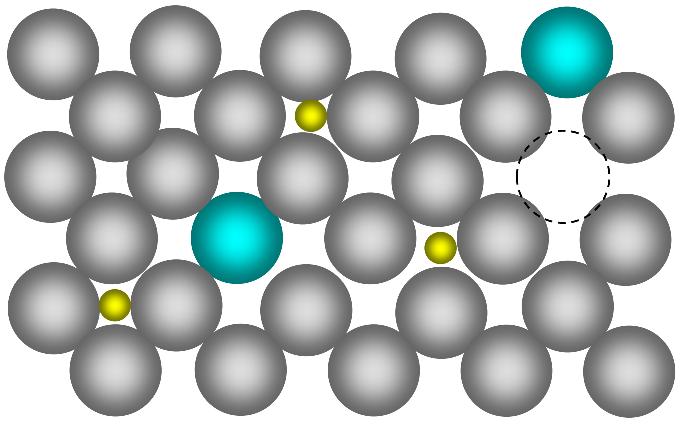
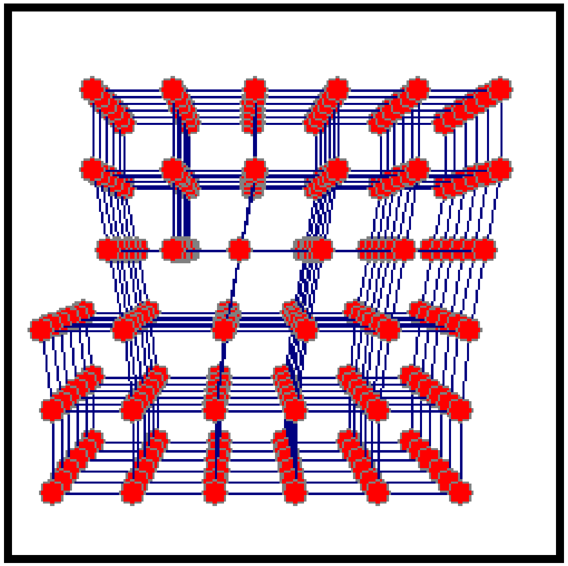
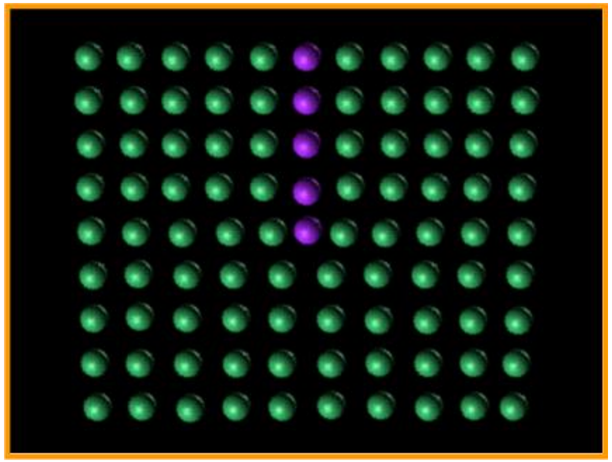
4. Imperfections in Solids

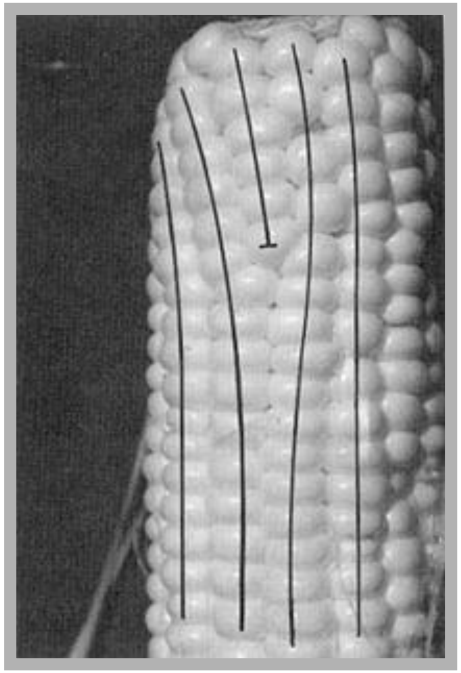
- point defect
- diffusion
- line defect
- planar defect

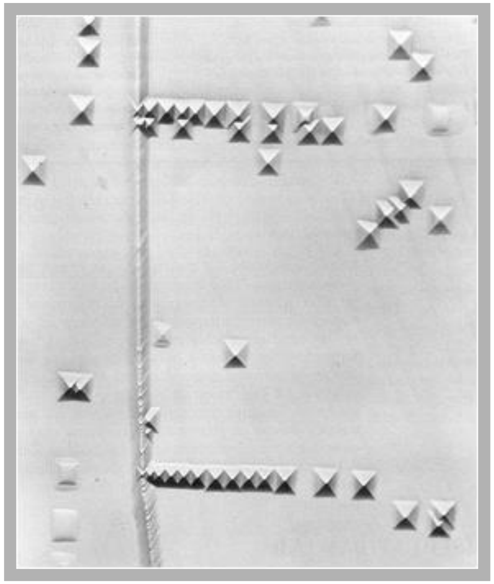


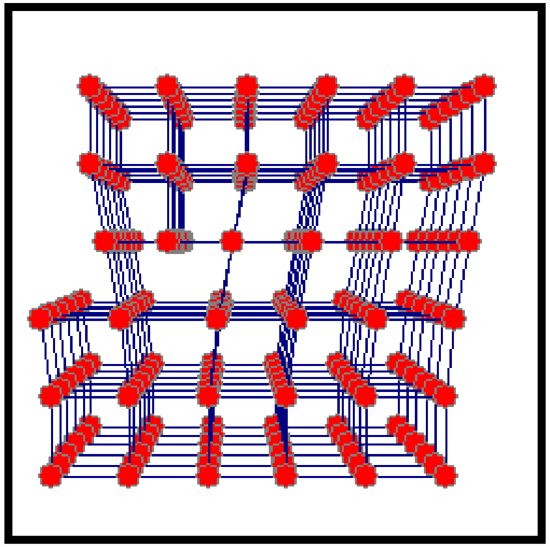


Dislocations



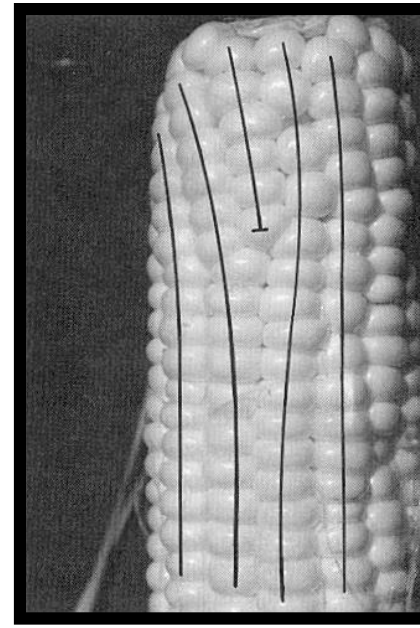


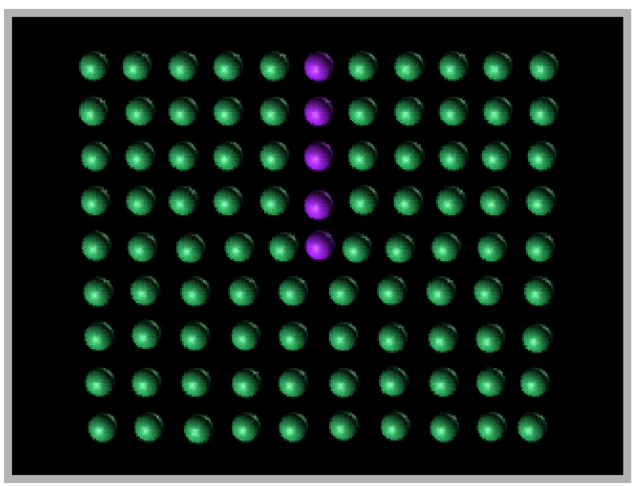


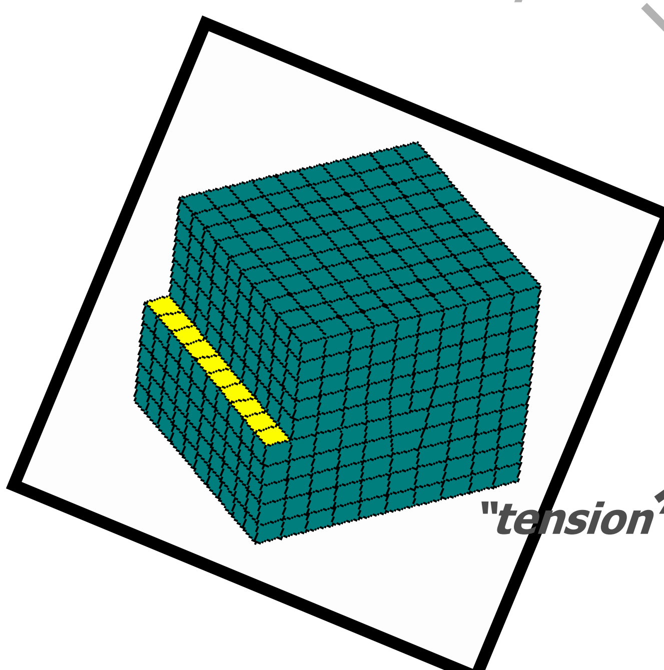


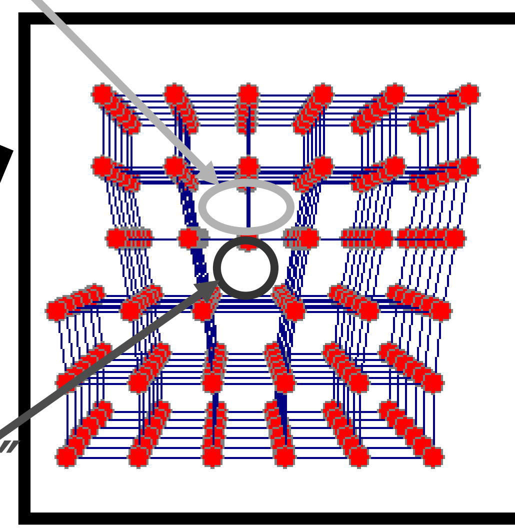
Types of Dislocations

- Edge:
  - extra half-plane inserted into an otherwise ideal lattice
  - ⇧ elastic distortion of the lattice
  - severe distortion in the vicinity of the end point of inserted plane.
  - Types: positive and negative



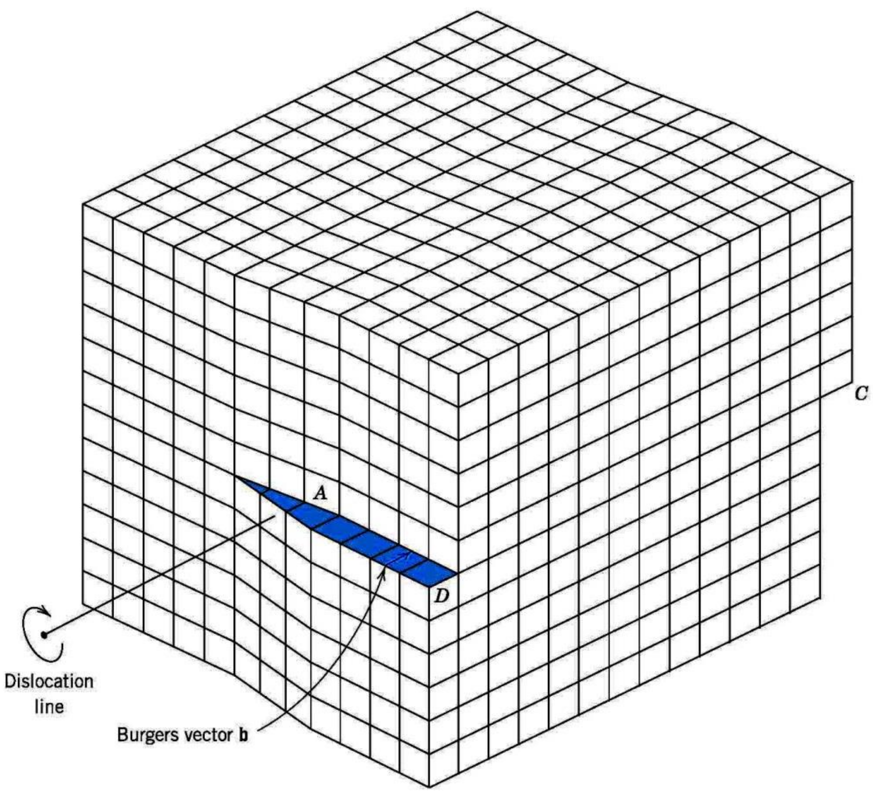


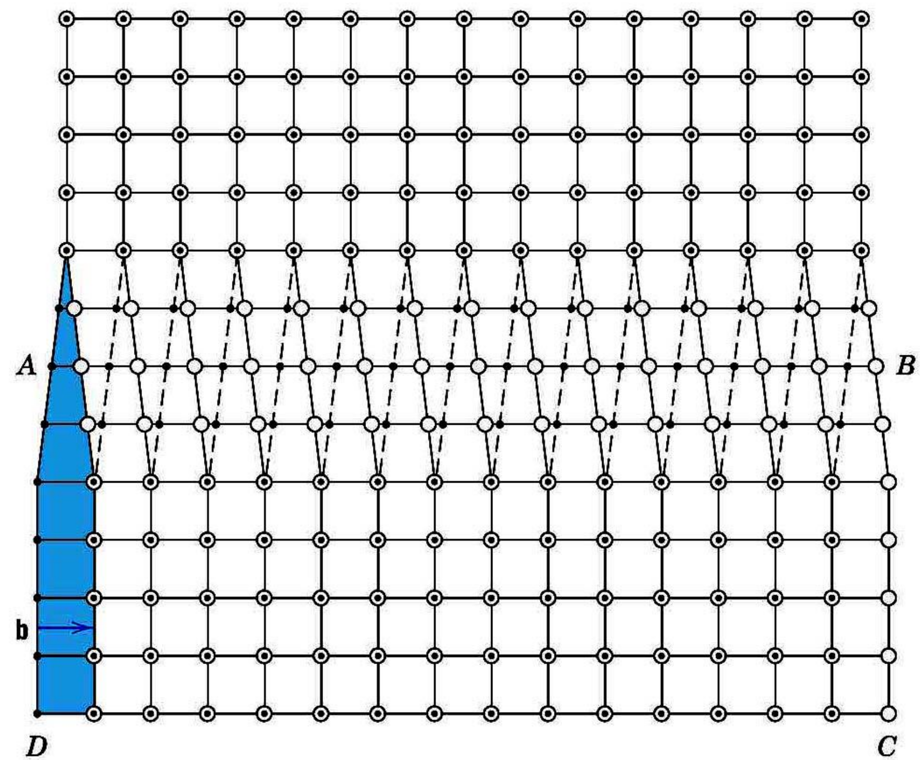




Types of Dislocations

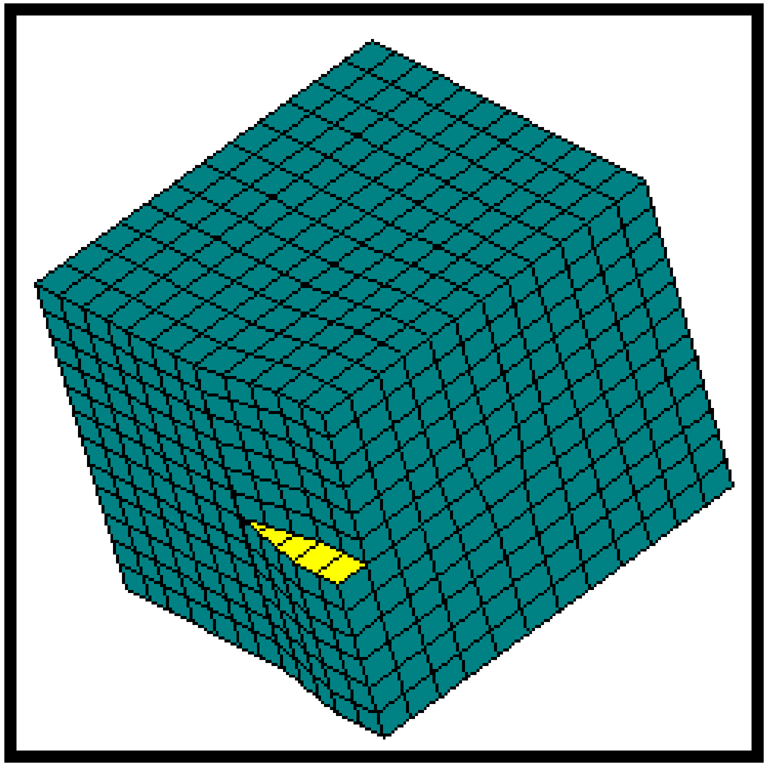
- Screw:
  - predominantly involved in the plastic deformation of BCC metals.
  - Types: right hand side, and left hand side.

