AML 883 Properties and selection of engineering materials

LECTURE 10. Defects in materials II

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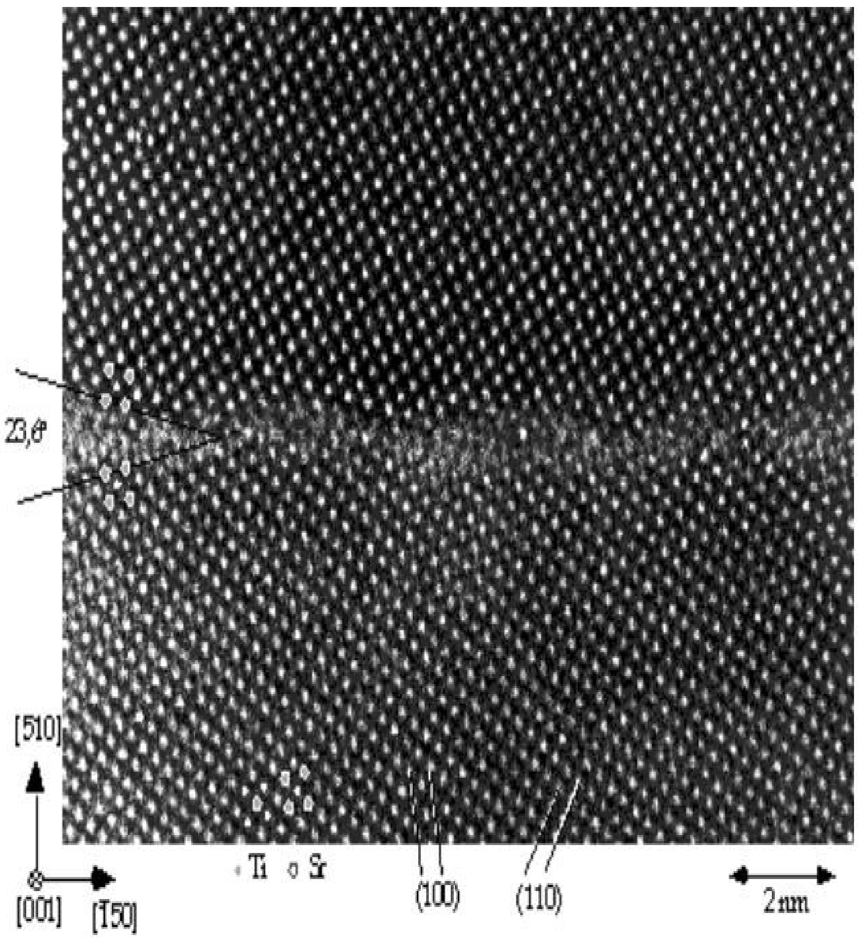
Grain boundaries

- Zinc grains and boundaries
- Differently oriented crystallites in space
- Sources and sinks of defects
- Also move
- Image courtesy: wiki

Grain boundaries



- HRTEM image in strontium-titanate
- Grain boundaries – high angle and low angle
- Image courtesy: C Carter, NANOAM, at mit website

Dislocations and plastic flow

When a large force is applied to a crystal two things may happen; the atoms in the crystal may slide past one another; and they may pull part. The purpose of this book is to describe the theory of the first of these processes. This does not mean that the theory of plastic flow in crystals is now complete, for it is still all too easy to confound it by asking certain questions, even some that are apparently of a very simple kind.

Continued

Dislocations and plastic flow

Neverless, a few permanent features have now been established in the theory; even if all the devious convolutions of the action have not yet been sorted out the main characters in the plot are plain enough. The theory of dislocations constitutes an advance in the degree of precision with which we can describe the structure and properties of matter in the solid state.

