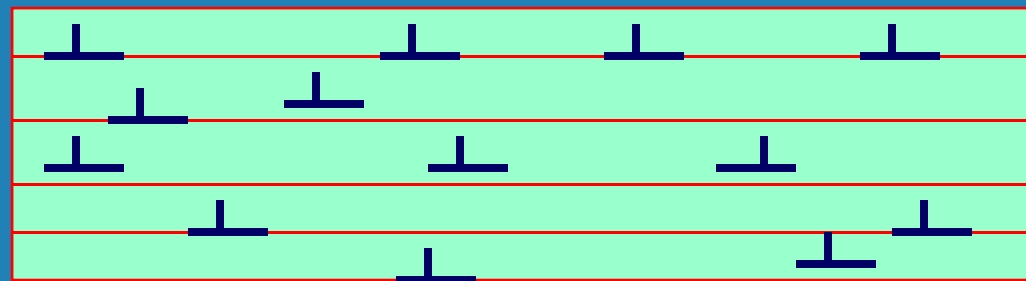




Cold work, recovery, recrystallization

Example: Single crystal

State I: Annealed metal



$\rho_{\perp} = 10^6/\text{cm}^2$ Fairly strong and ductile

Low internal energy: stable

Cold worked

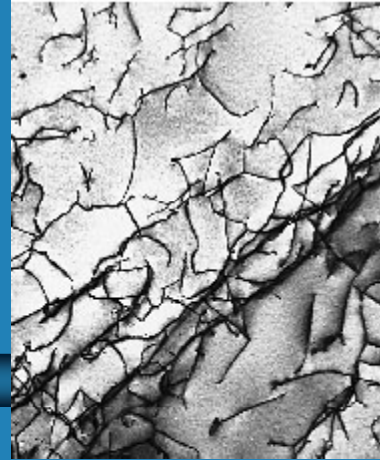
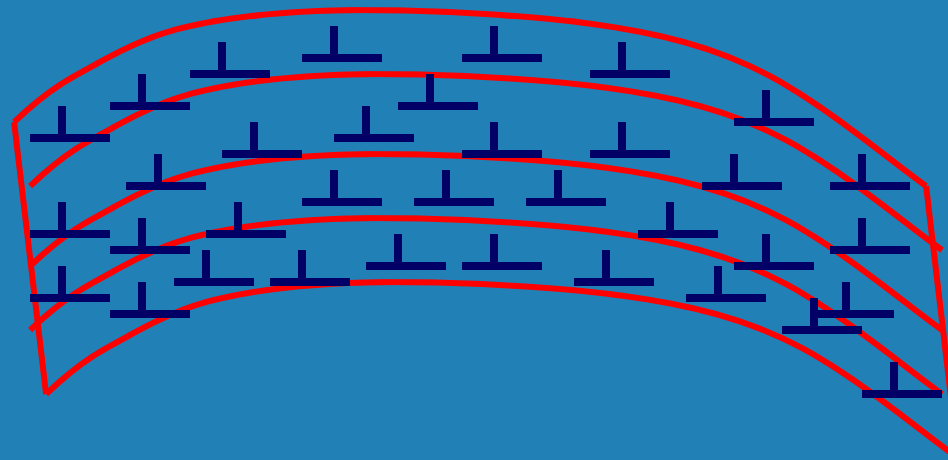


FIGURE 4.6 A transmission electron micrograph of a titanium alloy in which the dark lines are dislocations. 51,450 \times . (Courtesy of M. R. Plichta, Michigan Technological University.)

State II: Cold worked metal



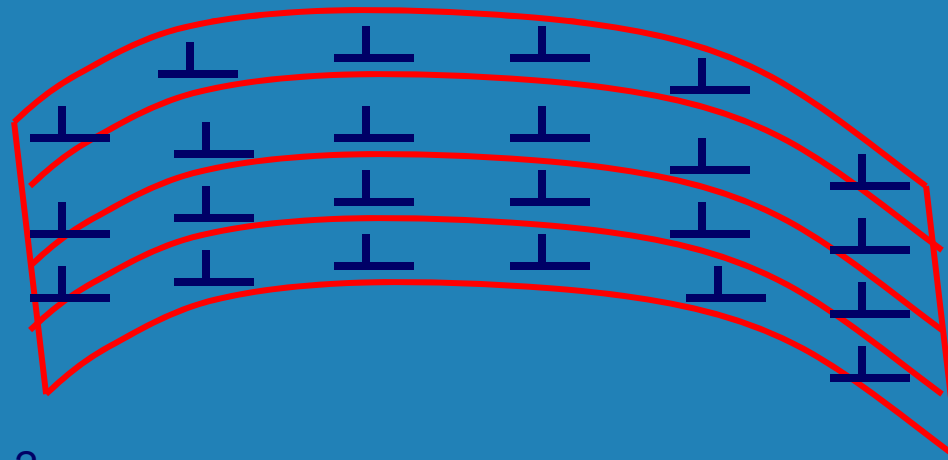
$$\rho_{\perp} = 10^{10-12}/\text{cm}^2$$

