Properties of Materials (Nature and Properties of Materials: III)

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Lecture 27

Dislocation and Peirells Nabarro Stress

So, welcome again to the new lecture of the course, Properties of Materials. So, let us just begin, let us just start with what we did in the, where we were and what we did earlier.

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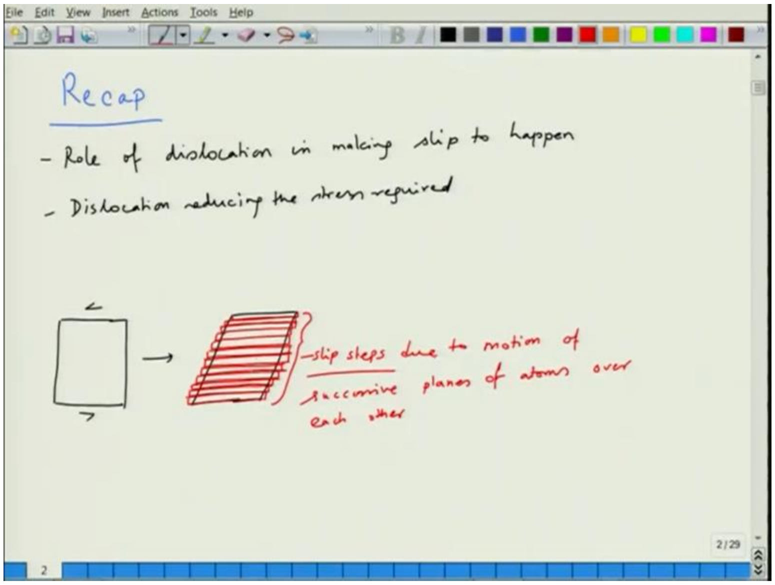

Recap

- Role of dislocation in making slip to happen
- Dislocation reducing the stress required

slip steps due to motion of successive planes of atoms over each other

So, what we did was we looked at the role of dislocations and making slip to happen and this is basically by dislocations reducing the stress required and you saw that if you have crystal like this and when you apply shear stress to it, then, it sort of takes this shape. But this microscopically speaking if you look at it, then this basically happens by looking at the, by having the slip occurred in the crystals. So if you look at the, if you look at how the steps are formed, the steps are formed by, we will show you.

So, essentially you have one crystal like this and the next crystal could be something like this and so you sought of create these steps which are microscopic steps formed as a result of slip between successive planes, I am sorry if I am not drawing it well, but basically I hope you get an idea. So, these are the sort of you can say the slip steps on the surface due to motion of successive planes of atoms over each other.

So atoms have, so when dislocation moves from one part to another, you, it causes a formation of step on one side and this leads to and when, when it look at, when you look at it microscopically you tend to form many steps. So, in order to visualize this. Let me show you a sort of power point presentation, which can help you understand, what do these, what is the slip looks like microscopically in the real crystals.

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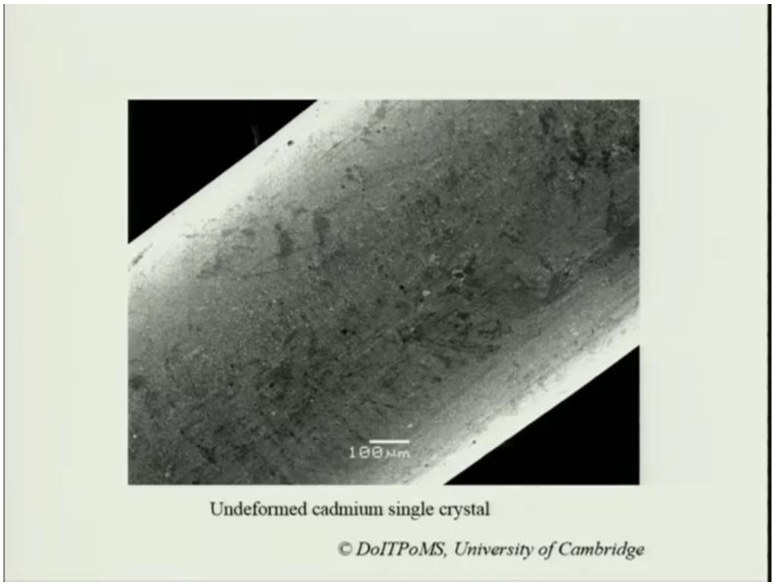

Undeformed cadmium single crystal

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So this is, these are certain photographs, which have been taken from doitpoms.ac.uk. So, let me just show you. So if you look at this crystal, this is cadmium crystal, so this is taken form doitpoms.ac.uk form university of Cambridge website. So you can look, there is a whole module which you can look at there.

So, this is the undeformed crystal when looked at under a scanning electron microscope at certain resolution we can see that this scale bar is hundred micron. So, this whole thing would be about 15 times of this. So, it is like 1.5 mm thin wire.

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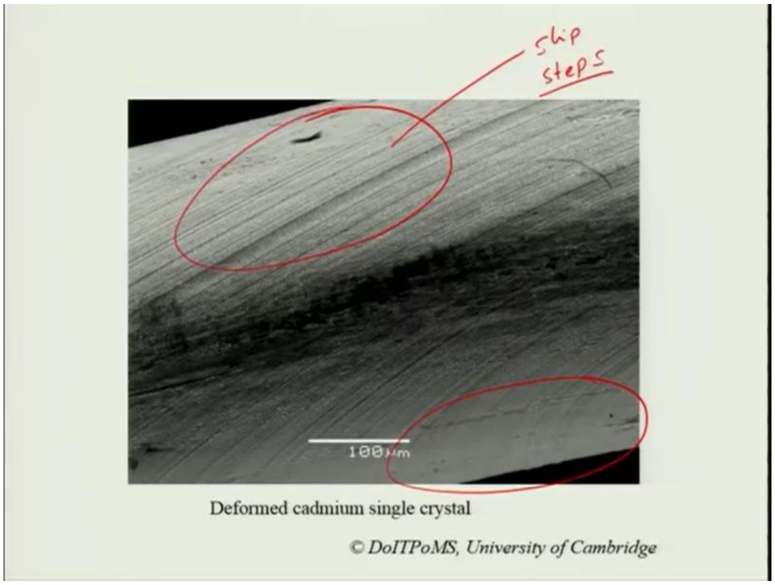

Deformed cadmium single crystal

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So, when you start deforming it, this is a deformed cadmium single crystal when you start deforming it, then you see you can form these step on the surface. So, these are basically, so you can see the steps here on the surface you can see the steps here. So, these are basically, you can say the slip steps, which have formed because of slip of atoms against each other in successive planes in the slip plane of course the slip has to occur in the slip plane.

