#12: Dislocation Mechanics

From the previous lecture #10

•Real crystals yield at stresses that are three or four orders of magnitude lower than the "ideal" yield stress.

•Line defects are the reason for the lower yield stress: they are called dislocations.

•Dislocations are defined by (i) the line vector, which can meander in the slip plane, and (ii) a slip vector, $\vec{b}$, also called the Burgers vector, which is a constant for the entire dislocation line.

•The plastic strain is related to the density of dislocations, ρ, the distance that the dislocations move, x and the magnitude of the slip vector,

$$\gamma_P = \rho b x \qquad (1)$$

Note that the strain is dimensionless.

Today's Topics

•What is the physical relationship between the distance that dislocations have to move to produce "measurable" plastic deformation.

•How does an applied shear stress produce a force on a dislocation and what is this relationship?

•What happens if dislocations get pinned (unable to move) or if they meander?

(i) Numerical assessment of Eq. (1)

Dislocation Density

Typical spacing, L, of dislocations is 1 - 10 μm, that is the dislocation density

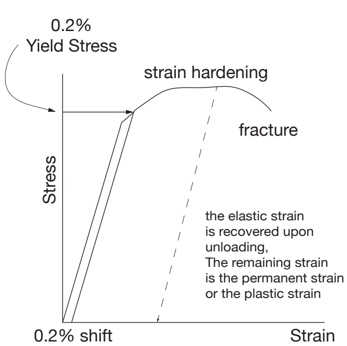
$\rho = 10^{10} - 10^{12}\,\mathrm{m}^{-2}$

The Slip Vector

b is the interatomic spacing typically 0.1 to 0.2 nm

Distance of slip

x = 1 mm to 10 mm



Notes *(the sketch on the left is for a uniaxial stress-strain curve)*

•The point of yielding is not sharply defined but is rather "rounded"

•The engineering value of the yield stress, called 0.2% yield stress by drawing a line parallel to elastic deformation shifted to the right by 0.2%.

•The plastic strain can range from 1% to 15% in a uniaxial test.

L	10	um
ro	1.00E+10	/m^2
b	0.2	nm
	2E-10	m
x	1000	um
	0.001	m
gamma_P	2.00E-03	
	0.2000	%

Influence of Dislocation Density

L	1	um
ro	1.00E+12	/m^2
b	0.1	nm
	1E-10	m
x	1000	um
	0.001	m
gamma_P	1.00E-01	
	10.0000	%

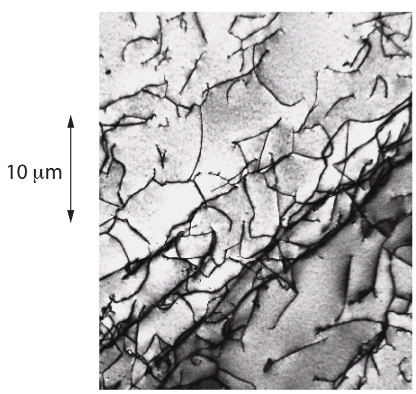
Influence of Glide Distance of Dislocations

L	10	um
ro	1.00E+10	/m^2
b	0.1	nm
	1E-10	m
x	1.00E+04	um
	0.01	m
gamma_P	1.00E-02	
	1.0000	%

A typical stress-strain curve measured in uniaxial tension is shown on the right.

