Defects in Materials
Prof. M Sundararaman
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Madras

Lecture - 28
Dislocations in Ordered Alloys and Dislocation-Dislocation Interaction

Welcome you all to this course and the Defects in Material. In the last few lectures we have discussed at length and dislocations in FCC BCC and HCP metals, but these metals which we have considered essentially are we can say that they are disordered materials, but there are many materials, which form ordered alloys are ordered compounds are prohibited form in many of the materials which have disordered FCC structure. Or there are cases where alloys undergo transformation from disorder to ordered state. In such cases what is the sort of dislocations which will be responsible for deformation in the material. Let us have a brief discussion about that in this class.

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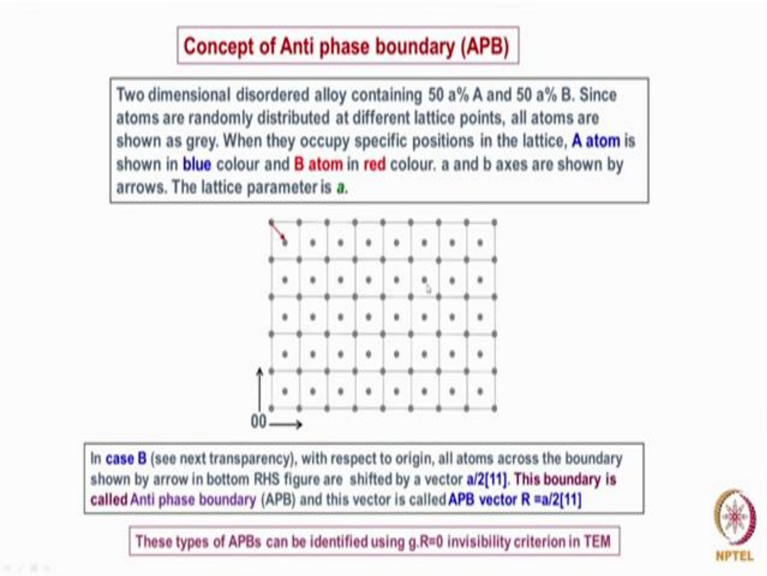

If you consider the best example is to take a 2 dimensional lattice. The lattice which is being shown here is essentially a disordered lattice actually it is an alloy you consider to be alloy which contains of an atom A and B which is in 50 percentages A and 50 percentage B and the atoms are randomly distributed.

So, we cannot identify in which position A atom is occupying which lattice position B atom is occupying. So, that I had shown it by a gray color. In this the shortest translation vector essentially if we look at it is what is being shown by this arrow. And what will be the magnitude of this vector.

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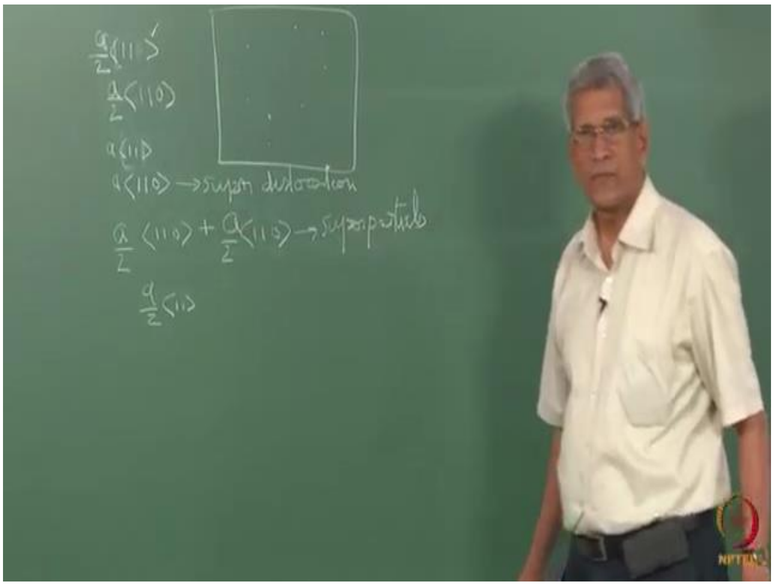

Essentially is of the order of a by 2 1 1 0 1 1 1 it will be in 2 dimensional lattice. Generally, in 3 dimensional lattice if you consider it will be 1 1 0.

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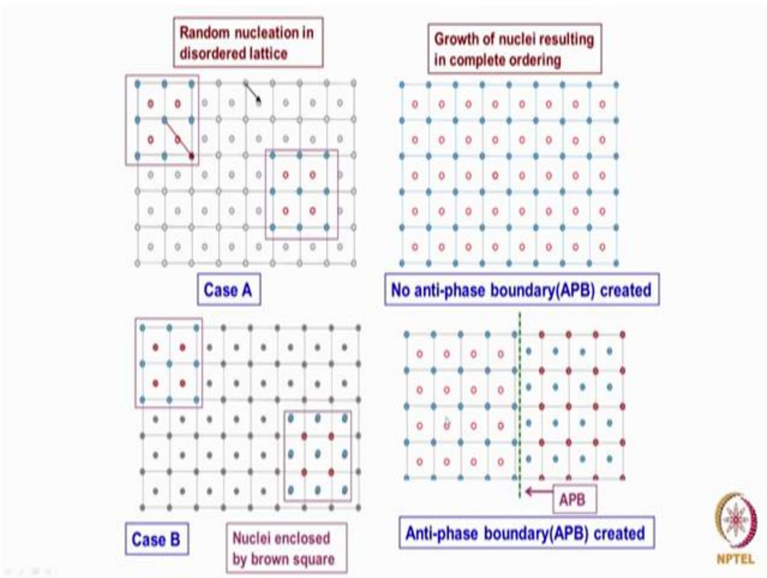

And let us consider the case these alloy gets ordered. When ordering occurs what is the way the ordering occurs. It is not that the ordering starts from one point and it is split, is most of the time what happens in a sample, like if you consider a sample which is like this, disordered nuclei maybe occurring at different points like this. These ordered nuclei will grow and then join together then it will completely transform to the ordered phase. That is the case which we are considering here. We have 2 nuclei we are considering it, where we have shown these to nucleate in these nuclei. If we considered it, the translation vector for a perfect dislocation are the translation vector in the disordered lattice shortest translation vectors in this is a by 2 1 1 1.

This is the translation vector when it is order, because how do we decide the translation vector, because from one point to another point if you displace an atom position it goes from one opposition to another identical position. If we apply this criterion then immediately we can see that from here to here is there, this vector is the burgers vector of the ordered lattice correct that is the shortest translation vector. That is essentially a 1 1 1 are if we consider a 3 dimensional lattice it could be a 1 1 0 correct if you consider a lattice with this burgers vector. The self-energy of dislocation is going to be very high. Because of this it would prefer to exist in a condition, where the self-energy could be reduced. If that has to happen then this should split into partials of that type a by 2 1 1 0. That is 2 dislocations of the type a by 2 1 1 0, if you this split is into to it

Then what is going to happen is that the self-energy of the dislocation has reduced. These dislocations can move together as one group. And since both the dislocation of the same burgers vector they will repel each other. And then they repel each other and they move away. A new interface is created that region is called as the anti-phase region are the anti-phase boundary. This is one way to look at it.