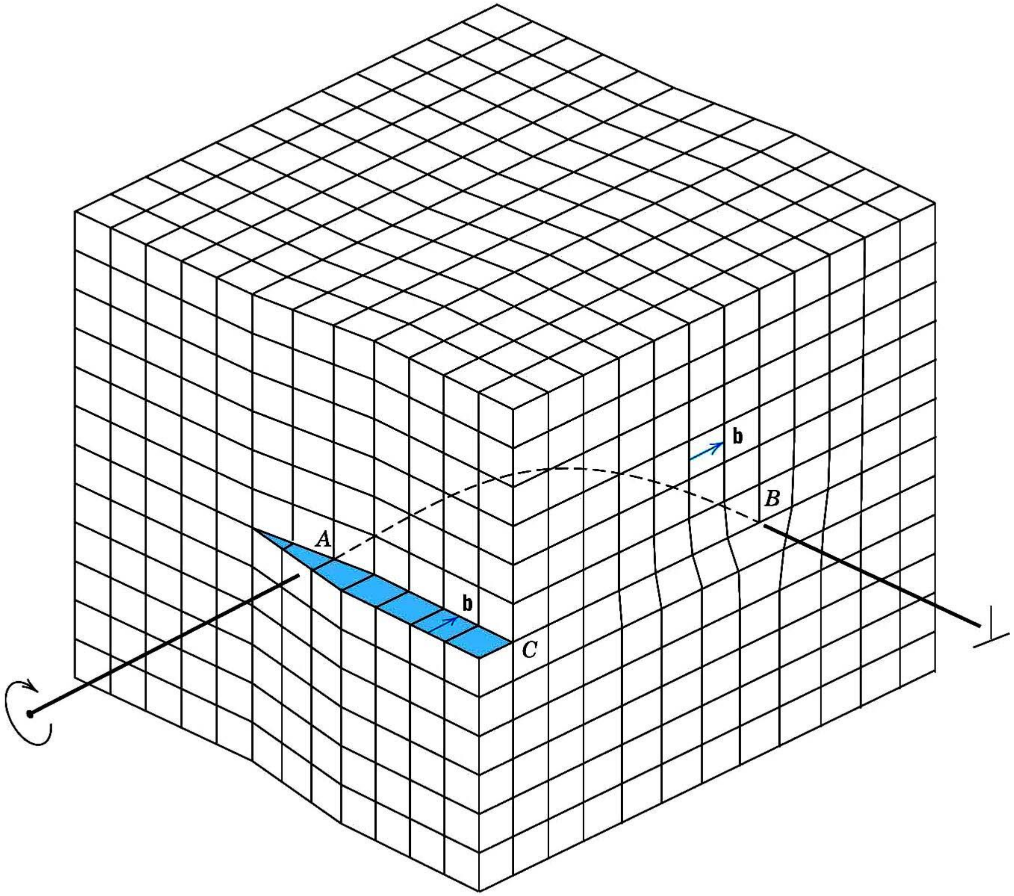




Types of Dislocations

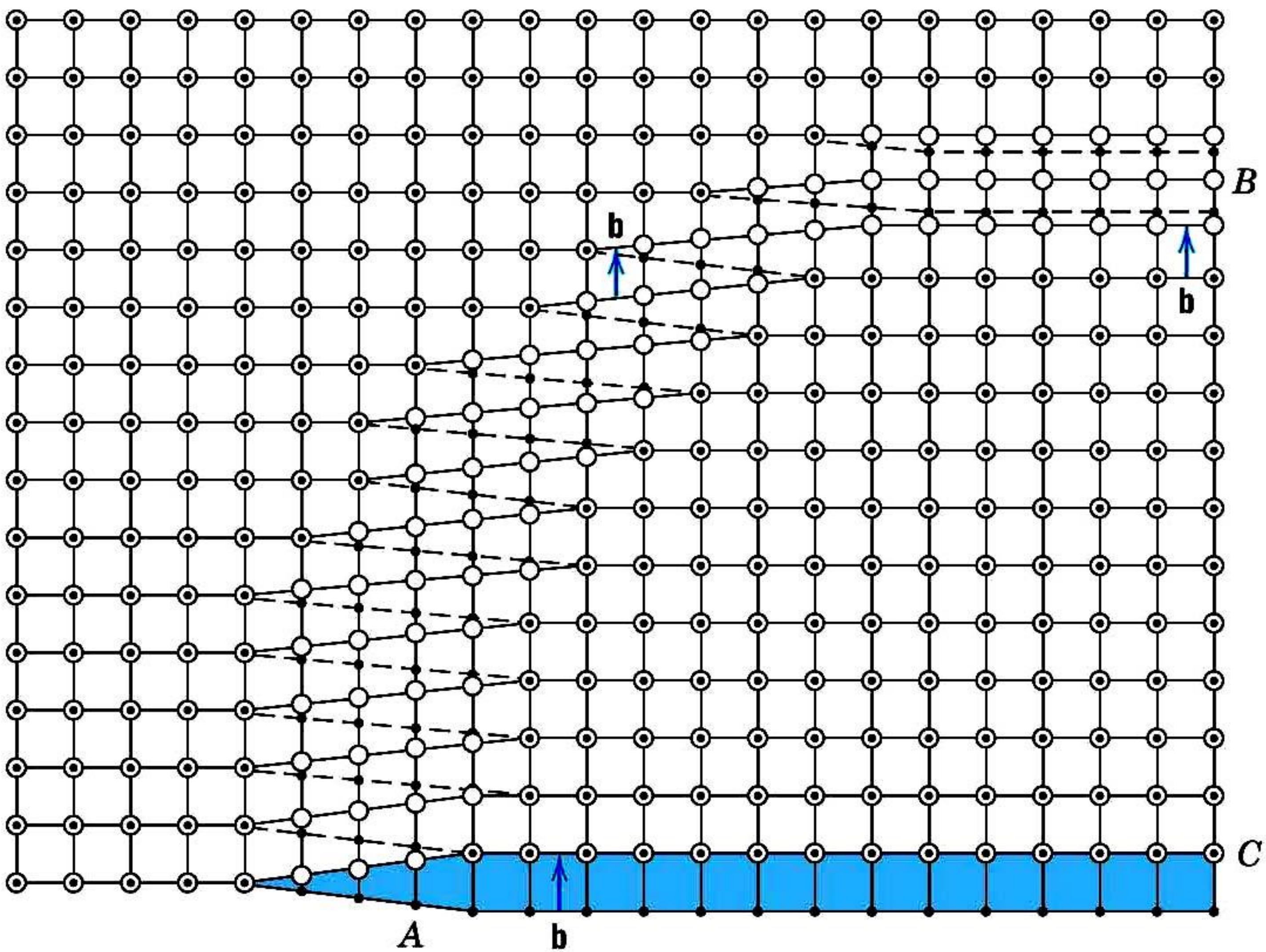
- Mixed:

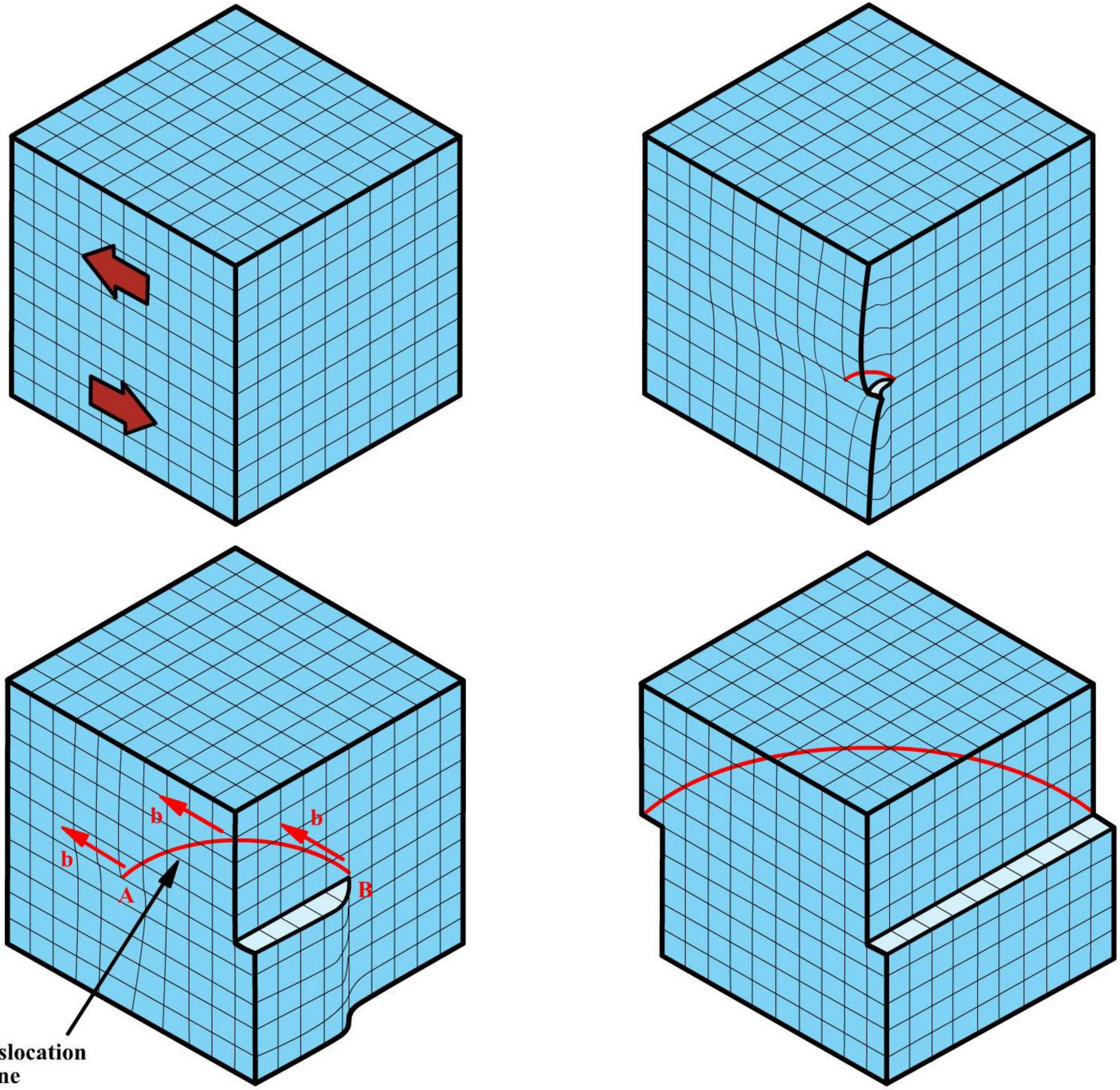




Mixed Dislocations

- open circle-atoms above slip plane
  solid circle-atoms below slip plane



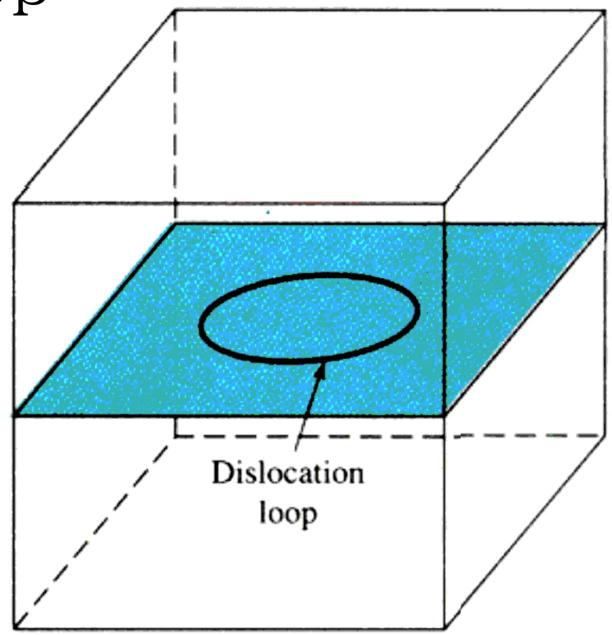

b
b
b
A
B
Dislocation
Line

Types of Dislocations

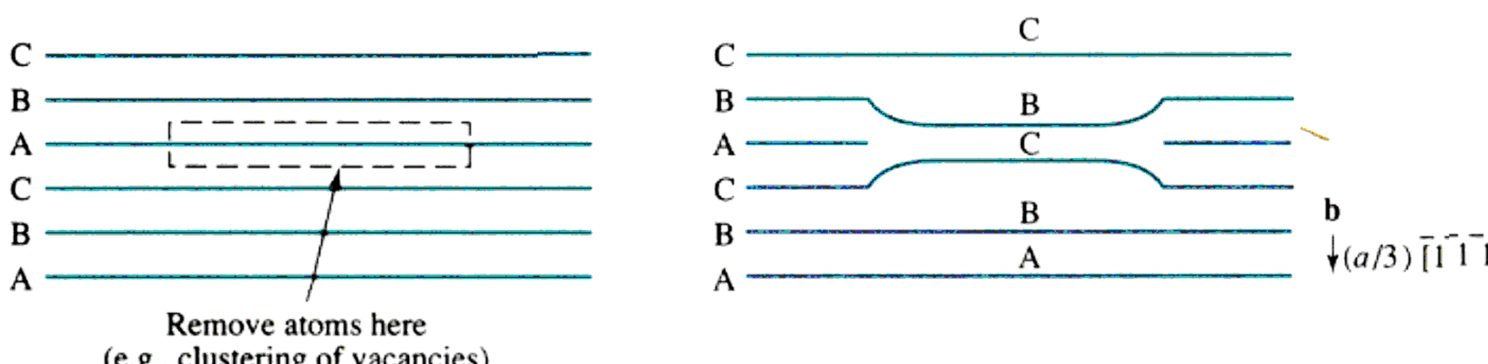
- since a dislocation line defines the boundary between one region of the crystal in which the slip already taken place and another which has not yet slipped, it follows that it cannot terminate within the crystal.
- a dislocation line can form a closed dislocation loop, or its two ends can terminate at the surface of the crystal.
- dislocation loops are common