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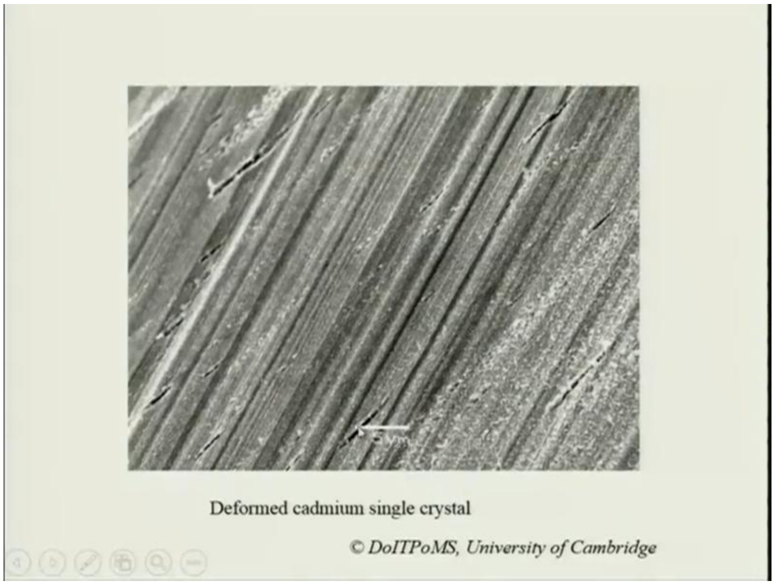

Deformed cadmium single crystal

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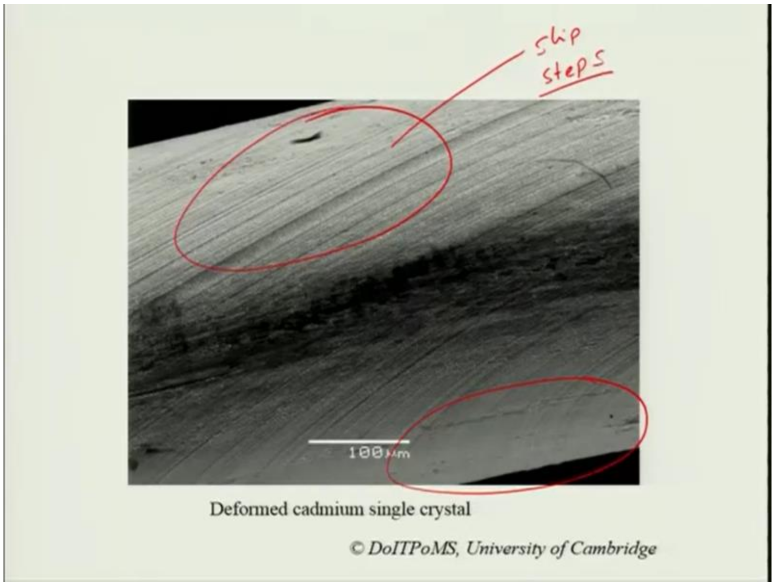

Deformed cadmium single crystal

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So, you can see this, this is what is happening, if you look at it microscopically at a further high. So, this magnification you can see that here its scale bar is 100 micron. Now if you increase the scale part, if you increase the magnification reducing the scale bar to 5 micron, you can see that these are microscopic steps that you form on the surface of the sample.

So, this is what basically microscopically speaking, slip phenomenon is. I will show you a video of how does it happen. So let me, let me just show you the video of these, the slip, the microscopically, microscopic phenomenon of slip when viewed under electron microscope live.

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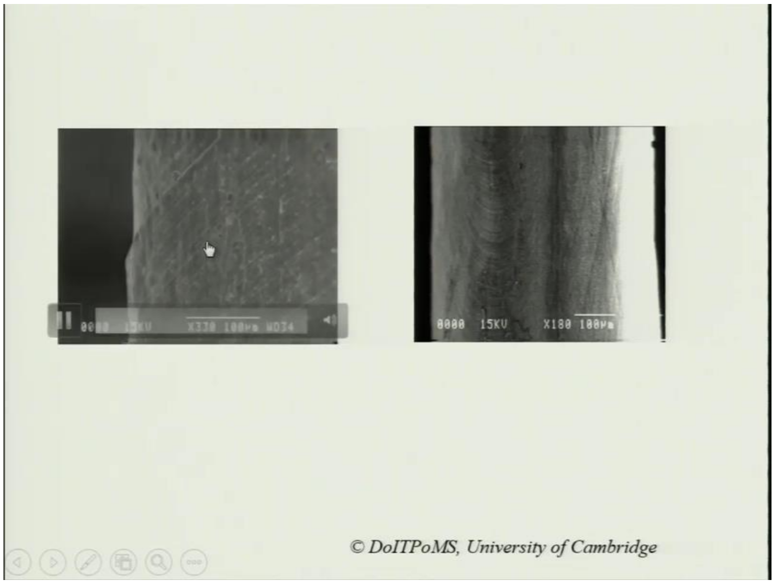

