Defects in Crystalline Solids (Part-I)
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Lecture - 36
Observations of dislocations contd... + Dislocation Dynamics

So, we looked at one method of dislocation observation which is surface method where you do etching and then you observe under optical micrograph.

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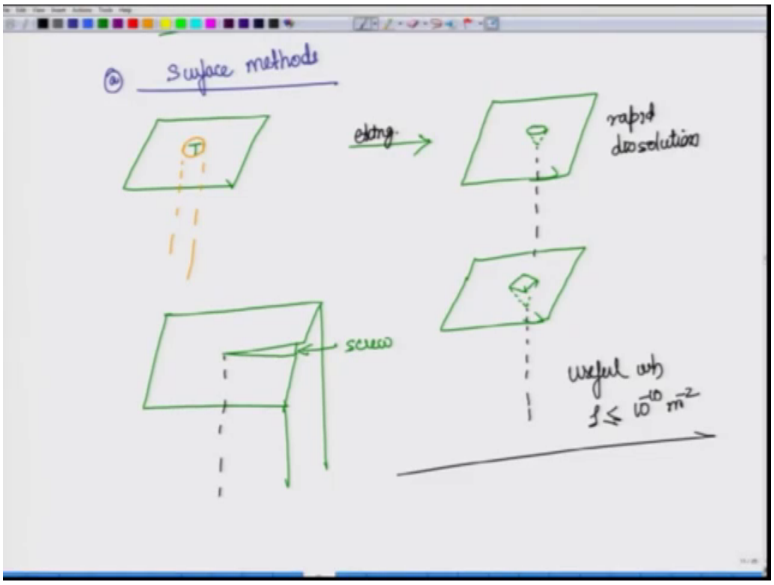

And in fact, it is not all over let us see there are a few more information about this. So, when I said that it is useful for dislocation density less than 10 to the power it should be 10 to power 10 meter per square.

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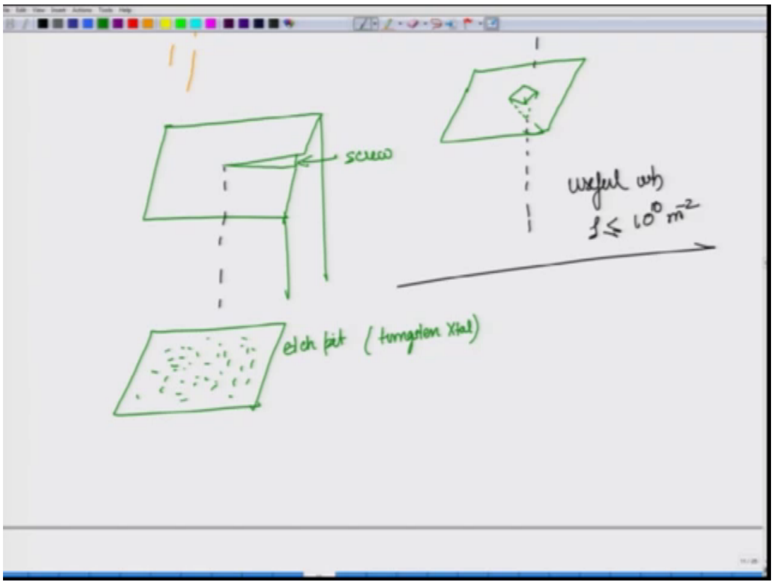

If it is more than that what will happen what you would see is just etch bits lots and lots of etch bits on the surface. So, this what you would see is etch bits for example, people have done study in tungsten crystal. And only when they are far distant there is certain amount of distance between them that you will be able to resolve it. And that is why this method works best when dislocation density is less than 10 to the power 10 per meter square. Now, I earlier mentioned when I started this surface method that this method has also been used for studying dislocation motion.

