Class 2024

HW1 Solution

1.(30 points)

- Low temperature region: impurity scattering dominates (5) -- dominating scattering

  The carrier velocity increases with the temperature increases, which have enough energy decrease the effect of impurity. Less collisions with impurity decrease the scattering cross-section area which lead to higher mobility. (5) -- explanation

  The mobility increases in proportion to T ➔ $\mu \propto T^{\frac{3}{2}}$ (5) – relation

$$n_s\ independent\ of\ temperature\ (fixed\ impurity\ concentration)$$

$$As\ v_d \uparrow, \sigma \downarrow, kinetic\ energy \leftrightarrow potential\ energy$$

$$v_d{}^2 \propto \frac{1}{r} \propto \frac{1}{\sigma^{\frac{1}{2}}} \rightarrow \frac{1}{\sigma} \propto v_d{}^4 \propto T^2$$

$$\mu \propto \frac{l}{v_d} = \frac{1}{\sigma\ n_s v_d} \propto \frac{T^2}{T^{\frac{1}{2}}} \propto T^{\frac{3}{2}}$$

- High temperature region: lattice scattering dominates (5) dominating scattering

  The thermal vibration of the lattice is increase with the temperature. Phonons are vibrations in the material which become more and cause more collisions with carriers. The increasing of scattering decreases the carrier mobility. (5) -- explanation

  The mobility decreases in proportion to T ➔ $\mu \propto T^{-\frac{3}{2}}$ (5) – relation

$$\mu \propto \tau = \frac{l}{v_d}\ (\tau{:}\ relaxation\ time\ between\ two\ collisions, l{:}\ mean\ free\ path)$$

$$l = \frac{1}{\sigma\ n_s} (\sigma{:}\ scattering\ cross\ section, n_s{:}\ scattering\ center\ concentration)$$

$$n_s \propto T, \frac{1}{2}mv^2 = \frac{1}{2}kT \rightarrow v_d \propto T^{\frac{1}{2}}$$

$$\mu \propto \frac{l}{v_d} \propto \frac{\frac{1}{T}}{T^{\frac{1}{2}}} \propto T^{\frac{-3}{2}}$$

2.(30 points) Explanations + Properties in each point

Take Fe-C phase diagram as example

Heating: As the temperature continues to rise, ferrite transforms into austenite, increasing the solubility of carbon. (4) At this stage, the strength and hardness decrease, while ductility improves, allowing the release of residual stress. (4)

Cooling: Based on the cooling rate, it can be classified into rapid cooling and slow cooling. (2)

- Rapid cooling: Inhibits grain growth, resulting in smaller grains, higher strength and hardness, but lower ductility. Under rapid cooling conditions, a Martensite phase will form. (4)
- Slow cooling: Grains have enough time to grow, leading to larger grains, reduced strength and hardness, but improved ductility. Austenite is slow cooled through the eutectoid temperature (which is about 727°C for plain carbon steels) and this transformation produces pearlite (consisting of layers made up of ferrite and cementite). (4)

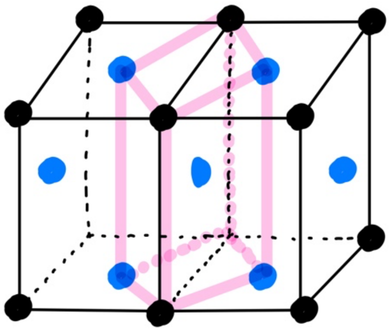
Forging: By applying external force to induce plastic deformation in the material (2), the internal grains become smaller (2), which increases strength and hardness, but also increases residual stress. (4)

Carburization: Heating the metal in a carbon-rich environment to increase its carbon content. By introducing additional carbon atoms through carburizing, the surface strength is significantly enhanced while maintaining the original ductility of the core. (4)

3.(25 points)

FCT (face centered tetragonal) ➜BCT (body centered tetragonal) (5) -- Transformation

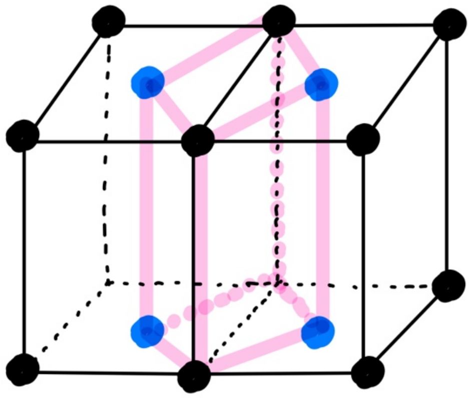
BCT is a smaller/simpler unit cell (2 atoms per unit cell) compares to FCT (4 atoms per unit cell) (2.5) -- explanation



(5) -- graphic illustration

BCT (base centered tetragonal) ➜ST (simple tetragonal) (5) -- Transformation

ST is a smaller/simpler unit cell (1 atoms per unit cell) compares to BCT (2 atoms per unit cell) (2.5) -- explanation



(5) -- graphic illustration