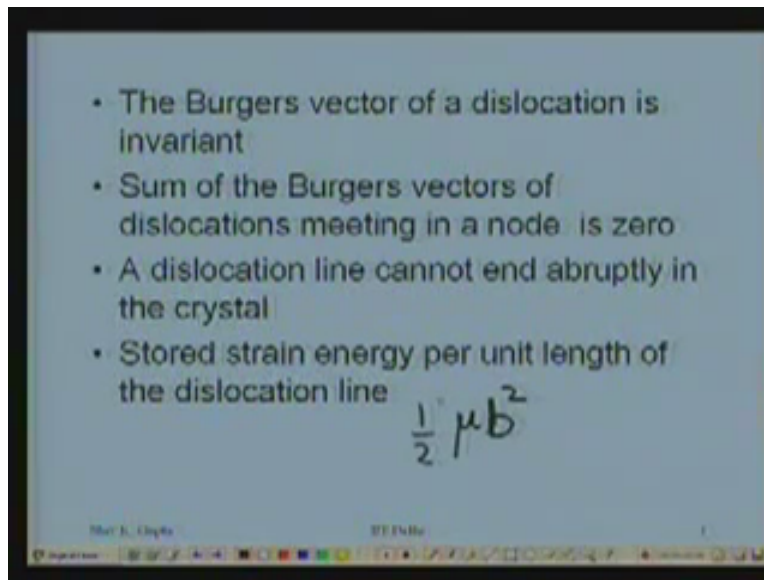


Materials Science
Prof. S. K. Gupta
Department of Applied Mechanics
Indian Institute of Technology Delhi
Lecture 15
Crystal Imperfections

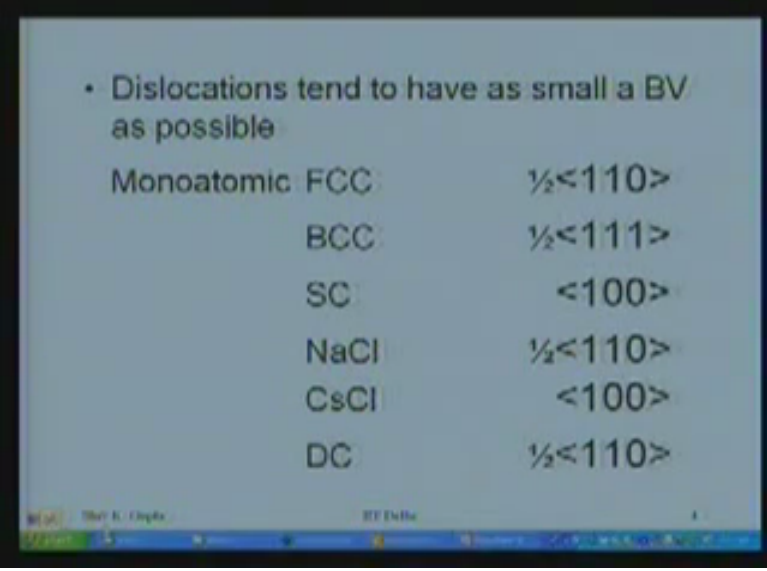
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Well, in the last class we were talking about dislocations and before we proceed let us just have a look at what we were talking about. We said about the dislocations. The Burgers vector of a dislocation remains invariant where the dislocation line may be the curvilinear line. And sum of the Burgers vector of dislocations which meet in a node is 0. And we also said that dislocation cannot end abruptly in the crystal. It either meets in a node inside the crystal.

It can close on itself in the form of a loop or it has to end at the extremities, the surface of the crystal. And then we also said that stored strain energy per unit length of the dislocation line is $\frac{1}{2} \mu b^2$, μ is the shear modulus, times the square of the magnitude of the Burgers vector. So that is something we talked about in the last class.

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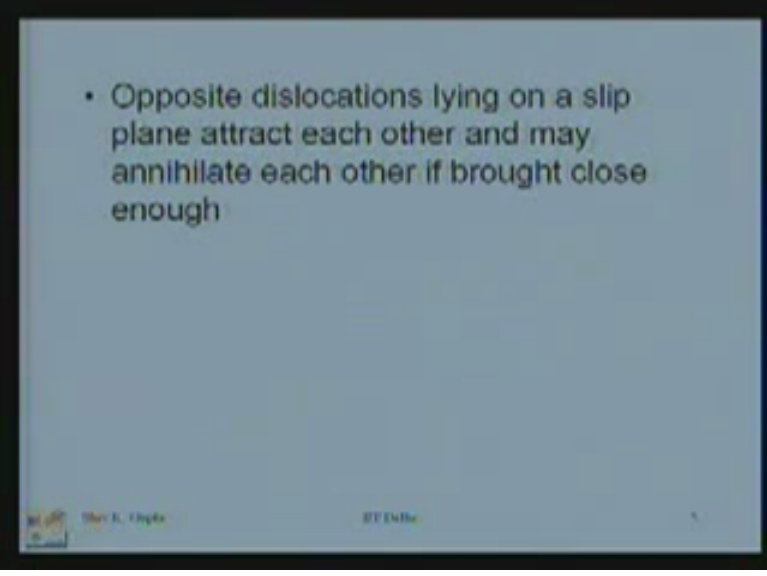
• Dislocations tend to have as small a BV as possible

Monoatomic FCC	$\frac{1}{2}\langle 110 \rangle$
BCC	$\frac{1}{2}\langle 111 \rangle$
SC	$\langle 100 \rangle$
NaCl	$\frac{1}{2}\langle 110 \rangle$
CsCl	$\langle 100 \rangle$
DC	$\frac{1}{2}\langle 110 \rangle$

Slide 4

And we also said that because the energy of the dislocation is proportional to squares of its Burgers vector, the dislocations tend to have as small a Burgers vector as possible. Because I also said that by their presence dislocations in the crystal they are increasing the free energy of the crystal. Okay. So therefore the tendency for them is to have as small Burgers vector as possible and this is what we found out are the smallest displacements which are possible in these crystals for a full dislocation.

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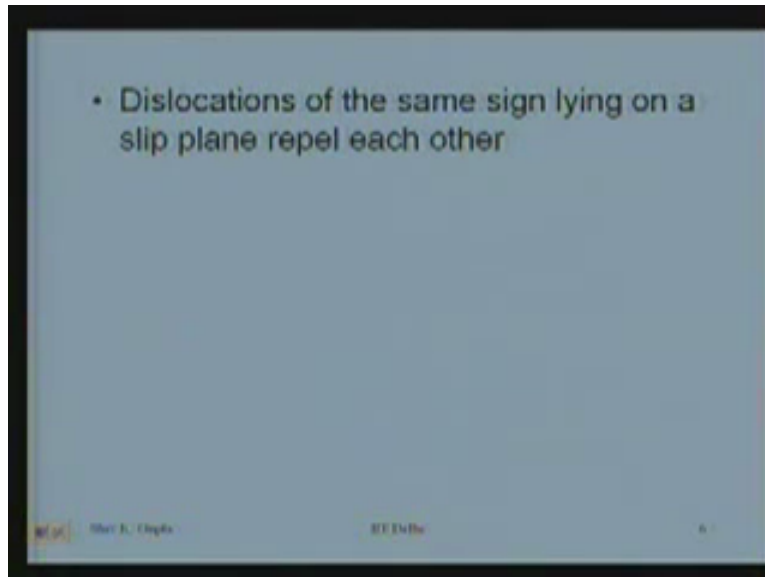


• Opposite dislocations lying on a slip plane attract each other and may annihilate each other if brought close enough

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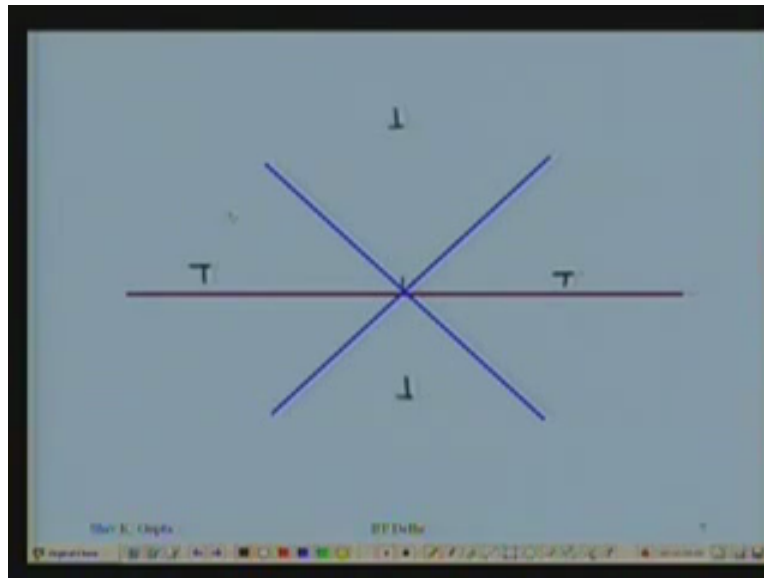
And we also said that opposite dislocations lying on a slip plane they attract each other, there is an attraction between them. If the facility is provided to come, for them to come closer, they can annihilate each other completely.