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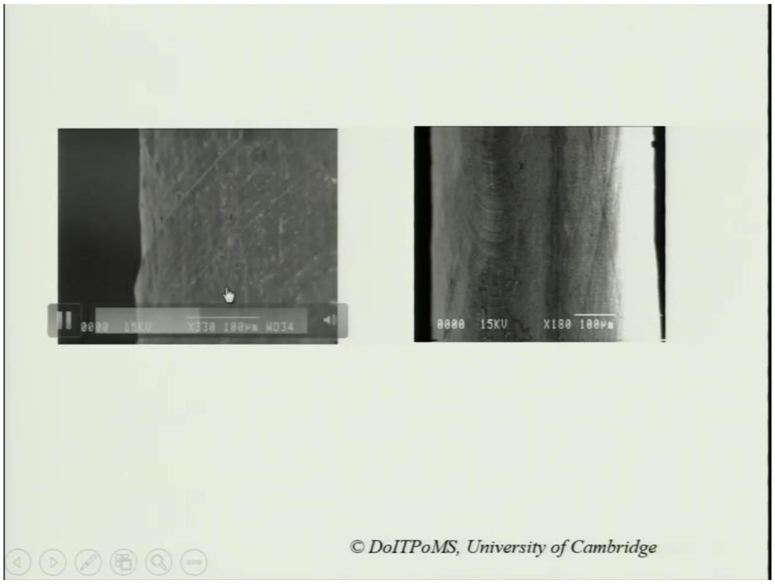
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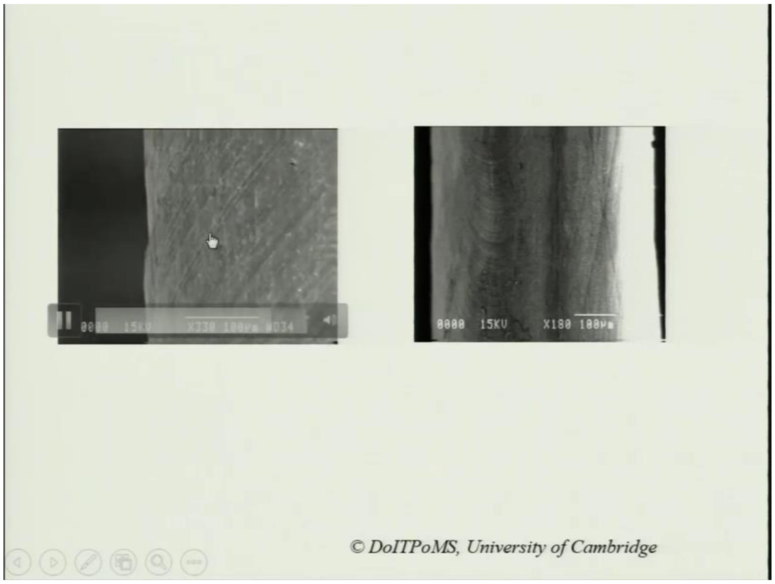
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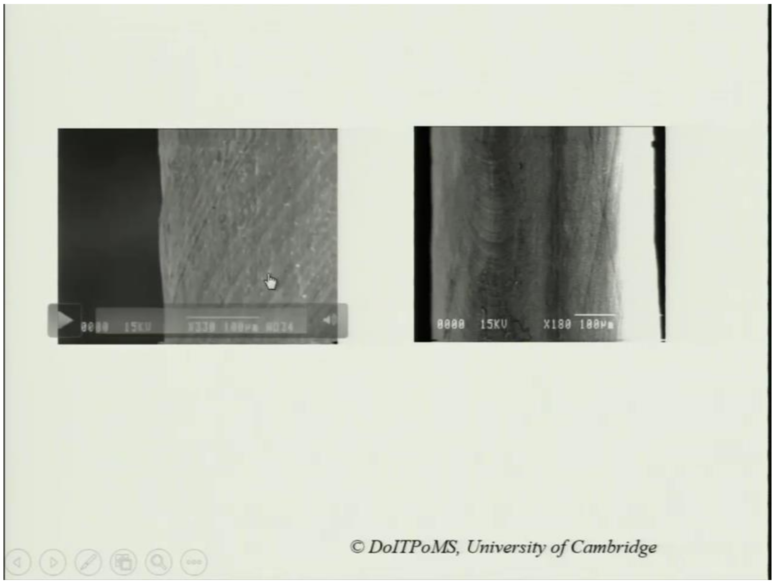
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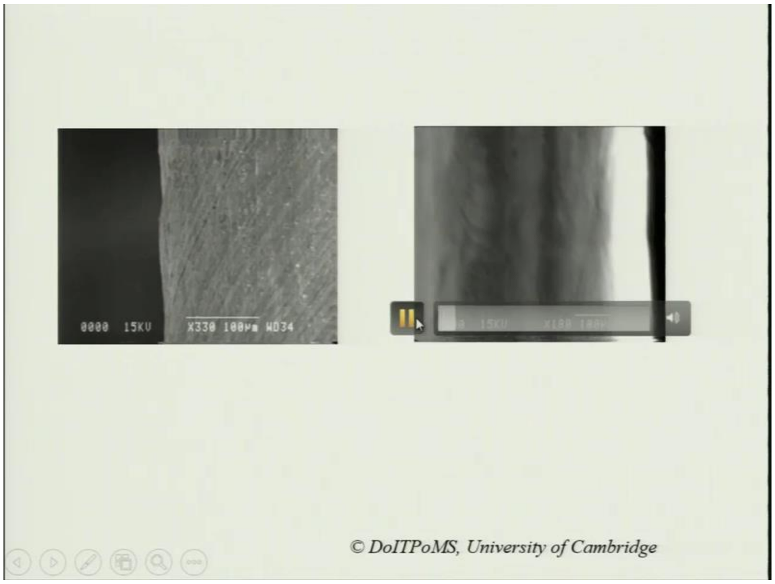
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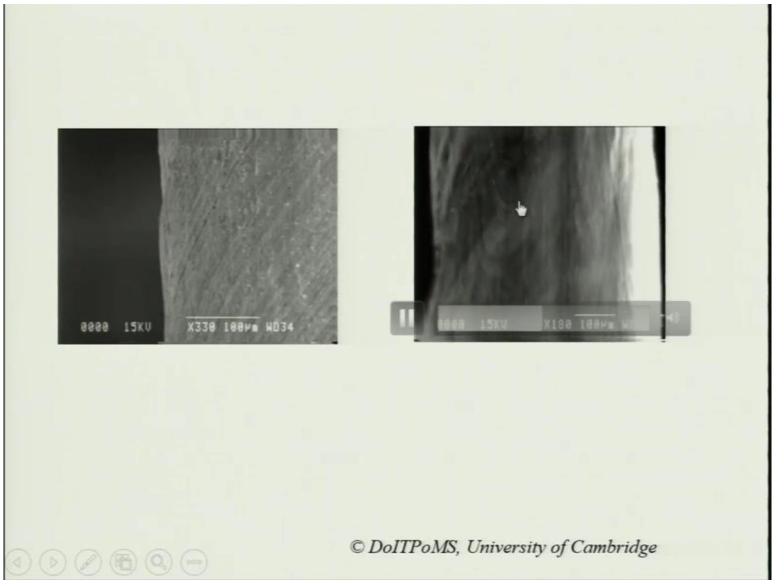
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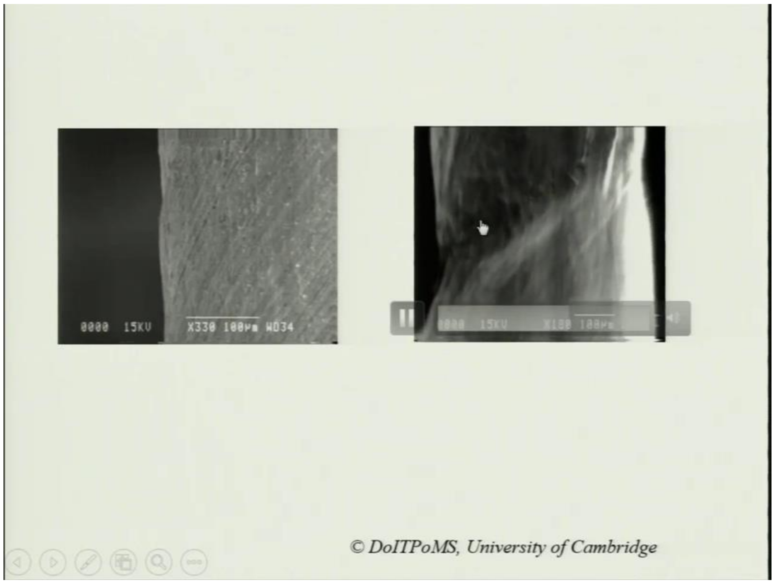
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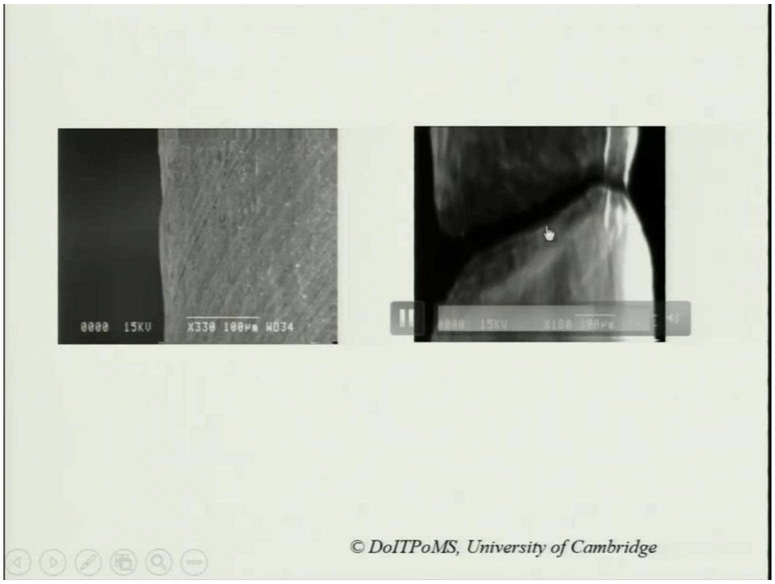