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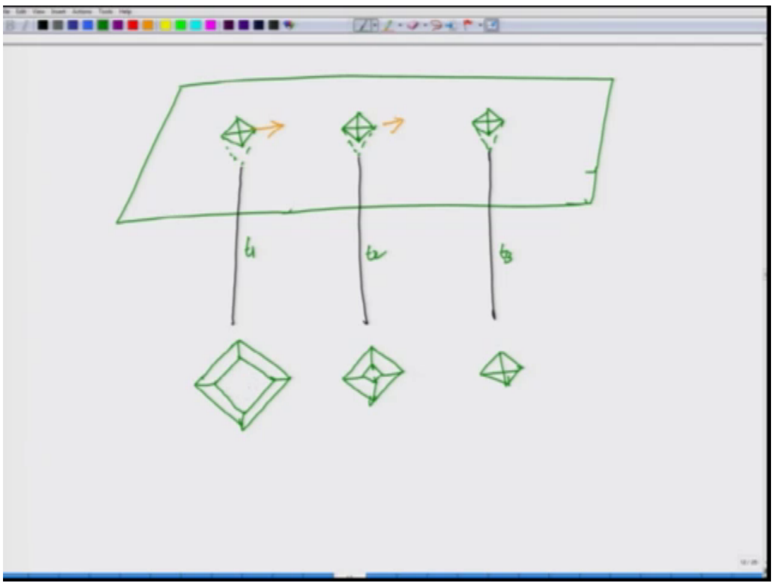

And, what people have done is for example you take when the dislocation density is; obviously, when small you make a etching somewhere and you observe something like this and then actually it will be much larger. And, let us say stress is applied such that the dislocation is expected to move in this direction. So, what will happen is that the dislocation let say applied some stress for a certain amount of time and the dislocation has so here was your, so here was your original dislocation so this is let us say t1.

Now let us say some stress was applied of for certain amount of time and this dislocation has moved. So, what will happen the same thing you would observe over here and then. So, this is at t2 and then, let us say you apply the stress for some more time and then you may see this over here so by and in fact, what is interesting is that you can even see the remnants of the earlier dislocation; meaning what you would see over here, it would something look something like this of because it is getting etched and the dislocation on the bottom has vanished. So, it will get a flat bottom and you would see something like this.

So, if you have after the third time interval when you etch it you would see a much larger etch bit over here, but with a flat bottom because the dislocation has moved out. And since this one moved out only certain only a small time ago. So, you would see a smaller etch bit with a smaller bottom surface and it will be like this and only in this you would see a sharp where it will be more like a diamond shaped indent into this. And, this clearly tells you that the dislocation is present here and it was present earlier here and it was present earlier here.

And when it has moved away you see a flat bottoming of it and by measuring the distance and know the time, you can find out that for applied given applied given stress. And a given amount of time, how much the dislocation moves you can find out the velocity and other related information can be obtained. So, this is one method which is the surface method. Now, let us look at still another method which is decoration method.

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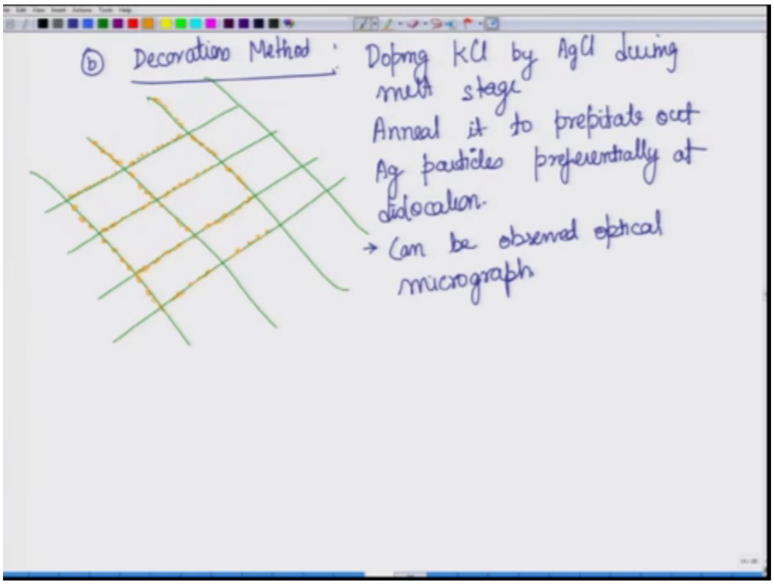

Now, remember that in optical microscope dislocations cannot be observed directly. And therefore, you need certain you need a third material to actually reveal it and this is where decoration method comes into picture. So, for example, this people have done study by doping so in potassium chloride people have doped it with silver chloride during the melt stage itself ok. So, once it has solidified it has some amount of very small fraction of silver chloride present in potassium chloride. And then people anneal it something like aging operation, anneal it to precipitate out silver precipitates silver particles.

