Defects in Crystalline Solids (Part-I)

Prof. Shashank Shekhar
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Lecture - 35
Strain and strain-rate due to dislocation motion, Velocity of dislocation and Observation of dislocations

So, we were discussing kinks and jog that are formed after intersection.

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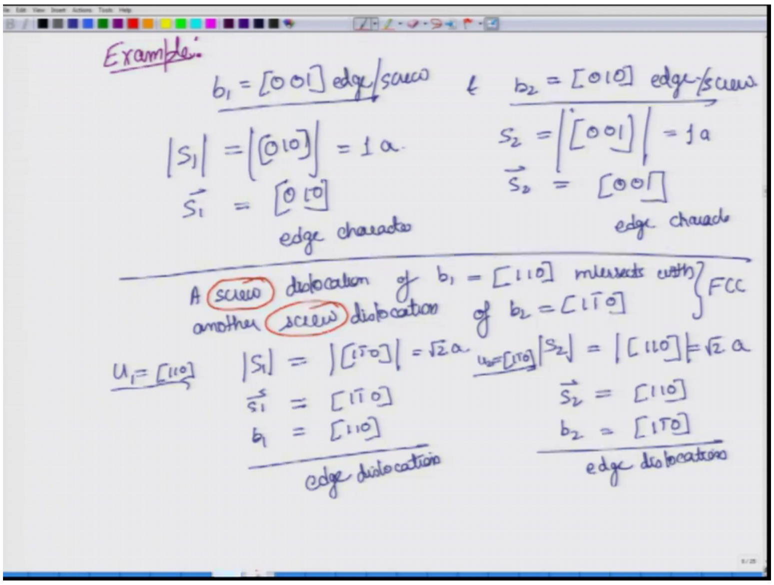

Example:

$b_1 = [001]$ edge/screw & $b_2 = [010]$ edge/screw

$|s_1| = |[010]| = 1a$ $\qquad$ $s_2 = |[001]| = 1a$

$\vec{s_1} = [010]$ $\qquad$ $\vec{s_2} = [001]$

edge character $\qquad$ edge character

A screw dislocation of $b_1 = [110]$ intersects with another screw dislocation of $b_2 = [1\bar{1}0]$ } FCC

$u_1 = [110]$ $\quad |s_1| = |[1\bar{1}0]| = \sqrt{2}a$ $\qquad$ $u_2 = [1\bar{1}0]$ $\quad |s_2| = |[110]| = \sqrt{2}a$

$\vec{s_1} = [1\bar{1}0]$ $\qquad$ $\vec{s_2} = [110]$

$b_1 = [110]$ $\qquad$ $b_2 = [1\bar{1}0]$

edge dislocation $\qquad$ edge dislocation

So, we had taken a example, where we said that burger vector 1 is 0 0 1 and assuming edge dislocation b 2 equal to 0 1 0 for the edge dislocation and these are final information that we obtained regarding the steps. Now let see if instead of edge dislocation if we had a screw dislocation would anything be different? And the answer would be no. So, whether you start for this particular information all we needed was burger vector and we do not need to know whether it is edge dislocation or a edge screw dislocation.

So, this could has will be edge or screw and where in the edge dislocation we never worried about what is the line vector. In fact in for this particular 1 if the line vector is along the 0 0 1, then this is similar to case 1 where the step is along the line vector and therefore, it is not observable, but we are not worried about that. We are trying to show is that whether the starting dislocation is edge or screw does not matter and all that matters is the burger vector, because that is what forms the step in magnitude as well as in vector.

So, now this is for a simple case, now I like I have always said that in the real system the dislocations are little bit more complicated. So, let us talk about a screw dislocation of burger vector 1, b 1 equal to 1 1 1 and it intersects with another screw dislocation of burger vector 2 equal to 1 bar 1 0, actually this is 1 1 0 and this is 1 bar 1 1.