Types of Dislocations

- Dislocation loop:

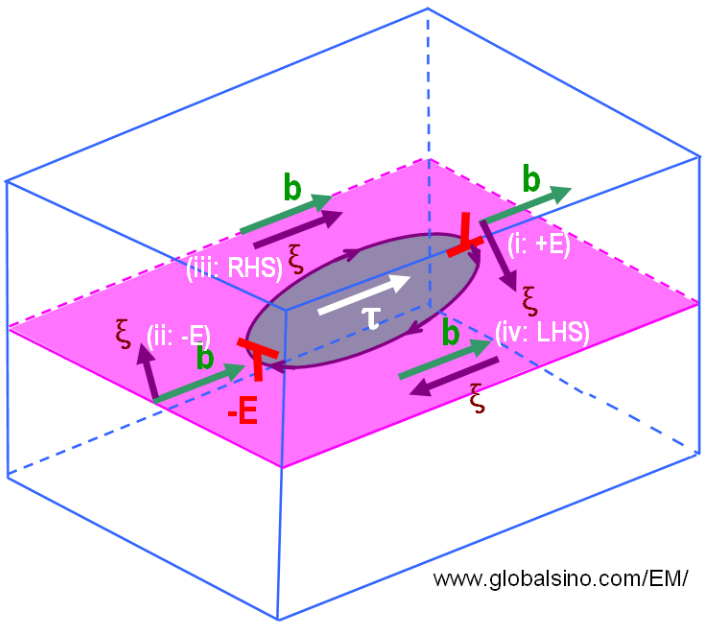


(a)



Types of Dislocations

- Dislocation loop:



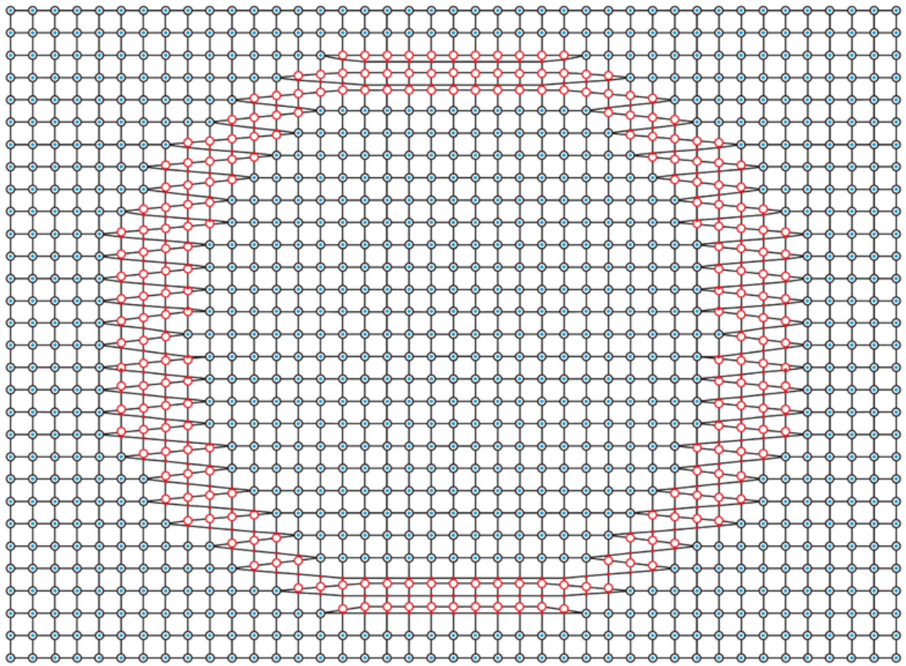
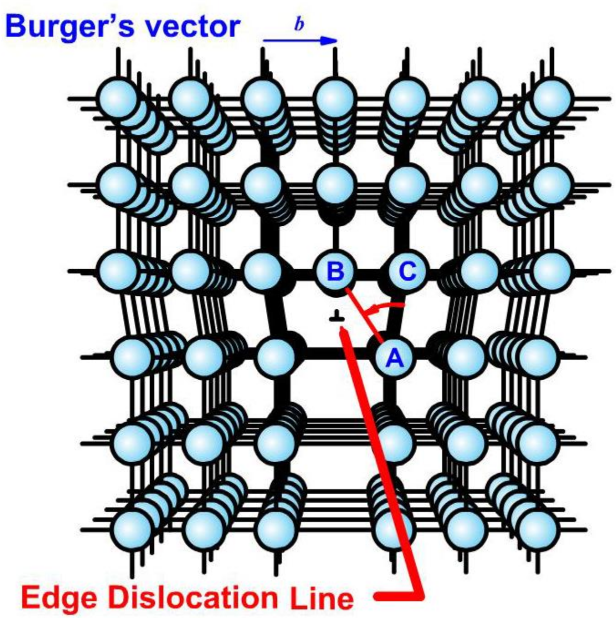


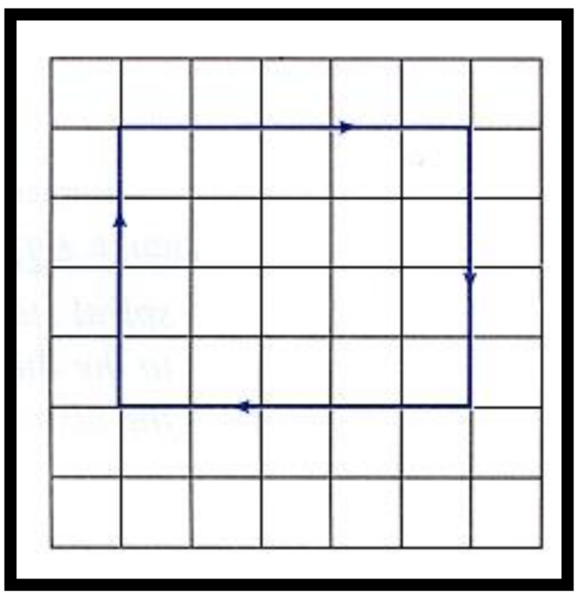
Figure 3454. Glide and dislocation loops.

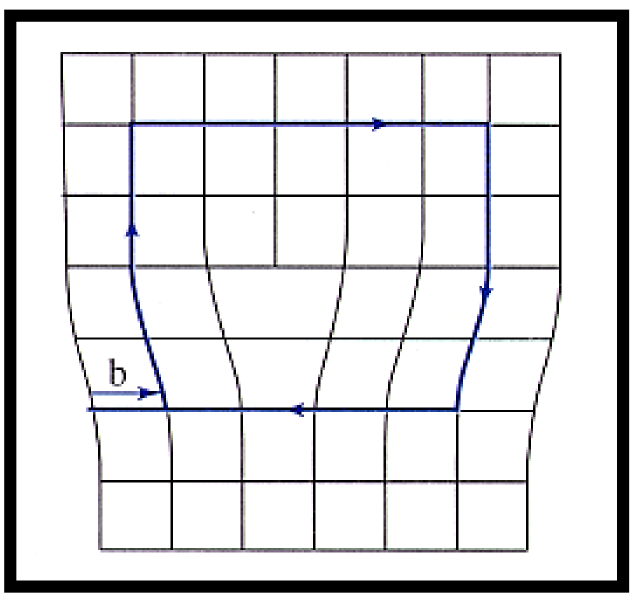
https://www.globalsino.com/EM/page3454.html https://commons.wikimedia.org/wiki/File:Dislocation_loop.png

Characterization of Dislocations

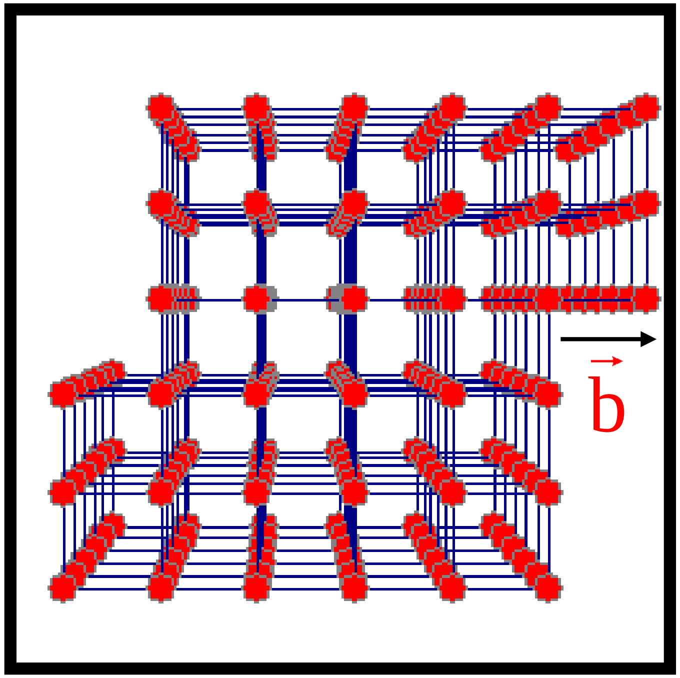
- **Burgers vector:** $\vec{b}$
  - expresses the magnitude and direction of the main lattice distortion.
  - it is always **parallel** to the ***slip*** direction
  - dislocation line.

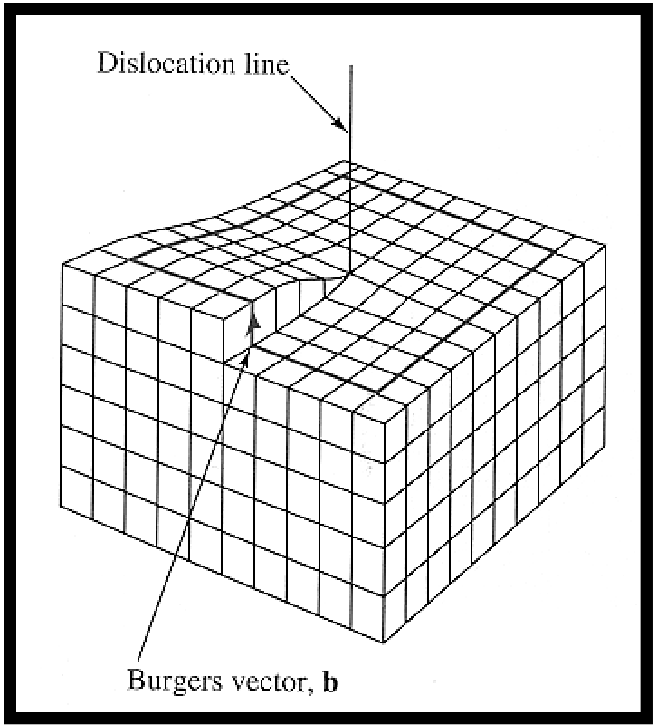






Characterization of Dislocations





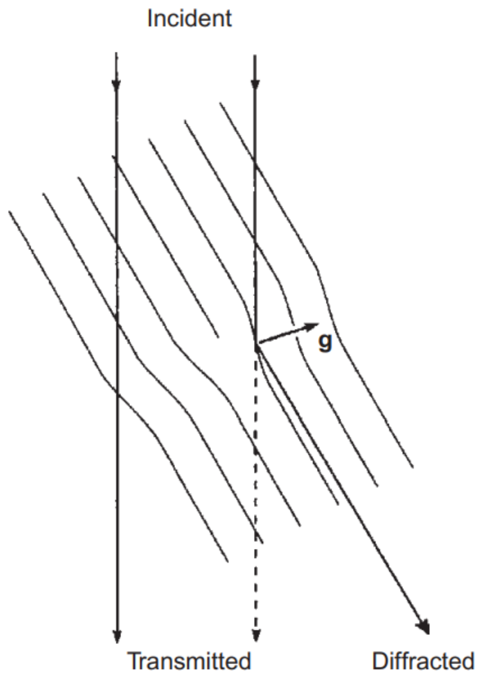
edge dislocation- $\vec{b} \perp$ dislocation line

screw dislocation- $\vec{b} \parallel$ dislocation line

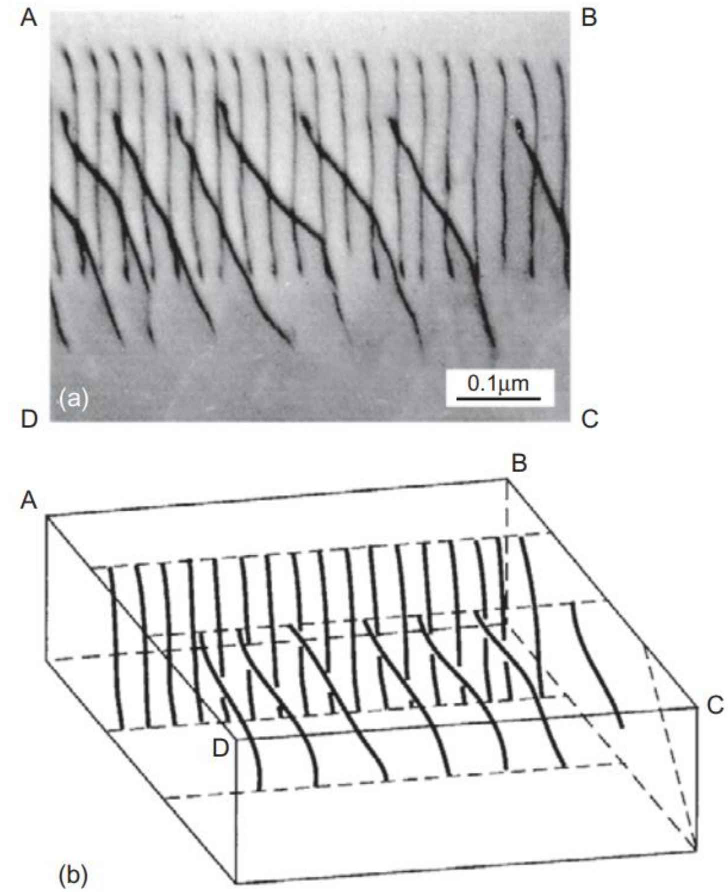
Observing Dislocations

- Etch pits - Tiny holes created at areas where dislocations meet the surface. These are used to examine the presence and number density of dislocations.
- Slip line - A visible line produced at the surface of a metallic material by the presence of several thousand dislocations.
- Slip band - Collection of many slip lines, often easily visible.

Observing Dislocations



Planes near an edge dislocation bent into the orientation for diffraction.