-- **A H Cottrell**, in his preface to his classic *Dislocations and plastic flow in crystals* (1953)

Dislocations and plastic flow

- Discrepancy between observed strengths and calculated ideal strengths
- Mystery – solved by G I Taylor, E Orowan and M Polanyi
- Dislocations move easily through the crystal – by a process called slip – which is compared to the movement of heavy carpet by pushing a fold across or that of a caterpillar

G I Taylor

- Image courtesy: wiki
- MIT – Brenner – Classical physics through the work of G I Taylor

E Orowan

- Image courtesy: iMechanica

M Polanyi

- Image courtesy: wiki

Dislocation movement

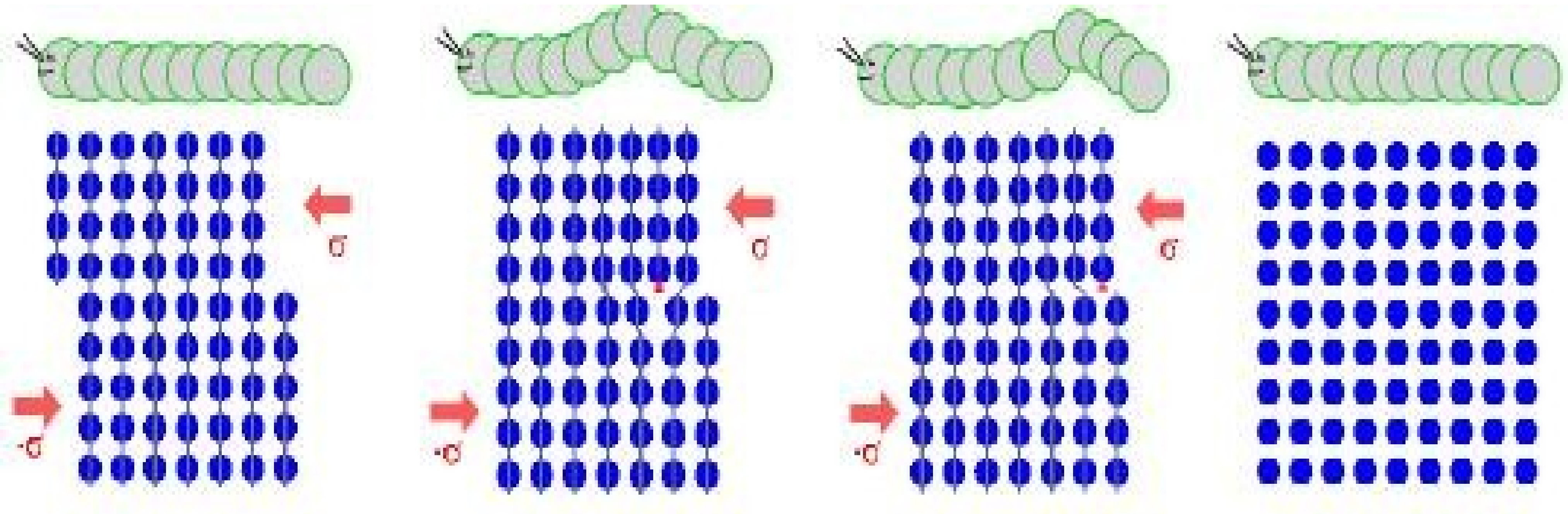


Image courtesy: Lecture notes of Leonid Zhiglei

Slip

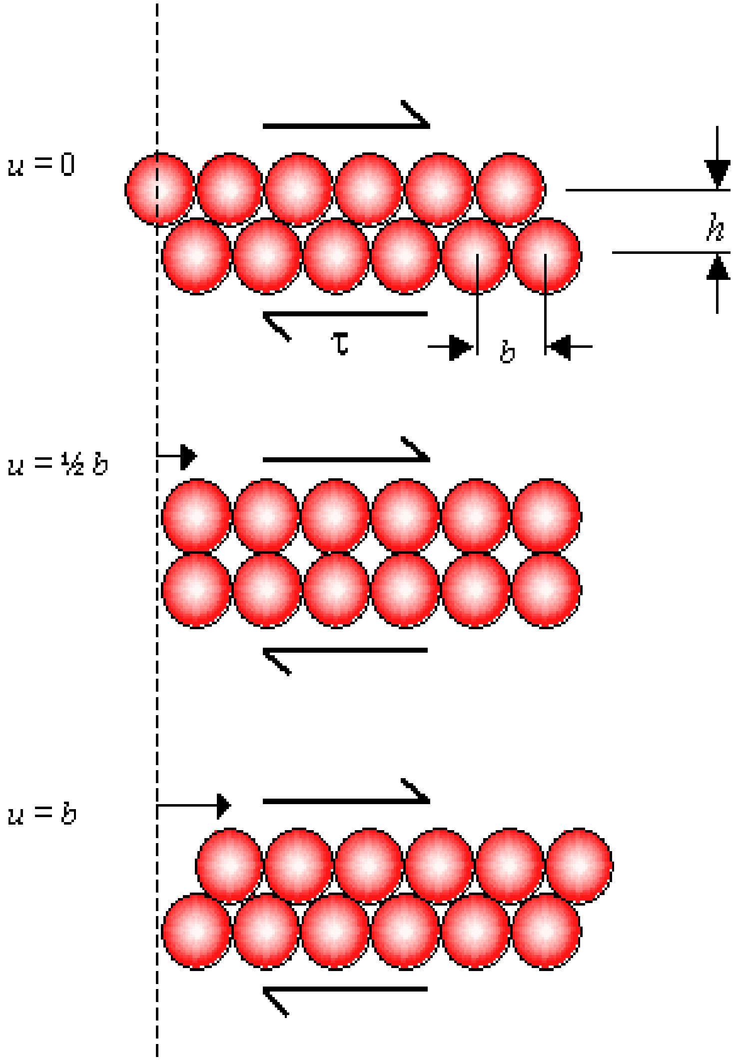
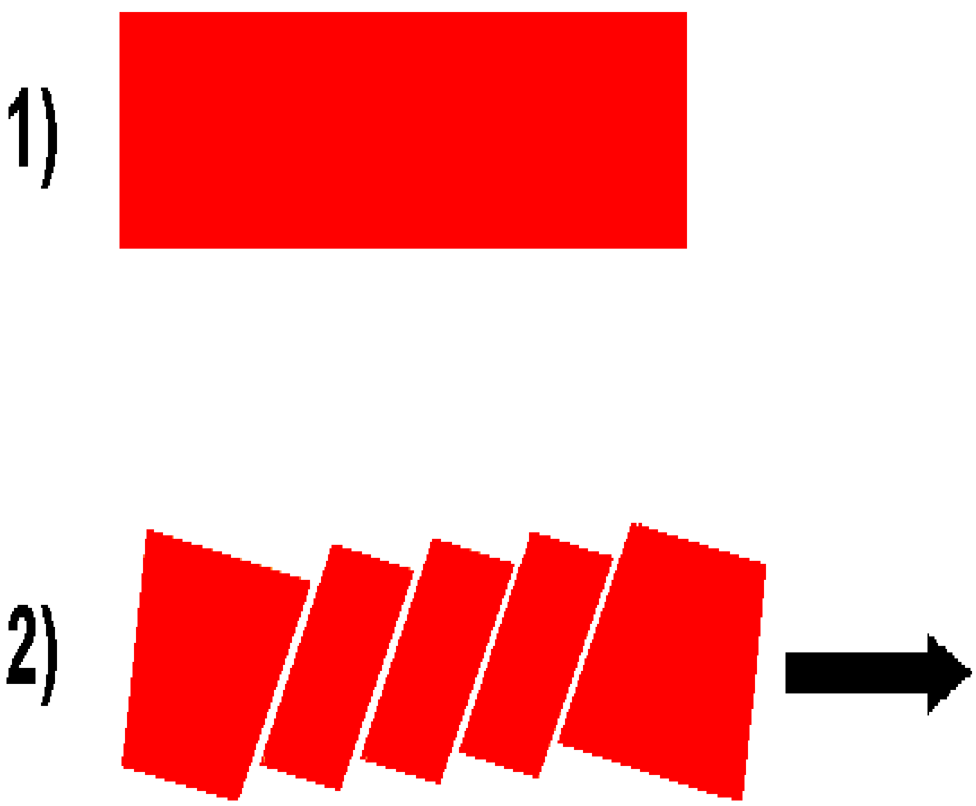


Image courtesy: University of Cambridge
(Go there for movies too – of bubble rafts)

What is the idea?

- Theoretical strength – calculated using the breaking point of springs – related to Young's modulus
- In crystals, dislocations exist – and, they help in rows of atoms sliding past one another – related to shear modulus
- Which planes slide, and along which direction?