Now the same case where one nuclei has formed here, you will come back to it again with respect to some specific system, easy just to show that the dislocations can split in 2 and these partials are called the super partials. These things we will come later. When these dislocations that 2 nuclei are formed when they grow and joint whether what happens let us look at it when this nucleus grow and join their perfectly fit, there is no interface are nothing is being created.

Now, let us look at another case they are exactly identical to nuclei form. These to nuclei grow and die in together then what happens? Now if we look at it we can see that from this region to this region if we go, the atom positions are interchanged. These boundaries between these 2 regions are called us anti phase boundary. If you look in this region this is perfectly ordered. You look here also this also is the same type of a structure, but when they join together at the interface the atoms are not matching correctly. If I move an atom from here to this position, by this vector a by 2 1 1 0 0, when this is being moved this will come back to a correct position; that means, that this vector is called as the fault vector. So, the fault vector of the anti-phase boundary here is a by 2 1 1 1. This is how the fault vector is defined is it clear.

So we have considered two cases: one the perfect dislocation in the ordered lattice splitting into partial. When that happens this dislocation is called as super dislocation. These dislocations these 2 are called as super partials, that is you remember that when we talked about the FCC the dislocations, which form stacking faults we call them as partial dislocation. The same terminology is being used here. These are called as super partials because these dislocations are perfect dislocations in the disordered lattice, but in the ordered lattice they create a fault. So, they are called as super partials right.

Now, let us take some few specific examples of crystal structures. This is 1 1 2 structure. This is the structure in which, the precipitates in many of the important nickel based super alloys have, and stoichiometry of the compound is Ni3AL where sometimes aluminum is replaced with partially with titanium are niobium and all these many elements.

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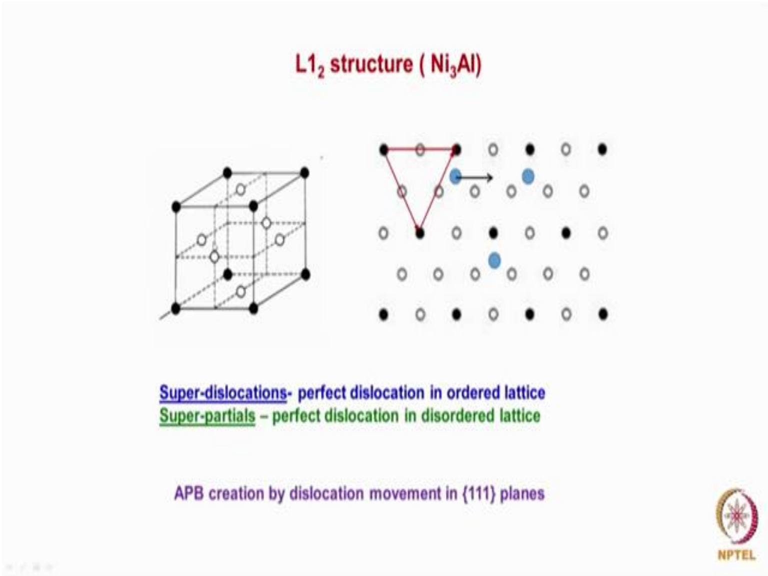

Here, if you look at it, the aluminum occupies that corner positions nickel are the phase centers. This is the close packed plane here also is 1 1 1 plane. In this plane if you look what is the perfect translation vector it is from going from here to here, or from here to here or from here to here. In the disordered lattice if you consider half of it from here to here is essentially what is going to be the translation vector in the disordered lattice.

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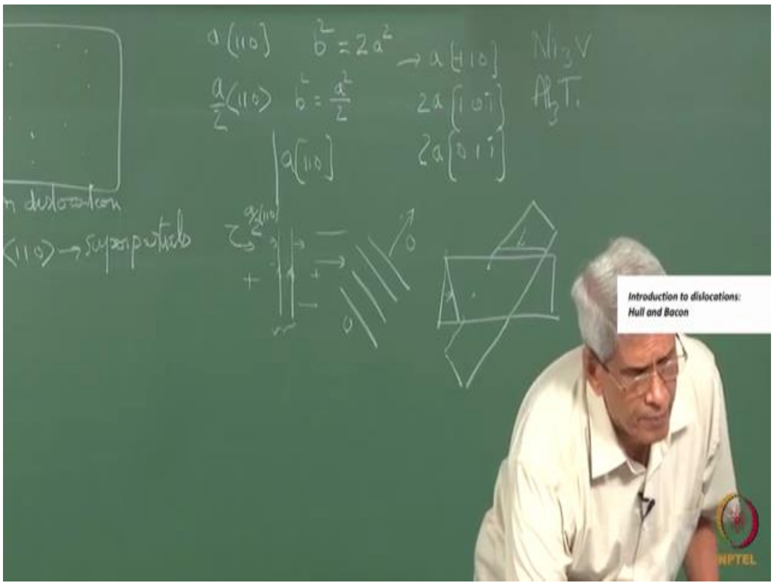

So, this super partial as I mentioned, if you consider for a 1 1 0 for burgers vector the b squared becomes 2, a square correct and for this dislocation a by 2 1 1 0 this b squared becomes.

Student: A square.

A square by 2; so if it split is into 2 that for both of them together is only a squared. So, there is a gain in energy. So, this reaction is always possible are as a general principle any dislocation which tries to split into partial, is smaller burgers vector there is always anything gain in energy, it would prefer to role then when there is a gain in energy the material is now going to exist in a much more stable state. Provided that is possible.

Here, when this sort of a separation takes place, these 2 dislocations have got the same burgers vector a by 2 1 1 0 type of a burgers vector. So, since the burgers vector remains the same and they are in the same slip plane as we have discussed earlier in a few classes back these dislocations will repel each other when they repel each other. And they start moving there is an anti-phase boundary which is being created. That means, that an atom here, if we consider it the atom in the next layer is being put here. It is being moved from this position to an another position, where if you consider here it has one unlike neighbor and here 2 like neighbors are there which shift to all the 3 of the same type of a neighbor; that means, that bonds are changing if the bonds change; that means, some new interface is created that required some energy.

And if a boundary is creator, so depending upon the anti-phase boundary energy of the material that will decide what is going to be the separation between the 2 partials. This can be also considered in a different way the way in which we can perceive this is that one dislocation with a burgers vector a 1 1 0 it split is into 2 dislocations. It is burgers vector a by 2 1 1 0. These dislocations assume that they have the same burgers vector. Both of them they repel each other. So, when the repel each other assume that this dislocation is, they will separate. When this dislocation moves assume that are in this configuration, when they have reached an equilibrium separation. We apply an external stress when you apply an external stress what is going to happen is that the stress is in this direction this dislocation will try to move in this direction. When this dislocation moves in this direction, it is in an ordered lattice it is there. So, it has to create the first dislocation which it moves, it moves atoms from this position to this position; that means, it is a clear disorder has to be creator.