(a) Thin film transmission electron micrograph showing two parallel rows of dislocations. Each dark line is produced by a dislocation. The dislocations extend from top to bottom of the foil which is about 200 nmthick. (b) The line diagram illustrates the distribution of the dislocations in the foil and demonstrates that the photograph above represents a projected image of a three-dimensional array of dislocations

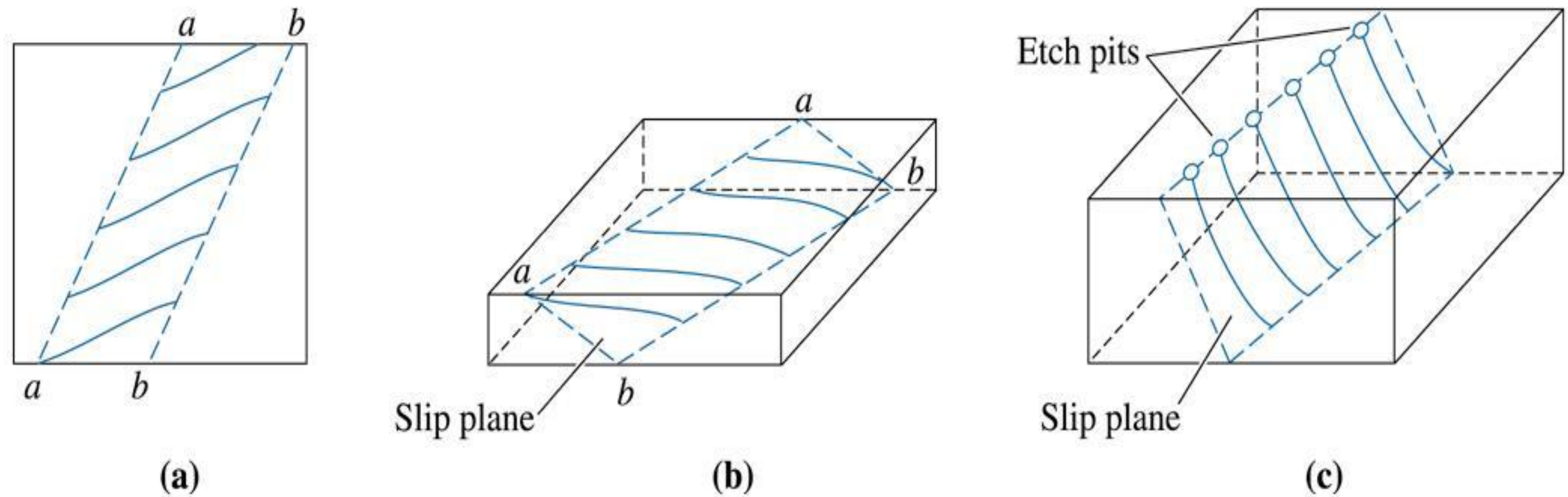
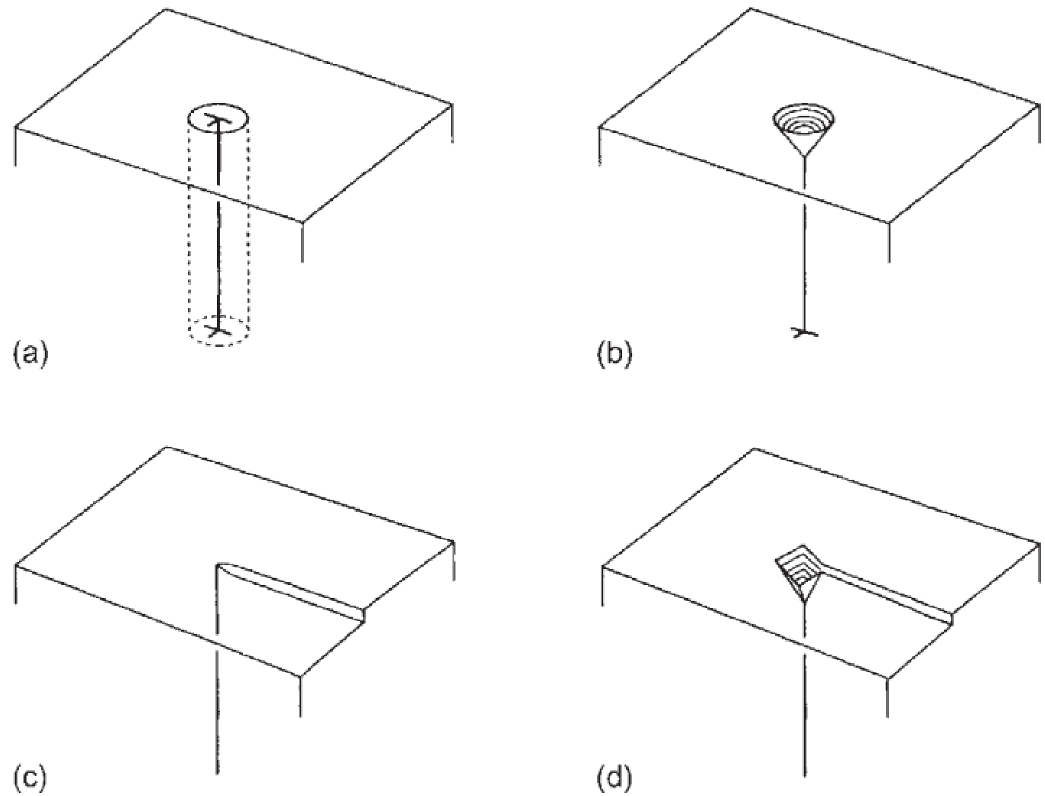


Figure 4.11 A sketch illustrating dislocations, slip planes, and etch pit locations. (*Source: Adapted from* Physical Metallurgy Principles*, Third Edition, by R.E. Reed-Hill and R. Abbaschian, p. 92, Figs. 4-7 and 4-8. Copyright (c) 1992 Brooks/Cole Thomson Learning. Adapted by permission.)*



Formation of etch pits at the site where a dislocation meets the surface. (a) Edge dislocation, the cylindrical zone around the dislocation represents the region of the crystal with different physical and chemical properties from the surrounding crystal. (b) Conical-shaped pit formed at an edge dislocation due to preferential removal of atoms from the imperfect region. (c) Emergent site of a screw dislocation. (d) Spiral pit formed at a screw dislocation; the pits form by the reverse process to the crystal growth mechanism.

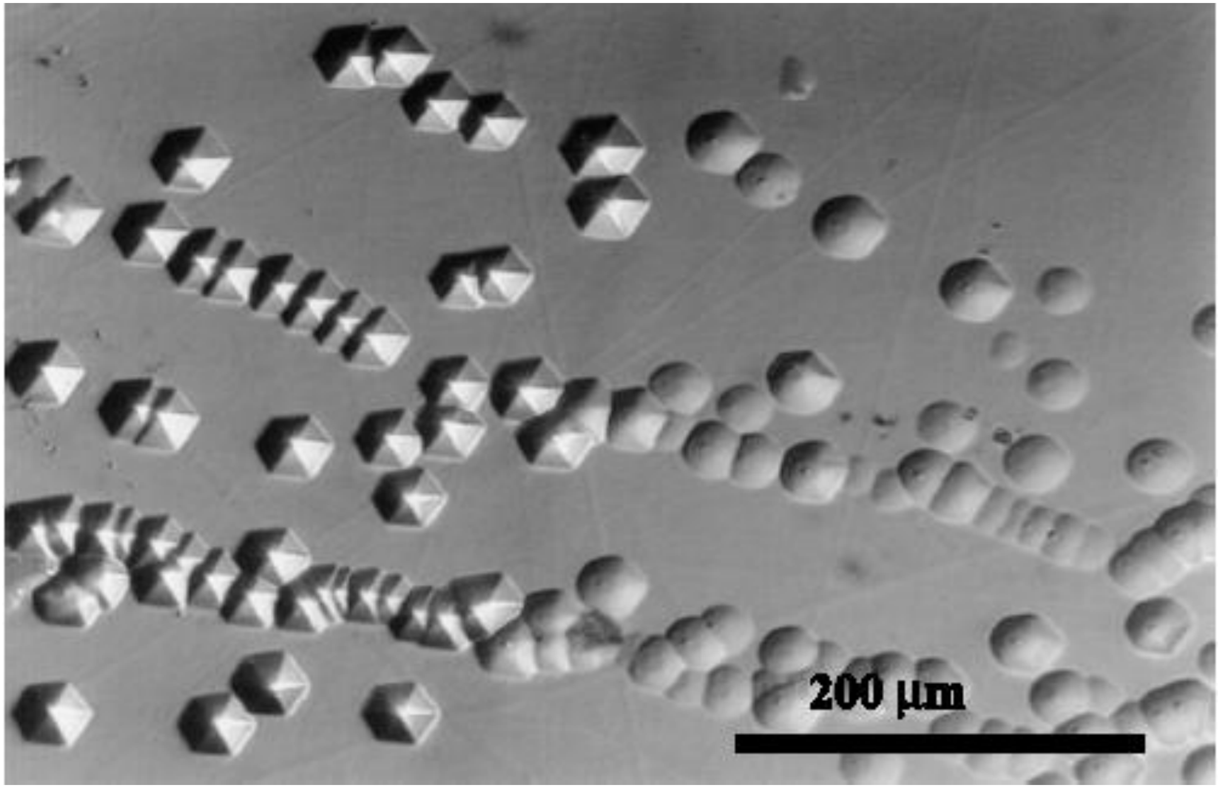
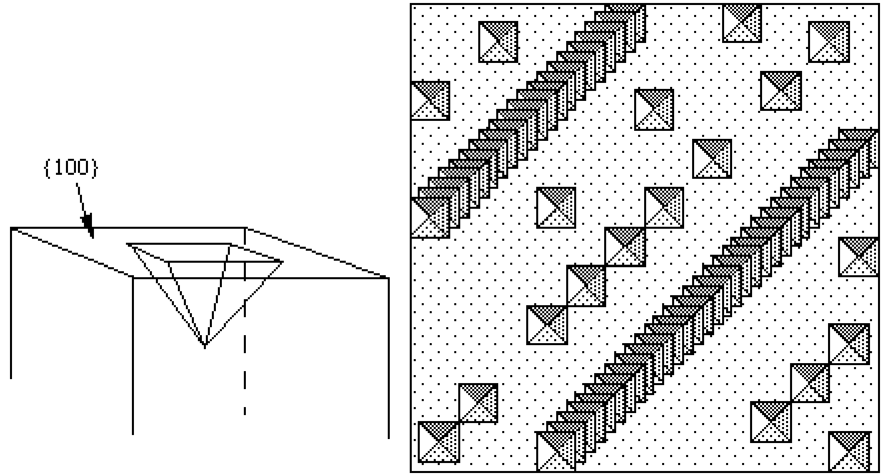
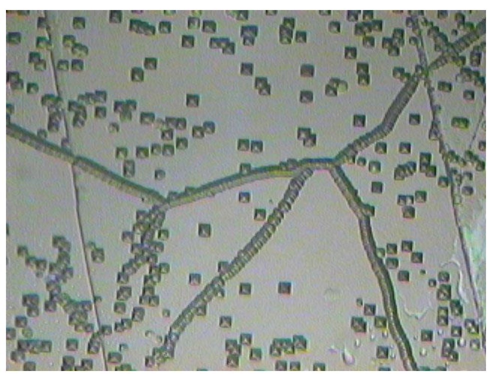


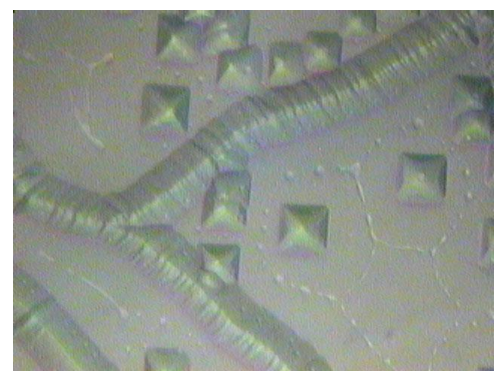
Figure 4.12 Optical image of etch pits in silicon carbide (SiC). The etch pits correspond to intersection points of pure edge dislocations with Burgers vector a/3 $\langle 1\bar{1}20 \rangle$ and the dislocation line direction along [0001] (perpendicular to the etched surface). Lines of etch pits represent low angle grain boundaries (*Courtesy of Dr. Marek Skowronski, Carnegie Mellon University*.)



(a) (b)

Figure 5. Dislocation etch pits. (a) a three dimensional view of a pit with square pyramidal facets. (b) Projection showing schematic distribution on the surface.





The following micrographs illustrate typical dislocation etch pits on cleaved rock salt surfaces

http://mimp.materials.cmu.edu/rohrer/defects_lab/polygoniz.html

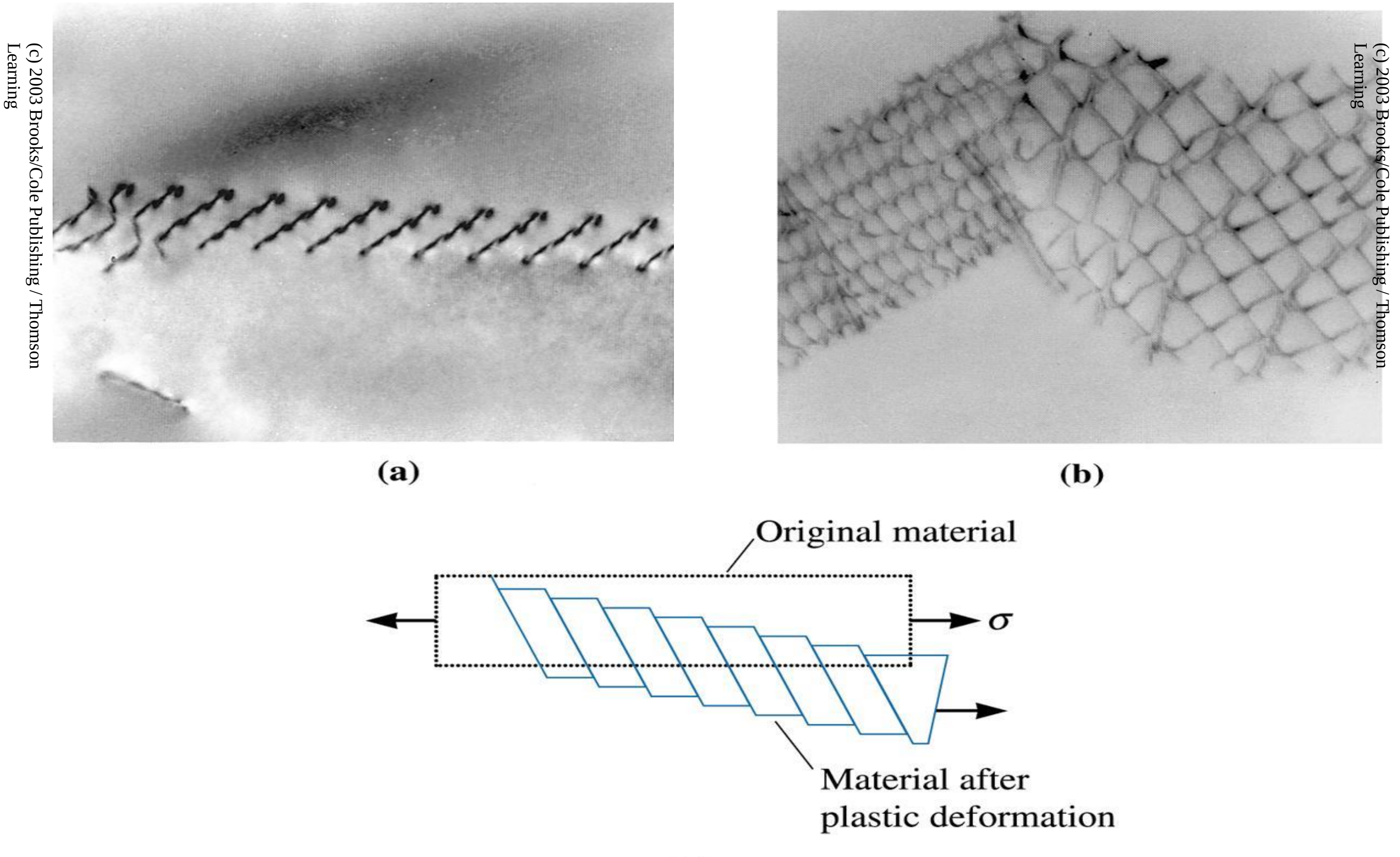
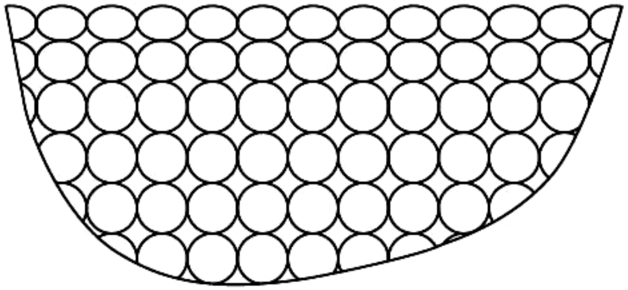


Figure 4.13 Electron photomicrographs of dislocations in Ti_3Al: (a) Dislocation pileups (x26,500). (b) Micrograph at x 100 showing slip lines and grain boundaries in Al. (c) Schematic of slip bands development.