Slip -- Schematic



- Image courtesy: wiki
- 1) Single crystal without deformation
- 2) Slipped crystal

Slip steps

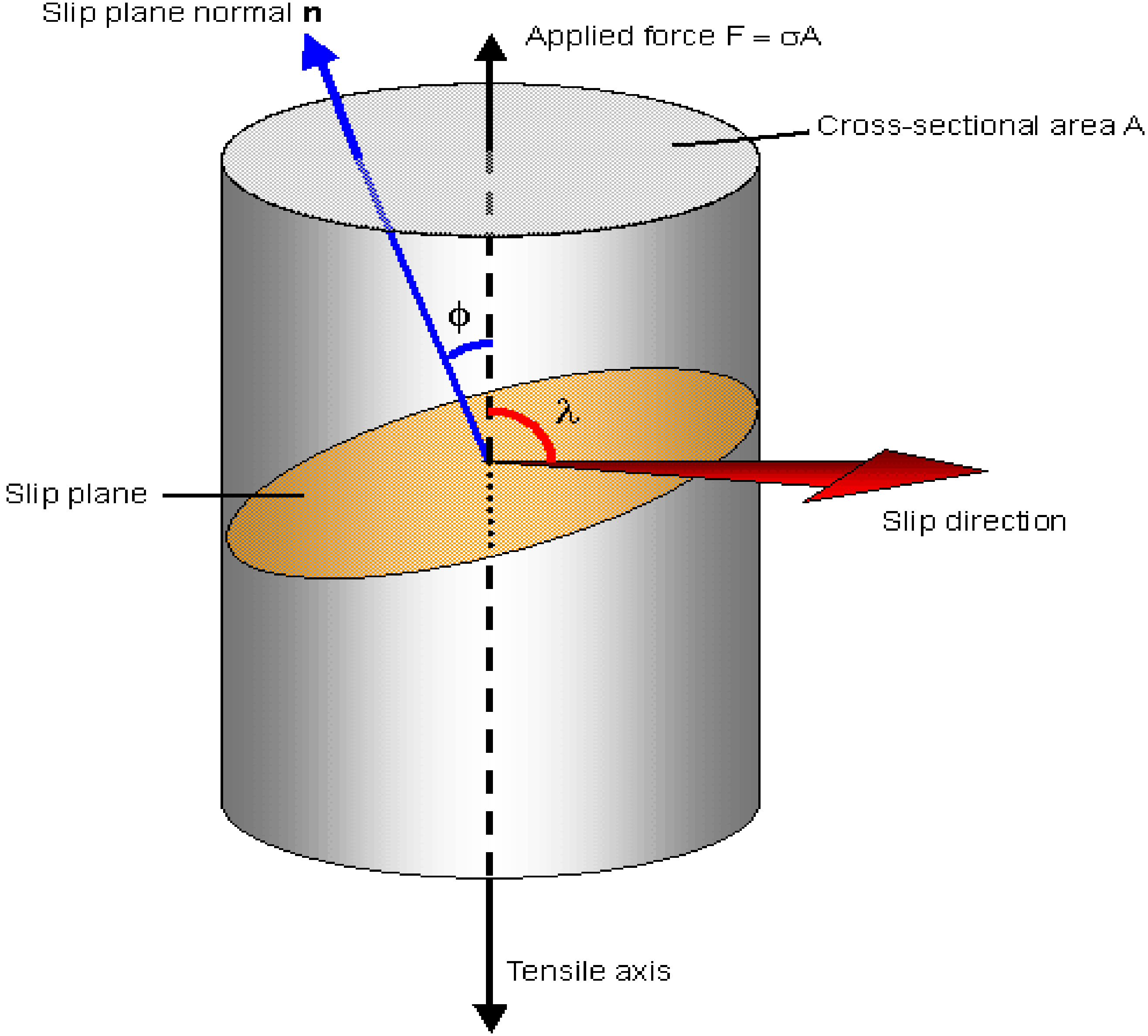


Image courtesy: University of Cambridge

RSS

- Resolved shear stress – force per unit area in the direction of slip
- Force on the slip plane $F\cos\lambda$
- Area of the slip plane $A/\cos\phi$
- Resolved shear stress