And where will it preferentially precipitate; obviously, on dislocations dislocation near the dislocation core because that is the large free volume area, where the additional particles can easily come and attach to. We will talk more about it in the next part of the course where we talk about plasticity aspect. So, silver particles preferentially precipitate out silver particles preferentially at dislocations. And then it can be seen by can be observed by optical micrograph. So, what you would see is like let us say there is a regular spacing of dislocation.

So, the dislocation maybe let us say like this, but you would not have observed these dislocation lines per say. But now that there are silver precipitates so what will happen is that there will be silver precipitates all around this. And you are not observing the green lines when you look at the look at it through the optical microscope. But what you would be looking at these will be these orange particles which represent here the silver particles. So, you would know that this is where the dislocation lines are present. So, this is the decoration method which is also used to find or to observe dislocations.

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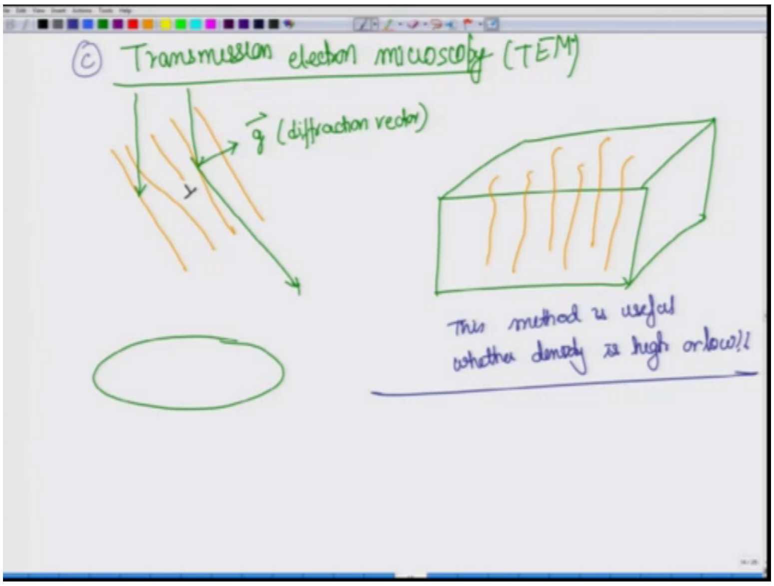

Next let us move on to the most powerful technique, which is Transmission electron microscopy which is the method which was used for the first time to observe dislocation. So, note that we are not saying any electron microscopy. So, for example, scanning electron microscopy cannot show you dislocations, only transmission electron microscopy can show you and that is because transmission electron microscopy depends on diffraction. So, near the wherever there is a dislocation the planes around it get distorted and so the diffraction takes place and that diffraction is what leads to.

So, for example, let us say there are certain planes like this and this is your half plane so the dislocation line is somewhere over here. And so, let us say the dislocation line is over here and your beam is coming like this. So, the beam is get coming in and getting diffracted and some of the beam which falls like this will get diffracted in a different direction because of what is called as Diffraction vector. We are not going into the details of this transmission electron microscopy, because that is course in itself. But understand that there is a diffraction vector and wherever the planes are distorted you get a distorted line.

And hence what when you look at the image that is formed on the bottom side where there is so the all the lines come here, but some of them get diffracted. And therefore, what will happen wherever there was dislocation it will appear as dark lines; so what you would see is something like this. So, let us say this is a thin foil which is which has been observed and that thin foil will have lines like this, what do these lines represent these are dislocation lines.

So, this is one of the best methods to observe dislocation lines and particularly, if the density is high. So, this method works even if so this method is useful whether density is high or low. So, transmission electron microscopy is regularly used and even to calculate dislocation density people use this method. So, you can take micrographs and over there you can count lines where you are measuring measure the length of the lines to find out the density of the dislocations. So, this is one method that is regularly used.