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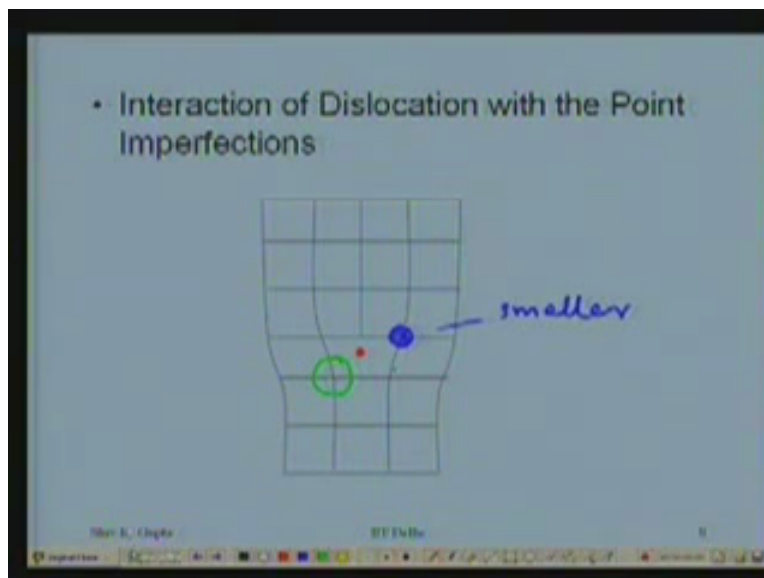
And on the other hand, if the dislocations are of the same sign, they are lying on the slip plane, they are repelling each other. If they have to come together, they have to be, lot of increase in energy is there, that energy you provide by an external source. So they cannot be normally brought together. They can go away from each other.

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Then we saw the interaction of dislocations. Dislocations of the same sign will attract in this region and in this region while the attraction would be of the opposite sign dislocation in that region. And just lines, blue lines are the ones which are dividing these regions into four parts and that is what we saw because the strains below this are tensile in nature and strains above this are compressive in nature. And therefore in this volume, there shall be a cancellation of the strains.

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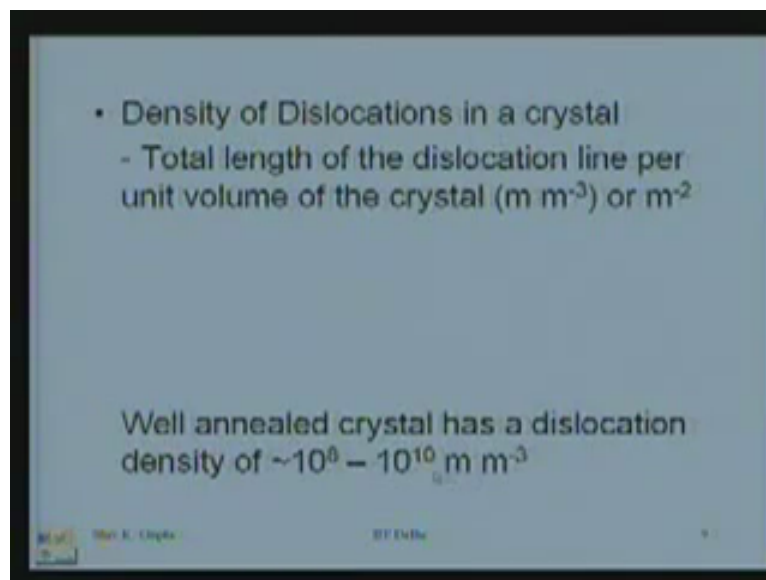
Then I think in the last of the class we have talked about the interaction of dislocation with the point imperfections. If I have an interstitial impurity atom, it would like to stay here because that

is where the interstitial void is the very big in volume as compared to anywhere else. And if it is a smaller substitutional atom, it would like to sit in a compressive region here where the space is small available.

However the space here is bigger, so bigger atom would like to sit there. So that is how these point imperfections are interacting. The purpose is, or the intention is to reduce the stored strains in the material. And with the strain, are stored the strain energy which goes to increase the enthalpy of the crystal and thereby the free energy of the crystal. If that is to be taken care of, the interactions would be such that free energy is lowered.

And therefore this bigger atom which causes compressions all around, would like to sit in a tension side or the dislocation so that part of the strains of this compression are cancelled by the tensions of the dislocation, or tensions in the dislocation are cancelled by the compressions around the bigger substitutional impurity atom and so on and so forth.

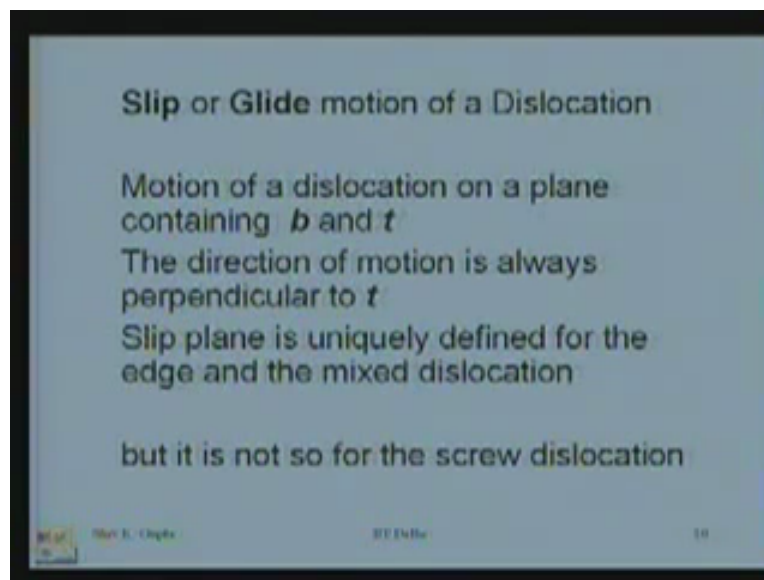
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While the density of a dislocation is usually given as total length of the dislocation line in the unit volume of the crystal, therefore it is expressed as meter per cubic meter, which also can be written as per square meter. There is small difference between them, is a factor of 2. We, in this course we shall ignore that because in the second case instead of measuring the length in the total crystal we are measuring the intersection the dislocation lines are making on a given unit area.

And we count those points in the given unit area, so that number per unit area or the per square meter is expression for that and that is what we use. But anyway we will use this interchangeably, meter per cubic meter or per square meter because even in a well annealed crystal where dislocations with the help of thermal energy has gone out of the crystal as far as possible, still I am left with of the order of 10^8 to 10^{10} meter length of the dislocation line in a cubic meter of the crystal. So that high density is still there.

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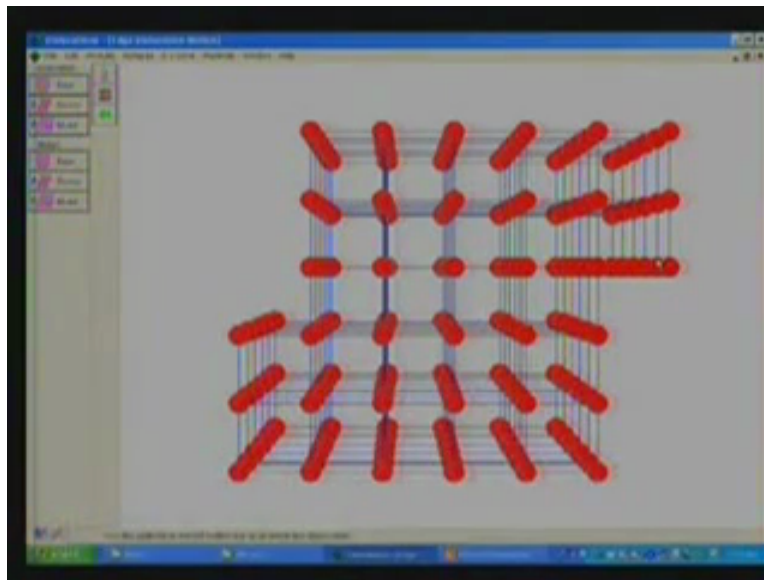


Now we shall look at, after having looked at the static properties of the dislocation, we shall like to look at the dynamic properties, the motion of the dislocation in the crystal. One simple motion of the dislocation in the crystal is called the slip motion or the glide motion of the dislocation line. The plane that contains the Burgers vector and the dislocation line vector, you would have noticed is the slip plane. That is how I call the plane the slip plane. It contains both the Burgers vector and the dislocation line vector.

And when the dislocation moves, it moves on a slip plane, remains on a slip plane in the slip motion or the glide motion. And the direction of motion of the dislocation line is perpendicular to t irrespective of what way the b is pointing, it is a material, it goes perpendicular to t . And for the edge and mixed dislocation, it is uniquely defined. The slip plane for screw dislocation cannot be uniquely defined, why?