$$\tau_R = (F/A)\cos\phi\cos\lambda$$

- CRSS – a critical value of shear stress at which dislocations flow

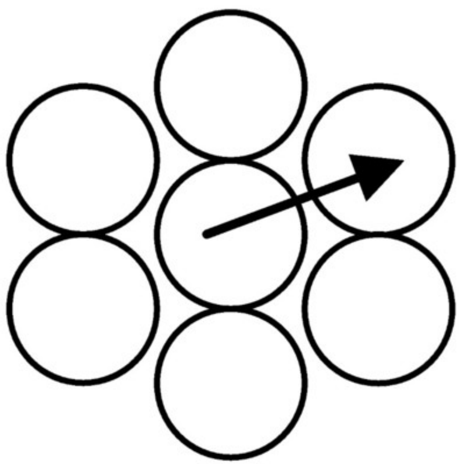
CRSS

- $\tau_R = (F/A)\cos\phi\cos\lambda$
- (F/A) when the LHS is the CRSS is the yield stress
- As the stress is increases, for some slip plane, the stress reaches this value first – primary slip
- Slip systems – slip and direction combinations

Maximum shear stresses

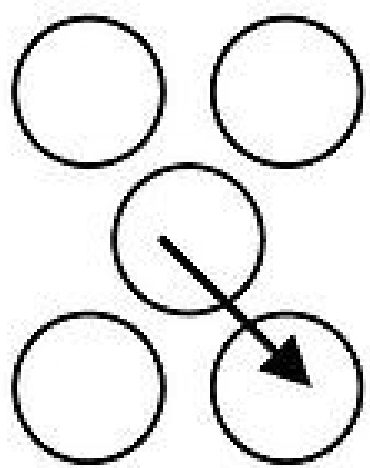
- In general, the angles $\phi \& \lambda$ need not lie on the same plane; however for maximum value, they should lie in the same plane and should add up to 90 degrees
- Implies, that both these angles are 45 degress with respect to the applied stress (See Fig. 6.20) of your textbook
- Polycrystals – Taylor factor (3) times the single crystal strength is the polycrystalline yield strength

FCC – slip system



- {111} planes and <110> directions
- 12 slip systems in fcc
- Makes it more malleable
- Image courtesy: wiki

BCC – slip system



- {110} planes and <111> direction
- 12 slip systems in bcc
- Easy to shape!
- Image courtesy: wiki

HCP – slip system

- Basal planes {001} and <100> directions
- 3 slip systems in hcp
- Generally, brittle!

Slip -- schematic!