So, we have 1 screw dislocation was burger vector is 1 1 0 and the another screw dislocation was burger vector is 1 1 1 bar 1 0. So, in this particular case you can realize that this is the case for FCC; in FCC we have this kind of system. So, this is the realistic system where we see a dislocation with the system like this. Now what I want to know is to get the information of the step dislocation. So, the magnitude of step dislocation is how much? It is equal to 1 1 0 is equal to root 2 a sorry this should be the magnitude will come out same, but I should have written 1 bar 1 0, because it has to be equal to b 2 s 1 is equal to b 2 magnitude. Now s vector direction of s 1 that is equal to 1 bar 1 0.

Over here what we have? For the second case S 2 magnitude we take for this we take the magnitude of 1 1 0, and then this again comes out to root 2 a and the vector of S 2 is equal to 1 1 0. So, here again we see that what we obtained are with respect to the other dislocation, now in this particular case I had given that the initial dislocation was screw dislocation. So, here the initial line vector is equal to u 1 equal to 1 1 0 here the initial line vector is equal to 1 bar 1 0.

And in this we are getting a step which is 1 bar 1 0 and this and the burger vector for this is still the same which is. So, what do we see here? Over here this line vector is perpendicular to the burger vector, which means line vector is perpendicular to burger vector would mean what? Edge dislocation; here also what we see 1 1 0 is perpendicular to 1 bar 1 0 if you take a dot product it comes out 0, and therefore, again here also it is a edge dislocation. Now here again if you look at it I had given extra information screw dislocation of burger vector b 1 and b 2, data I were used this information screw dislocation I have given the value u 1 here and u 2 here, but I am never using this.

So again this information is extraneous, it is not required at this stage if we just want what is the character, what is the step size magnitude, its all these information these can be obtained alone from the burger vector and that is what we see here. So, with that we move on to another aspect regarding dislocation motion. So, you can realize that whenever dislocation is moving, when it moves in response to stresses being applied and when there is stress been applied plastic deformation is taking place. So, there must be strain. So you can say the outcome of dislocation motion is that some strain is produced.

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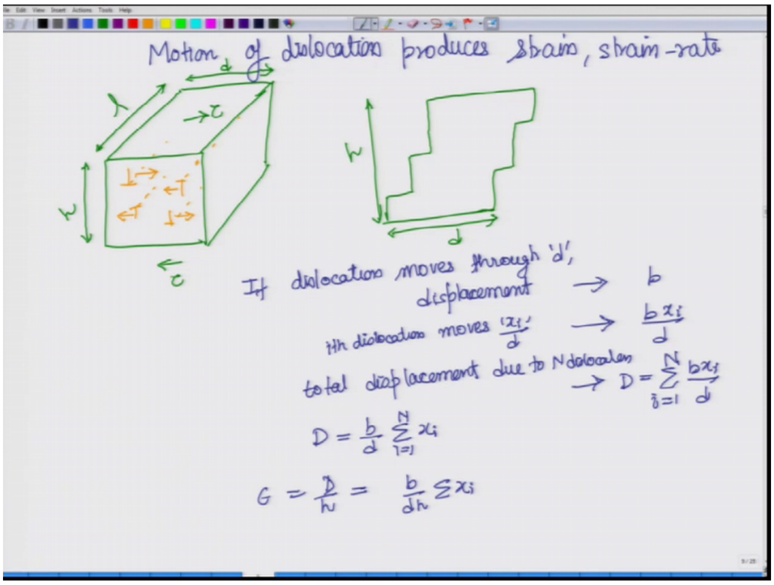

Motion of dislocation produces strain, strain-rate

If dislocation moves through 'd', displacement → b

ith dislocation moves $\frac{'x_i'}{d}$ → $\frac{b x_i}{d}$

total displacement due to N dislocation → $D = \sum_{i=1}^{N} \frac{b x_i}{d}$

$$D = \frac{b}{d} \sum_{i=1}^{N} x_i$$

$$G = \frac{D}{h} = \frac{b}{dh} \sum x_i$$

So, motion of dislocation produces strain, and we can if there is a strain then there will also be strain rate. So, here we will look at a simple model, which is which has been simplified to a great extend to be able to derive a relation for strain. So, what is this simple model? We assume that we have a rectangular block where all the dislocations are aligned along one direction, although we will assume that there are positive as well as negative.