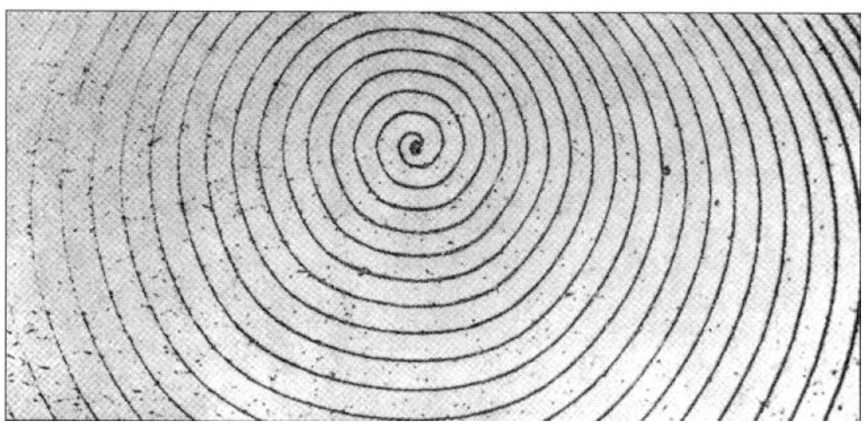
Planar Defects

- surface
- twin boundary
- stacking fault
- grain boundary
- domain boundary

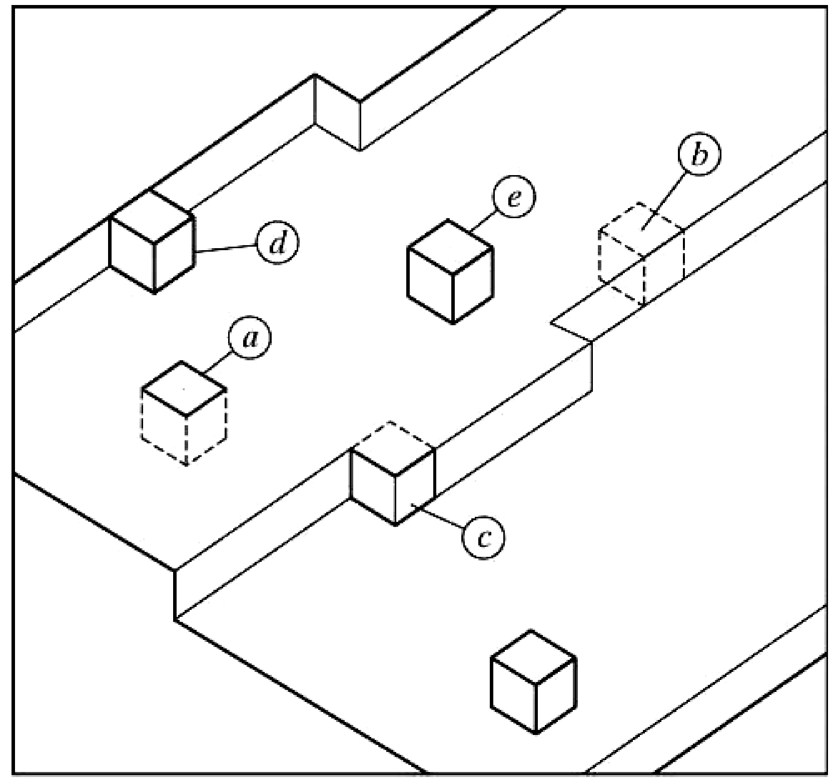
Surface



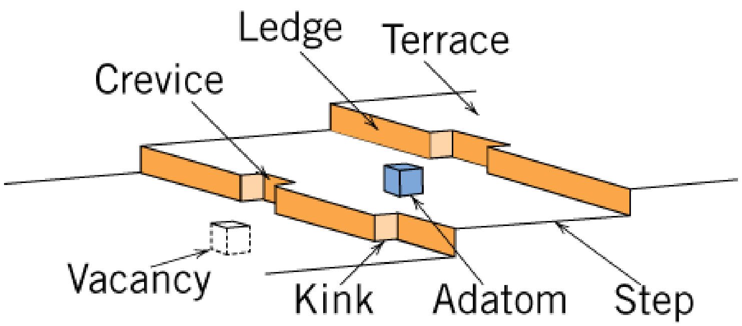
fewer nearest neighbor
Higher energy- surface
tension or energy



crystal growth from vapor phase
around a screw dislocation in SiC



Hirth Pound model
ledge & kink



Single crystals of
$(Ce_{0.5}Zr_{0.5})O_2$
used in an automotive
catalytic converter

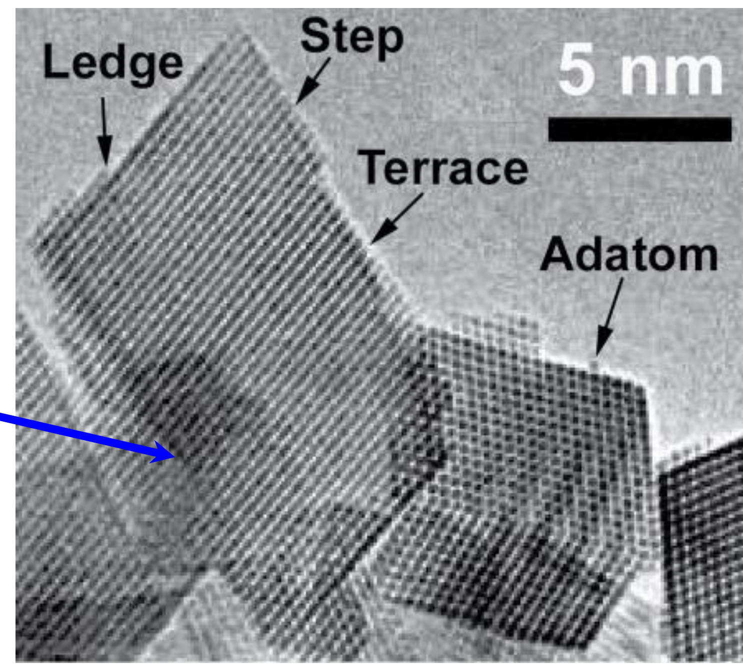
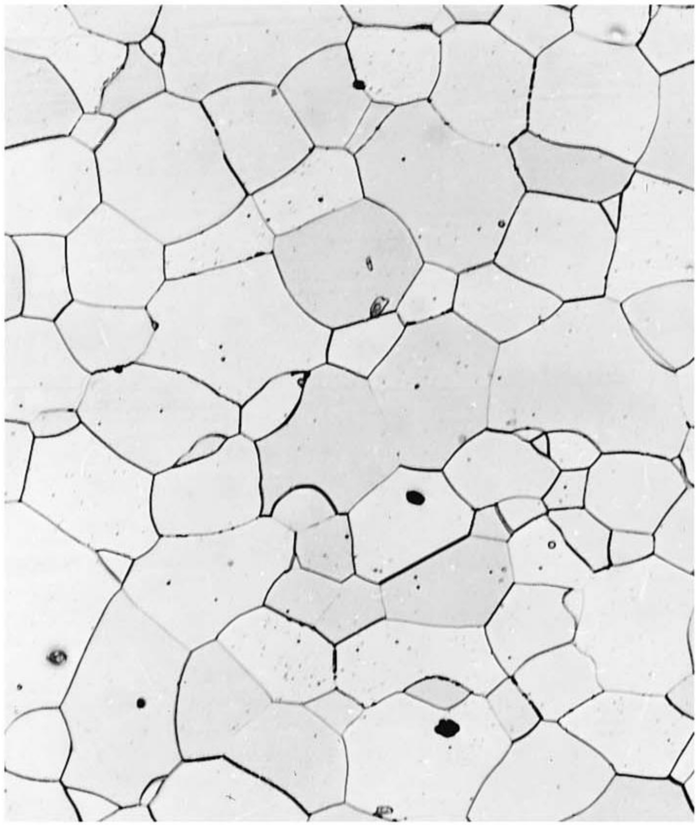
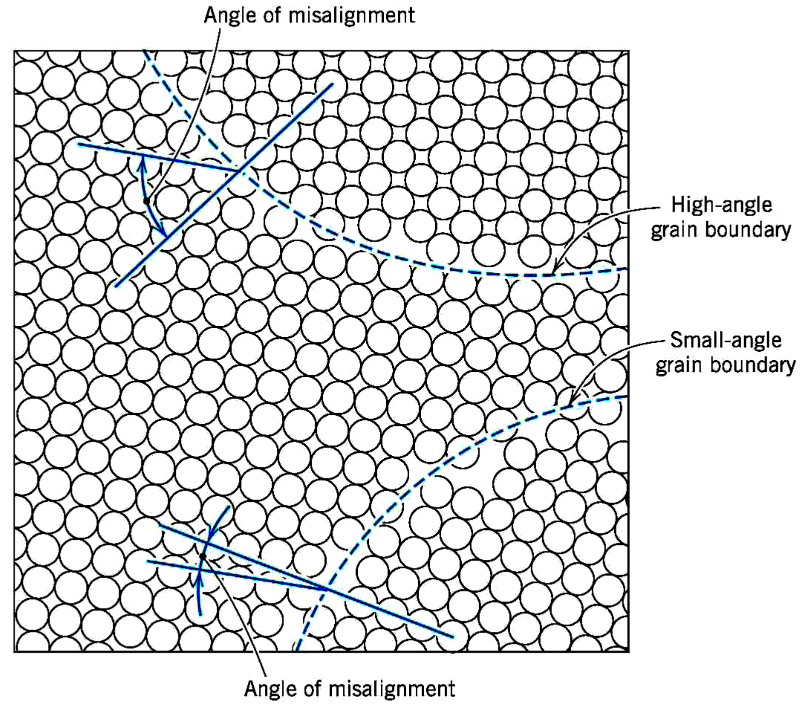
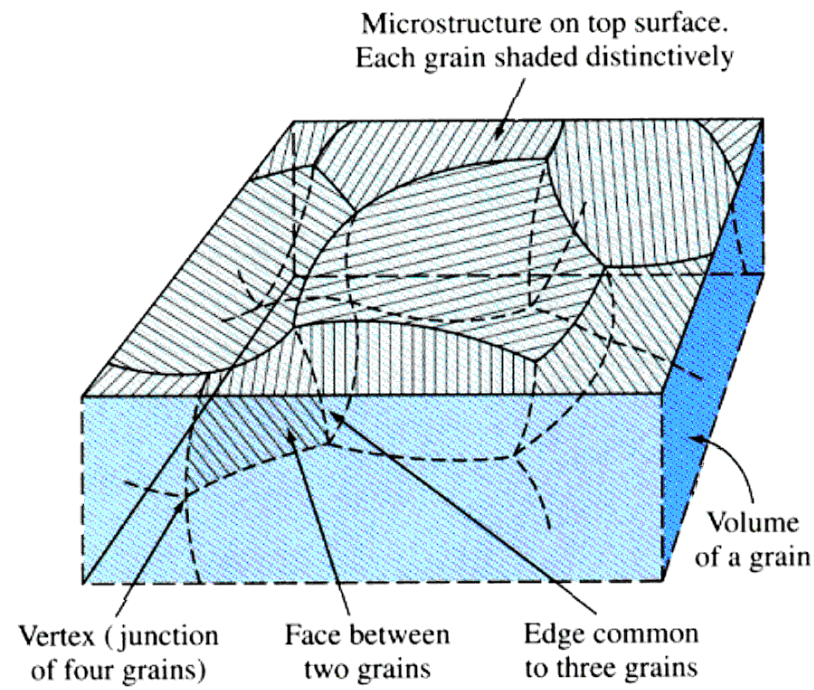


Fig. 4.12, *Callister & Rethwisch 10e.*
[From W. J. Stark, L. Mädler, M. Maciejewski, S. E. Pratsinis, and A. Baiker, “Flame Synthesis of Nanocrystalline Ceria/Zirconia: Effect of Carrier Liquid,” Chem. Comm., 588–589 (2003). Reproduced by permission of The Royal Society of Chemistry.]