So, extra energy is required for the dislocation to move, because as it creates it has to create an interface also, not only just the movement. When the second dislocation comes it moves in a region which is already disorder right. It requires less stress to move so it will come quickly close to this dislocation, but then it finds that that repulsion between the dislocations will start acting and then you (Refer Time: 14:16) it will just repel it. So, they try to maintain an equilibrium separation which is dictated by this anti phase boundary energy. Essentially the repulsive force can be equated to the anti-phase boundary energy.

Multiplied by the distance will give the force this way we can find out what should be the if you can measure the separation between these 2 dislocation, we can get some idea about the anti-phase boundary energy.

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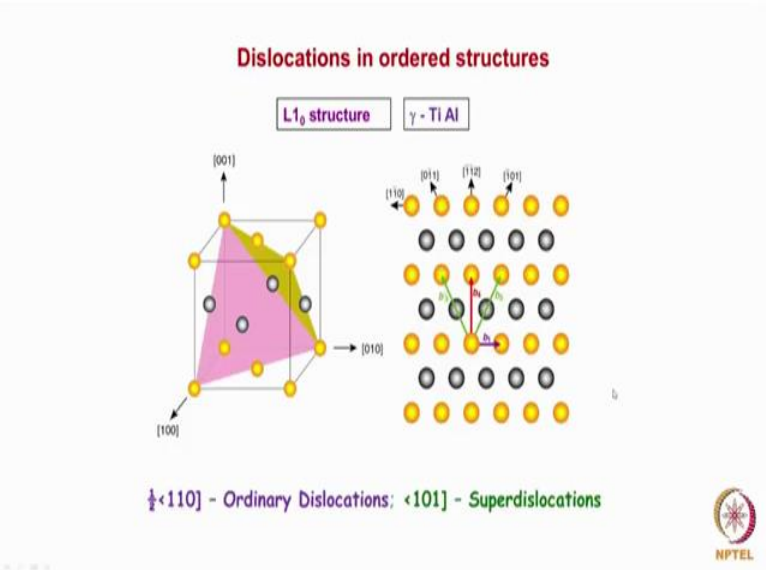

In that structure which we considered all dislocations are like here, you feed look all these dislocations are super partials correct a super dislocation.

This is another structure which we consider which is 1 1 0 structure. This is gamma Ti AL there are copper gold 50 atom percentage. There are many alloys which go into this sort of a structure. Here it is like an FCC lattice. This layer is consisting of one type of an atom. The next layer consist of another type of an atom, this consist of the same type of an atom. So, it is like a layered structure, each layer consisting of a particular type of atom along the c direction they are stacked in an a b a b type of the stacking sequence, when such a type of a stacking sequence is present.

Let us look at in this one also the close packed plane if I look at it this is the way it appears. These structures for all practical purposes if you assume that the atoms we cannot identify which position they occupy it is like an FCC structure. So, this is the close packed plane here. Now if we look at it from here to here now burgers vector turns out to be the same as the burgers vector and the disordered lattice. Whereas, and from here to here also it is in the disordered lattice, but from here to here this dislocation is a super dislocation, which is essentially double data b 1 in magnitude? That can still split into partials.

So, in some of the structures depending upon the crystal structure in some of them in some direction because (Refer Time: 16:33) slip systems are there. Some slip system is essentially the perfect dislocation of the disordered lattice, which moves in this. In another slip system slip plane, if you look at slip direction to look at it. It is the ordered one. So, it will split into partial creating a super partial creating an anti phase boundary region between them. So, this is one way it can happen. Because I am just trying to give you a flavor of what all the types of dislocation the actions which are possible in ordered lattice.

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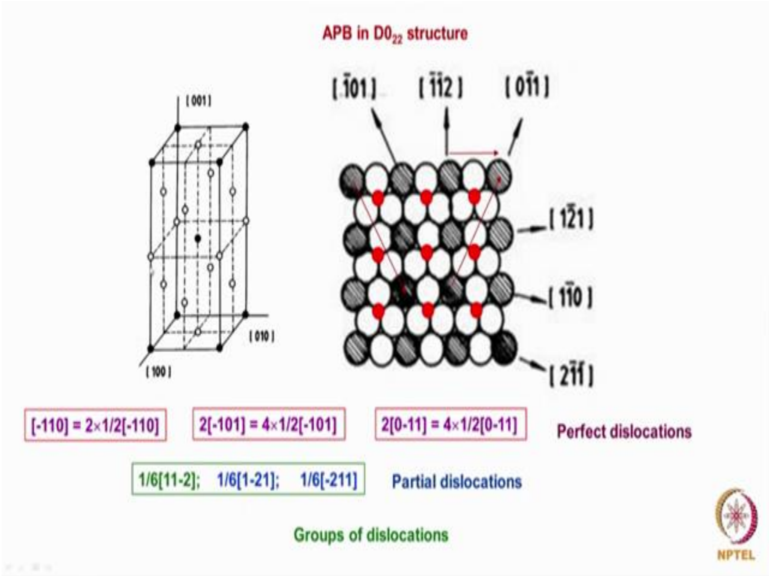

Let us consider a third case with this case we will stop talking about these order lattices. Here if you look at it, this is a structure where the c by a ratio is 2. This is equivalent to 2 FCC lattices, if you keep one on top of the other. And the atoms are arranged at specific positions. A type of an atom that is suppose, we assume that the stoichiometry will be a b 3 type, A atoms occupy all the corners and the center the B atoms occupy all the phases and the edge here. In this lattice if you look at the close pack plane with respect to FCC, if we talked about it FCC indices this is a 1 1 1 type of a plane.

This is how the arrangement of atoms is. The red atom shows the atom on the next plane. Why I am talking about this particular structure, is that in many nickel base alloys like alloys 718 alloys 625 a or many other alloys, are precipitates form with this type of a crystal structure. Not gamma prime with this this called as gamma double prime in the super alloy terminology which is used these precipitates form. Here again if you look at it if you go from here to here this is the perfect translation vector in the ordered lattice. This is in this direction which is essentially nothing, but 1 1 bar 0.

Now let us look at in this direction, are in this direction. In these 2 directions from this position to this position, only that this translation vectors tells that if you move from here to here only we reach a perfect identical position; that means, that perfect translation vector now turns out to be twice 0 1 bar 0. That is essentially in one case it is a 1 1 bar 0.

Another case it is twice a 1 0 1 bar 0 1 1 bar, that is in these 2 directions burgers vector of the dislocation is extremely large. For all these dislocations will try because it to split into partials. So, when that happens the super partials in this direction is going to be 2 dislocations 2 super partials will have to move. In these directions 4 super partials they will split in 2; that means, that when all the 4 that is in the direction in this particular direction, when 2 dislocations have passed through the region, that is in this particular this is the one direction in which this dislocation is going 2 partials are there. In this region as well as in this region, it is perfectly ordered, a p b is between them first dislocation creates an a p b the second dislocation that it removes it. So, that is how it moves.