So, there is a shear stress acting like this. So, this is the length l along which we will assume all the dislocation lines are located. This is height h and we will say call this width as distance t. Now if we will assume here we have to show there are some dislocations, there can be positive and we will for the sake of simplicity I will just put for dislocations over here. So, these are long dislocation line, which terminate from end to end.

Now under the affect of this stress what will happen? All these positive dislocations will move like this, negative dislocations will move like this and what will be the final shape what you will get would be something like in the cross section this is how it will look like. So, shear stress is being applied. So, we want to calculate a shear strain. So, for that first let us see, what is the total displacement along this direction d. Now if a dislocation moves through a whole of this length d, then what will be the displacement? Displacement will be equal to 1 burger vector equal to 1 b.

Now let us say that one particular ith dislocation moves through only xi distance. So, ith dislocation moves through a fraction of it, which is shown by xi by d therefore, it will produce a displacement equal to b x i by d; now if there are n dislocations. So, total displacement due to n dislocations this can be given by D equal to summation b xi by d where i goes from 1 to N.

Over here we can say that D b and D are common or basically constant. So, it becomes b over d and xi I equal to 1 to n. If we were to calculate shear strain, the shear strain the stress is applied on this surface. So, the shear strain will be displacement along this divided by h. So, shear strain would be equal to D by h and therefore, it will become b by dh summation xi.

So this will be the shear strain that will be caused because of several dislocations that are moving inside this and the assumption that we have taken is that all the dislocations are from end to end along this length l.

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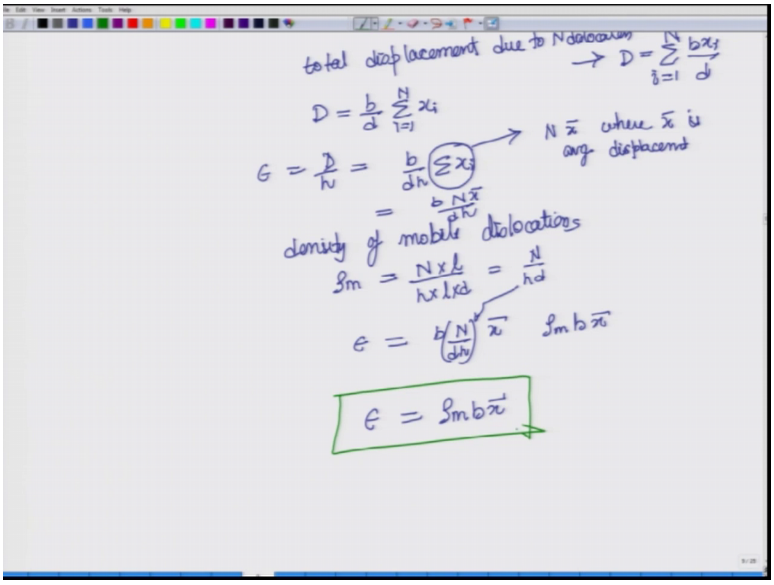

total displacement due to N dislocations $\rightarrow D = \sum_{i=1}^{N} \frac{b x_i}{d}$

$$D = \frac{b}{d}\sum_{i=1}^{N} x_i$$

$$G = \frac{D}{h} = \frac{b}{dh}\sum x_i$$

$\rightarrow N\bar{x}$ where $\bar{x}$ is avg displacement

$$= \frac{b N\bar{x}}{dh}$$

density of mobile dislocations

$$\rho_m = \frac{N \times l}{h \times l \times d} = \frac{N}{hd}$$

$$\epsilon = b\left(\frac{N}{dh}\right)\bar{x} \quad \rho_m b \bar{x}$$

$$\boxed{\epsilon = \rho_m b \bar{x}}$$

Now this density of mobile dislocations this can be given as. So, here we will see 2 things; one there is xi this x summation xi can be written as actually 1 over n times x bar, where x bar is average displacement. So, if you know the average displacement of the dislocations. So, we can find the approximate value of summation xi summation xi would be equal to n times x bar, this is simply statistics. So, summation xi can be replaced by Nx bar.