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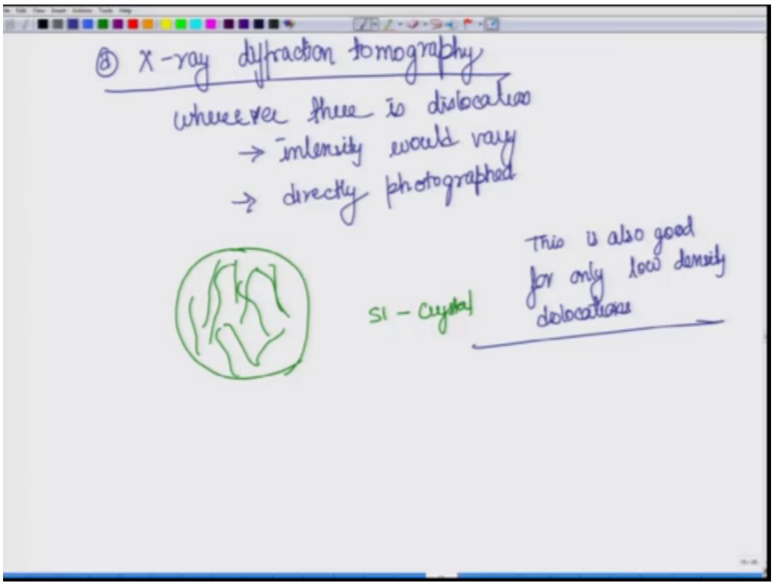

Another method which is known to be used for direct observation is X ray diffraction tomography. So, this is the tomography meaning you are taking X ray diffraction in cross sections. So, usually a crystal is rotating and X ray diffractions are done along if along the direction one particular direction and it keeps rotating so it takes a cross section for all the overall material overall system and then all these images are integrated.

Now, over here wherever there is a dislocation something similar to tm wherever there is a dislocation what will happen; wherever there is dislocation what will happen what will happen is something similar like I said in tm and over there the intensity would vary, so intensity would vary. And this can be directly photographed and in fact people have done this for something like silicon crystal, so in silicon crystal people when we when they have done X ray tomography people have seen images like this. And you can see this even in Holland bacon so all these lines represent dislocation lines.

So, X ray tomography because of the difference in intensity is where dislocation line is present. What you observe is a photographic image like this which directly represents the dislocations. However, the caveat here is that this is also only good for low density of dislocations. Why? Because usually that the resolution of this tomography method is very poor is very low compared to tm you cannot compare it with tm anyways; it is orders of magnitude different. So, this method is good only for low density dislocations.

So, now you can see that there are so many different methods to observe dislocation. And you would also realize that tm is the most powerful method; it does not matter what is the dislocation density and you can measure the dislocation density using this particular technique. So, now we have covered a lot of aspects about dislocation.

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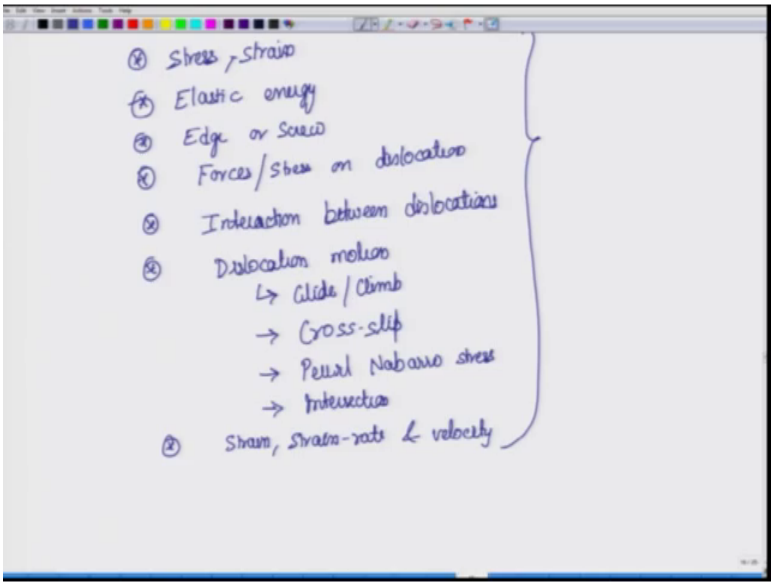

So, for example, we have covered stress, strain; what is the stress strain field around a dislocation? We have looked at their elastic energy that is stored, we have looked at different kinds of dislocation whether it is edge or screw, we have looked at forces or stresses that act on the dislocation which leads to their motion, we have also looked at interaction between dislocation. So, if there is a large pool of dislocation or like in a material like if you are looking at a microstructure there are several dislocations and each one of them will be influencing or basically it has a stress field because of which it will cause influence on the other dislocation.