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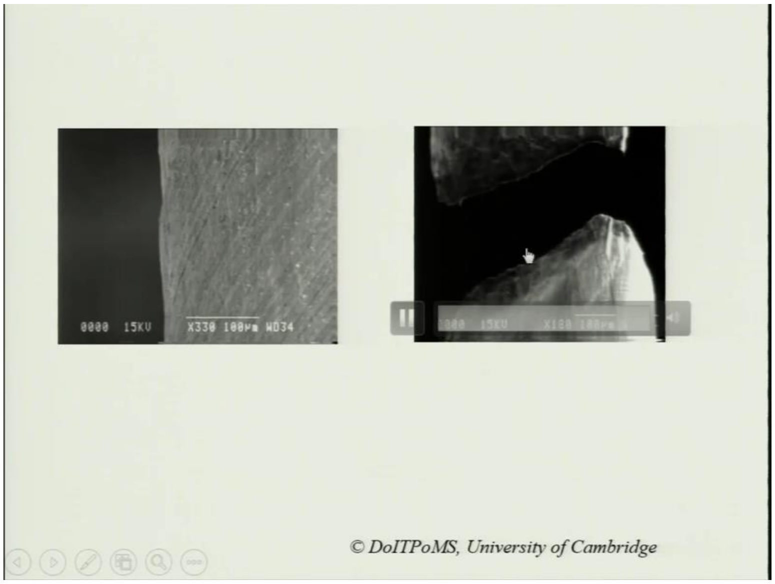

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So this is one of the video, again these are the videos taken from doitpoms.ac.uk university of Cambridge website. So, if you look at these for an example. So if you look at this, this is the crystal which is been deformed and you can see formation of these steps on the surface of the single crystal. So, you can see very clearly see the steps are forming on the surface, it is very visible and this is another video which shows you how does it happen until fracture.

So, you form the slip planes and then you have this formation of a neck, followed by, followed by fracture. So, this is a beautify example of how the slip happens and of course you can, you can see that, so this sort of replicates what you saw in engineering stress, strain curve, you form a neck. So, this is where instability comes in and then it leads to fracture.

So this is, this is basically it replicates saw in engineering stress-strain curve that you form a neck followed by fracture which is basically reptile facture. So, this is microscopic examination of basically how the slip happens. Now, let us what, what we are going to do now next is we just going to look at some of the quantitative ways of defining slip.

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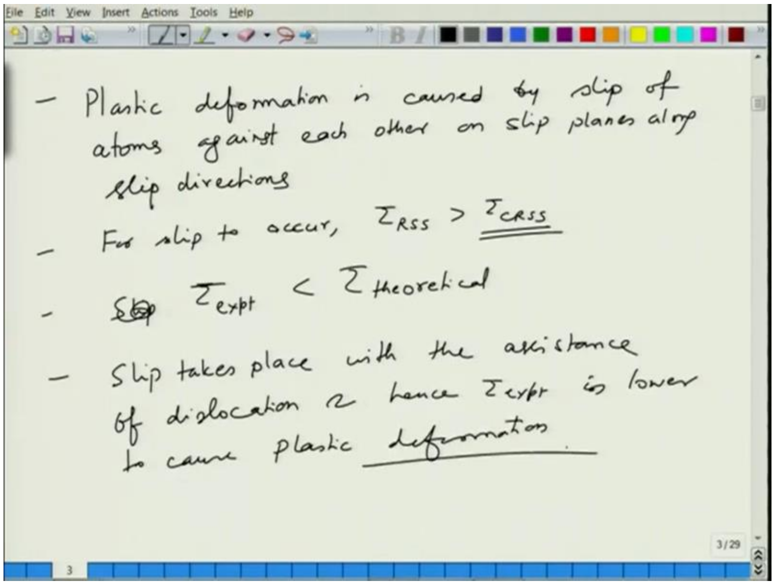

- Plastic deformation is caused by slip of atoms against each other on slip planes along slip directions
- For slip to occur, $\tau_{RSS} > \underline{\underline{\tau_{CRSS}}}$
- ~~Slip~~ $\tau_{expt} < \tau_{theoretical}$
- Slip takes place with the assistance of dislocation & hence τ_{expt} is lower to cause plastic <u>deformation</u>.

