MECH 221 – Materials Science
Fall 2017

Lecture 7

Dislocations and Strengthening Mechanisms

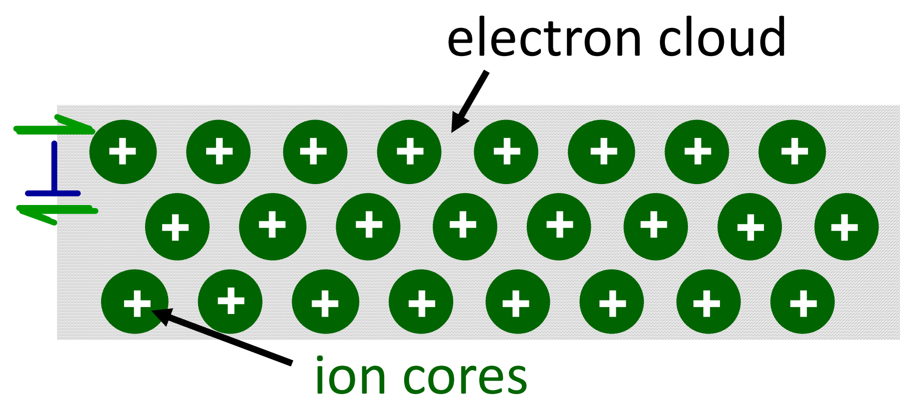
Note: There is some data/text missing from online copies of handouts. This data is available in the appropriate lectures.

Plastic Deformation

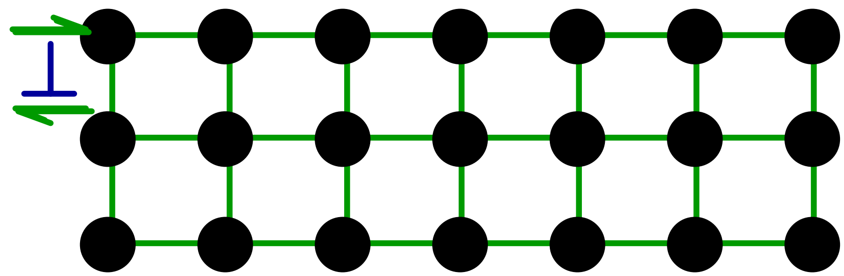
- Why metals could be **plastically** deformed?
- Why the plastic deformation properties could be changed to a very large degree by forging without changing the chemical composition?
- Why plastic deformation occurs at stresses that are much smaller than the theoretical strength of perfect crystals?
- Plastic deformation – the force to break all bonds in the slip plane is much higher than the force needed to cause the deformation. Why?
- These questions can be answered based on theory proposed in 1930s: Plastic deformation in metals and alloys is due to the motion of a large number of ____________.

Dislocations & Materials Classes

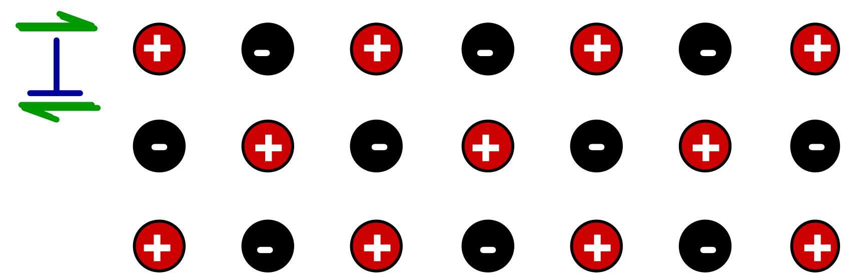
- Metals:
  - Disl. motion easier.
    - non-directional bonding
    - close-packed directions for slip



- ____________ Ceramics (Si, diamond):
  - Motion hard
  - directional (angular) bonding