Why I cannot uniquely define this slip plane of the screw dislocation? It is because Burgers vector and the dislocation line vectors are parallel, is the same vector, is one vector. And one vector can lie on infinite number of planes passing through it. Okay. So therefore it has large number of slip planes, not infinite. There are some crystals where we place, it has large number of slip planes in the screw dislocation. Slip plane is not unique for that but we shall see the slip motion in all kinds of dislocations.

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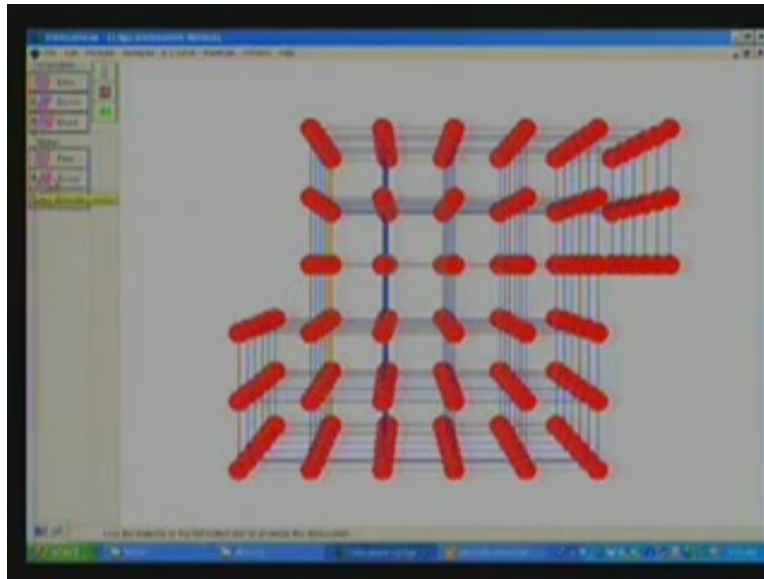
Let us see this edge dislocation first. This is the edge dislocation. And dislocation is located here. From this place if I apply a stress to these atoms which are above the, slip plane is here, above the slip plane I apply the stress to the right and to the atoms below I apply to the left, I can bring this atom closer to the right slightly and this one slightly to the left so that this row of atom joins with this row of atom and forms a bond.

And this dislocation or the part plane would have come here because this bond would have broken when the bond is formed here. This bond would break. And therefore this becomes a part plane, let me show you that how it happens when I apply the stress. This is how it happens step by step. Then if you continue to apply the same stress, this row of atom will now still shift to the right, this one will try to shift to the left and they will form the bond while this bond will break.

See what happens next. Okay. Similarly this force which you applied, continue of the stress, the shear stress and see what happens. It goes on and dislocation goes out of the crystal. Now there is

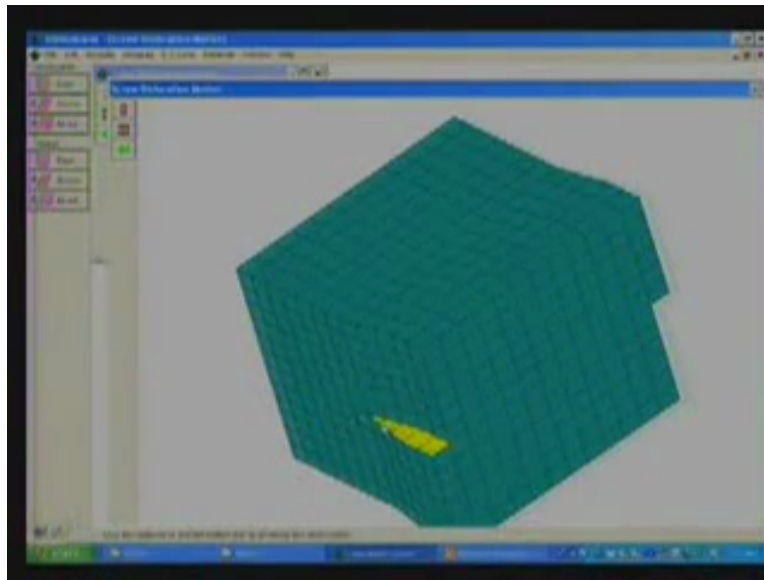
no dislocation in the crystal, is a perfect crystal. Only thing is shape of the crystal has changed. It has formed a step here, it has formed a step there. You might have started with the perfect crystal and dislocation got introduced at this end. And when it made to move, it went onto the other side and caused a step. Shape of the crystal has changed. Right.

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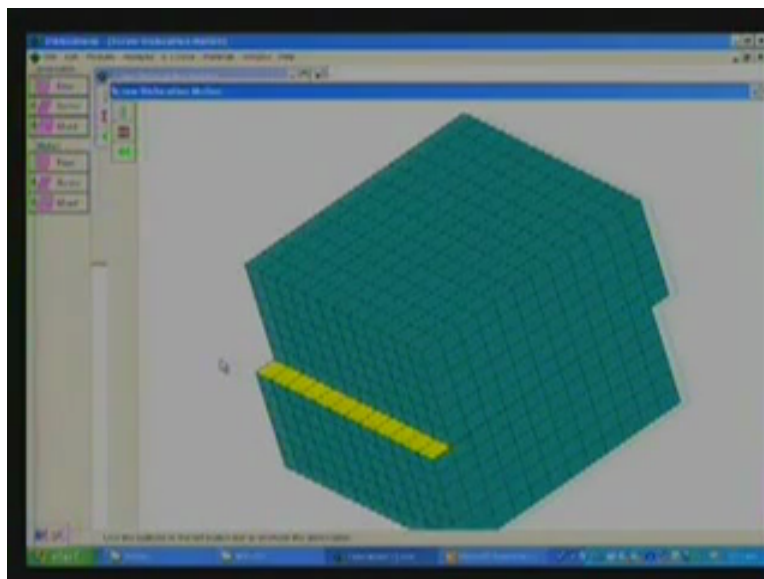
Let us go back and start in a faster mode. See how it is going. You can see it again. This is what is the slip motion of the edge dislocation. And it is moving on the slip plane. And the dislocation line is perpendicular to this plane of the screen and dislocation is moving perpendicular to that. Right. Let us look at the screw dislocation.

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Let us look at the screw dislocation, the same motion. Continues in that, I mean, I think in, see this is configuration which I have for the negative screw dislocation which we saw earlier. And dislocation line is from here going inside the crystal to the other end. And this is the Burgers vector of dislocation line which is opposite to the dislocation line vector depending upon which way I chose the dislocation vector. It is a negative screw. And this is a slip plane. This is a slip plane for the dislocation line, right, because right now it is on this plane.

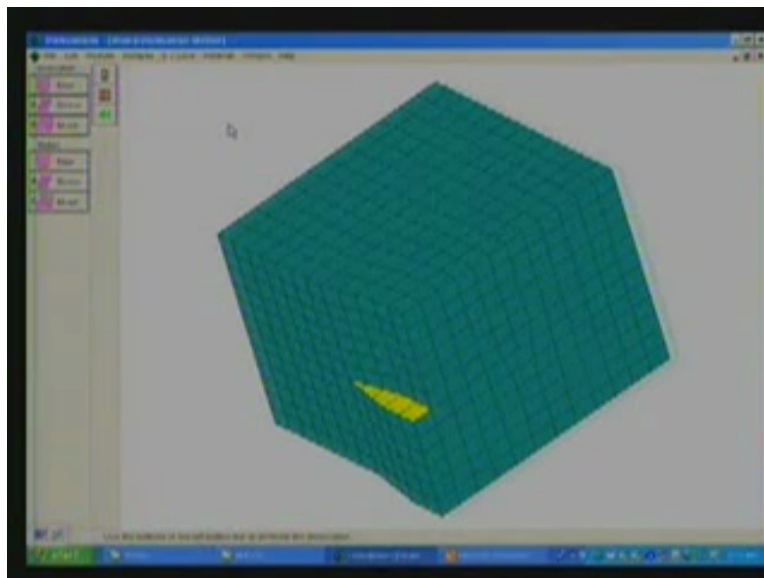
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We shall see what happens when it moves step by step. It goes backwards. When I am applying the stress, top part to the right, bottom part to the left, this moves on and the dislocation is moved by one step. See, it moves by another step. It moves by another step, moves by another step. Then dislocation gone to the back surface, we got a step formed like you form the step in the edge dislocation. It is a similar to that.