So, we have looked at it which was given by the relation (Refer Time: 14:55) relation. So, this is the most important when it comes to understanding the interaction between dislocations or evolution of dislocations. We have also looked at dislocation motion it takes place by we saw that it can take place by glide, which is usually room temperature phenomena. While there is also a process like climb, which is usually dominated at higher temperature. Then we also looked at there is cross-slip which is possible particularly, only in the case of screw dislocation. And we also looked at look at the fact or we found that there is a minimum stress required. Critical resolved shear stress or we can also we looked at it from a (Refer Time: 15:44) which is the stress Peierls–Nabarro stress.

So, there is a Peierls–Nabarro stress, which must be overcome for the dislocations to move continuously. And we also looked at intersection and we also looked at strain, strain rate, and velocity of dislocations. So, now, having and looked at all of this there is now we are in a position to be at least at the fundamental level without talking about a specific system. Because in when we talk about a specific system which will come as the next stage, we can at least say how the dislocations would react in the presence of others or because of the presence of other stresses. And because of that will they move, how much they will move, what will be the final configuration, where will be the 0 energy configuration, and this study is called Dislocation Dynamics.

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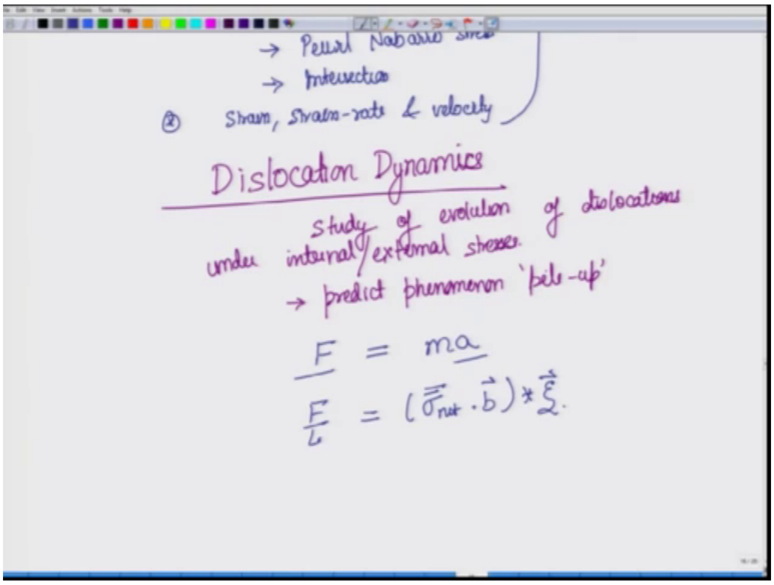

So, all that we have established so far we are in a position to describe what is dislocation dynamics. All the important elements that are needed for dislocation dynamics are already been have already been covered. What we will what we need to cover in later stages or to look at dislocations in a particular system in more depth for example, FCC, BCC, HPC or super lattice structures, which we will come to in the later stage. So but for now let us understand: what is dislocation dynamics. Dislocation dynamics it is study of evolution of dislocations under internal or external stresses.

So, this describes for example, there are dislocations, but their dislocations will be applying stresses on through other or which will result in forces onto them or because you are applying stresses externally because of which there will be there will be forces or again on the dislocation and then they will it should cause motion of the dislocation. So, we should be able to using if you are if you know all the values that is stress strain, Peierls–Nabarro stress, and we know the velocity strain, strain rate, all these concepts we have. Then we should be able to using the dislocations the information or dislocation. we should be able to predict phenomena like pile up.

What is pile up? Will come to about in more detail, but it is just the dislocation getting accumulated at one place when you apply stress. Now when you apply stress what is happening, everything that is happening is understandable in the in terms of concepts that we have given over here. So, this is where dislocation dynamics come into picture.

whatever phenomena that is observed should be we should be able to explain or in fact even predict or simulate using the concepts here. So, what is the governing equation over here.

The governing equation is F equal to ma there is some force acting on to on to the dislocation because of which it should accelerate, meaning it should move. So, these are the two important for the important terms that we have over here F and ma. Now let us look at it in more in a greater detail. What is the force relation that we have if you remember the force relation is already with us which is known as the peach correlation, where we had written like this. And now I will put sigma as sigma net meaning the overall stress that is acting on to a particular dislocation dot b, cross e or u whatever you want to write. So, force part is already known to us now a can be written as d2 x by d t square.