- Ionic Ceramics (NaCl):
  - Motion hard.
  - need to avoid ++ and -- neighbors



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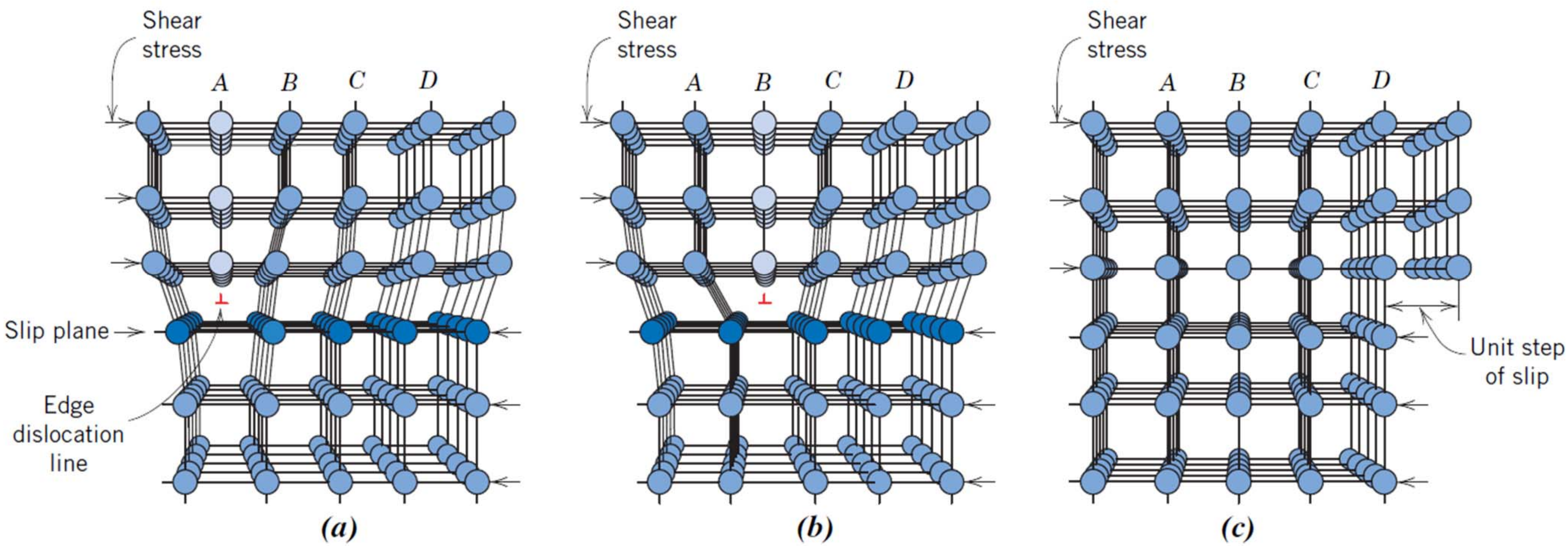
Dislocation Motion

- Under applied shear stress, dislocations can move by breaking bonds consecutively (rather than simultaneously) ➔ Requires **less energy**.

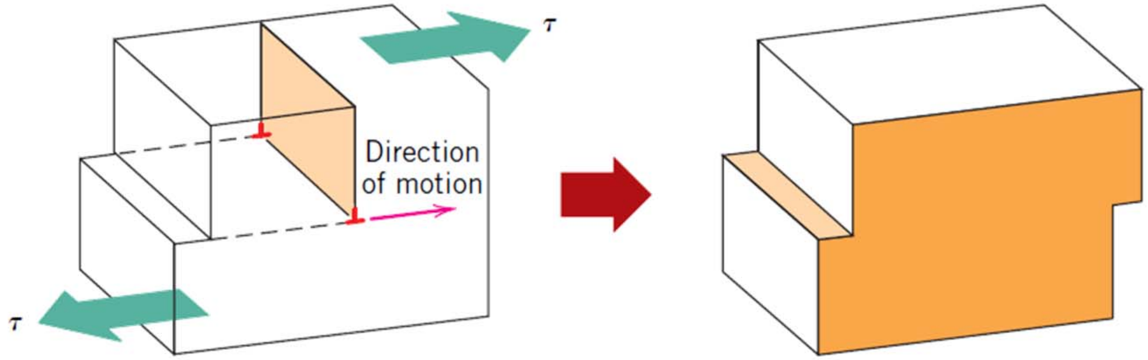


- The movement of the dislocation requires the breaking (and formation) of only **ONE** set of bonds per step.
- **Dislocations** are very important to mechanical properties. They make metals weaker than they should be, BUT also allow metals to be deformed (i.e. If dislocations don't move, plastic deformation doesn't happen!).