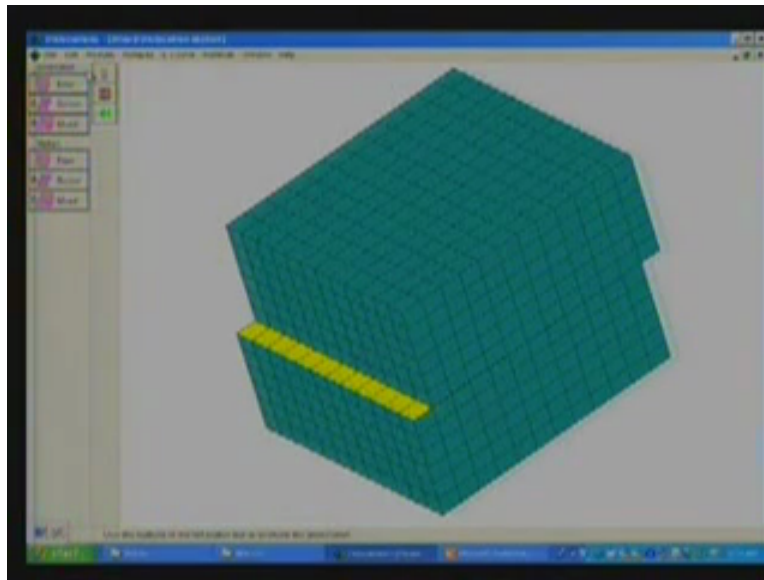
Other words, the step which you have formed here and there, that is in terms of the Burgers vector. Irrespective of whether was an edge dislocation or a screw dislocation, these displacement ultimately which we have got on the surface of the crystal is the Burgers vector of a dislocation line. And displacement in this case has moved backwards. The stress applied was the same. It is you applied top part to the right, bottom part to the left, that is a shear stress in that fashion. All right. You can see this in a little faster motion now. Okay. Once more. This is the glide motion or the slip motion of the screw dislocation. Right.

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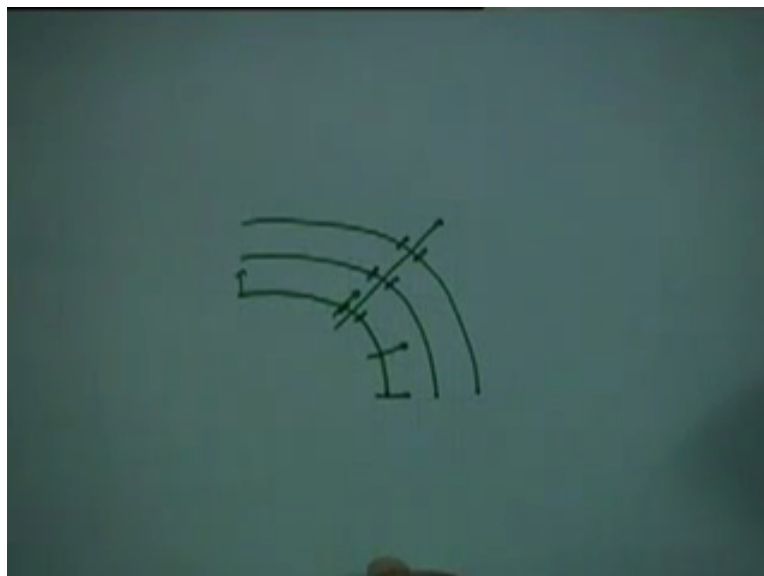
Now let us look at the mixed dislocation line. Here is a mixed dislocation line with edge dislocation component on this and screw dislocation component here which is the negative screw. This is the positive edge and the dislocation line goes inside the crystal like this. I showed this in a transparent picture, this is the opaque picture. But let us see how the dislocation moves step by step. Notice that this position is for the edge dislocation, that position is screw dislocation.

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Carefully look what happens when it goes by one step. Edge dislocation moved by one step to the right, screw dislocation component moves to the back by one step. That means the loop which is or the arc which is inside is increasing in size. Right. Just see that, next. It has further gone down there, so arc has become still bigger. Edge is still, and now in the next step it will go out of the crystal. Again the step formed finally is the same as the Burgers vector of dislocation line. So now you can try to see the same motion. This is the slip motion or the glide motion of the dislocation line which is mixed dislocation line.

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So all the time dislocation is moving perpendicular to itself. See for example, what, on this slip plane, let us say this is the dislocation line I have. It shall move this component perpendicular to itself, this component perpendicular to itself, like this. So this moves here. Next time it moves like this. So all components move perpendicular to itself, okay, all the time. So any segment you take of the dislocation line, you will be going perpendicular to itself all the time. That is how it is moving this direction of the motion.

“Professor-student conversation starts.”

Student: Can you show that previous slide again? Glide motion.

Professor: Glide motion, again.

Student: Just to have.....

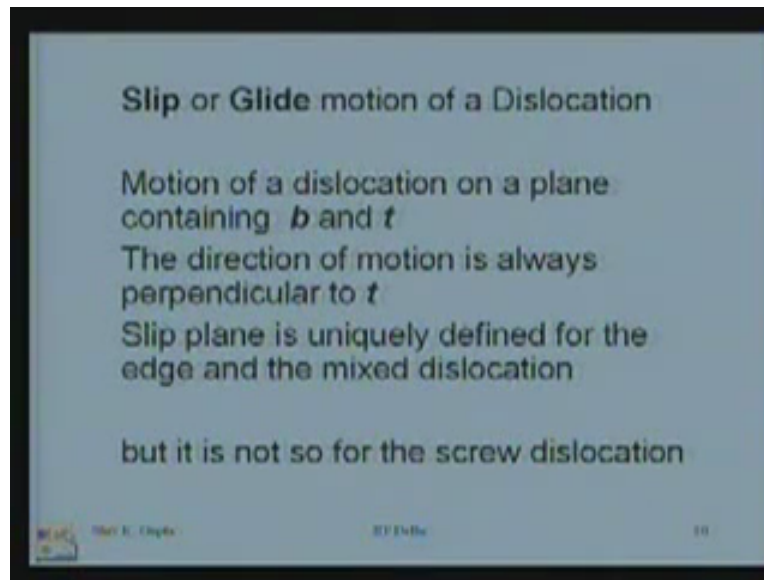
Professor: I have to, okay, I like to show, I have cancelled it actually. Recall it again. All right. Which one? You want the mixed dislocation?

Student: Which one, the notes like, which had written material, it might be slide motion.

Professor: You want that. I am sorry, okay. All right. You want to see the motion, we will come back that.

“Professor-student conversation ends.”

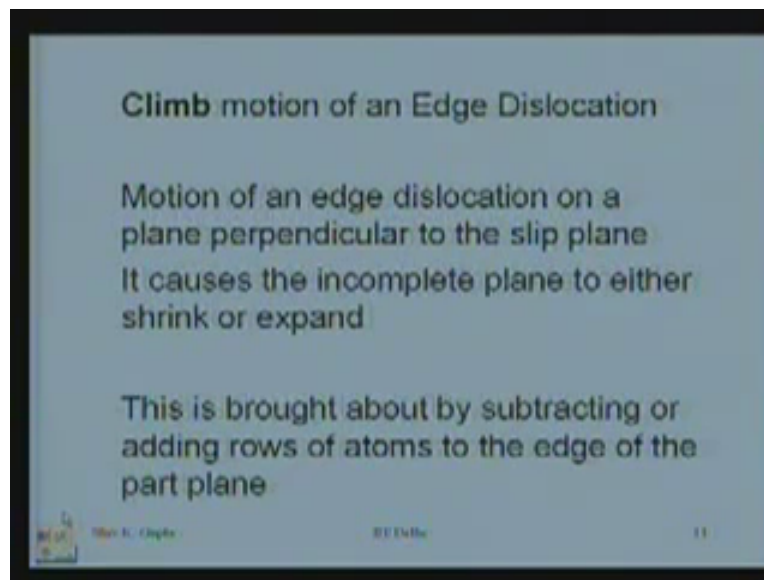
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Yeah, this is the one you were talking about. So that is what you saw, in the case of a screw dislocation, there it could be more than one plane. But in plane if it is travelling, it is travelling like this. At times when the dislocation is moving in a crystal or slipping in a crystal, after all moving dislocation is a moving strain field because there are strains around the dislocation. Okay. And a strain field can be obstructed by another strain field in the crystal if they are present.

This could be dislocation, this could be imperfection, these could be other strains which can come about by the other kind of defects. So it is possible that dislocation is unable to slip further at a point in the crystal. And dislocation wants to move, you are applying stress, you are increasing temperature, you are doing many things to the crystal possibly. So how should it move further? If it is edge dislocation, the only way it can move is it should change the slip plane because slip plane is unique and to change the slip plane, it has to jump up or jump down because slip plane is unique.

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Just to either jump up or jump down. That motion of a dislocation is called the climb motion of an edge dislocation. Edge dislocation is climbing up or climbing down. Okay. That is the dislocation motion perpendicular to the plane of slip. Okay. Therefore it causes the incomplete plane either to shrink in size or it allows it to expand in size. If it is climbing down, positive edge dislocation is climbing down mean part plane is expanding.

