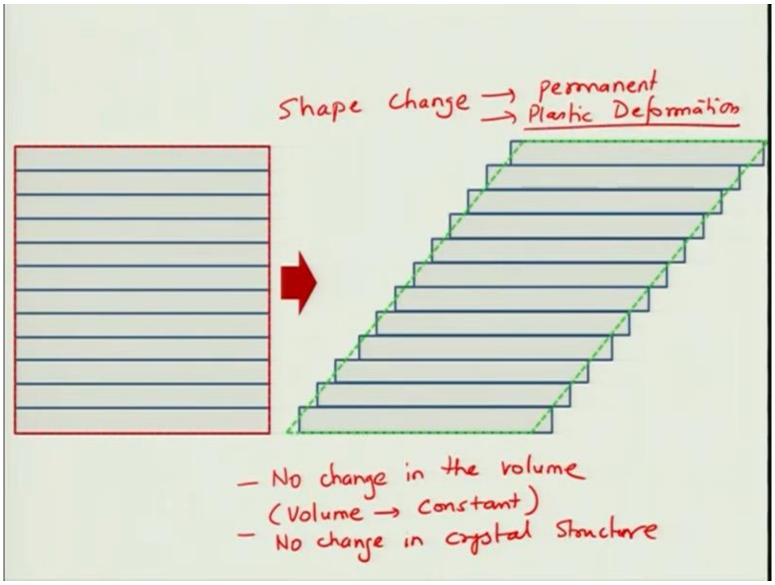

So this how it is going to look like. So a perfect crystal when deformed by motion of dislocation in the successive plane, it leads to creation of these steps and you can see that it creates a deformation, what happens basically is there is no change in the volume. Volume remains constant. So, the constancy of volume has to be followed, there is no change in crystal structure which means the crystal structure of the material does not change.

So, the volume does not change, the crystal structure does not change. You only obtain what we call as shape change and this shape change is permanent and this is what is basically we can say is plastic deformation and so essentially what we are saying just to summarize we say.

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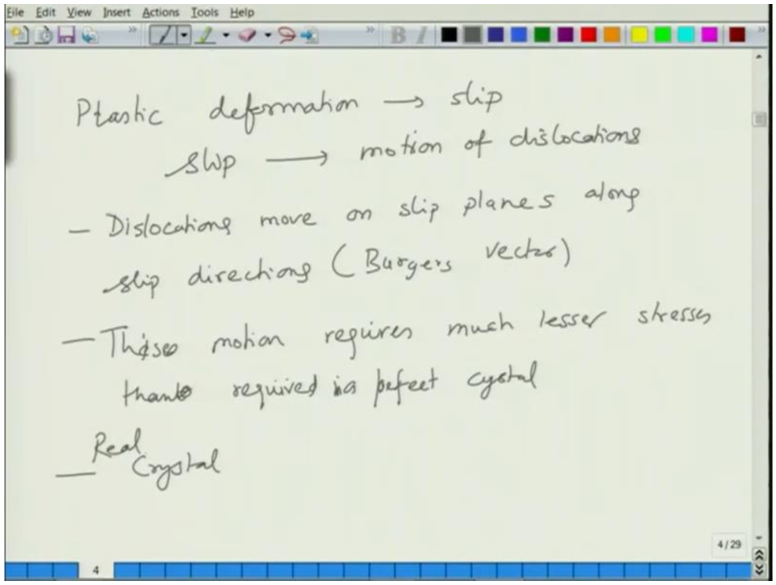

So, just to summarize, we say plastic deformation happens by slip and the slip takes place by the motion of dislocations. Because of theoretical strength for slip is very large that is not practical, experimental observed value of much lower and they happens by the presence of these defects called as dislocations. So, basically dislocations move on slip planes along slip directions which are also defined as Burgers vector. These, this motion requires much lesser stresses than required in a perfect crystal and that is why crystals are, real crystals are softer.

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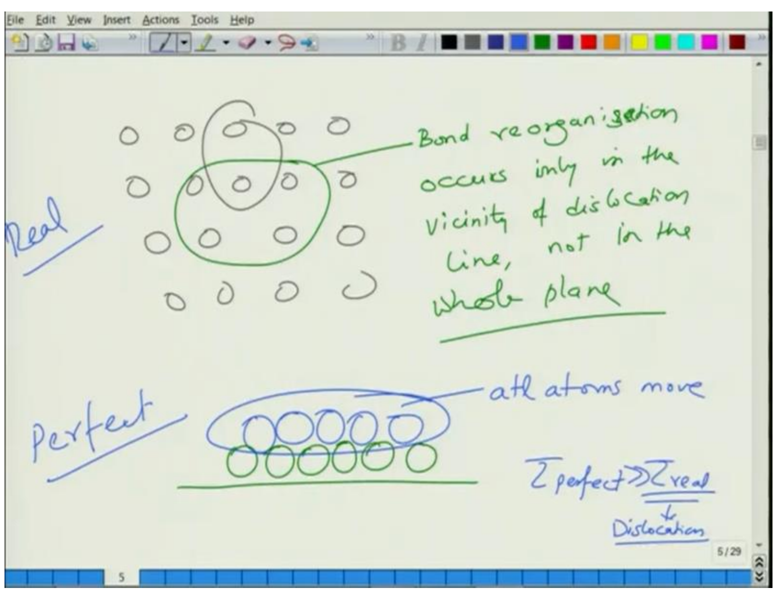

So, basically the real crystals will have these, let me just again reiterate this point just before we. So, when you move this extra row of atoms. It is not whole plane that moves, it is only the group of atoms where the bond reorganization occurs only in the vicinity of dislocation line, not in the whole plane.

So, all though it looks as if the whole plane is moving it is just that line which moves, just that moves, only a few, only bunch of atoms required. In the perfect crystal on the other hand if you had a perfect crystal like this in the perfect crystal, all these atoms move. So, this is perfect and this is real.

So, that is why tau perfect is larger than tau, much larger than tau real and this is due to dislocations. So, I hope it is clear that why the stress required to move dislocations is small of in real crystals which consist of dislocation than in perfect materials. We have restated this part actually, the plastic deformation, we have introduced the concept of dislocation. We have also shown that why the stress required to move stress required to deform a real crystal is lower than the perfect crystal. We will do more detailed discussion on this in the next video. Just thank you.