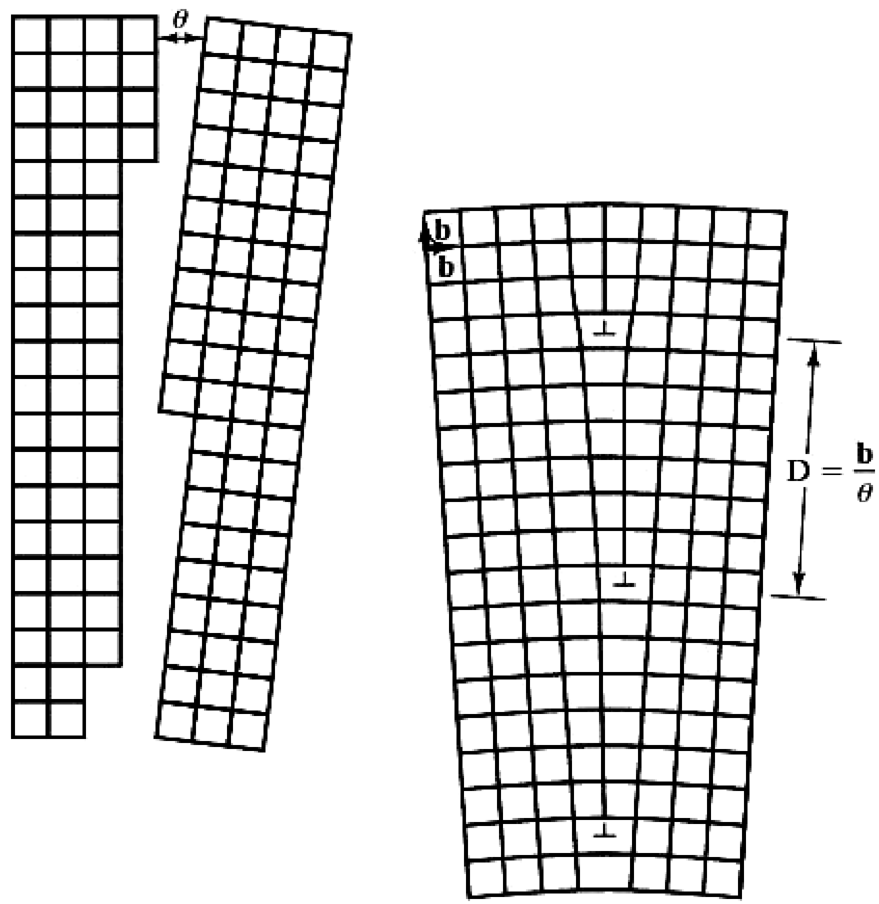
Grain Boundary





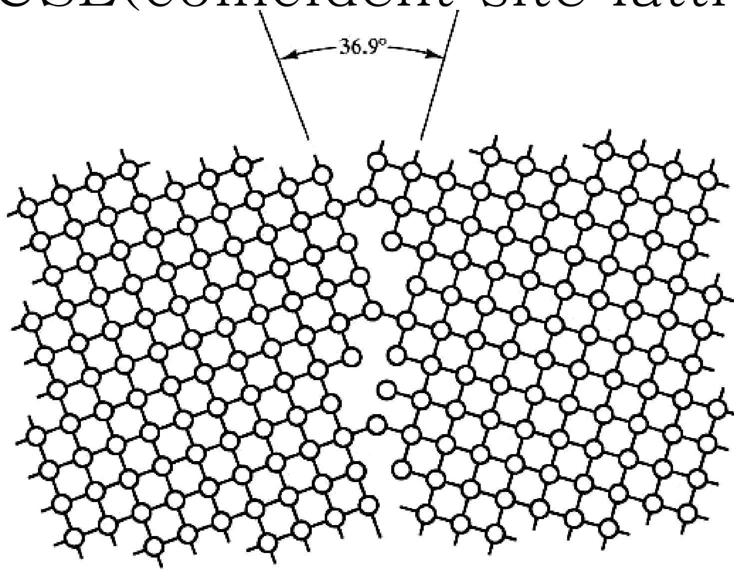


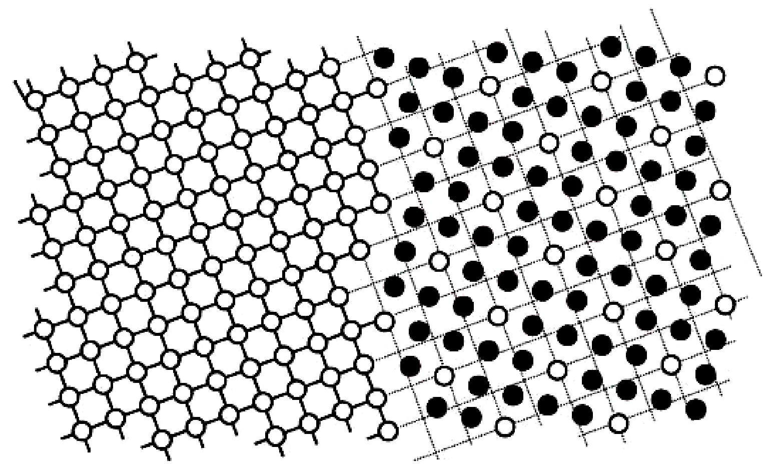
Low Angle Grain Boundary

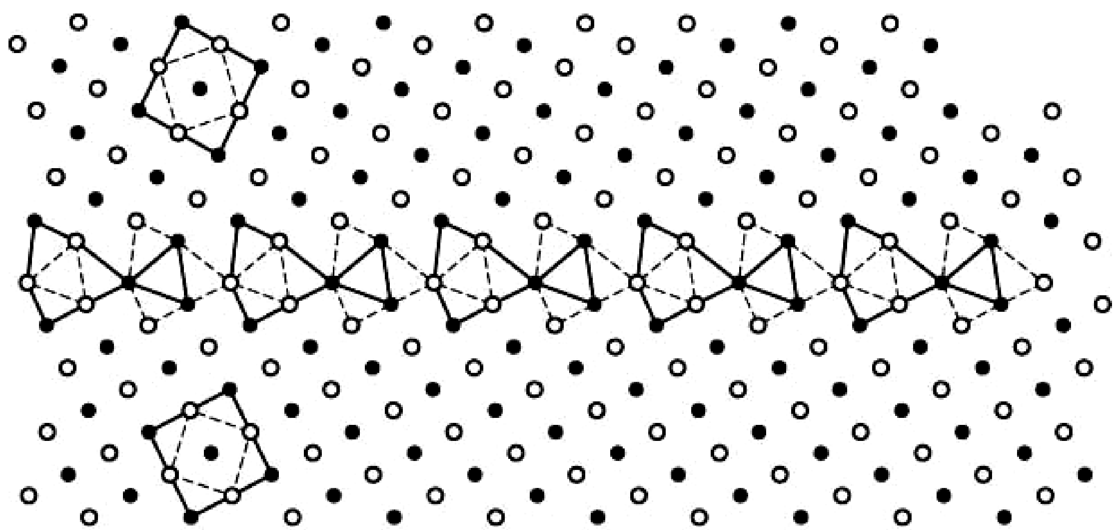


High Angle Grain Boundary

- CSL(coincident site lattice)- Σ5 boundary

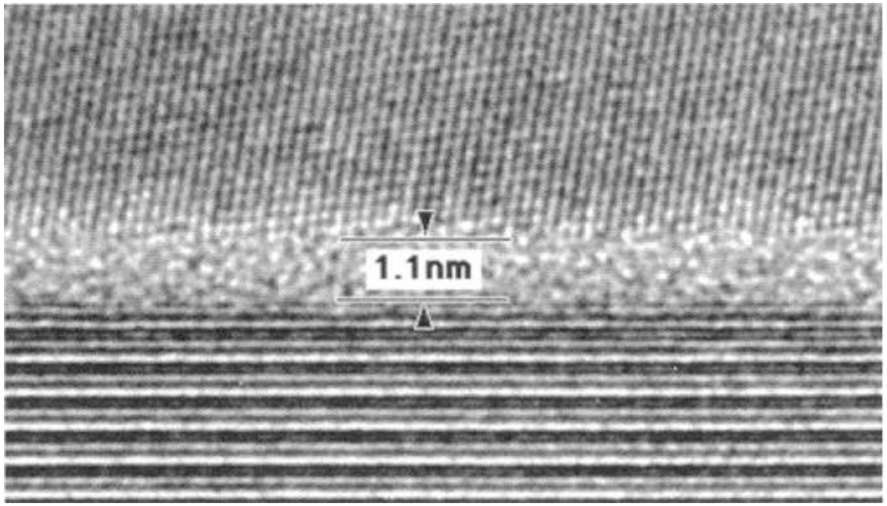




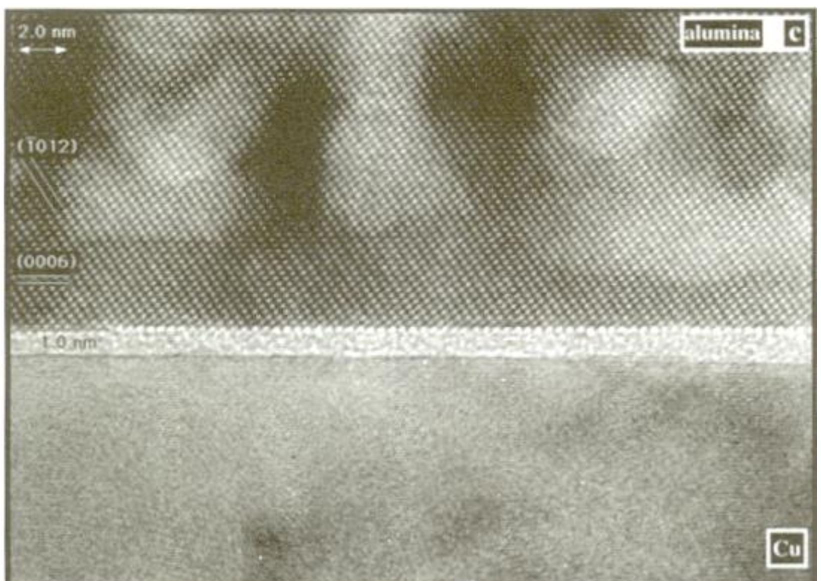


Σ5 boundary
for an FCC metal

Grain Boundary

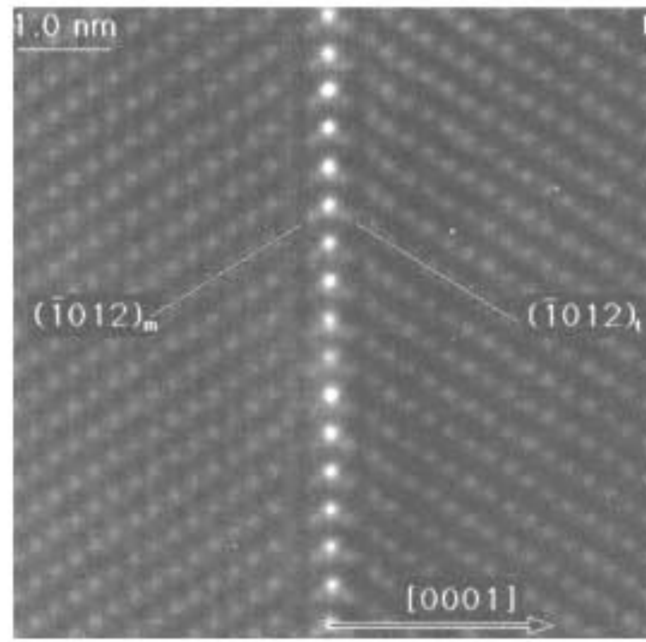


amorphous glassy In Si_3N_4

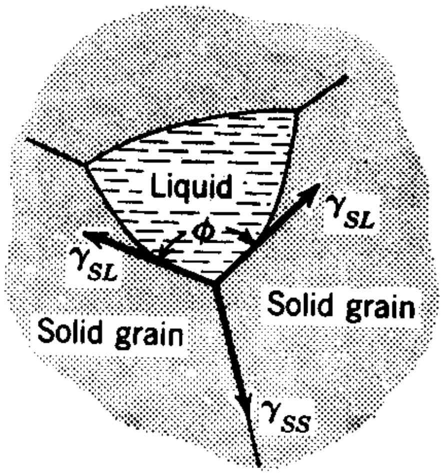


Si-Ca glass in alumina

Ca segregation

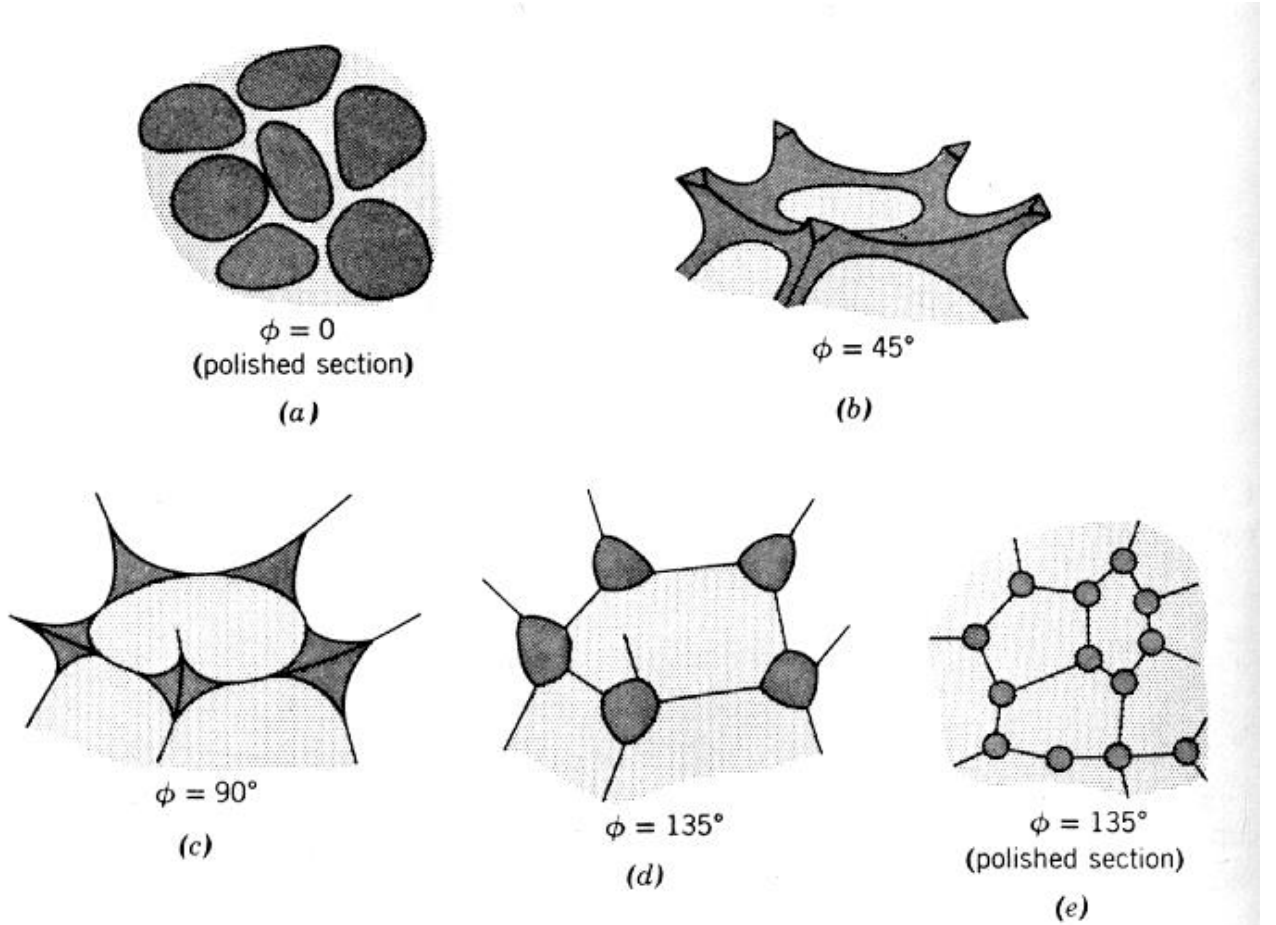


Grain Boundary

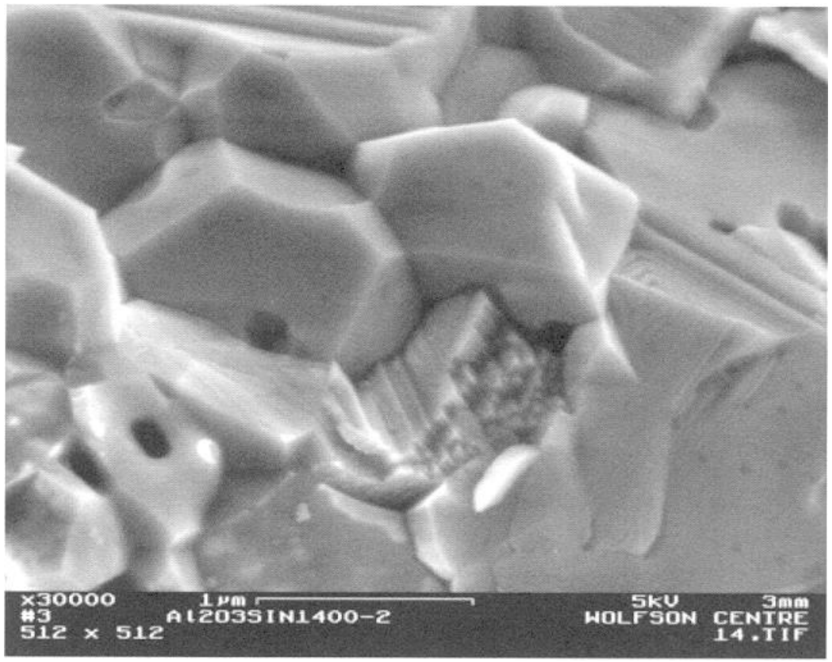


$$\gamma_{SS}=2\gamma_{SL}\cos\frac{\phi}{2}$$

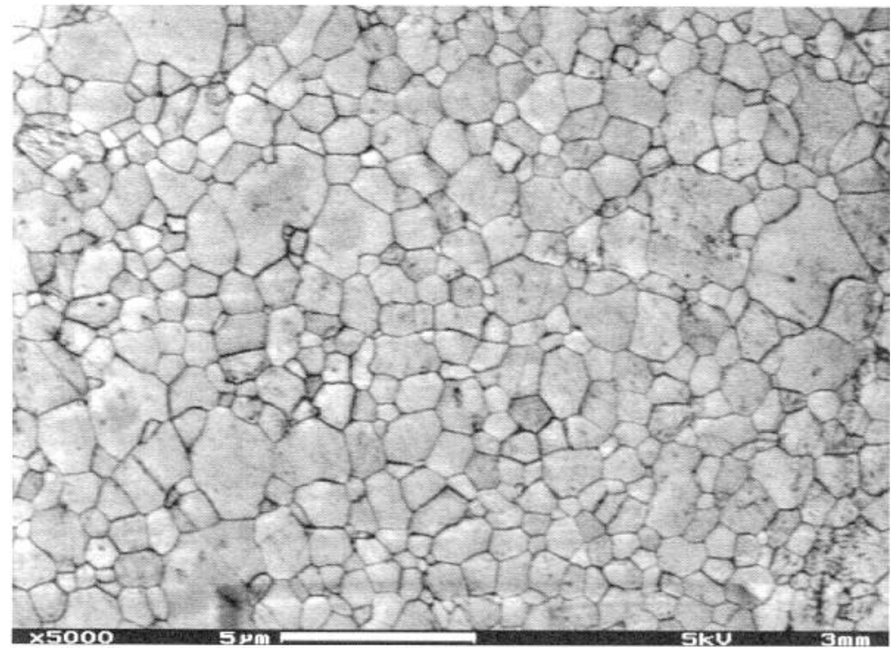
ϕ: dihedral angle



Observation of Grain Boundary



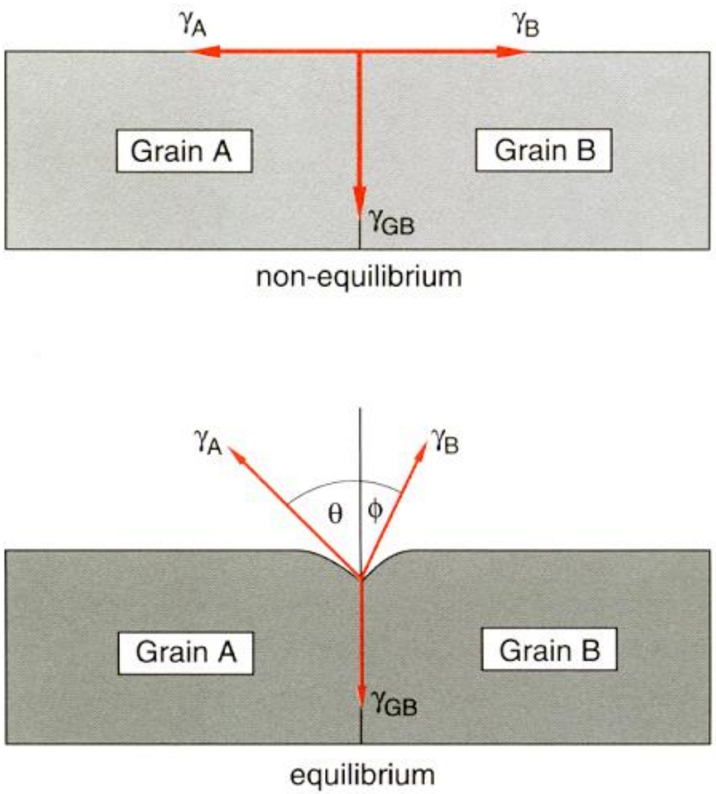
fracture surface of alumina

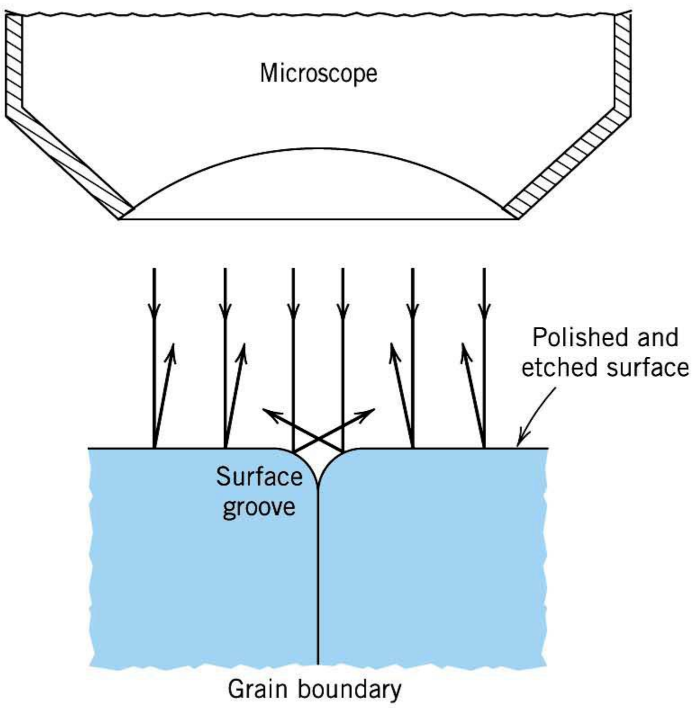


thermally etched alumina