Now, the same thing when it has to happen in a direction like this, which is the slip direction, is in this direction. Now we should have 4 dislocations should be there, should go through it. After all the 4 dislocations are passed through it only we will find that ordering it is perfect ordered in this region perfect ordering is going to be then, in between region that is anti-phase boundary is going to be creator, this is clear.

So essentially generally people say a that whenever the many material ordering is there, if you see pairs of dislocation, we say that ordering is there. That is not correct, because that depends upon the crystal structure. This is one example where in this direction 4 dislocation; that means, essentially what we should look at it if groups of dislocations pass through some region, and the number of dislocations is dictated by their burgers vector of the super partial, burgers vector of the super dislocation and that of the super partials which they formed in that this is how many. In the case of gamma prime case in many of the super alloys 2 dislocations are good enough; people that everybody extrapolates it and tells that that is good enough.

So, if you see 2 dislocations ordering is that that is not the case. Depending upon the specific system in some cases it could be true or good enough here what happens is that in this direction if 2 dislocations pass through order is not completely restored you require 4. This is perfectly.

Student: Yes.

Now, having talked about these various types of what we have considered is we have considered 3 cases. One case only super partials are formed, we split is into partial. Another type of a structure where we can have a super partial as well as a perfect dislocation of the disordered lattice can be present.

Let us the third case where we are seeing that the super partial itself can have different types of different magnitude depending upon that the number of super partials which are required to pass through the lattice to restore order, can turn out to be more than 2. This is here what I have tried to do it is the same structure which I have considered.

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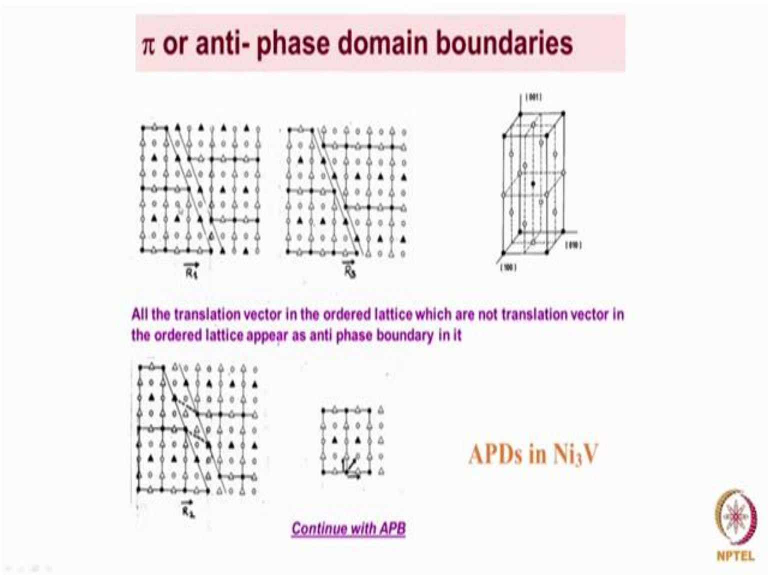

And showing that this same crystal structure. This we considered in an ordered lattice if dislocations are present, what is the type of dislocations could be there super dislocations. And the same structure like if you remember how we define that a p b in a 2 dimensional lattice. This is also this precipitate forms in many cases like nickel 3 vanadium.

AL3Ti there are many systems; the disstoichiometry composition of nickel 3 vanadium or AL3Ti. In this case also the crystal structure is d o 22. When we h at below the other temperature the nuclei ordered phase, form they grow. And when they grow some cases they will join together without creating a fault. Some cases when they join together they will be creating anti phase boundaries. What all the types of anti-phase boundaries which form is being shown. Depending upon the way the shift between them, I mentioned earlier how to define the anti-phase boundary vector, depending upon that we can see that between these boundaries here this is one type of a structure. This is the same burgers vector in a different direction. It creates another type of a structure; this is as again creating a third type of a structure.

All these structures which we are seeing now, is essentially nothing, but structure of another phase, like in a stacking fault FCC, stacking fault creates HCP structure. Similarly, anti-phase boundary also because it is a super partial which pass through, they will create a fault the faltered region could correspond to a nuclei of nuclei are the unit cell of another structure. That is what typically which we can see in these cases. There is a 2 dimensional projection of the 3 d lattice is being shown. This is along 1 0 0 direction projection having talked. So, much about it, now let us go back to dislocation interaction these dislocation interactions.

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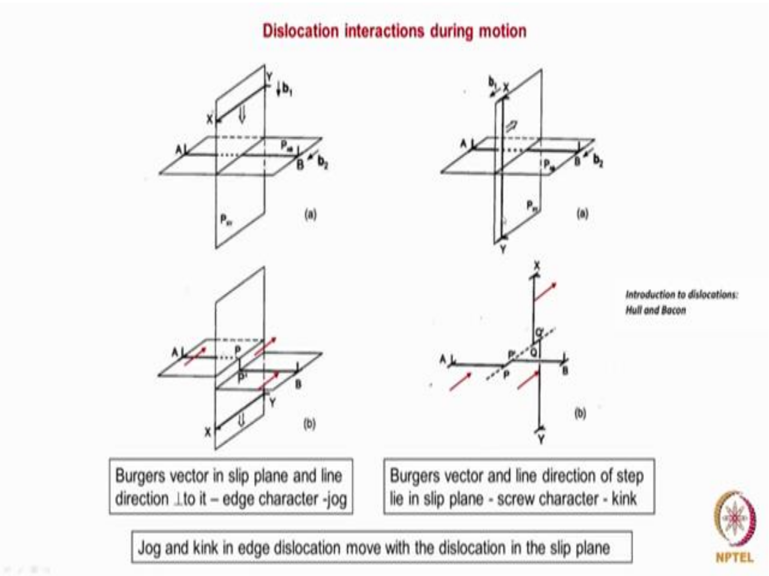

We have discussed earlier, what we said is that when dislocations of the having burgers vectors which are opposite to each other are the same burgers vector, but the line sense which are opposite to each other when they come they will be attractive. As we mentioned if the dislocations have the same burgers vector, they will repel each other. This we considered with respond dislocations in the same slip plane. Suppose we consider a dislocation one dislocation is moving in this plane in real material what will happen is that another dislocation is moving in this direction. And this is moving down this is moving in this direction when take and it can so happen this dislocation the burgers vector is such that the force can be a repulsive force. They may not attract, but under the action of a applied force. Since I have to move across they will try to cut through this precipitate.

These are all the cases which we have considered, and what is the consequence of it let us look at it. Here we are one dislocation; here we have considered that case where the slip planes are perpendicular to each other. There is one dislocation here, with the burgers vector in this direction. In this slip plane perpendicular slip plane there is a dislocation with the burgers vector in this direction. These 2 dislocations when they cut pass through each other, what as essentially has happened is that, these dislocation has a burgers vector in this direction as if cut through it. It will create a strap.