So, essentially what we are saying is that slip, just to summarize this part, plastic deformation is caused by slip of atoms against each other on slip planes along slip directions. Second point is for slip to occur, your resolve shear stress has to be more than critical resolve shear stress. So, it is a function of yield stress and orientation.

So, only your yield stress and orientation are such that, the stress applied is such that, you are able to exceed this CRSS, then only you are going to be deforming. Now that you fulfil these two conditions, the slip, the value of experimental is lower than the value of theoretical stress and this is because slip takes place with the assistance of dislocations. So, dislocations and hence tau experimental is lower to cause plastic deformation. So, this sort of a summery of what we have done over past few lectures.

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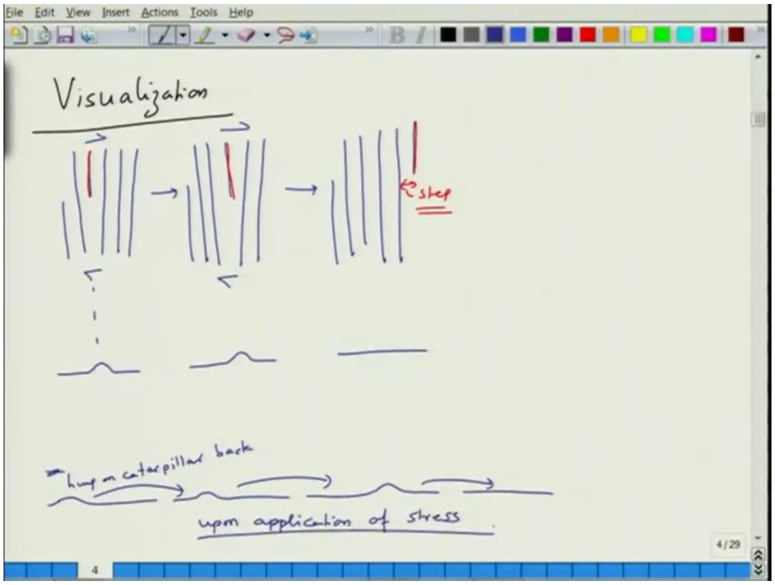

Now what we are, another way of visualizing this slip is, the slip can be visualized by visualization. So, when we say the sleep takes place by you know you have formation of let us say, you have a plain of atoms, you have an extra plane here, another plane there and then and then when you apply stress to it, then this moves further up and eventually, as you keep applying stress, this dislocation, which is this extra plane.

So, let me depict this extra plane here and this eventually moves out of crystal, giving rise to formation of a step. So, this is the dislocation movement which is taken out. So, this is the step that we create and this movement can be seen by the sort of caterpillar kind movement. So, let us say at this position if you have a caterpillar, the caterpillar shows a hump like this.

When you apply stress, the hump moves forward and when you apply stress further the hump is in the forward direction and before it becomes, at this point it will become flat, basically. So the caterpillar is going to, so it is going to be like this.

Then it is going to move like this, than it is going to move like this, finally it becomes flat. So, this is you can say hump on caterpillar back. So, it goes from here to here, here to here, here to here upon application of stress. This is another visualization that one does.

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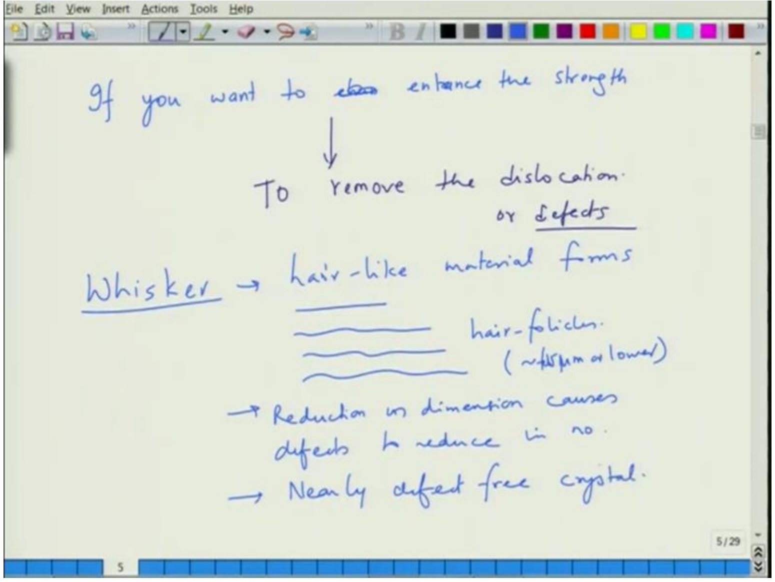

If you want to enhance the strength

↓

To remove the dislocation.
or defects

Whisker → hair-like material forms

hair-follicles.
(~ $5\,\mu m$ or lower)

→ Reduction in dimension causes defects to reduce in no.

→ Nearly defect free crystal.

So, what we have said is that, the theoretical strength is high but the practically the strength required, stress required to cause, cause plastic deformation is lower, because of stress. So, what does it tells you in other ways that, if you, if you want to increase the strength, if you want to enhance the strength then, one of the recipes is going to be, to remove the, the dislocation or defects and this is what basically we do in something called as Whisker.

Whisker are basically you can say hair, hair like materials forms. So, very thin like this, so just like hair follicles and these are extremely thin of the order of let us say, micron or lower, a few microns let us say or lower. So, when you reduce the dimensions of a materials to this small. So, reduction in dimension causes defects to reduce in numbers. So, as a results in Wiskers it is nearly like defect free. You can say it is basically a defect free crystal. So, when it is a defect free crystal. If you conduct for example, stress-strain test.