Observation of Grain Boundary

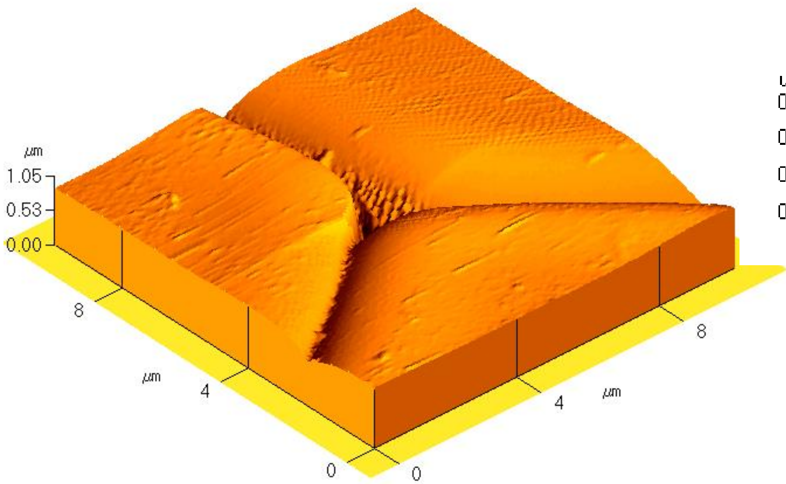
- etching- chemical
  thermal- groove

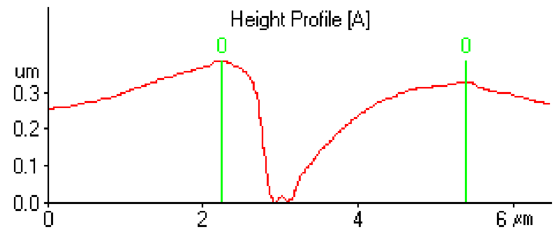


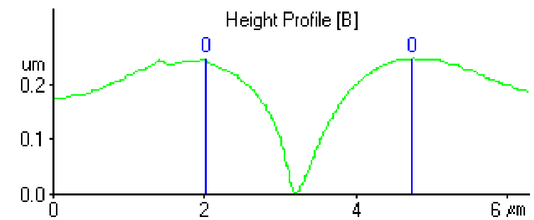


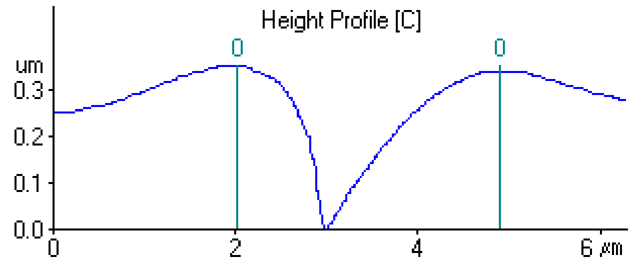
Thermal Grooving

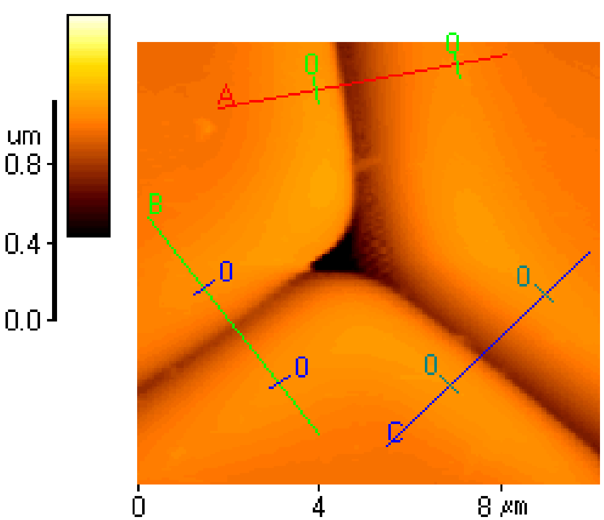
- alumina





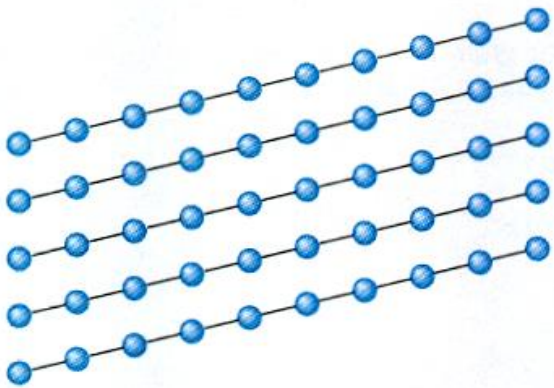




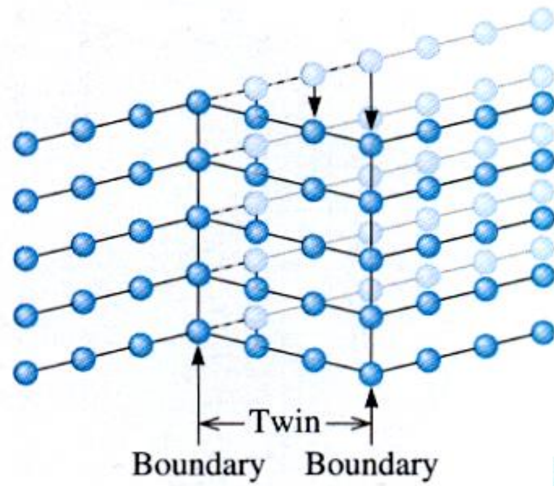


Line	Height	Distance	Angle
[A]	0: 581 Å	0: 3.16 um	0: 1.1 °
[B]	0: 60.5 Å	0: 2.72 um	0: 0.1 °
[C]	0: 124 Å	0: 2.87 um	0: 0.2 °

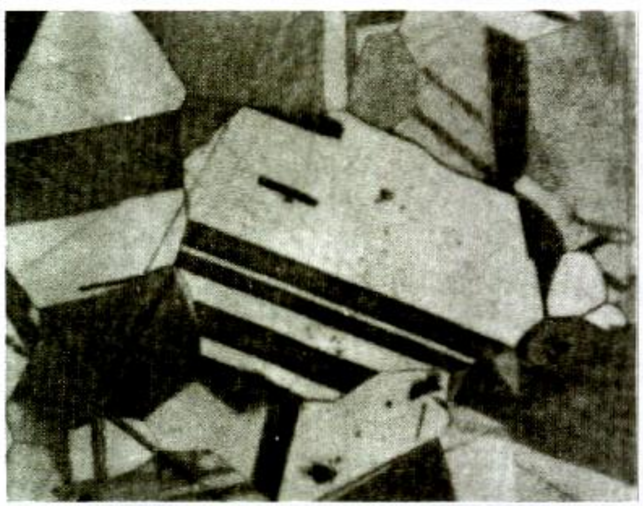
Twin Boundary



(a)

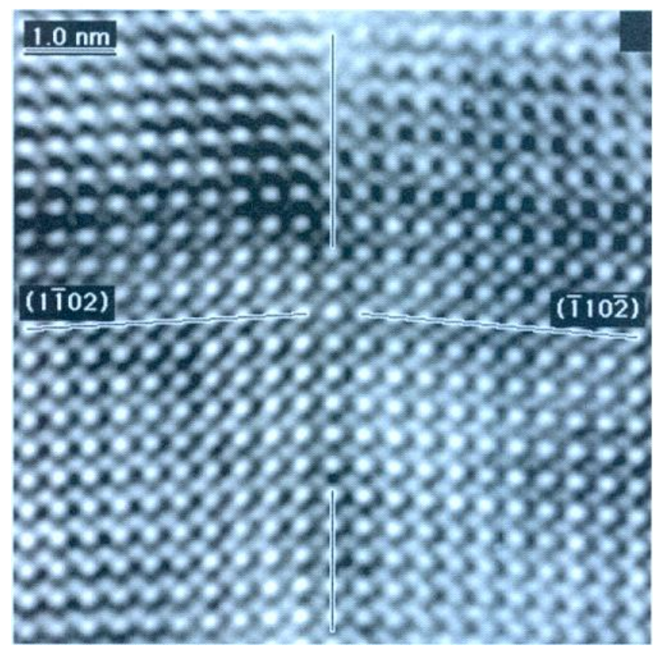


(b)



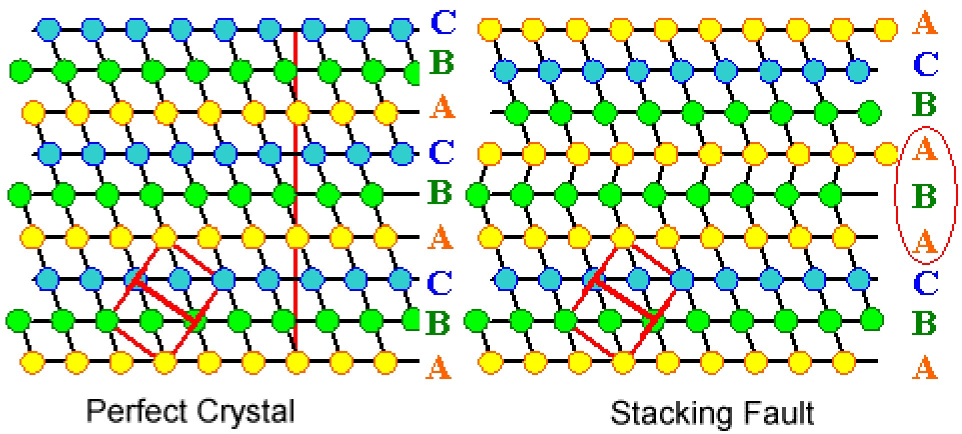
(c)

Figure 4-20 Application of a stress to the perfect crystal (a) may cause a displacement of the atoms, (b) causing the formation of a twin. Note that the crystal has deformed as a result of twinning. (c) A micrograph of twins within a grain of brass (×250).