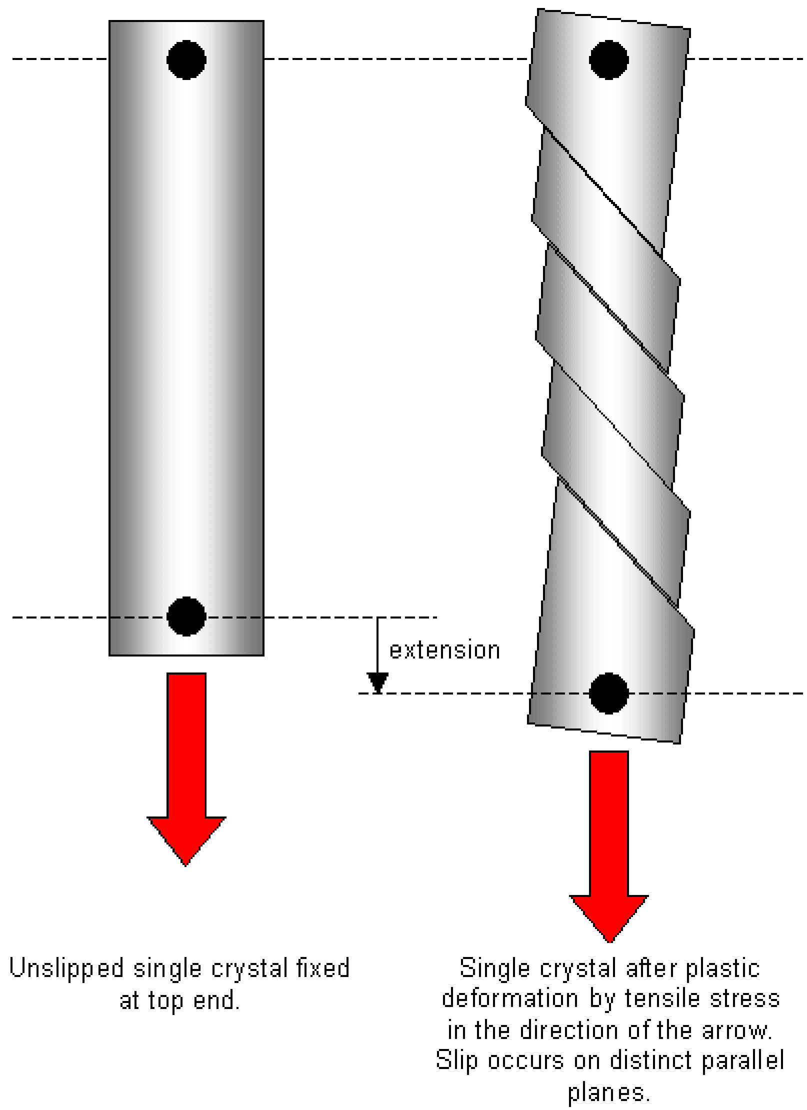


Image courtesy: University of Cambridge

Proof of the pudding

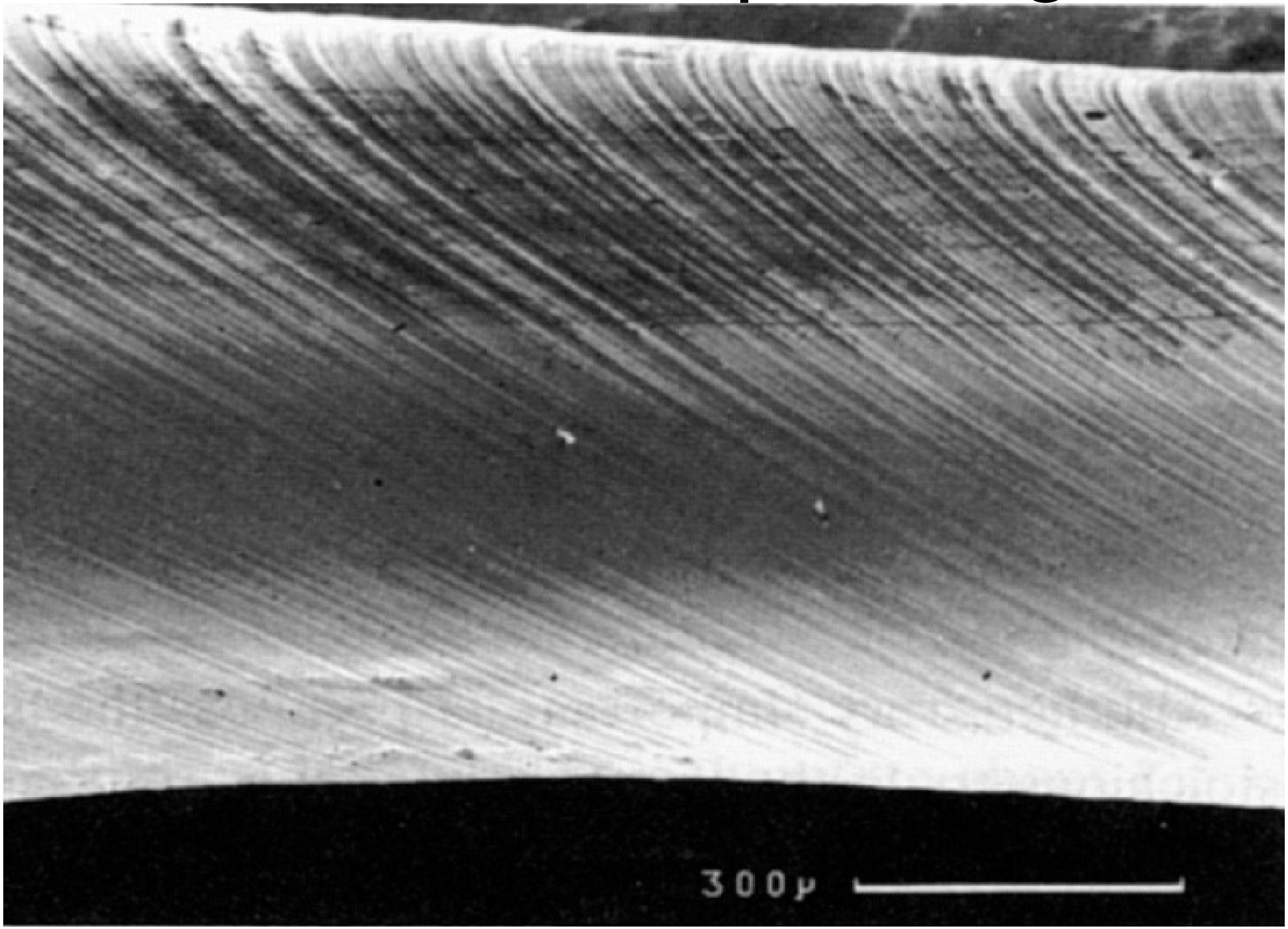


Image courtesy: University of Cambridge

A question

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- Angstroms!
- How much is the change in length of a specimen loaded in tension?
- Macroscopic
- How many dislocations should move to give you the required extension in the dimensions of the sample?

Dislocation density

- Total length of dislocations per unit volume
- Units: per square metre
- Typical, well-annelaed sample: 10^{10}
- Cold-worked: 10^{15}
- Remember these are strange numbers: for example, the annealed density means 1 km of dislocations in a cubic centimetre