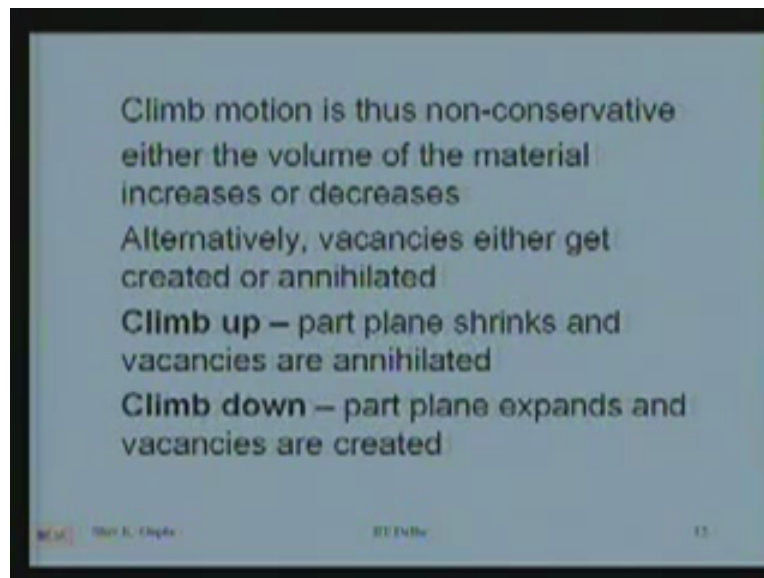
That is what we mean by climb down, part plane has to expand in size whether it is the positive edge dislocation or negative. So in other words, you can say climb up and climb down with reference to the positive edge dislocation. It remains the same for negative dislocation also. So when part plane shrinks in size, dislocation is climbing up. Now a part plane expands or a part plane contracts, where the atom is going to go or atom is going to go come? If it contracts in size, atoms have to leave the edge of the part plane.

And where do they go? They go in the neighboring vacant locations. So ultimately what happens to the volume of the crystal? Increases or decreases? Since these atoms which have left the edge of the part plane have gone and occupy the vacancies. Vacancies have got lost from the crystal. And if there is a vacancy present in the crystal, it occupies as much volume as one atom does. So therefore there would be a decrease in the volume of the crystal.

Number of atoms have remained the same but number of locations where they can sit is reduced. Those vacancies are gone. So when the part plane shrinks in size, there is a decrease in volume.

Similarly when the part plane expands, atoms from the neighborhood have to come and join the edge of the part plane and thereby they leave behind vacant locations, so volume expands. So this is not a conservative motion of the dislocation. So we have to either add atoms or we have to, to the edge of the part plane or we have to take them away from there.

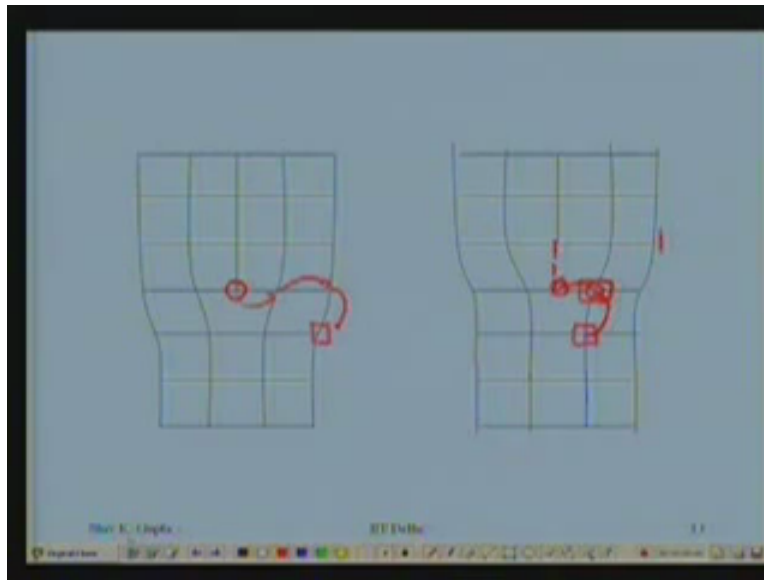
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And since I am saying that volume is either increasing or decreasing in this motion, I call it a non-conservative motion. And alternatively as I already said, vacancies are playing role. The vacancies either getting created in the crystal or they are getting annihilated from the crystal. Right. So climb up as I said part plane shrinks in size. For a positive edge dislocation, it goes like this. For a negative edge dislocation, it goes like this. Okay.

Climb down, part plane expands in size. For a positive edge dislocation, it goes like this in the crystal. For a positive edge dislocation, it goes like this in the crystal. All right. That is the meaning of climb up and climb down.

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Let me show you with the picture as to what is the meaning of this, part plane is shrinking in size or part plane is expanding in size. Say this is an edge dislocation here. In this edge dislocation, I remove one row of atoms from here. This row of atoms is removed. So I have the part plane only up to here. That row of atoms is gone from there. Either your configuration here tries to go up by one step but these (dislocat) atoms which are removed, they have to go let us say here there was a vacant location.

Maybe this atom jumps here, this atom jumps here, and this atom in turn jumps there. So it will come and occupy the vacant location, vacancy is lost. This is the process of climb up. And opposite of this is going to be climb down. Suppose I start with this dislocation. I add a row of atoms here. If I add a row of atoms, I have to bring some atom from here neighborhood, it is brought here. Okay, thereby it becomes a vacant site and this vacancy in turn can come from here. So this atom from here it can jump into there. So vacancies will be somewhere in the crystal neighborhood of the dislocation line but this part plane is extended like this. That is.....

“Professor-student conversation starts.”

Student: Volume increases in the space.

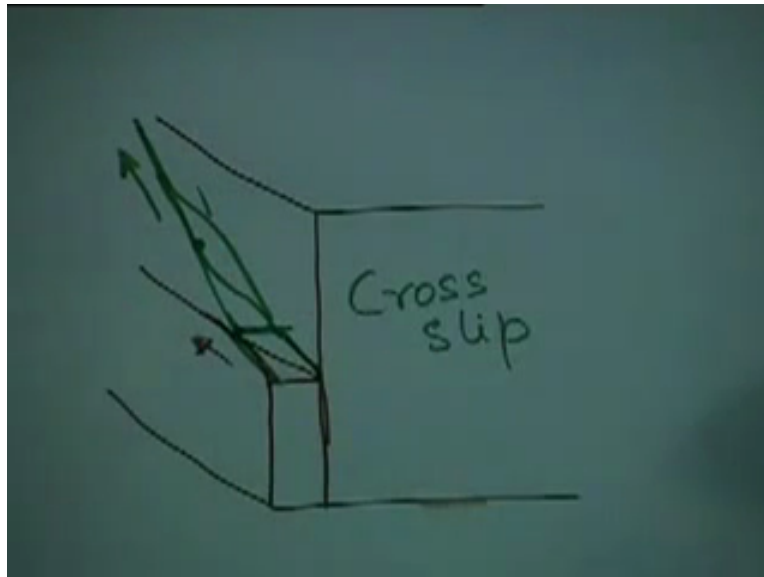
Professor: Naturally, volume increases in climb down and volume decreases in climb up. That you can see from this picture itself. And go from here to there, there is a decrease in volume. You

go from here to there, there is an increase in volume. From this configuration, I come to this configuration, it is climb down. From this configuration, I go to that configuration, it is climb up. All right. That is the climb up and climb down motions of the dislocation line.

“Professor-student conversation ends.”

As I said in a screw dislocation, there is no unique slip plane. Since there is no unique slip plane, so if there is an obstruction to the motion of a dislocation, it can change the slip plane right at that location and start moving on that location in that direction. Right. Let me show that.

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There is a screw dislocation like this in the crystal which is moving in that direction, the slip planes. Right here it finds an obstruction, it cannot move. So what it can do is for this dislocation line as I said, this is also a slip plane. So it can start slipping on this. What would happen is it has moved up to here, from there it has gone there. But here has formed a step here. Then this shall move on this one. I will keep moving, it goes on moving like this till it comes out of the crystal on the surface. So that is the direction of motion has changed. It has gone from this to this. This is what we call the cross slip. It means crosses over to another slip plane.

Dislocation line instead of moving on this slip plane, it has begun to move on that slip plane. Right. In the crystal that is also a slip plane for it. That is I have tried to write that. So it can move onto another plane, comes across an obstacle, it will glide on 111 provided the applied

stress on 111, okay. Maybe I think what I want to say here is let us say here is, it start can probably on one bar plane. If there is moving on.....

“Professor-student conversation starts.”