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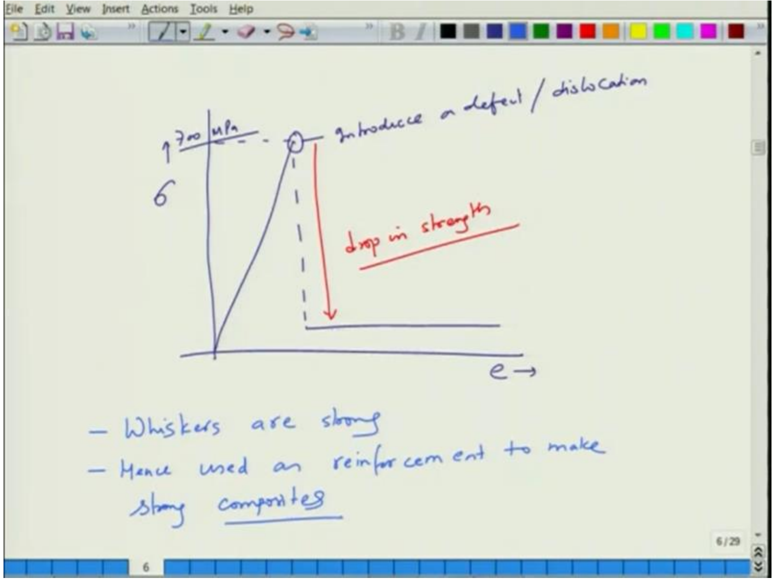

- Whiskers are strong
- Hence used as reinforcement to make strong composites

So, this is a stress-strain test on Whisker and when you apply the stress basically, you go to a value of nearly. So, let us say this is stress-strain curve on Whisker. So, you reach a strength of order of let us say 700 MPa which is close to 1 GPa very high strength and then when you reach very high strength you are able to reach some bonds and at this point you introduce a defect or dislocation and this is where there is a sudden, drop in strength.

So, basically you can say Whisker are defect free crystals whose dimensions are about micron thick and whiskers are generally used for, so they are very strong and hence used as reinforcement to make strong composites. So, they can be blended with let us say polymers or ceramics to make them strong very strong. So, this is the idea of (())(13:23).

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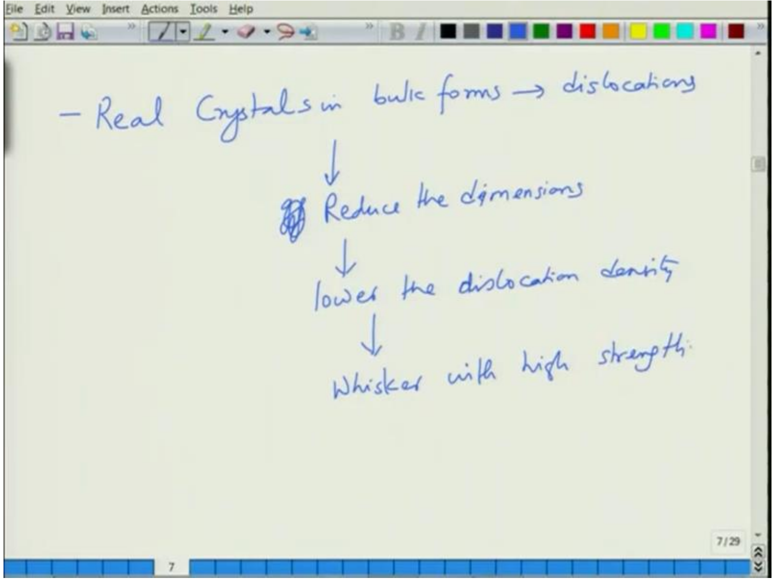

- Real Crystals in bulk forms → dislocations

↓

Reduce the dimensions

↓

lower the dislocation density

↓

Whisker with high strength.

So, basically what we have said is that, real crystals in bulk forms have dislocations and if you, and if you reduce the dimensions, you lower the dislocation density to extent that you can eliminate them and then you make what we call as Whiskers with high strength. So, this is the converse of what we have. Now what is quantitative way of estimating this kind of strain.

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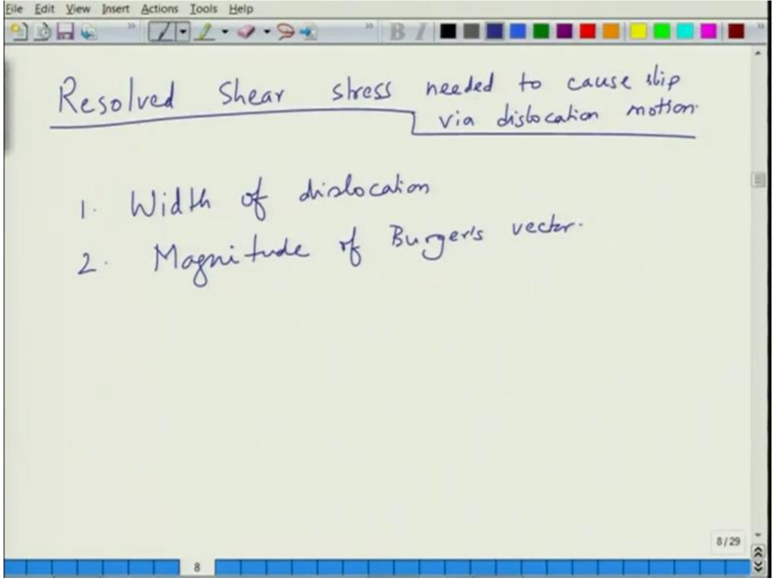

Resolved Shear stress needed to cause slip via dislocation motion.

1. Width of dislocation
2. Magnitude of Burger's vector.

So, the resolved shear stress that is required, shear stress needed to cause slip via dislocation motion. So, this depends upon two factors, one is width of dislocation, second is the magnitude of Burgers vector. So, basically what we mean here is, what do we mean by first of all width of dislocation, dislocation thing.

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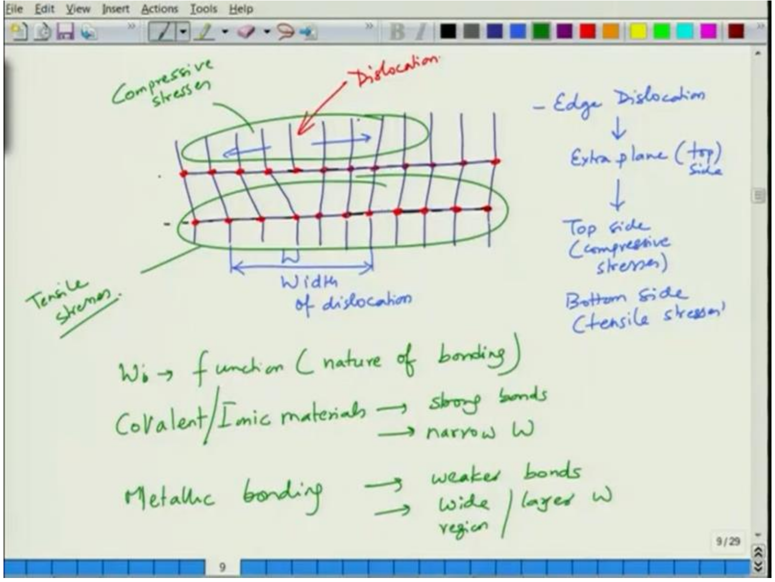

- Edge Dislocation
↓
Extra plane (top side)
↓
Top side (Compressive stresses)
Bottom side (tensile stresses)

W → function (nature of bonding)

Covalent/Ionic materials → strong bonds
→ narrow W

Metallic bonding → weaker bonds
→ wide region / larger W

So, let us, let us just make a schematic drawing. So, let us say this is a atomic plane, another atomic plan and let us just draw few of these, these are the let us say atoms and then we have somewhere around let us say we have. So, the way connect these is, so we have this, so we have these connected as this fashion and we have these connected in this fashion. So, here connected, so I and, so let me just make a little bit of. So, these are let me remove this one which is in between. So, these are basically you can say atoms, sitting here, here, all the places.