So, this is the one step and atomic step will be created which will be equivalent to a burgers vector. Because that has to move the atoms on this plane when this dislocation passes through this region, it has to move all the atoms in this plane burgers vector it should be shifting. So, the dislocation line would have shifted here. So, this is how now the dislocation looks like. The step is created and the step creation means that there is an increase in length of the dislocation. This way as the dislocation interacts length of the dislocations can increase. So, this also leads to multiplication of dislocation. And let us look at this particular one; in this case, when this dislocation cuts through the dislocation in the horizontal plane cuts through the dislocation in the vertical plane.

Since the burgers vector of this dislocation is in the same direction. It does not create a strap. Because the strap which is creating in the same direction as there. So, essentially a strap is created only in this dislocation, but not in this dislocation. And if we look at what is the plane in which the strap is line, this is the line direction the burgers vector of this dislocation is all in this direction. Here also the burgers vector in this direction where the arrow is being shown; that means, that it is a edge character, but lying out of the slip plane.

And when we know this is the line direction and this is the burgers vector, and they are perpendicular to each other. The slip plane is this plane the strep itself is the slip plane. If we apply a stress in this direction all the dislocations will be moving in the same plane, only in their slip plane. So, they can easily move. So, this type of a dislocation which is created, which is not in the same original slip plane in which it is moves we call them as jog, the terminology which used to describe them is they are called as jogs. So, jogs are created, but the jogs which are created in an edge dislocation it is able to move easily under the action of an applied stress.

Let us look at than another case. These also the same type, but only thing is that the burgers vector of the dislocation has changed now. This is the line direction and the burgers vector is in this same. So, both the dislocations lying in two perpendicular slip planes, but the burgers vector is in the same direction. Here what happens is that when this dislocation is being cut by this dislocation, since the burgers vector is in this direction it will create a strip here like this one strip is created in this. In these also a strip is created both the dislocations the strips are created. And if we look here, these are direction of the burgers vector, correct. And the line direction is also in the same direction. It is a screw component.

Here again if you look at it this is the line direction, for this segment. And burgers vector it is a screw component. And if you look at this one this term is all lying in the slip plane only. When this strip lies in the slip plane we call them as kinks. So, they have screw character. And since they are all lying in the same slip plane if you apply a stress they will move easily. That means, that whether a jog are a kink is created in an edge dislocation, under the application of a stress they are able to move easily.

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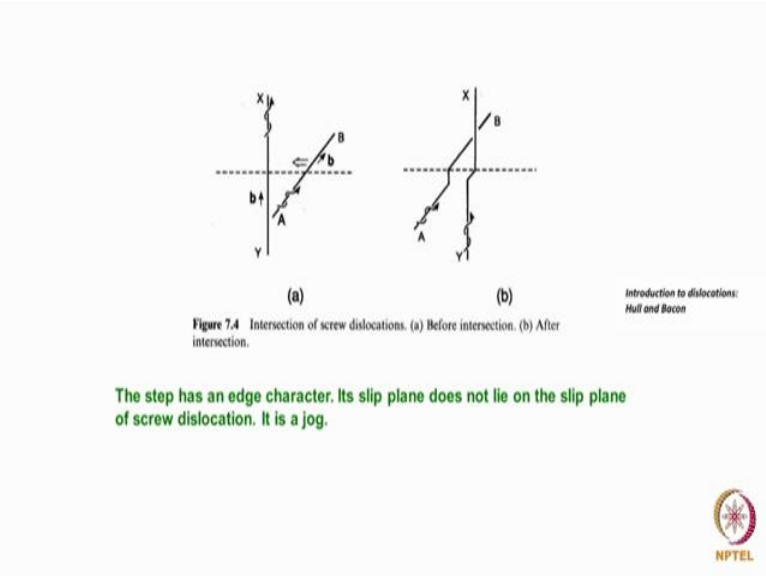

Let us consider the case of a screw dislocations intersection of screw dislocations. Here we are considering one screw dislocation with a burgers vector in this direction, another screw dislocation with a burgers vector in this direction. When they cross each other since the burgers vector of this dislocation is in this direction as it cuts through this dislocation, it will create a strip in this one, is what the strip is created. This dislocation where it has cut through this particular one since it is in these direction a strip is created in the upward direction. If you look at this strip this is the slip plane.

This is also the parallel slip plane, it is out of the slip plane; that means, that it is a jog, and the burgers vector is in this direction that is the burgers vector is in this direction the line direction in this direction they are perpendicular to each other. So, it is an edge dislocation and the slip plane of this dislocation is going to be in this direction. And when we apply a stress like this this one will try to move either in this direction, but slip plane for the extra segment is going to be in this in this plane. So, it will try to move in the opposite direction which is not so being pulled in different directions.

So the jog which is created, it is not able to move easily under the application of a stress; that means, that the screw dislocation on both the segments on to slip planes adjacent slip planes they move, but the jog will move highest stress is required to make the jog move. Now let us look at the case how does the jog move. These are that there is a jog the jog is lying in a plane because if the stress is applied in this direction and if the dislocation is going to lie in this slip plane, these 2 are perpendicular to each other; that means, that in the case of a edge dislocation when stress and the dislocation line directions are perpendicular to each other, actually the stress will not have any effect. So, the dislocation need not move correct.

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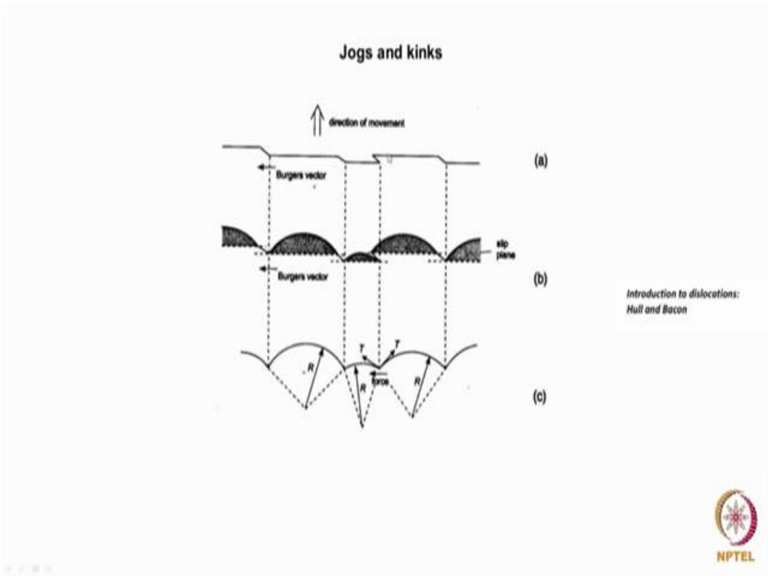

So, if these dislocations have to move they can move, only by claim the force which connect. That is precisely what given, because here this is a case where these are all the jogs which are created in the screw dislocation. We are applying a stress while maybe in this direction, which applies a force in this direction which makes the dislocation move. So, this dislocation has bend, because this is like something which is holding on to a dislocation. This is which is holding the dislocation from moving. So, the ends are as if they are pinned, these gets bend. And this is the straight of affairs. If this whole dislocation has to move up, what should happen this segment also should go up flying.