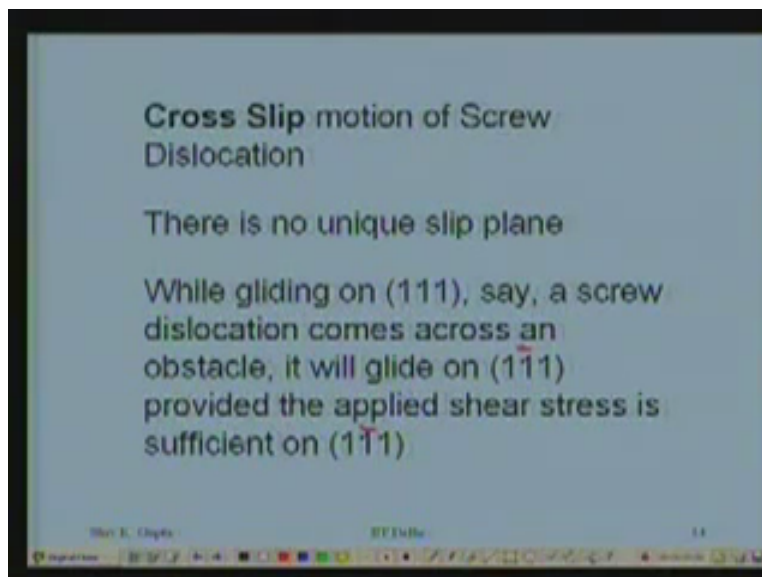
Professor: Pardon?

Student: Switch the....

Professor: Yeah.

“Professor-student conversation ends.”

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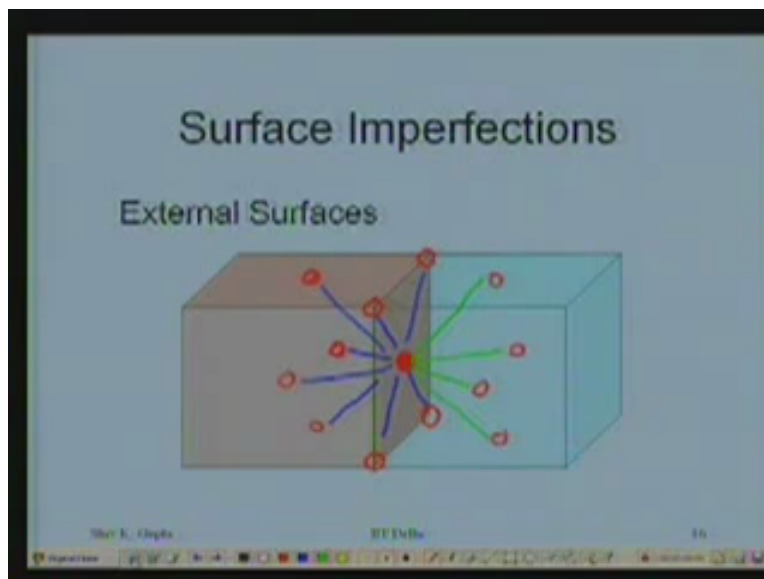
It was moving on 111 plane, okay and it comes up across an obstacle. It can start moving on bar 111 plane. 111 and one bar 111 you have seen that they cross, interact the, intersect each other somewhere. So this can move on, this provided the shear stress is enough on that. That is only your consideration. The shear stress is actually which you have applied on the 111 plane earlier. If the component on 1 bar 111 is sufficient, it shall start this or you may have to increase the applied the shear stress so that it can start slipping on 1 bar 111 again. So that is the cross slip or the screw dislocation slips over or crosses over to another slip plane. I think this regard the static and dynamic properties of dislocation.

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We shall move on to see 2-dimensional defects which are called the surface defects because they are two-dimensional in nature. Though I said that this two-dimensional is not a surface, geometrical surface, it has certain thickness, certain volume of the crystal is in defect.

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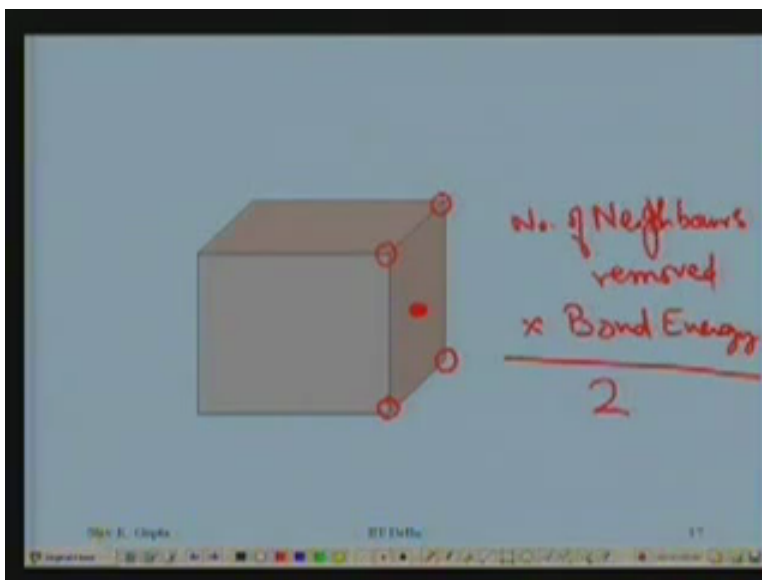
As I said when I started these imperfections, external surface of any crystal is an obvious imperfection. Here I show you that this is probably let us say an FCC crystal. In the FCC crystal, I have this central atom on the face surface and these are the corner atoms which are its neighbors. And therefore atoms on this surface, the bottom surface and back surface which are

also its neighbors. Similarly I have the four neighbors here. So these four neighbors in the face center, these four neighbors are the face centers and these are the four corners for this central atom here. All right.

That means these are the 12 neighbors in the FCC and it is bonded to the 12 neighbors like this. And these are the four neighbors also it is bonded to. Suppose this is broken away and that become the surface, then what has happened? These four neighbors from this atom have been removed. And means I have broken away these bonds, 1, 2, 3 and 4. These are the four bonds which I have broken.

But I have not only broken the bond for this, I have also broken the bond for that, also broken the bond for that, also broken the bond for this and for that. So any bond is broken is broken for the two neighbors. The energy increase now because of this will be shared by both of them. So these atoms and these atoms are now once it become the surface, it is a high energy atom as compared to the atom inside. They have all the 12 neighbors but this is the one which has only 4 neighbors on the surface and 4 below, 8 neighbors. It does not have these four neighbors. So the energy or the enthalpy of this atom goes up.

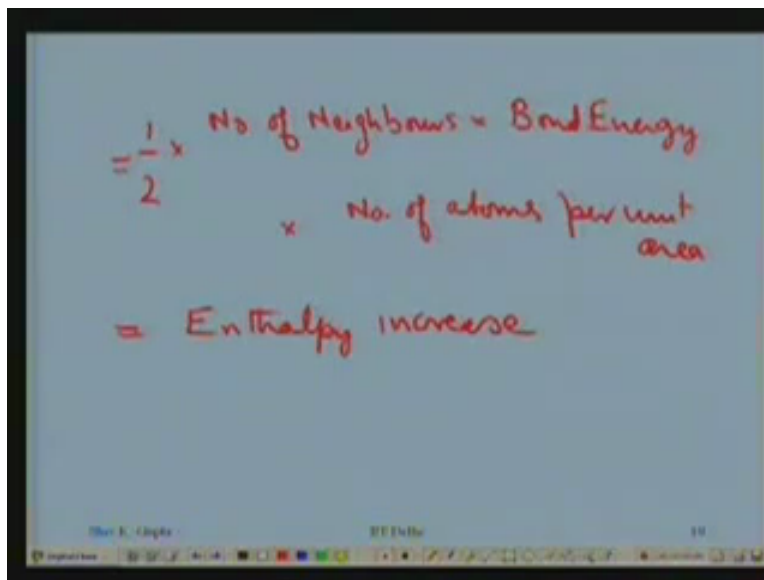
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So to should that here this has only 4 neighbors on the external surface. This is the external surface. And 4 neighbors are inside, 4 are gone. So energy of this neighbor, this atom is increased by the fact that number of neighbors removed, I am sorry, into a bond energy. And this is shared

by both of them, so it is 2. This is the energy increase of this atom. Same is going to be true about this atom, same is going to be true about this, same is going to be true about this, and same is going to be true. So on the external surface whatever is the area, total energy is increased for each atom. So that we have to see how much it is increased for all of them. Okay.

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$$= \frac{1}{2} \times \text{No. of Neighbours} \times \text{Bond Energy} \\ \times \text{No. of atoms per unit area} \\ = \text{Enthalpy increase}$$

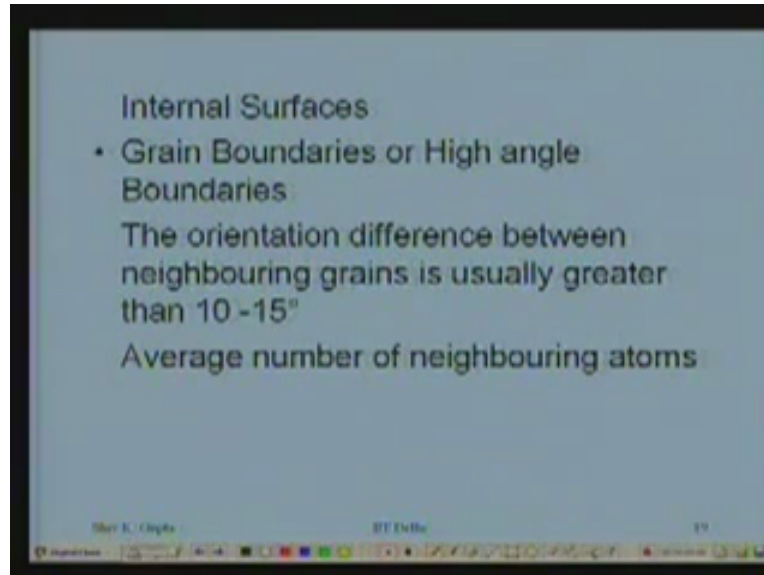
So for the whole area of the surface, it is increased, sorry, it is increased equal to, of course the factor of 2 you know, number of neighbors, bond energy. If bond energy is expressed per mole, then you have to divide it by one mole because you are talking about one particular bond, right. And then this is to be further multiplied by number of atoms per unit area of the surface. That shall be the increase in the energy or enthalpy.