And let me write it here. So, if we write it in these terms b Nx bar by dh. Now next thing that we want to know is dislocation density which is mobile dislocation density and over here you can see in the given context, it will be equal to n is the number of dislocations and it is per length density is number length per meter cube. So, it is per meter square quantity. So, N into l. So, total length divided by the volume, which is h into l into d which will be equal to N by h d meaning this term here N by hd can be replaced by so, our term epsilon can be which was written by written like b N by dh, x bar this can be replaced this term can be replaced as rho m. So, we will have rho m b x bar.

So this, under this configuration we have derived the relation for strain in terms of mobile dislocation density, the burger vector and average displacement of the dislocation. So, if we know these 3 quantities, we can find out what will be the strain in the material. And what will be strain rate? If we take the derivative of this with respect to time we can get strain rate.

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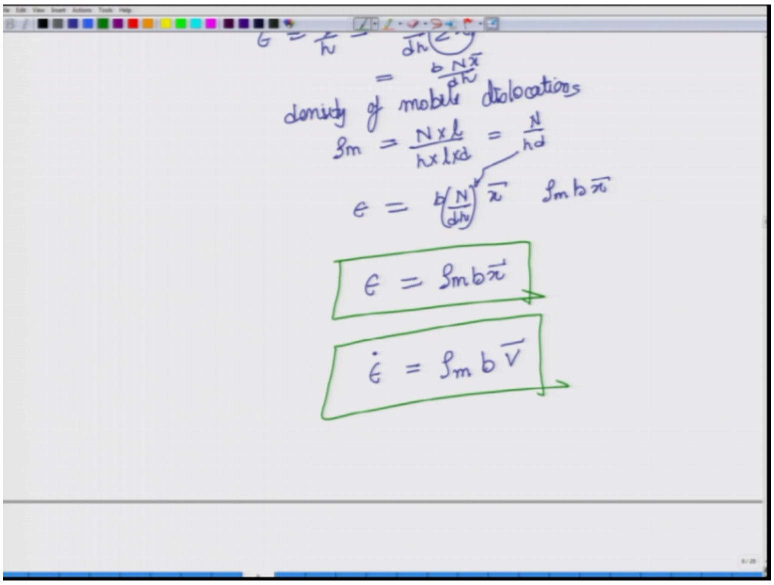

$$= \frac{b N \bar{x}}{dh}$$

density of mobile dislocations

$$\rho_m = \frac{N \times l}{h \times l \times d} = \frac{N}{hd}$$

$$\epsilon = b\left(\frac{N}{dh}\right)\bar{x} \quad \rho_m b \bar{x}$$

$$\boxed{\epsilon = \rho_m b \bar{x}}$$

$$\boxed{\dot{\epsilon} = \rho_m b \bar{V}}$$

So, strain rate can be written as and here what is the on the other side, what is the term that can be for which we can take derivative of time that is x bar which will become v bar. So, average velocity so, this derivation has lead us to a relation on the right hand side of which are all internal quantities and on the left side we have the external quantity, which is the for example, in during a deformation process, but the strain rate that you will apply and because of that how the density will change or what velocity it will the dislocations will obtain. So, we can relate the 2 quantities. So, it is a very useful relation. So here we also introduce a term velocity. So, let us try to understand a little bit about velocity of dislocations.