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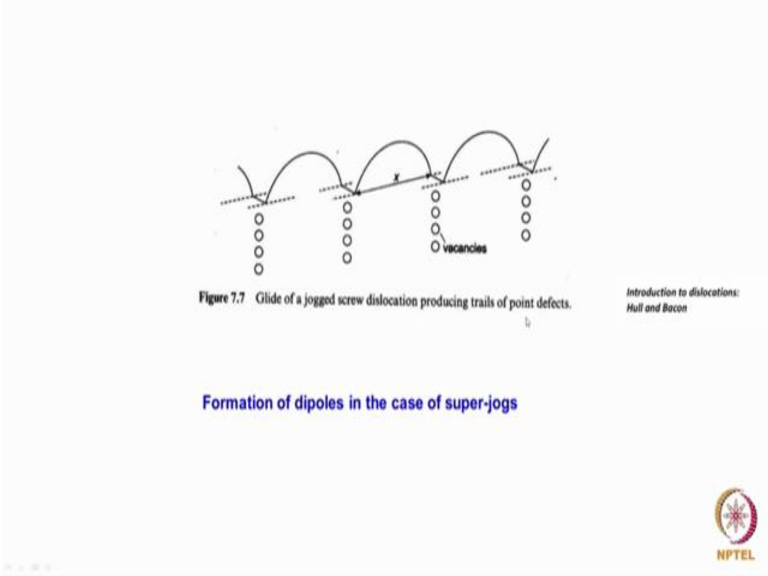

So, if a climb process takes place, either interstitials have emitted are vacancies are emitted from that region. Here that is what essentially happens is that when these go was a we are considering their case where vacancies are emitted; that means, that the screw dislocation when they interact they create a jog. The jog to move we require a very high stress though the increase in segment of the dislocation line is very small, but the stress. Which is required to make this dislocation most is very high. So, the jogs have an important role to decide the strength of the material.

So, this is one way in which it can go. Here if you look at what is the strip which is being created this strip is only of an atomic strip which we are considering. It you can so happen that the many dislocations have cut through. So, the steps could be very large.

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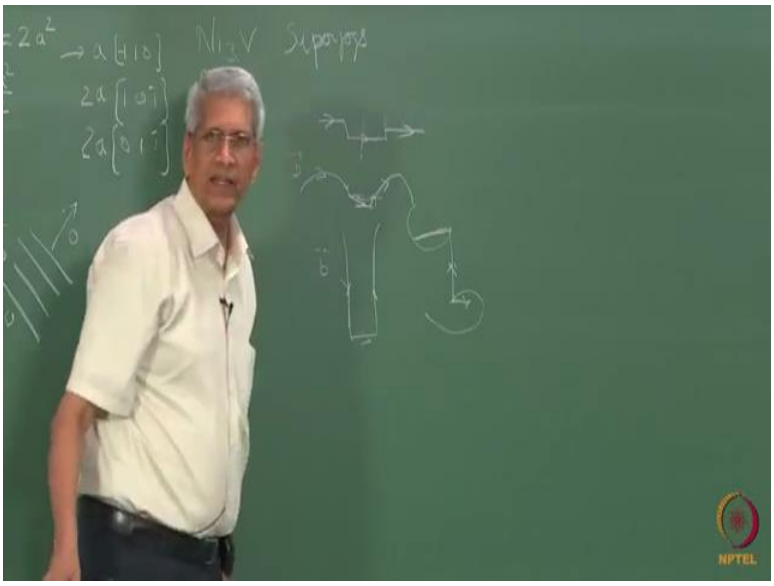

In this itself if you look at it we will just try to draw this diagram itself, and let us see how it looks. This the line direction you can consider and then if this segment bends like this, this segment is always cut here. And then this segment again bends like this. So, what is going to happen is that, if you consider here and here, the dislocation line sense is in different direction, but the burgers vector is in the same direction there of opposite type a. So, under the action of the stress what can happen is that this can move quite high. This is stuck in this region. So, we will have 1 1 regions has come like this another region has gone up like this. This is how this sort of dislocations with the same burgers vector and different lines sensor means this we call it as a dipole.

So, this sort of reaction can happen where dipoles can be created. This is one possible reaction with which it can happen. So, further depending upon the size of the jog in some when there is a size of jog is unit burgers vector a unit translation vector in that direction, and then vacancies can be created. If they are slightly larger than that it is. So, possible that a jog could be created when more than one-unit translation vector is there that type of jogs are that terminology which is used is they are called the super jogs. This is one case. That is another case which it can happen is that one region is like this another region is like, this the dislocations are there these 2 are in the slip plane and this is out of the plane very large. Depending upon the local stresses bending could in one of them, the bending could take place in this direction, and another bending this could bend in this direction correct. There are all types of reactions which can occur in these dislocations.

So various ways in which the jogs that is the finally, if the jog has to move. It has to generate the dislocation they can there is either vacancies are inter sections and move, but when the jogs are not moving they can and their held because the stress is not sufficient to make them more. Then what is going to happen is that dipoles could be created. And many other shapes in which the dislocations could expand then. So, we talked about 2 types of this one jogs and kinks, and the kinks which farm due to interaction between dislocations.

And even in equilibrium cases, mixed dislocation, is the state in which the dislocation domains, the line direction is it in a stable equilibrium condition. This is important when we consider a crystal line material. This aspect we will look at it now. How it happens generally.

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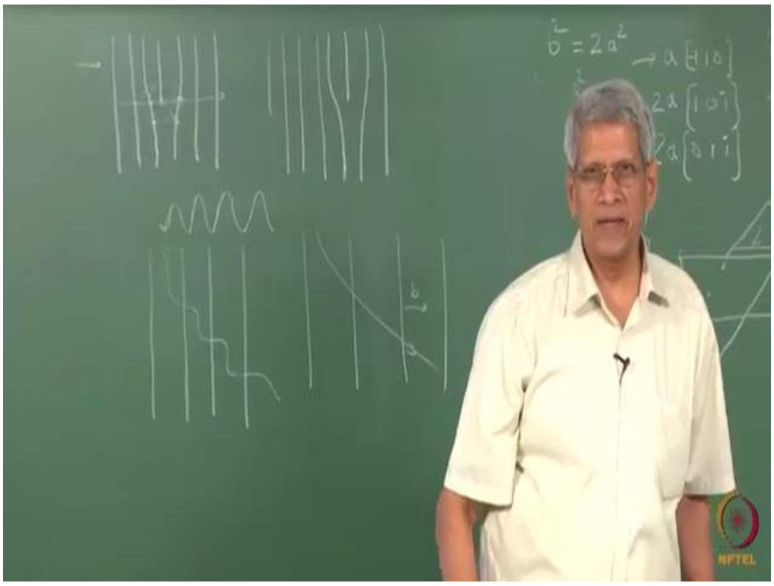

Then we look at a let us consider the case of an edge dislocation. This is how we see, that the lattice planes are there correct. And then this is the slip plane, above which an extra plane is there correct. If a dislocation moves then what will happen is that by one step, in this case if I dislocation has to move from here because atoms are going to be there on this slip plane. Here atoms are going to be there on this plane. Under the action of the stress, suppose this plane is being pushed a little bit then this distance will become shot and this distance will increase.