As I told this is not getting compensated by the increase in the entropy which goes with it. Therefore there is a free energy increase which will be slightly less than this. So this is what is happening on the surface and we have the extra energy. Everywhere you see this point defects, we have increase in enthalpy of formation. Dislocations around this, I had all strains and strain energy increase, energy increase, enthalpy increase.

Then now I have a surface energies, bonds are removed. So energy of atom which are on the surface, that is increased. So what are these defects? These are all the defects which are increasing the enthalpy of the crystal. Right. They all go to increase the enthalpy. Only point

defects which can lower the free energy by increasing the corresponding value of the entropy but others are not increasing the entropy as much.

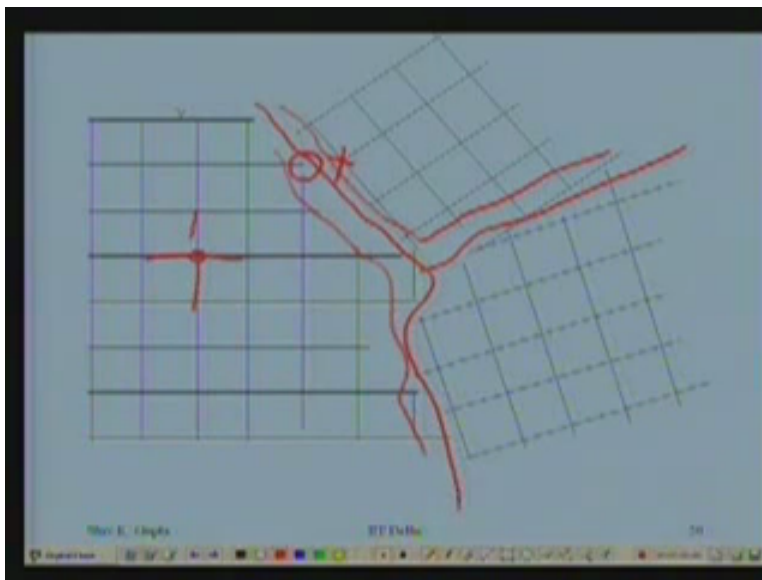
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But beside the external surfaces, we do have internal surfaces in crystals. These some of the internal surfaces which we shall describe. One of them is called the grain boundary or high angle boundary. It is a boundary between two crystals. Other words, if I have a solid which has more than one crystal, means the polycrystalline, maybe millions of crystals, orientation of two neighboring crystals need not be same, it would be different, sorry.

And as a result, now as a result when the atoms are coming at the boundary region, they do not find themselves suitably placed to be part of this crystal or that crystal because the orientations are different. Let me just show you that with the help of a small picture which I tried.

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This is one crystal, this is another one and this is third one. And they are all meeting in this region, just see this. This is the bordering boundary here. That is the boundary there and the boundary is going here. These neighbors which are here, see this distance between this atom and that atom is shorter than the normal distance. So either I can have this atom or I can have this atom, I cannot have both. Right.

Similarly here there is enough space, this can be there, that can be there. But when I come here, this and this may find a distance to be shorter. Either this is there or this is there, both of them are not there. Other words, this is a region which is not as thin as I have drawn the line. These atoms in around this region, you will find that either one is there, other is there. Say for example, I put this one, I cannot have this atom here. This atom will not be there, it cannot be there.

Or it is possible that they compromise both of them and sit somewhere here. They extend the bond length here, they extend the bond length and compromised position they can sit. In other words, what would happen is in the same space each atom was arranged will be finding itself in a non-crystalline manner. Neither it is a part of this crystalline arrangement, nor it is a part of that crystalline arrangement.

And also they will not have as many neighbors as they have here. Say for example, here in these two diagram, two-dimensional picture, this atom has 1, 2, 3 and 4 neighbors. It may not have four, okay. So there is number of neighbors is getting reduced. In other words, how out of the 12

in FCC, if I have now 10 or 10.5 on an average, that much energy is gone up. Like we showed it for the external surface, atoms on external surface. So this region which is inside the crystal, a two-dimensional defect is also giving us an increase in energy or enthalpy of the crystal. So this is called a grain boundary.

“Professor-student conversation starts.”

Student: How do the grain boundaries come into the existence inside the crystal? It is crystalline.....

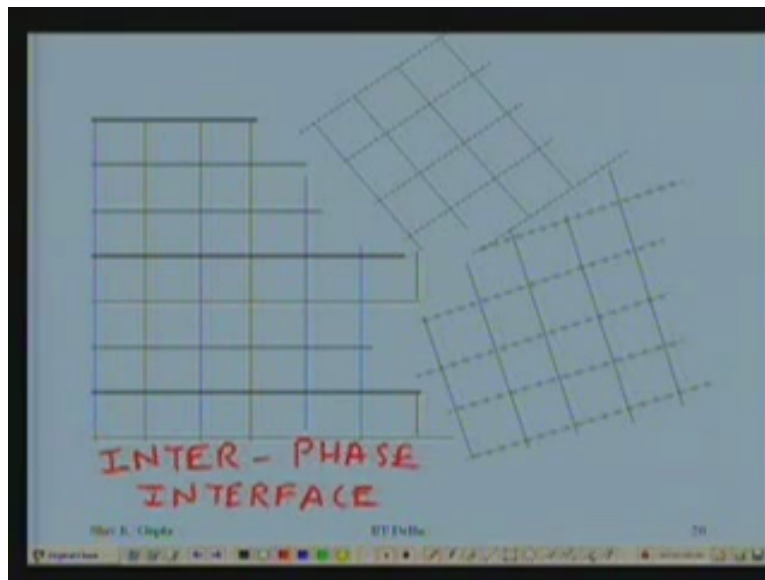
Professor: Crystalline solid if it is not a single crystal, normally when we solidify your melt, we end up getting a polycrystalline solid, we do not get a single crystal. Going single crystal requires lot of effort. For this I shall show you how the solidification occurs when I come to there in the course.

“Professor-student conversation ends.”

I will show that if I need a single crystal, I must have only nucleus to start with but when I, from the melt when I am solidifying this. From the melt when we are solidifying general on its own, I get polycrystalline solid where millions and billions of crystals are present. And they all start going in different orientations. When they are going, they while going there is a space in between, while the liquid is used up, no more liquid is there, they impinge on each other. Once they impinge different orientation, that is how the grain boundary region comes about. Okay. All right.

So this is a high energy region but angle of misorientation is usually exceeding 10 to 15 degrees. And such things are called simply the grain boundaries, not high angle grain boundary, simply the grain boundaries. Each one of these crystals, which is let us say FCC solid it is, FCC copper, this is the copper crystal, that is another copper crystal. This is another copper crystal, copper each crystallite of a copper is called the grain in the polycrystalline copper. So this grain, this grain, this grain, it is a boundary between these grains. Is it clear? There are, this is a surface which is curvilinear. It need not be a straight line or need not be a flat plane, okay.

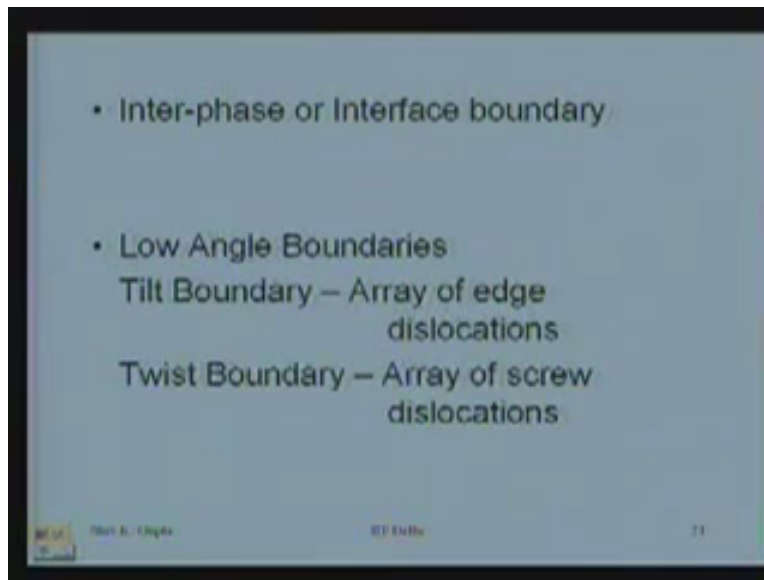
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There are others which could be flat planes. Before we talk about that, similar to these grain boundaries, I could have interphase boundaries or interface boundary which will be identical to this. Identical in the sense, this crystal I said FCC copper now, FCC copper, FCC copper, so it is, these are same crystallites, so I call them $\{111\}$ (44:12). But suppose this is an FCC copper, this is HCP zinc, okay, and this is another let us say BCC, another phase could be iron. So these are there, there are there present in a solid. Then this crystal is different from that crystal, is different from that crystal. Then I do not call the grain boundary, I call it an interphase boundary. Okay.