So the dislocation, dislocation width is decided by it is basically a function of bonding first of all and dislocation width is essentially the region up to which you can see the distortion. So, this is roughly the dislocation width. So, this is the dislocation we have, this the dislocation and the core of dislocation.

So, basically up to the point wherever you have stress filed of dislocation extending. So, this is the width of dislocation W. So basically dislocation, let us say we have edge dislocation, edge dislocation will mean you have extra top plane, extra plane let us say in top, top side, if it is in top side which means top side will expand and bottom side will contract. So, as a result top side will have, will face compressive stress and bottom side will have tensile stresses.

Because this extra plain will try to push these here and this. So, this side the spacing it will try to push the lattice apart. So, as a result the pushing the lattice apart, this region will undergo you can say compression. So, it will have compressive stresses and this region will have tensile stresses. So and this width of dislocations so not only.

So, basically how far the stress field is an indicator of width of dislocation. But width of dislocation is also W is also a function of nature of bonding. So, generally covalent materials, covalent slash ionic materials will have strong bonds and as a result. So, when the bonds are stronger the extent, the region in which the bonds will get stretched and compressed is also lower.

So as a result you have narrow W and if you have metallic bonding whose bond strength is lower, this will lead to weaker bonds and as result you will have higher or larger W. So, larger W or you can say the wide region. So basically and smaller the width is, more is the stress that will be required to move a dislocation.

So this dislocation width. So if you so this is for example. So, you can see that this is the distortion, you can see that atoms are corresponding with respect to each other. So, whenever at the point at which they start becoming sort of normal up to that point is the dislocation width.

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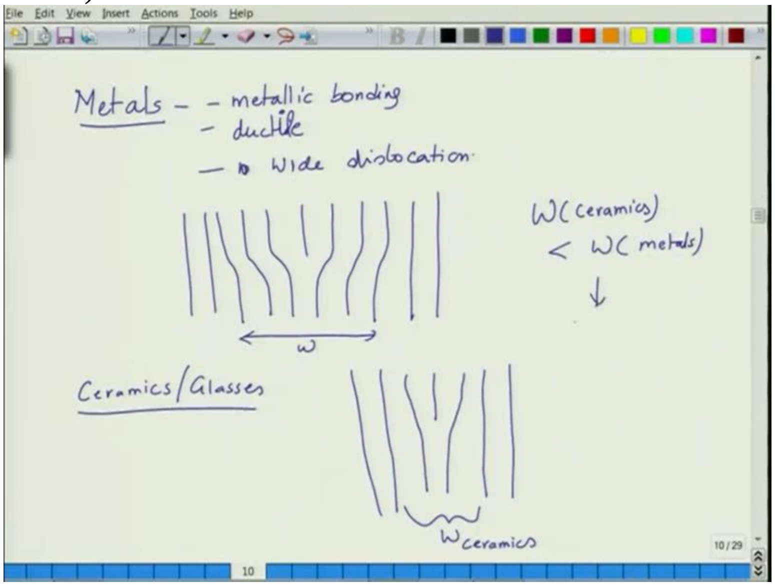

Metals – – metallic bonding
– ductile
– wide dislocation

W(ceramics) < W(metals)

Ceramics/Glasses

So, basically in metals, which show metallic bonding and are ductile, they show wider wide dislocations. So, schematically speaking you can say in a, in a meatal the scenario would be. So, in the case of let us say metal, this is W. In case of ceramics or glasses, the scenario is something like this.

So, this is W in case of ceramics. So, we can say W for ceramics, in general is W for metals and this means and we will see the equation and another thing is the Burgers Vector, the so we will come to Burgers Vector a little while.

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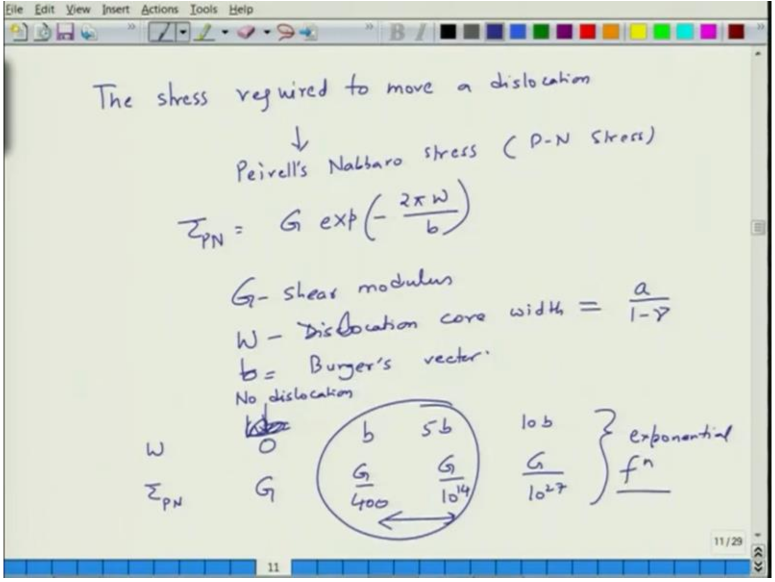

The stress required to move a dislocation

Peirell's Nabbaro stress (P-N Stress)

$$\tau_{PN} = G \exp\left(-\frac{2\pi W}{b}\right)$$

G- shear modulus
W – Dislocation core width = $\frac{a}{1-\nu}$
b= Burger's vector.