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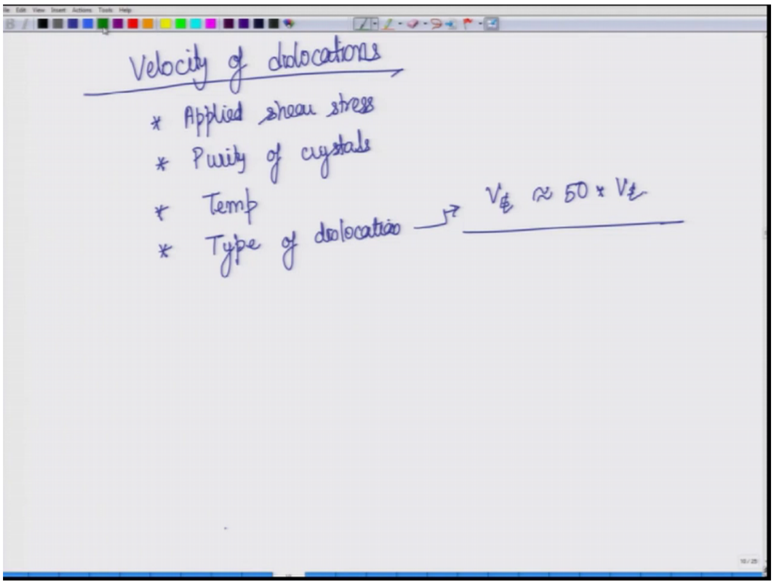

Velocity of dislocations

* Applied shear stress

* Purity of crystals

* Temp

* Type of dislocation → $V_{\perp} \approx 50 \times V_{t}$

So, next what we want to look at. So, dislocations as we saw as response of shear stress, they will move and they will move with the certain velocity. So, what is the relation of velocity with respect to shear stress that is what we want to explore over here. So, in this not explore, but I want to show you or give you the just of the in data or information, that people have obtained so, far regarding velocity.

So, first and for most velocity is dependent not just on shear stress, but there are other factors also. So, velocity is a parameter or velocity is value which of the dislocation, which depends on of course, it will depend on the applied shear stress. This is the first and formost, but this is not the only 1 in meaning that not all material will experience same amount of velocity for the same amount of stress.

So, what are the other factors that will depend? Purity of crystal so, even of you talk about a pure 99.999 percent copper verses 99 percent copper, there will be difference in velocity of dislocations. Then temperature obviously, at higher temperature you would expect the dislocations to move at a faster rate. So, temperature is also a factor which will determine what will be the absolute velocity of the dislocations.

And one of the other important factor we are relating only the important factors there can be several mode type of dislocation. So, for example, if you look at the velocity of edge dislocation it is known to be approximately, 50 times velocity of screw dislocation. So, the type of dislocation also does make a good amount of difference to the velocity, that can be obtained applied shear stress now let us see what do we know about the effect of applied shear stress.

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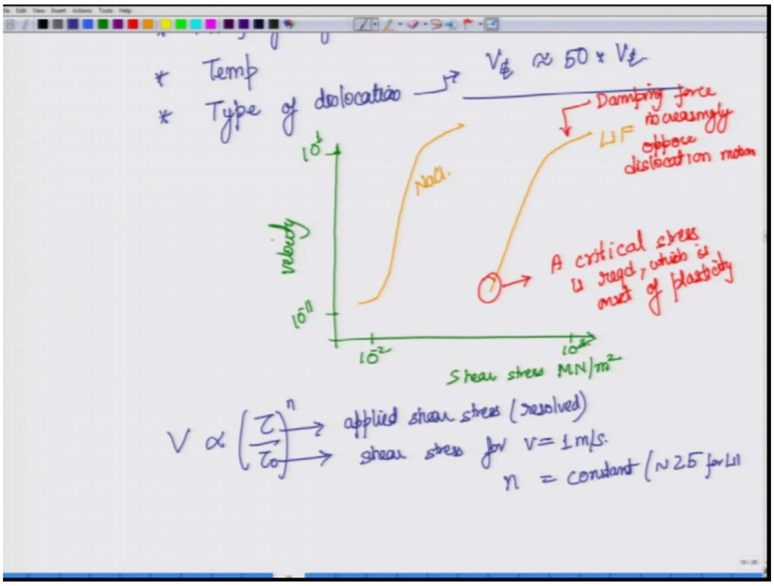