So, that is how this layer gets connecter this can be considered as equivalent to when an atom when an extra plane remains in this position. It is equidistant from these 2; that means, that is in an equilibrium position. If it has to move from this position to reach this position it has to reach a position intermediate, where if this plane has to come on top of this one correct. That position it will have a higher energy; that means, that if you look at the core of the dislocation as a function of distance if you look at it, energy wise it will be like it is a minimum, like this this is how the energy of it is going to change.

So if this extra plane, which is the line direction of the dislocation? I will just draw like this this is the dash line is the dislocation line. If it lies between these 2, it is an equilibrium position. When it has to go from here to reach this position it has to go through a high energy. Barrier correct; this will be this will be seen prominently in the case of covalent bounder material or ionic materials where the directionality of bonding is going to be there. Now let us consider a case where the dislocation line is like this; that means, that this is a burgers vector is in this direction, this is the line direction.

Now the dislocation is lying in a region there is higher energy and lower energy if you look at the energy of dislocate the core is going to vary. So, it is not in a minimum low energy configuration, what is the way in which it can assume a low energy configuration, is that, if it part remains like this. That is a strip is creator comes like this another strip is created. So, minimum path of the dislocation line only has to be in the high energy region. Then if it is strip is created like this if it moves this is equivalent to this one. And all these are nothing, but a kink the slip plane.

So, this way also kinks could be created. Because the dislocation line would try to remain in a position, which is overall there it is in a low energy position. This can be prominently seen in many ordered the alloys are in; that means, that the long length of the dislocation line will be seen either an edge or a screw type mix type of planes with is there. Wherever it is possibilities try to minimize the energy and the just like the dislocation line will be there like this, maybe it will be moving like this is how we will be observing the dislocation line.

So this is another form in which kinks could be generated. Now So, far we talked about dislocation interaction. And we said that in this sort of dislocation interaction, there is a slight increase in a length of the dislocation is taking place. And this gives rise to some multiplication, but the increase in length is very small, but generally we had seen that when we deform a sample, the dislocation density goes from maybe 10 to the power of 4, to 10 to the power of 6 times orders of magnitude not 6 times 10 to the power of 4 10 to the power of 6 times it increases correct. Not 6 times it is increasing. So, that sort of an increase in dislocation exist takes place.

So, it cannot be accounted for these small steps which are created. What could be the reason for this; that means that there should be some sources which should be operating within the material correct which is responsible for such a high increase in dislocation density. What are the sources which you can think of? One of the sources which have been put forward is the frank read source.

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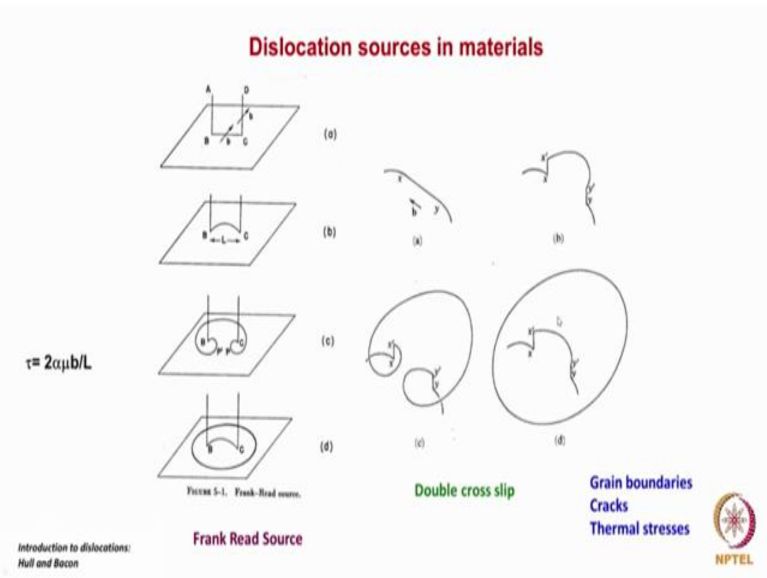

Here, what is being assumed is that a dislocation line is there; a segment of the dislocation line that is the B C is in the slip plane. And A B and C d/ are out of the slip plane. If we apply s burgers vector is in this direction, if you apply a stress what is it going to this is being pinned, under the action of the stress the dislocation will climb we would like to bend correct.

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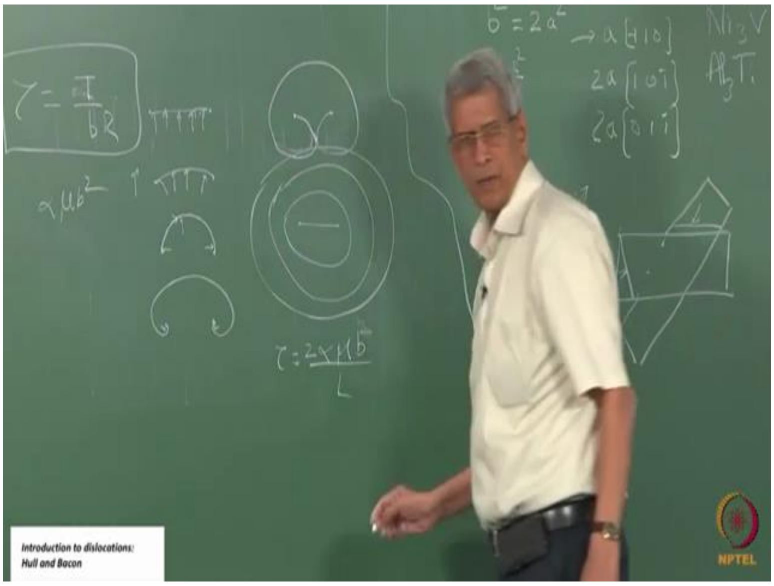

So, essentially when the dislocation lines are in between these 2 regions. It is initially straight, under the action of a stress applied in this direction, the dislocation lines bends like this. Initially the forces are all going to act in this direction. Because we have studied that the force is perpendicular to the line direction everywhere. And now the force is going to act in this way. As the dislocation line bends and reaches a critical value a semi-circle.

Now the force is going to act here like this in this one it will be in this direction. Here it will be in this direction. So, it will make the dislocation expand because that this the pinning center, it will try to expand this expansion is what it will give rise to this particular type of a shape which is shown in see in the figure. So, this will make it in the third case, this will be bent like this, but still the forces are going to here, force will be act in this direction here force will act in this direction.

It will expand further and further and at some stage these 2 with line direction in opposite sense same burgers vector when they join, they will attract each other and they will join, when they join together they will break and this will form a circle. And these regions are again joined together. So, this case if we consider it, that is a critical consider that they have just join together. When they just join together the stage it will reach these 2 the joint together they annihilate. So, this is a one which is a length like this that will try to shorten the length, and reach this position. Here you have one dislocation line there is one dislocation loop which has been generated shear loop.