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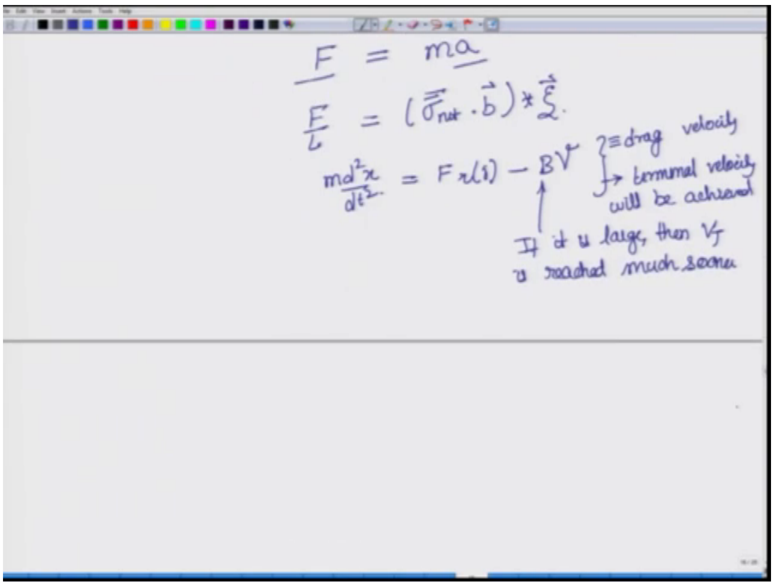

So, we can say F is equal to md 2 x by d t square. But there is also some amount of resistance to the motion of dislocation and where does this resistance comes from come from; if you remember that we talked about when we talked about the velocity that there are damping forces. So, this damping forces can be related in terms of B and it is proportional to V and the velocity so this will be F x i minus BV and. In fact, we should not write this term so the md 2 x by d t square which is the m into F force, is equal to some force which has acting on individual dislocation minus the resistance force because of damping.

And, now if you look at this relation it is very similar to the drag relation, if you are if we have been exposed to this concept the drag force the drag velocity relation. So, if a body is allowed to fall freely in the gravity then there are several forces acting on to it the gravity force and then the buoyancy force. And, then there is also a drag force and because of that eventually a body attains terminal velocity. So, drag velocity it is similar to drag velocity and hence what you should expect here is that a terminal velocity will be achieved.

And, what is more is that if the damping force that is B if it is large then terminal velocity is reached much more sooner V T is reached much sooner. So, in effect and we know that damping forces are very large. So, in effect what it means is that we can assume to begin with that the dislocations have attained a terminal velocity.

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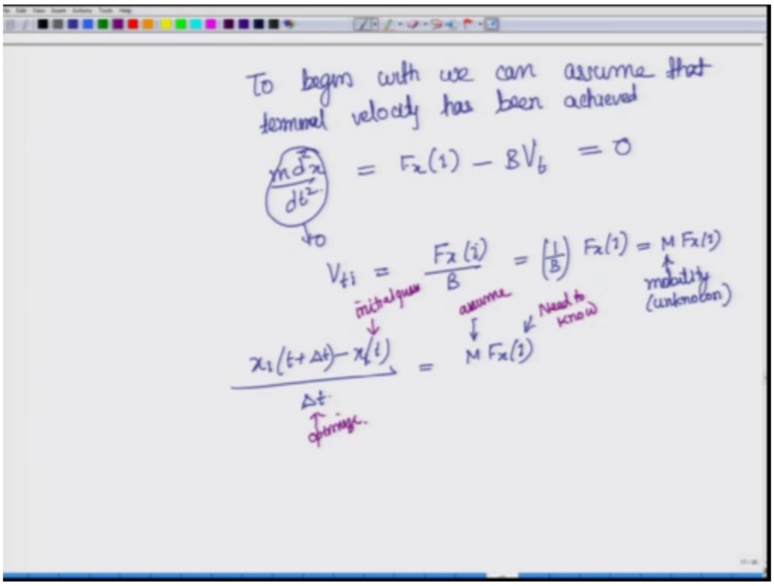

So, to begin with we can assume that terminal velocity has been achieved. So, let me write down this equation over here md 2 x by d t square is equal to F xi minus B. Now we have to say BV terminal and if the body has already it is not a instantaneous velocity it is V terminal. Therefore, it means that m d 2 x by d t square is equal to 0, which means that this whole thing is 0. So, this becomes 0 and therefore, this relation further boils down to velocity terminal for the ith dislocation is equal to Fx. When we say i we are denoting the i h dislocation F x i by B or this can be written like 1 by as if 1 by B is another factor times F x.