So, an approximate plot can be made like this where on the x axis, you have shear stress and on the y axis you have velocity. So, usual plot so, let me here first give you some approximate. So, velocity varies; so, usually velocity forms to vary from 10 to the power minus 11 to 10 to the power 1 meter per second.

And when a shear stress in this range is applied 10 to the power minus 2 to 10 to the power minus 3 and some of the material which have been largely studied include NaCl. So, for NaCl a plot like this is seen. So, you would. So, keep mind that over here what we have is a log log scale. So, this is not a linear scale. So, in the log scale you see a linear region and there are 2 tales of this is on the higher end and this is on the lower end.

Similarly you would see something like this, for a lithium fluoride. So, this is lithium fluoride this is NaCl. Now there are 2 and you look at this velocity as a function of shear stress there are 2 important aspects that need to be understood that which happens over here. Over here what you see is that a critical stress is usually necessary, I am using the word usually because material to material the response of the material a response of the dislocation is very different.

So a critical stress is required for dislocation movement, which is what? Which is on set of plasticity. If you are applying stress which is in the elastic regime, then of course, dislocations are not generated and therefore, you would not see any dislocation movement. So, this particular minimum stress that is required in the crystals is basically representing the onset of plasticity. Another thing that you see is towards the higher end and this is the damping force.

So, at as you keep there is a linear region you in the log log scale you keep increasing stress and velocity keeps increasing, but towards the higher side as you start approaching 10 to the power 3, this shear stress mega Newton per meter square the velocity does not increase as rapidly and that happens because of damping phenomena. And this damping as we will see it is represented particularly for FCC and HCP materials by parameter it increases so, damping force increasingly oppose dislocation motion.

So, beyond a point as you keep increasing the shear stress the damping force becomes increasingly large, and increasingly oppose dislocation motion. So, at higher velocity, we see this is kind of saturation. Now there are certain empirical relations people have obtained. So, now, let us look at some of those empirical relations, which describe a relation between velocity and the shear stress and is usually given by, here tau is the applied shear stress resolved along the burger vector, tau naught is the shear stress where velocity is equal to 1 meter per second. So, this is the relative quantity. So, shear stress for velocity is equal to 1 meter per second, and n is the constant.

So, this n is approximately for some of the materials for which it had been studied it is approximately equal to 25 for lithium fluoride. So, that is how the shear stress influences velocity, we are we will look at the dislocation motion from atomistic scale or atomistic perspective later on, here we are just trying to give you a perspective of what are the factors that will influence velocity of the dislocation. And as you can see as you would expect shear stress is one of the most important one and it does velocity does increase very rapidly with increasing shear stress. There is also effect of temperature as we have already mentioned.

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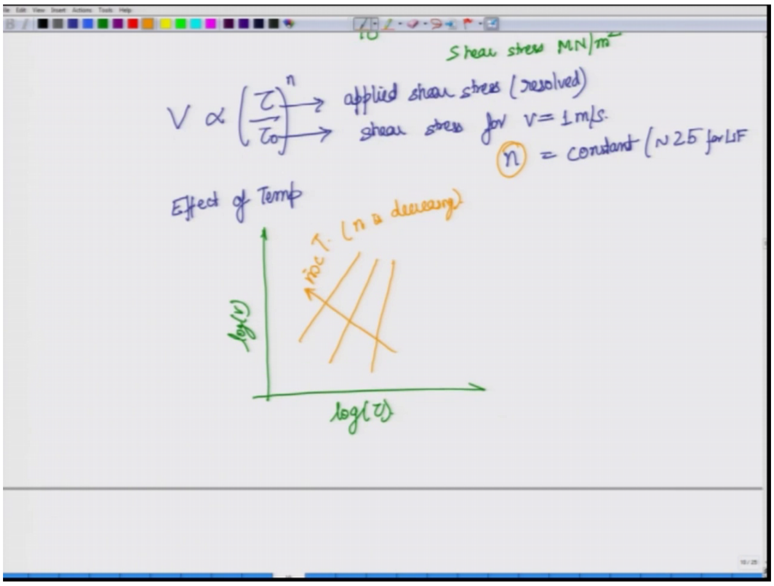