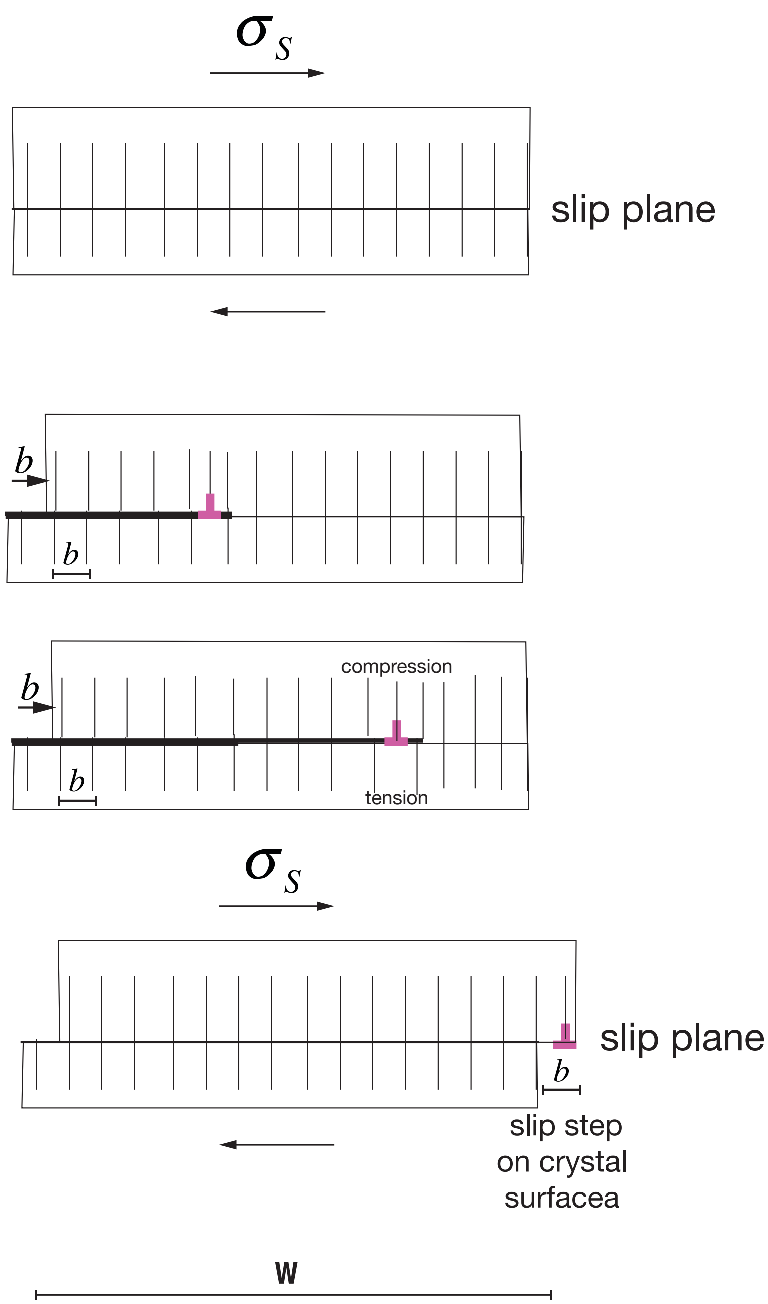
The dislocations have to move over a distance of a few tens of μm to produce a plastic strain of 0.2%.

Just below is a through sections plan view of dislocations obtained in Transmission Electron Microscopy



Note that the dislocations are discontinuous, meaning that they cross between slip planes.

(ii) Force on a dislocation arising from applied shear stress



Force on a dislocation

Units Force/unit length N m^{-1}

Apply the principal of virtual work:

The work done by the applied stress is equal to the work done in moving the dislocation.

Consider a distance, Z, normal to the plane of the paper.

The surface area of the crystal - W*Z

External force on the crystal = $\sigma_s WZ$

Distance moved by the applied stress = b

Therefore, the work done on the system by the applied stress =

$$\sigma_s WZ * b \qquad (2)$$

The internal work done by the dislocation of length Z, through a distance W =

$$F * WZ \qquad (3)$$

Equating (2) and (3)

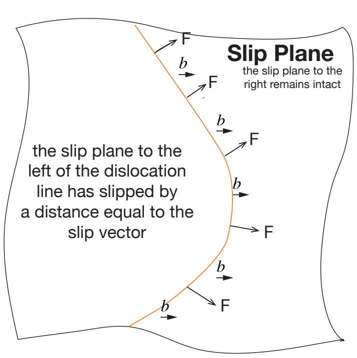
$$F = \sigma_s b$$

•Check the units

•The force acts normal to the line vector of the dislocation (only then can it do work by gliding)

Summary: we have derived a simple result that related the applied stress to the local force on the dislocation. The force has units of N m^{-1}, and it can act only normal to the line vector of the dislocation.

(iii) Dislocations can meander in the slip plane!



Notes (meandering dislocation)

(i) The full dislocation has the same slip vector. This slip vector describes the slip to the left of the dislocation line by the slip vector, b.

(ii) Note, however, that the force on the dislocation is always normal to the line vector. The force is exerted by the shear stress applied from the left to the right, parallel to the slip plane.