Dislocation Motion

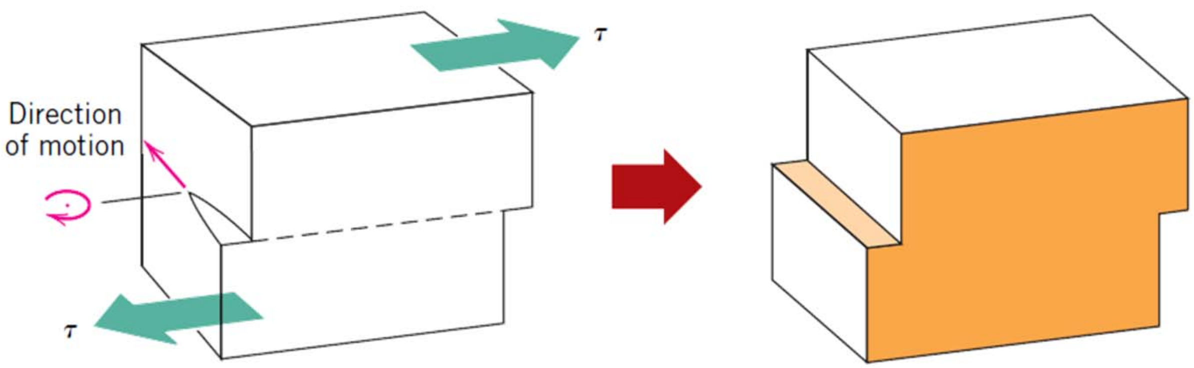
Formation of step by movement of an 'edge dislocation'

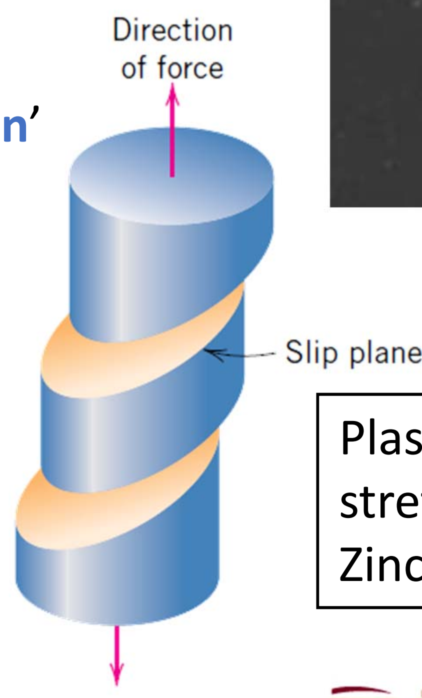
- Movement || to direction of shearing stress τ

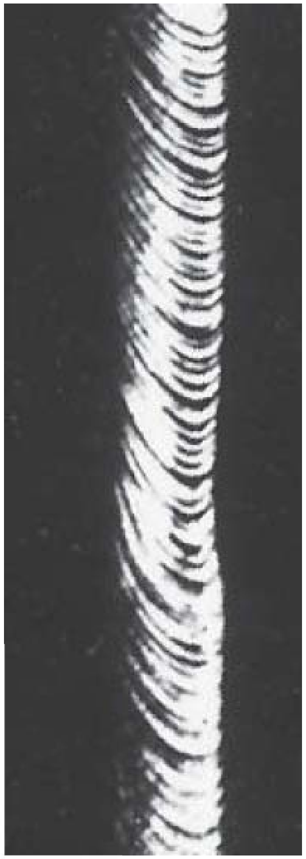


Formation of step by movement of a 'screw dislocation'