Shear stress MN/m²

$V \propto \left(\frac{\tau}{\tau_0}\right)^n$ → applied shear stress (resolved)

→ shear stress for v = 1 m/s.

n = constant (~25 for LiF

Effect of Temp

So, this effect of temperature has also been captured for certain material and what people have observed. So, if you take so, I will just try to log v over here, log stress over here then what people have observed that the linear portion if you increase the temperature. So, this direction temperature is increasing and it is in this direction that n is decreasing.

So, temperature has the largest influence on this characteristics on this parameter n and hence influences the velocity overall velocity of the material. But like I said earlier that the effect of stress on velocity is not same for all materials and particularly for FCC and HCP people have observed a different kind of a little different behavior.

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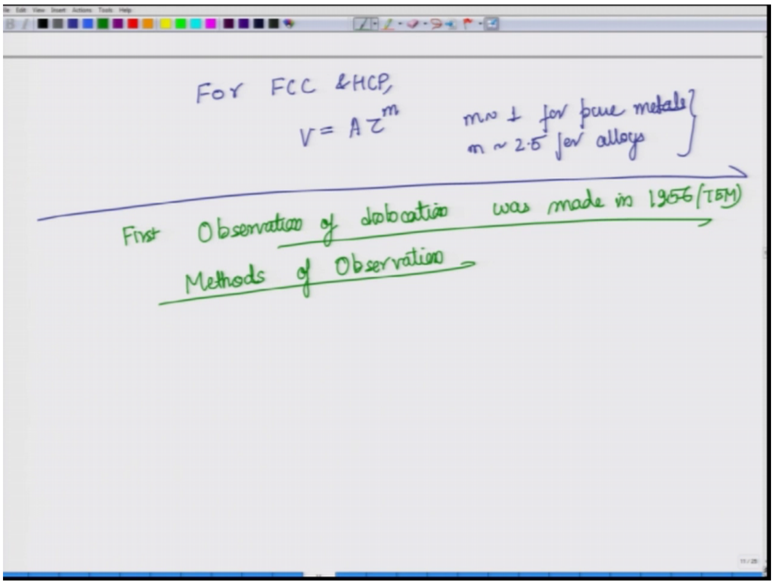

For FCC & HCP,

$v = A\tau^m$

$m \sim 1$ for pure metals

$m \sim 2.5$ for alloys

First Observation of dislocation was made in 1956 (TEM)

Methods of Observation

So, far FCC and HCP it has been found that velocity is equal to A tau to the power m, were m is approximately 1 for pure metals and so, this is a quantity which does not change much m. So, for most of the FCC and HCP you would now only thing you will change is A and it is approximately equal to 2.5 for alloys.

So, here you are also able to see a difference in the relation with purity of the material. So, for pure material and this coming out to be 1 and for pure alloys are this meaning that there is a heavy alloying then you would see 2.5, and if you are putting in just small amount of impurities it should be somewhere in between these 2.

So, now, we have looked at various aspects of dislocation, but one particular aspect of dislocation that we have not touched which we just briefly talked about in the very beginning is observation of observation of dislocations. So, if you remember in the very beginning, I informed you that dislocation theory was developed long before any observation was made and the first observation.