Very strong and brittle

High internal energy: not very stable

Heated at $\sim 0.5 T_m$

State III: Recovered metal



$\rho_{\perp} = 10^8/\text{cm}^2$

Dislocation alignment:

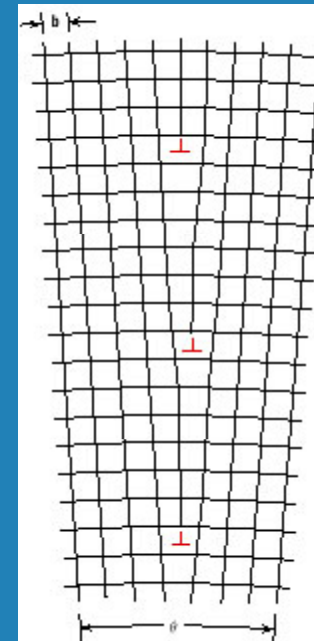
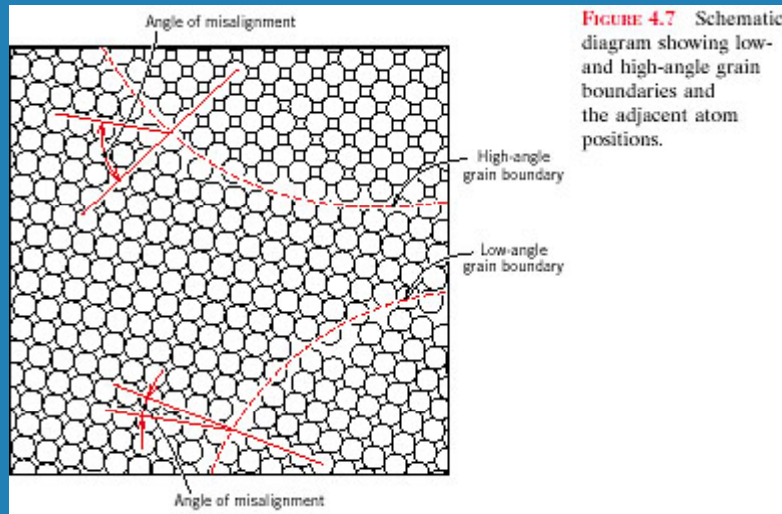
Polygonization (one recovery process)