Since the stress is being applied continuously loop after loop can be generated. So, this source is called as a frank read source. In many crystals it has been seen experimentally also institute electron micro doing institute electron microscopy, one can observe one has observed this type of sources operating in the sample. And all these dislocations like these when they form these are all moving in the same slip plane correct.

Because in the same slip plane it is being generated and they expand and go, that is one. And another is; what is the critical stress which will be required. That stress is essentially is we know that when a dislocation is being bent into an arc. The stress which is required tau equals t by b into R. This I think if you remember this is the expression which is being use. Now R will become 2 l/ R will become l by 2 t is alpha mu b squared.

So if we substitute these we will get the expression 2 alpha mu b by l/. Correct that is what the expression which is being given here. From these clear that what is the critical stress which is required for a frank read source to operate. There many mechanisms by which these sources one can think of. One is called as a if a dislocation is moving in a slip plane. Assume that a screw dislocation is moving in a slip plane. This screw dislocation it see an obstacle, in it is movement in some region. Then it cross slips onto another plane.

And then when a cross slips and plane it find that there is no obstruction. Then it can again do another cross slip and come back to a original slip plane. That is not the origin parallel slip parallel to original slip plane. And it can move in this. Now these 2 ends are these 2 ends can act as essentially happening centers the stress is less in this for the dislocation to move. This can again act like a frank read source, and generate dislocation loops. This is found to be one of the main ways in which more and more dislocations could be generated in the material very easily. Like if you think of FCC there are 4 slip planes are there, 3 slip directions. So, 12 slip systems. So, 12 types of frank read sources could operate in all these planes. And they could be generating dislocations when we are deforming the sample with small stress which is being applied.

So, these dislocations which are generated in all these planes, they will be interacting with each other as they move. That is how the dislocation multiplication occurs. Not only that these dislocations can interact amongst each other in the case of FCC are in BCC are in HCP. We have looked at what all the types of interactions which are possible all these things we have looked at it in the last few classes.

This class by which the source is generated is called a double cross slip process; and what all the other ways in which dislocations could be generator? Grain boundary it is a sink for this location. Similarly, it can be a source also from there it could be generator. When cracks are being generated, ahead of the crack tip dislocations could be generated. That could act as a source in a fracture mechanics people look at these aspects of it. Then simple case if we take, a sample heated to high temperature and quench it. The thermal stresses are there, the thermal stresses are relieved by punching out dislocations in the material, they could also act a source of dislocations generation in the sample.

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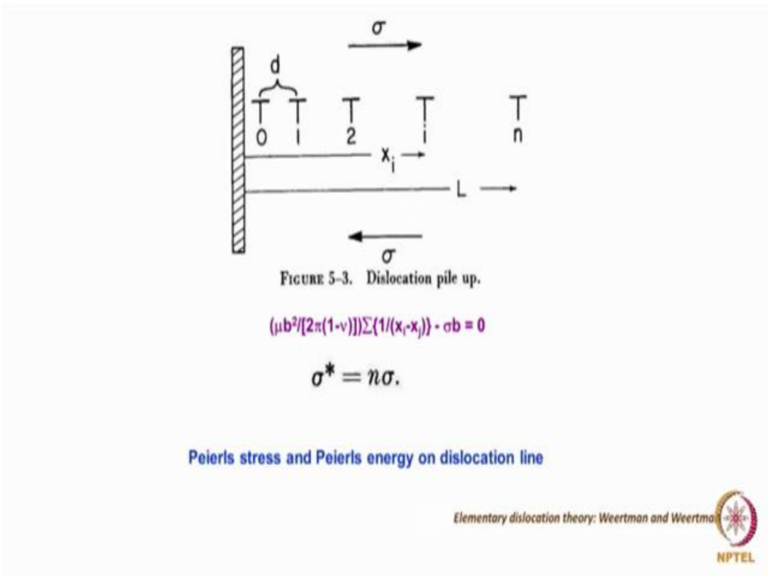

Here what we have done is that, when dislocations of these types have generated. This is the sort of here suppose this there is a boundary which is going to be there. Assume this a grain boundary. So, when these dislocations reach this grain boundary look at the grain boundary will stop that. That means, that in the same slip plane there are dislocations one after the other behind one another dislocation like this is there.

The same arrangement which is being shown here, with the dislocation line here perpendicular to a screen are coming out of that screen. When these sorts of arrangement of dislocations are going to be there, what is interesting is that all the dislocations have the same burgers vector. Some stress is being applied. When that is being done if you look at each of this dislocation, this dislocation together like that, it will apply a stress on a it is a repulsive force. This dislocation again will appear repulsive force on this. Correct all the dislocations are going to apply some repulsive force, but this dislocation will repel not only this it will repel this also.

So we can write an expression for the repulsive force between all the various dislocations. In the net some of this should be balanced by the applied, stress applied force. That is minus sigma b this is what the expression is. Another feature which becomes very prominent is that if this is solved what is going to be the stress which is going to be on this dislocation, from here to here getting each of this dislocation apply some repulsive stress. So, the stress multiplies. The solution to this is on the average if n dislocations are there, n times sigma could be the stress which is going to be there and the dislocation add of a, when such stresses are acting on the dislocation which is closer to the boundary.

A few processes which can happen if the stress is so high then this stress can be relieved either by generating some dislocation on the say. So, that the stress will be relieved and they can move. Or if that is not possible it can create a crack. Because once we create a crack at the boundary then the stress is relieved completely. This is when we deform a sample, where toughen one can notice that that all depends upon what is the stress which is required to generate a crack, begin the samples are at the boundary, we are considering a case of a boundary where the 2 possibilities are there. One it can generate this location on the other side of it the other grip and relieve, the stress or the crack could be generated. Then also that material failure will start this one of the way in which a failure could be initiated from the grain boundaries.

Especially it has been seen that when these sort of boundaries contains some precipitates which are going to be there which are very hard. Then it is possible that is getting a elastically strained and many of the order precipitates like oxides and all it is very difficult for dislocations to move when the stress reaches a value which is equal to theoretical strength, the stress concentration and this dislocation it will generate a crack in that. That has also been observed.

Looking at the samples and electron microscopy one can see that one can see a plane are arrangement of dislocations and come and meeting at a particle and do not can see that at small crack has been generated in the particle; that means, that in a planar arrangement, the all dislocations lead to increasing a stress which is going to act on the dislocation which is closes to the boundary. So, essentially now what we have done, is that you have looked at the various types of dislocation interaction and dislocation multiplication. Also what all the types of sources which can a operate, when these sort of sources are operating especial because when this plane arrangement will take place, especially when the applied stress is low, and only one slip system is activated, then the sort of reaction are when the stacking fault energy is low, then the dislocates are confined to move in only one particular slip plane. Then planer arrangement of dislocation will have take occur in the material.

In such cases lot of stress concentration can build up. Like we take in the case of aluminum where the stacking fault energy is high cross slip of dislocations can take place also to generate the stress. Here none of you if this is an edge one none of them can cross slip also. That is how a buildup of stress will occurred in the sample. So, we will stop here.