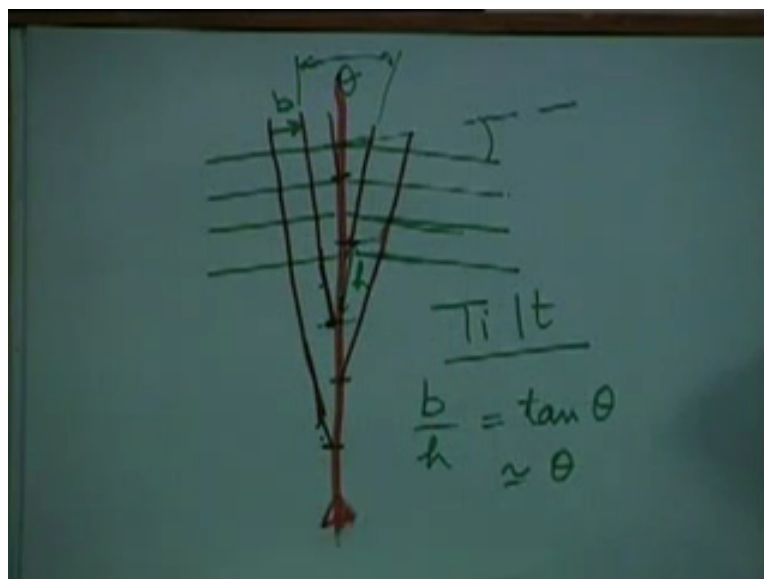
This is called, I shall define the phase in the next class and we also call it interphase boundary. It is an interphase between these two phases. Both names mean the same thing. But the character is the same like in a grain boundary the misorientation is very large. And the atoms in between do not find either part of that crystalline arrangement or the part of the other crystalline arrangement. That is what I talked about interphase or interface boundary.

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Then we have the low angle boundaries. Tilt boundary which has an array of edge dislocations and the twist boundary which is an array of screw dislocations. I shall show you the tilt boundary where the angle of misorientation is a few degrees, usually 4-5 degrees or maybe less.

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See this side of the crystal and this side of the crystal is a small tilt. And the angle of misorientation you can see is very small but slightly exaggerated, actually is given by this angle. This is the small angle and this is the actually is the same crystal, maybe you can say that

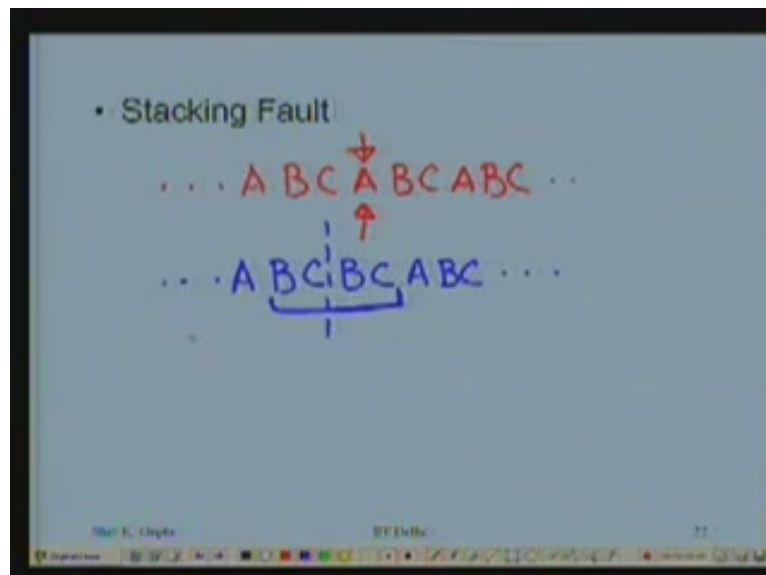
dislocations come and arrange one over the other. These are all positive edge dislocations which are arranged one over the other because they interact like this.

Tension underneath are nullified by the compressions here, tensions underneath here nullify the compressions of this and tensions of these are nullified by the compressions of this and so on and so forth. They arrange one over the other but it has caused a slight tilt on the two sides of the crystal. There are more number of planes on this side, less number of planes on the bottom, therefore there is a tilt. That is why it is called a tilt boundary. And this tilt angle let us say is θ , the Burgers vector of a dislocation line is b .

And the distance between two dislocation lines is h . Then we define b by h is equal to $\tan \theta$. Since θ is small, it is approximately θ in radian of course. Similarly the situation when array of screw dislocations arrange themselves on a plane. When they do so, they form a twist boundary. As a one crystal with respect to the second crystal is twisted like this because that is what is called a twist boundary. And these are the flat planes.

Like here the plane of this, this is the defect plane or two-dimensional defect is here. So this is the tilt boundary, is a crystallographic plane. Right. It is not a surface like the grain boundary, it is not a curvilinear surface, it is a flat plane. Same is true about the twist boundary.

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All right. Next we shall have stacking faults. These are also planes, crystallographic planes. It is a fault in stacking. Stacking, let us talk about in a closed-pack plane or closed-pack crystal like FCC, we have seen the stackings are ABCABCABC. Let us say in this stacking, it goes on with perfectly, so FCC crystalline solid, one plane misbehaves and this plane is not present, it is missed from its location.

“Professor-student conversation starts.”

Professor: What shall be the configuration if that happens? ABC, then A is missing, right? So what has happened? You see locally here.

Student: Arrangement.

Professor: It is an HCP arrangement. Is HCP going to have higher free energy or low free energy in FCC crystal?

Student: Low.

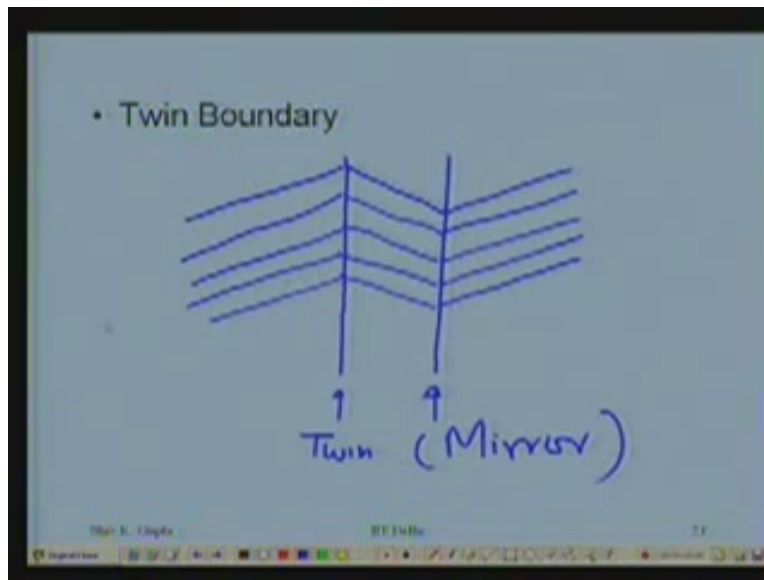
Professor: Higher or lower?

Student: Higher.

Professor: Higher. If HCP wants to say low, with lower free energy, the crystal itself would have said as HCP. Crystal is, the fact, the very fact the crystal is staying is FCC. HCP is going to be higher free energy. So this small volume in which atoms are, they are high free energy. And this is where the defect is. Same is true in HCP, AB, AB stacking, somewhere C plane comes in. Locally there will be an FCC arrangement and that shall be higher free energy region. Okay. So this is what is a stacking fault.

“Professor-student conversation ends.”

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Also the twin boundary, this always is, you can say it is kind of a special stacking fault. It has gone I think. Has it gone for me? These two lines go out from here. Okay. All right. This is special stacking fault which always comes in parallel in couple. You know that it is a pair. This is twin boundary, is another twin boundary. But what happens to the crystal? Let us see the arrangement of the crystal on this side is this.

On this side it comes as a mirror deflection which again reflects back. So within the same crystal it is possible. The crystalline arrangement here is shifted with reference to this and this boundary, twin boundary acts as a mirror plane. So this side of the crystal is reflected onto the other side. And this you can call it a special stacking fault because it always comes in pair. I think this we shall talk about in the next class.