No dislocation

W	0	b	$5b$	$10b$
τ_{PN}	G	$\frac{G}{400}$	$\frac{G}{10^{14}}$	$\frac{G}{10^{27}}$

exponential f^n

But the stress which is called as Peirells Nabharo stress or P.N stress and this is given as tau P N G into exponential of minus of 2 pi W divided by b. So, here G is you know the shear modulus and W is the dislocation let us say core width and b is the Burgers vector and W is also given as W is approximated as a divided by 1 minus nu.

Where new is the Poison’s ration and a is the lattice parameter. So this is how. So, basically you can see when you have different values of W let us say and if you want to measure that W PN. So for 0 W, you can see that Peirells Nabharo will be G. So, which means this is the case when you have no dislocation. So, it will be same as theoretical strength, essentially G divided by 2 pi, if you, if approximate it and if you look at, if W is equal to 1 Burgers vector, then this is G divided by 400 times.

So, essentially just introducing dislocation has cause the stress to decrease 400 times and if it is 5 b, this goes by G divided by 10 to power 14 and if it is 10 b this becomes G divided by 10 to the power 27. So, basically this is a exponential function. So, of course if we drop the strength the strength to these levels. But our strength is somewhere in between. So, this is the region in which most of the b values, W values are. So, basically we can see that there is a.

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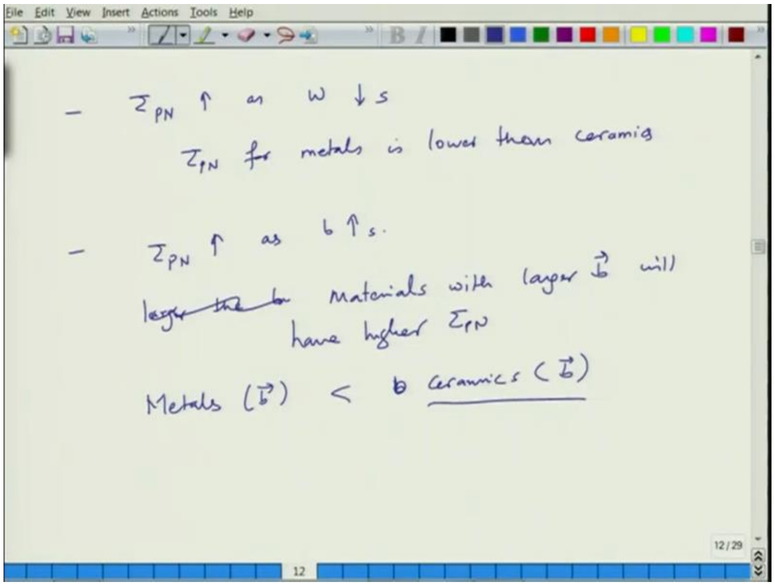


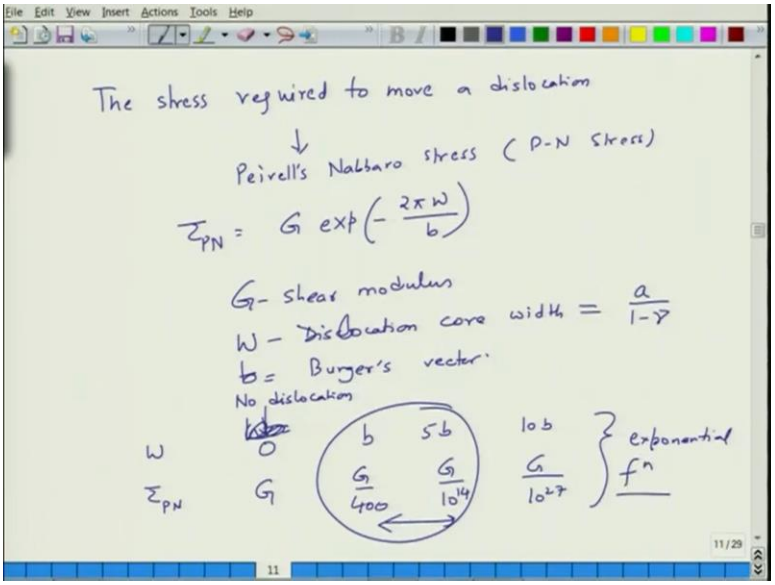
- τ_{PN} ↑ as W ↓s

  τ_{PN} for metals is lower than ceramig

- τ_{PN} ↑ as b ↑s.

  ~~larger the b~~ Materials with larger $\vec{b}$ will have higher τ_{PN}

  Metals $(\vec{b})$ < b Ceramics $(\vec{b})$



The stress required to move a dislocation

↓

Peirell's Nabbaro stress (P-N Stress)

$$\tau_{PN} = G \exp\left(-\frac{2\pi W}{b}\right)$$

G - shear modulus

W - Dislocation core width $= \frac{a}{1-\gamma}$

b = Burger's vector.

	No dislocation				
W	~~b~~ 0	b	5b	10b	exponential f^n
τ_{PN}	G	$\frac{G}{400}$	$\frac{G}{10^{14}}$	$\frac{G}{10^{27}}$	

And you can also see form this tau PN will increase as W decreases. So which means metal will have lower Peirells Nabharo stress. So, tau PN for metals is lower than ceramics. Another observation that we make is tau PN increases as b increase. So which means, larger the Burgers vector higher the Peirells Nabharo stress.

So, which means materials with larger b will have higher tau PN. So, metals, Burger vector is smaller than ceramics Burgers vector. So, that is why it turns out that. So in case of, because the Burger vector is going form one atom to another atom of same type.

In ceramics because they are ionic solids and they are not closed packed because the atoms and ions and cations have to, because anions and anions have to stay away from each other, because of cation, because of repulsion. So as a results the Burgers vectors in ceramics tend to be large, larger.

So, if you want to go from let us say one type of anion to another type of anion you have to go larger distance as compared to done in the metals. That is why the Burgers vector in ceramics is larger. So, these are the two reasons why shear stress of, to cause deformation in metals is lower than that in the ceramics and then of course we also saw that using this expression. So this is, this expression tells you that the fact that you introduced the dislocation, your stress goes down by 400 times and we are somewhere in between, the stress values are lower by 1000 times. So at least 10,000 times lower than the theoretical values.

So, the b values are generally between, the W values are generally between b to 3 b or 4 b something like that, b to 3 b. So this is a generally dislocation course are very narrow and as a result, how about that is good enough to cause the substantial reduction in the strength and depending upon the magnitude at W and b, different materials will show different strengths. So, we will stop here. We all are running out of time now, we will do the analysis of this little bit more in the next class before we move on to the strengthening mechanism in metals, thank you.