So, first observation of dislocation was made in 1956. So, this was the first direct in fact, any kind of observation or dislocation and theories if you remember in early 30s people had developed in full pleasure theory of dislocation. So, 25 years since the complete theory of dislocation was developed, that first observation of dislocation was actually observed and then people started making relation to what was actually understood previously using theories.

So, what are the different methods so, what we what we are trying to focus here his methods of observation. So, now, you can I already mentioned this was TEM. So, what are the other methods? In fact, even in tem. So, are what are the different methods of observation of dislocations. In this connection let us list out some of the important methods, which are available and the first and foremost that has been available to people is the surface methods meaning something simple as simple as.

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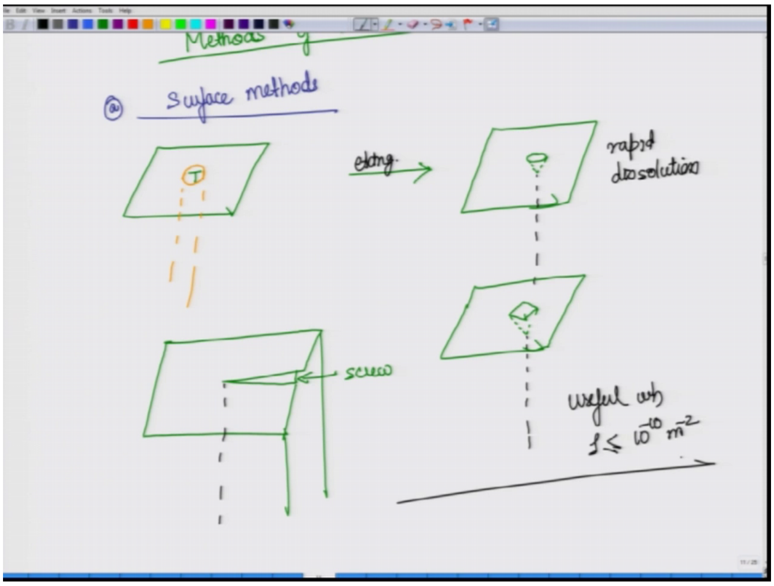

So, these are not direct observation indirect observation, but still some method which were available to people to be able to observe dislocation and in fact, as I will point out later that using this method people have been able to find out dislocation velocity, dislocation understand, beware of the dislocation motion etcetera.

So, what is this surface method? Now, I if you remember that in the dislocation core there is a lot of energy, and there is also you can see lot of strain in the system. Since there is a lot of strain and if you etch the material over there what do you expect let us say there is a dislocation which is. So, let me again as usual draw a edge dislocation. So, edge dislocation which is terminating on the surface I am drawing a surface over here and there is a core around it. So, this core as you expect has high energy and it is under severe strain, there is a lot of strain in this particular region. So, now, if you over etched it what would you expect? And you would expect a preferential etching over here and what people have actually observed.

So, in some cases people have observed. So, this kind of etched surface or on the termination and what it represents is that there is a dislocation line below it so, etching by rapid dissolution. In fact, etching can sometime also lead to this for edge dislocation for screw dislocation it will be different and otherwise mentioning is that, not only this cylindrical kind, but also see the effect of faceting. So, you may be see even for a edge dislocation what you may see in some in many a cases. In fact, not some cases because of the crystal in nature of the material, you may see this kind of faceted structure.

So, you will see something like this and what it implies is that below this is that the dislocation line. So, over here it gets etched and you are able to see the end part, but and if you allow it to etch for more and more time what you would expect is that it will keep etching towards the bottom side. It will keep etching deeper and deeper and deeper because this is the highly strained region with high energy.

So, it gets preferentially etched. And you may also see screw dislocation causing steps like this. So, because of preferential etching you may also see ledges like this, and this will be because of screw dislocation and there is a. So, this particular method is useful when rho is less than equal to 10 to the power minus 10 per meter square. So, this is one method and we will come back and discuss more methods of studying or observing dislocations.