- Movement ⊥ to direction of shearing stress τ



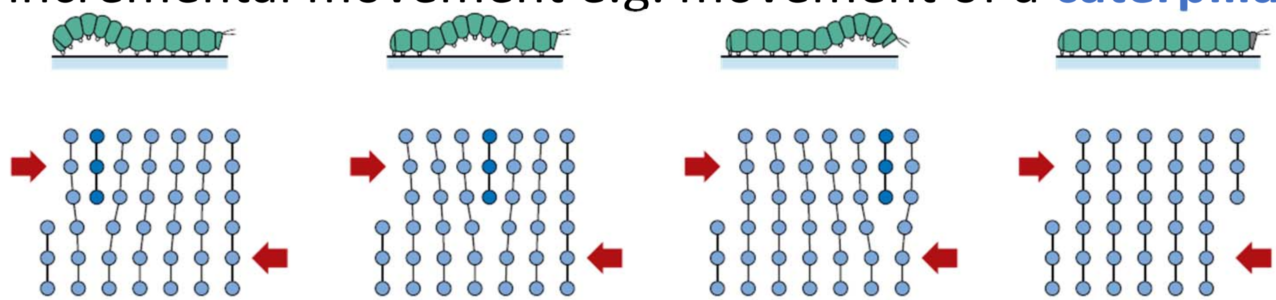




Plastically stretched Zinc crystal

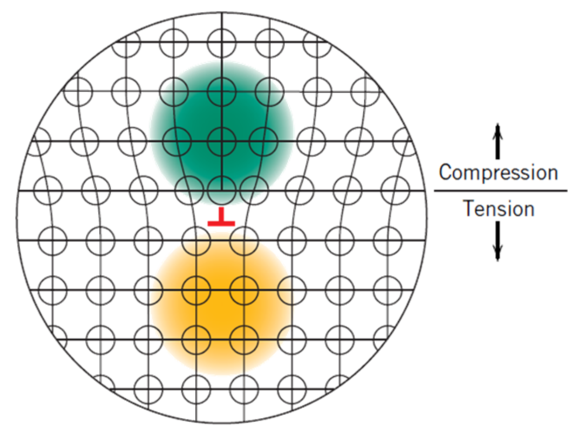
Dislocation Motion

- Dislocation motion lowers the required stress to deform material by allowing incremental movement e.g. movement of a **caterpillar**



- When metal is plastically deformed, most of energy is dissipated as heat.

- Distortions of lattice around dislocation line causes **Lattice Strains**.



- Movement of dislocations under applied stress is called “slip”.
- Direction of dislocation movement is “**Slip Direction**”.
- Plane swept out by the dislocation is called the “**Slip Plane**”.
- Combination of direction and plane = “**Slip System**”

Slip Systems

Slip system comprises: slip direction & slip plane

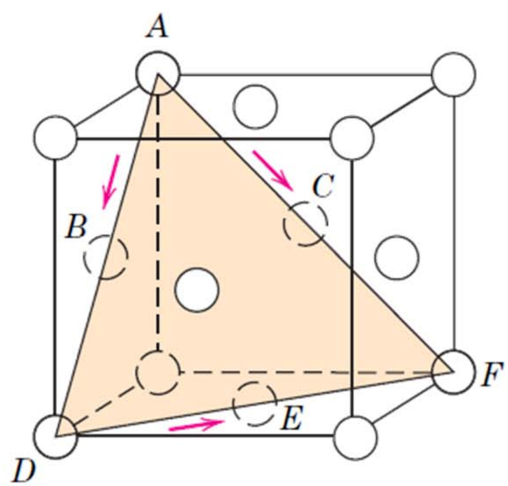
Slip occurs in systems that minimize atomic distortion during dislocation movement

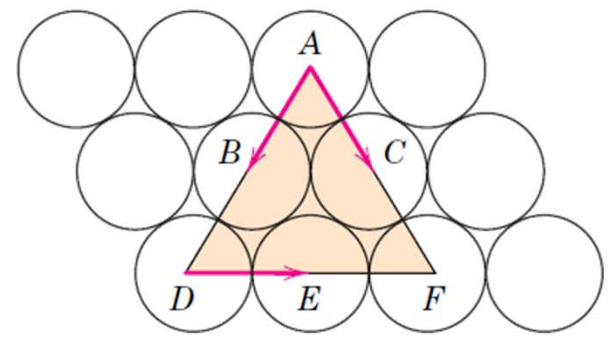
Each crystal system has preferred slip planes and directions:

- Favoured planes are most closely packed (highest planar density) These are "smoother" planes (with a high interplanar spacing d).
- Slip occurs more easily in closest packed directions (highest linear density).

e.g. FCC:

- {111} close packed planes
- <110> close packed direction
- slip system: {111}<110>





Slip Systems

- FCC and BCC metals tend to have high numbers of slip systems (≥ 12) so these metals tend to be ductile - deformable.
- HCP metals have few active systems so are normally brittle.
- Dislocations do not move easily in materials with covalent bonds (very strong and directional bonds). Usually break before slip occurs.
- Materials with ionic bonds are resistant to slip (due to disruptions in charge balance). Usually break before slip occurs.

Metals	*Slip Plane*	*Slip Direction*	*Number of Slip Systems*
	Face-Centered Cubic		
Cu, Al, Ni, Ag, Au	$\{111\}$	$\langle 110 \rangle$	12
	Body-Centered Cubic		
α-Fe, W, Mo	$\{110\}$	$\langle 111 \rangle$	12
α-Fe,W	$\{211\}$	$\langle 111 \rangle$	12
α-Fe, K	$\{321\}$	$\langle 111 \rangle$	24
	Hexagonal Close-Packed		
Cd, Zn, Mg, Ti, Be	$\{0001\}$	$\langle 11\bar{2}0 \rangle$	3
Ti, Mg, Zr	$\{10\bar{1}0\}$	$\langle 11\bar{2}0 \rangle$	3
Ti, Mg	$\{10\bar{1}1\}$	$\langle 11\bar{2}0 \rangle$	6