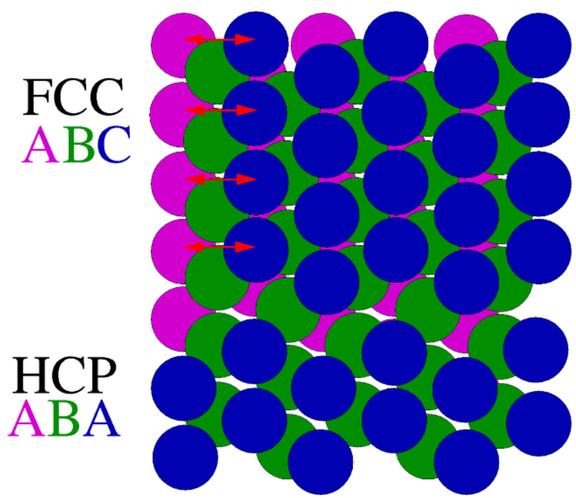


rhombohedral twin in alumina

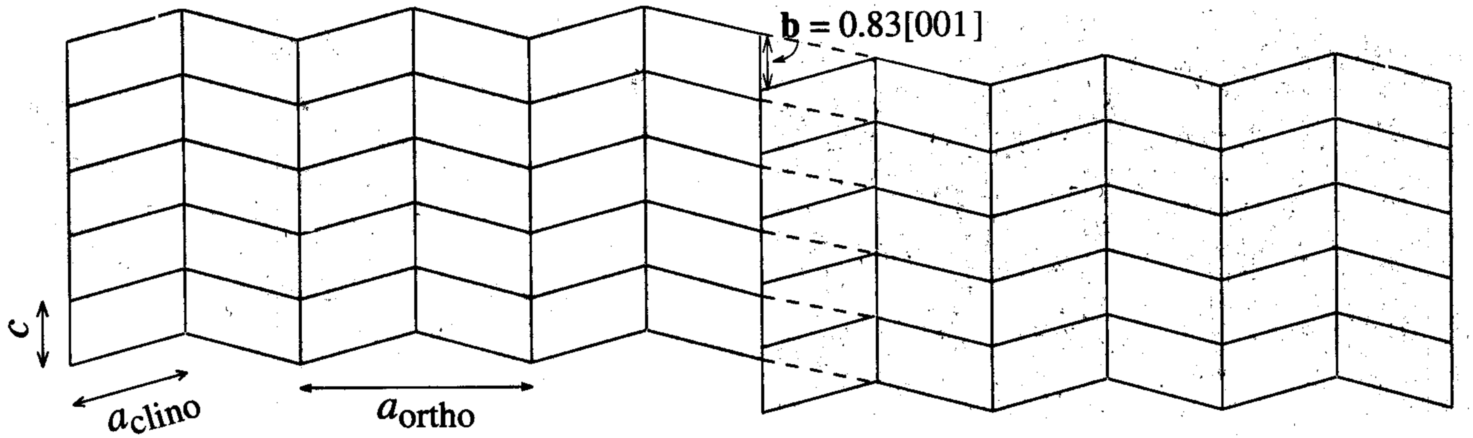
Stacking Fault

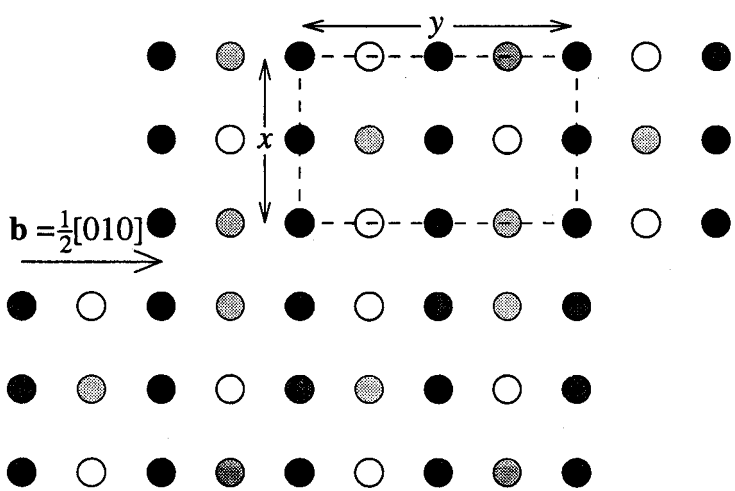


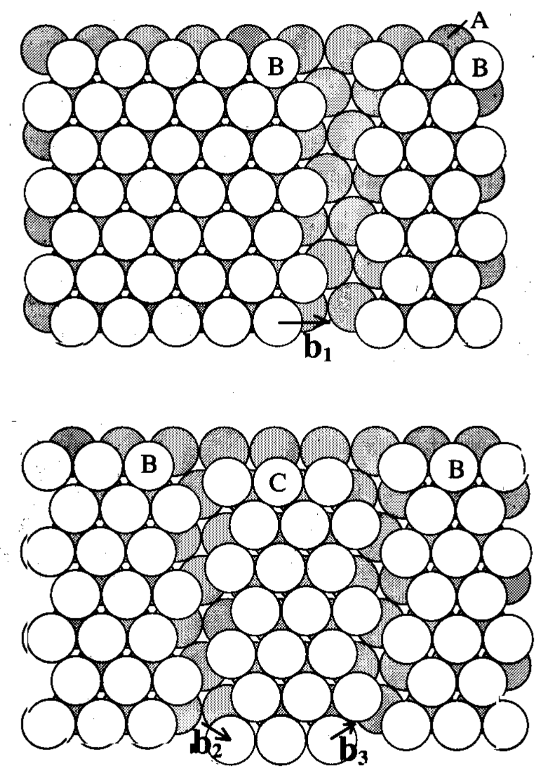
Perfect and faulted stacking sequence for an fcc crystal

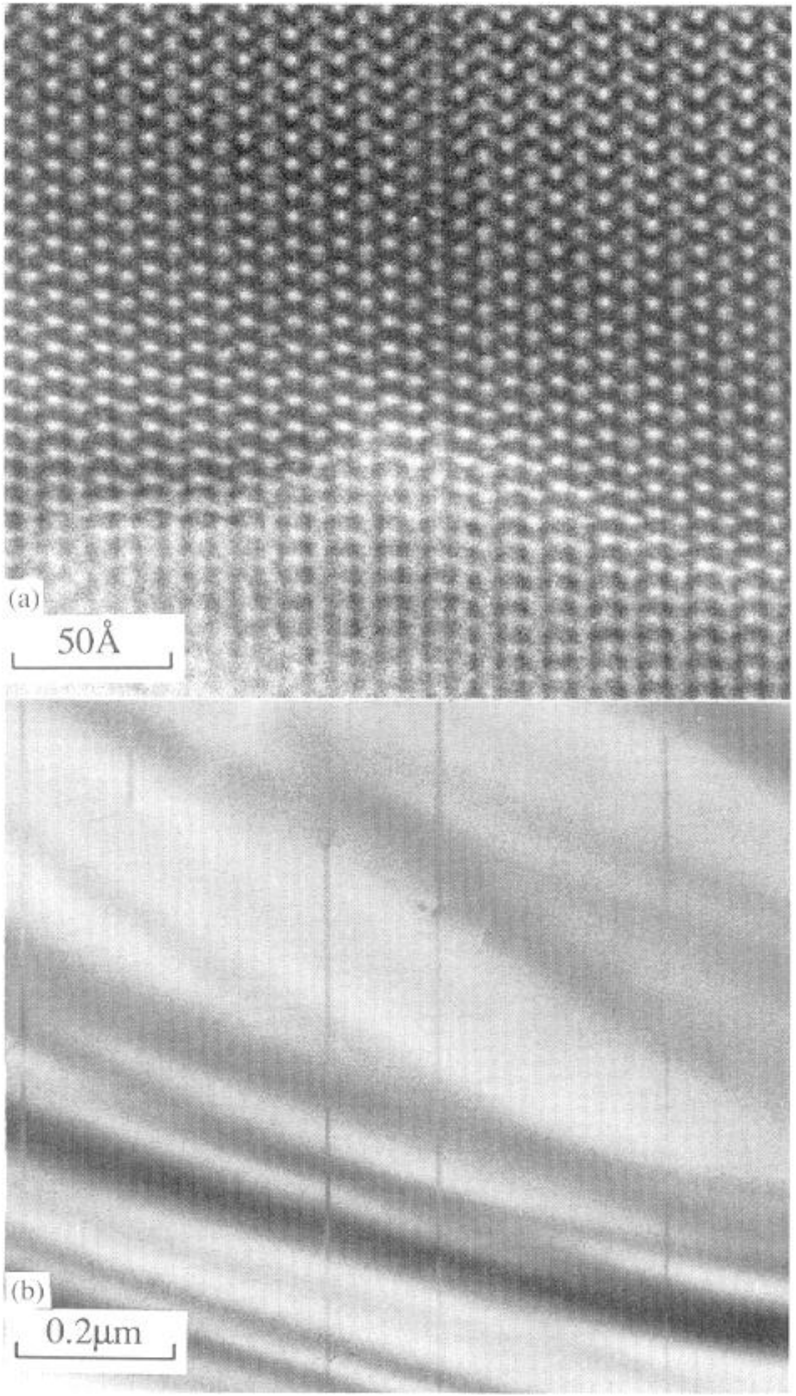


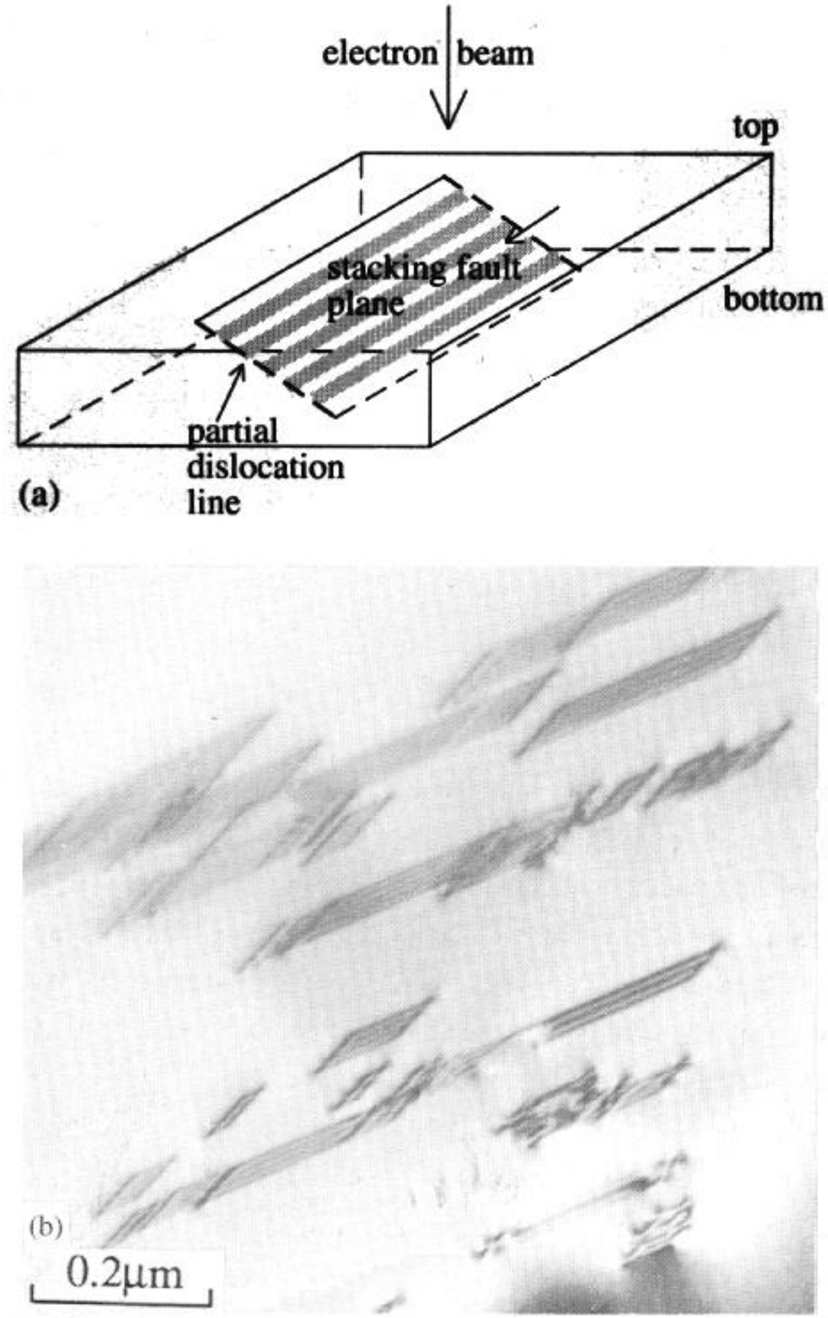
Stacking Fault








(a)
50Å
(b)
0.2μm


electron beam
top
stacking fault plane
bottom
partial dislocation line
(a)
(b)
0.2μm

Domain Boundary

- domain- a small region of the material in which the direction of electric polarization or magnetization remains the same

ex) ferromagnets (Fe, Co, Ni) ferroelectric (PZT, $BaTiO_3$)

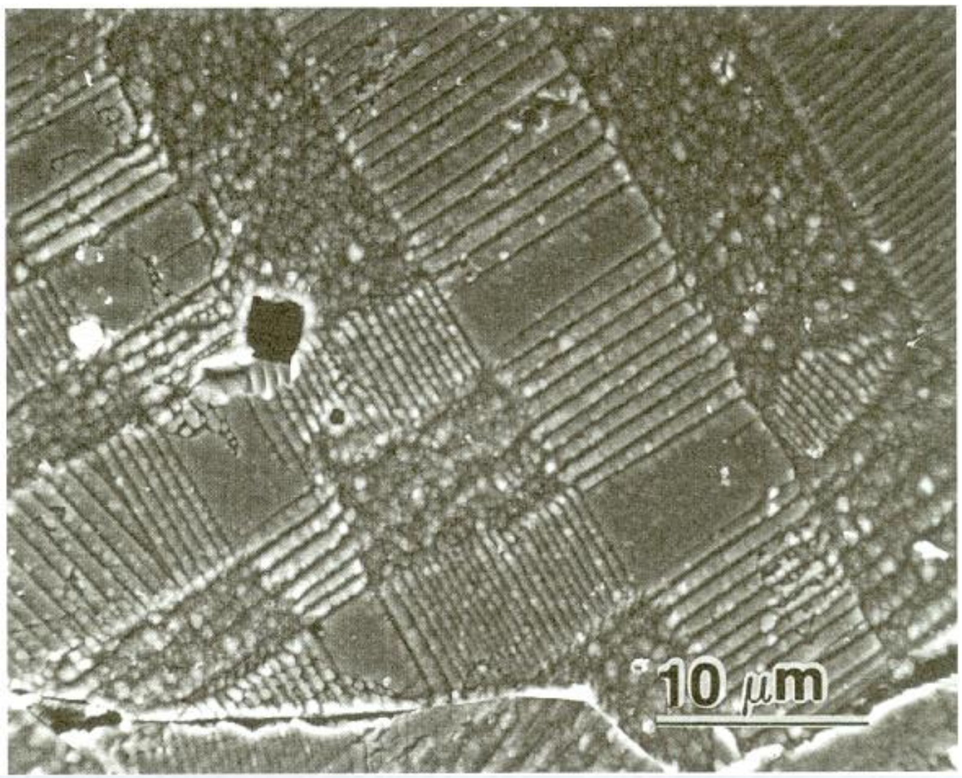


Figure 4-21 Domains in ferroelectric barium titanate. (*Courtesy of Dr. Rodney Roseman, University of Cincinnati.*) Similar domain structures occur in ferromagnetic and ferrimagnetic materials.