Strong and less brittle

Compared to state II

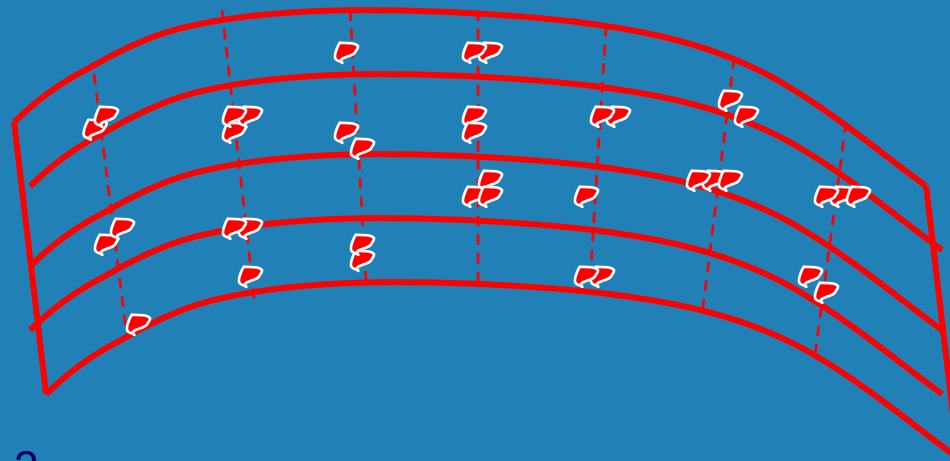
Internal energy is lowered

Recall what a grain boundary is



Heated at $\sim 0.5 T_m$

State IV: Recrystallization begins



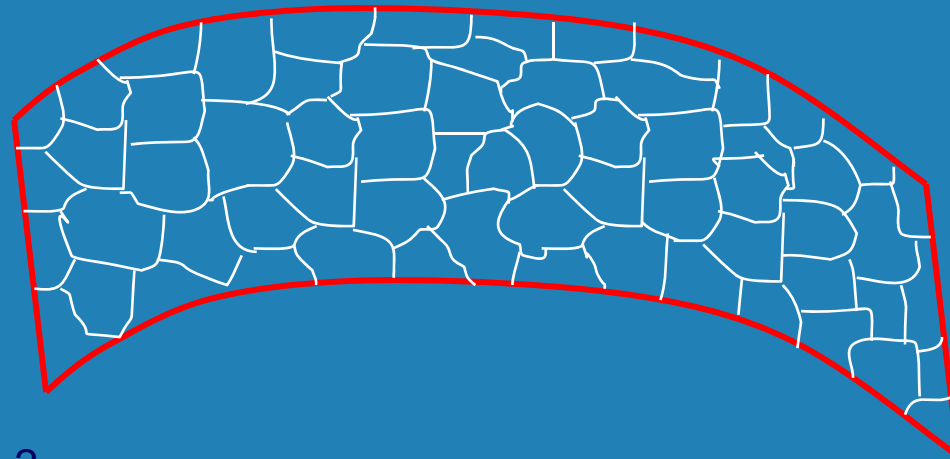
$\rho_{\perp} = 10^6/\text{cm}^2$
New strain free grains
are formed by
nucleation

Stronger than state I and ductile

Internal energy is further lowered

Heated at $\sim 0.5 T_m$

State V: Recrystallization complete



$\rho_{\perp} = 10^6/\text{cm}^2$
Recrystallized

Stronger than state I and ductile



In summary

- ∞ We started with a single crystal and ended with a polycrystal : grain refinement
- ∞ The driving force for this process is decrease in internal energy

For a polycrystals (in real life)



FIGURE 7.21 Photomicrographs showing several stages of the recrystallization and grain growth of brass. (a) Cold-worked (33%CW) grain structure. (b) Initial stage of recrystallization after heating 3 s at 580°C (1075°F); the very small grains are those that have recrystallized. (c) Partial replacement of cold-worked grains by recrystallized ones (4 s at 580°C). (d) Complete recrystallization (8 s at 580°C). (e) Grain growth after 15 min at 580°C. (f) Grain growth after 10 min at 700°C (1290°F). All photomicrographs 75 \times . (Photomicrographs courtesy of J. E. Burke, General Electric Company.)

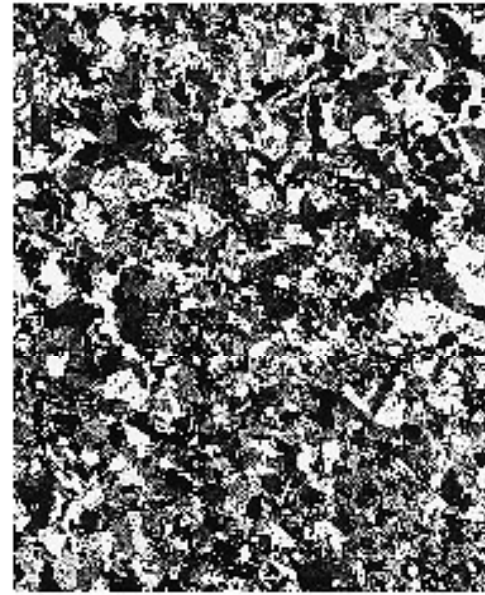
Cold worked

Initial recrystallization

FIGURE 7.21
(continued)



(c)



(d)



(e)



(f)

Recrystallized

Grain growth

Some facts

- ∞ Without a minimum amount of cold work (5-15%), there is no recrystallization
- ∞ After the metal is completely recrystallized, grain growth occurs
- ∞ Grain growth law at a constant temperature

$$D_i^2 - D_0^2 = Kt$$

D_i = final grain size

D_0 = initial grain size

t = time