So, whatever force is acting on to this into this factor 1 by B which is now which can be at many places it is written like m or the mobility factor. So, this now this mobility is something that we have not touched it is the unknown quantity, but this is also experimental quantity. So, this is something either that can be obtained from experiments or if you are doing simulation you can assume certain values which are appropriate for the given condition. And here V T i, if you are doing assimilation then this V T I, can be broken down to x i t plus delta t minus x I t by delta t is equal to M Fx i.

So, now we have set up an equation where all you need to know is what is the force that is acting and you can make certain assumption about this mobility. So, you need to know, you assume then you optimize this parameter delta t. And, this is something that you will begin with some initial guess and here you will so if you have some initial guess you would get the final value of x i.

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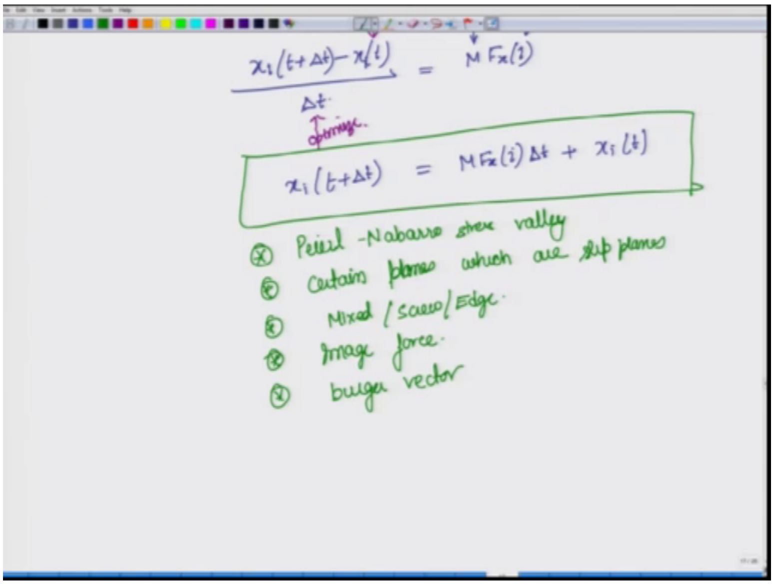

After one step t plus delta t so this will be equal to M Fx i into delta t plus x i t. So, this relation now allows you to calculate new position of a dislocation given that you know, what is the force acting on it which we should be able to calculate based on what are the stresses being created by other dislocation. And, once you have the stresses being created by the dislocation you just need to use the peach correlation which will give you sigma dot b cross e. So, you will know the force acting on to this and you will have to make some assumption regarding mobility. And, you will need to have an initial guess for what is the initial position once you have the initial position for t equal to 0, you can keep iterating it to get next and next and next and next position. So, they say this way how the dislocation is moving or how the shape changes are taking place all these things you would be able to predict using this relation.

So, in this particular one this is this can be very simple problem, by assuming a very simple by making lots of assumption or you can make it much more accurate and a little bit more complex by adding complexities; like you can add that there is there has to be a Peierls–Nabarro stress for the dislocation to move. You can say that the dislocation they will move out only on certain planes which are slip systems. You can say that there are mixed dislocation as well as edge and screw or you can say oh that only edge dislocation is there. So, all this will make it more accurate and more complex.

You can add image forces that will act on the dislocation and there are several other parameters that you can add over here; so for example, the burger vector and so on. So, this is this is not an exhaustive list you can keep adding different level of complexity to get a more accurate result. And, this is this system or this dislocation dynamics method is frequently used to understand the behavior of dislocation under different conditions and in different materials. So, we will this with this introduction to dislocation dynamics we will leave it here. And when we come back next time we will talk about two systems; one is the FCC, and one is the BCC. So, we will introduce we have only 2 hours left we will talk about FCC and BCC and then we will end this course.

Thank you.