Line tension of dislocations

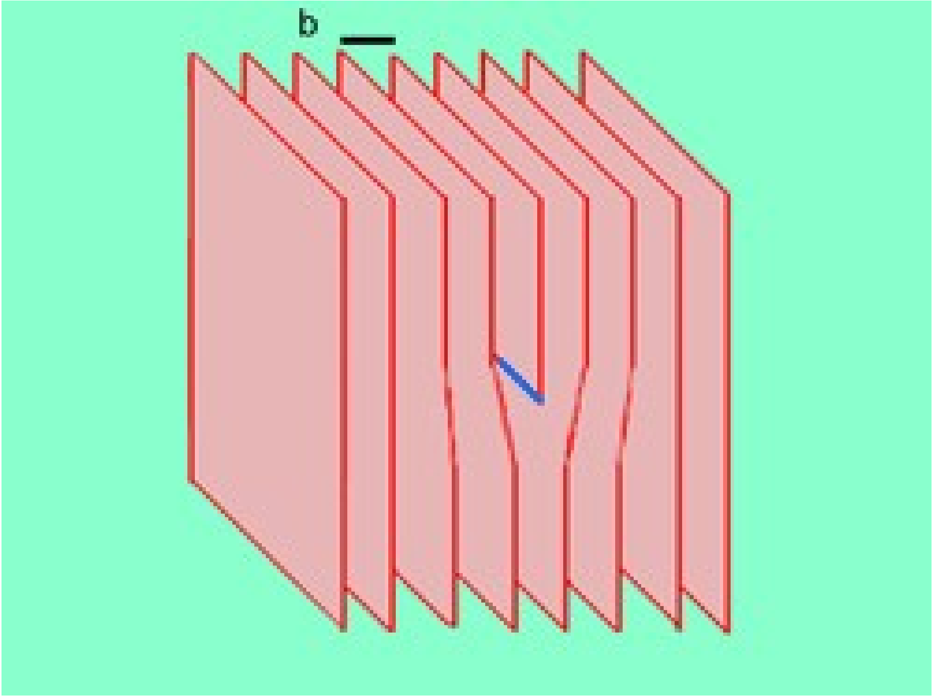

Image courtesy: wiki

- Introduction of dislocations produces lattice distortions near the core
- Dislocations like to keep their length as short as possible
- Line tension is of the order of $(1/2)Eb^2$

Strengthening

- Now that we know why there is a discrepancy between the observed and calculated strengths of materials, what can we do for increasing the strength of materials?

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- Now that we know why there is a discrepancy between the observed and calculated strengths of materials, what can we do for increasing the strength of materials?
- Make the motion of dislocations difficult
- How?