|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **lThe 7 lattice systems** | **The 14 Bravais lattices** | | | |
| Triclinic | [Triclinic](http://en.wikipedia.org/wiki/File:Triclinic.svg) |  |  |  |
| Monoclinic | simple | base-centered |  |  |
| [Monoclinic, simple](http://en.wikipedia.org/wiki/File:Monoclinic.svg) | [Monoclinic, centred](http://en.wikipedia.org/wiki/File:Monoclinic-base-centered.svg) |  |  |
| Orthorhombic | simple | base-centered | body-centered | face-centered |
| [Orthohombic, simple](http://en.wikipedia.org/wiki/File:Orthorhombic.svg) | [Orthohombic, base-centred](http://en.wikipedia.org/wiki/File:Orthorhombic-base-centered.svg) | [Orthohombic, body-centred](http://en.wikipedia.org/wiki/File:Orthorhombic-body-centered.svg) | [Orthohombic, face-centred](http://en.wikipedia.org/wiki/File:Orthorhombic-face-centered.svg) |
| Tetragonal | simple |  | body-centered |  |
| [Tetragonal, simple](http://en.wikipedia.org/wiki/File:Tetragonal.svg) |  | [Tetragonal, body-centred](http://en.wikipedia.org/wiki/File:Tetragonal-body-centered.svg) |  |
| Rhombohedral | [Rhombohedral](http://en.wikipedia.org/wiki/File:Rhombohedral.svg) |  |  |  |
| Hexagonal | [Hexagonal](http://en.wikipedia.org/wiki/File:Hexagonal_lattice.svg) |  |  |  |
| Cubic | simple |  | body-centered | face-centered |
| [Cubic, simple](http://en.wikipedia.org/wiki/File:Cubic.svg) | [Cubic, body-centred](http://en.wikipedia.org/wiki/File:Cubic-body-centered.svg) | [Cubic, face-centred](http://en.wikipedia.org/wiki/File:Cubic-face-centered.svg) |

**Lattice**- an array of points in space (a mathematical construction) with identical environment

**Motif**- assignment of atoms or ions to each and every lattice point in exactly the same way

|  |  |
| --- | --- |
|  | **Body-centered cubic (bcc)**  CN = 8  Unit cell contains |
|  | **Face-centered cubic (fcc)**  CN = 12  Unit cell contains |
| **Hexagonal closed packed (hcp)**  ABCABC stacking sequence | |

Density =

hkl denotes a lattice position, a point on the lattice

[hkl] denotes a lattice direction, the vector that connects the origin to hkl position.

Direction [uvw] and [u’v’w’], the angle between them is

<hkl> denotes the family of directions

|  |  |
| --- | --- |
| http://upload.wikimedia.org/wikipedia/commons/thumb/d/d5/Miller_Indices_Felix_Kling.svg/300px-Miller_Indices_Felix_Kling.svg.png | (hkl) denotes a plane, the integer reciprocal of the intercepts to each planes (xyz). If the plane goes through the origin, select an equivalent plane or move the origin.  Planes and their negatives are equivalent.  In the cubic system, a plane and a direction with the same indices are orthogonal.  {hkl} denotes the set of all planes that are equivalent to (hkl) by the symmetry of the lattice  Planes: (hkl) becomes (hkil), where h + k = -i  Directions: [UVW] becomes uvtw  u = (2U-V)/3, v= (2V-U)/3, t = -(U+V), w = W  U = u-t, V = v-t, W = w |
| the scattering condition is established to mimic reflection from the diffracting planes, so the incident angle is equal to the diffraction angle. | |  |  |  |  | | --- | --- | --- | --- | | Crystal structure | Diffraction doesn’t occur when | Diffraction occurs when | First few peaks | | Bcc | h+k+l = odd | h+k+l = even | 110 200 211 220 310 222 | | Fcc | h,k,l both even and odd | h,k,l all even or all odd | 111 200 220 311 222 400 | | hcp | H+2k = multiple of 3  l = odd | Any other cases |  | |

**Point Defects**

|  |  |  |
| --- | --- | --- |
| http://upload.wikimedia.org/wikipedia/commons/thumb/c/c1/Nacllattice.svg/220px-Nacllattice.svg.png  Defect-free NaCl | http://upload.wikimedia.org/wikipedia/commons/thumb/0/05/Naclschottkydefect.svg/220px-Naclschottkydefect.svg.png  Schottky defect/pair (vacancy) | http://upload.wikimedia.org/wikipedia/commons/thumb/8/86/Naclfrenkeldefect.svg/220px-Naclfrenkeldefect.svg.png  Frenkel defect/pair (interstitial)  It has an extended strain field |

Vacancies in solids participate in diffusion and increase the entropy of the material. There is a collapse into the gap by all contiguous atoms, which in turn stretch their bonds to the nearest neighbors, the equivalent response to a tensile load. So the strain field is “tensile”.

The creation of a single vacancy in hcp structure requires the breaking of 6 bonds. Two isolated vacancies therefore have 12 broken bonds, but a single divacancy has only 10 broken bonds. The energy difference makes the divacancy more favorable.

|  |  |
| --- | --- |
| **Linear Defects- Dislocations (participate in plastic deformation)**  **Burger’s vector-** the displacement vector necessary to close a stepwise loop around the defect point.    If dot product of the line direction vector and the Burger’s vector = 0, they are perpendicular, then this is a edge dislocation. The slip plane can be calculated by taking the vector cross product of the dislocation line vector and Burger’s vector. The slip plane must contain the burger’s vector. Slip direction is always given by the Burger’s vector. Slip plane dot Burger’s vector must = 0 | Filled are the atoms comprising the extra half-plane. Edge dislocation and dislocation line.    Burger’s vector and burger’s circuit (must enclose the dislocation line)  finish-start-right hand (FSRH) convention |
|  | Slip doesn’t occur simultaneously everywhere across the slip plane. Yielding must occur a bit at a time till it has occurred all over the slip plane. Bonds across the slipping planes are broken and remadein succession. The line that separates the slipped and unslipped region is the dislocation. |

Cold work induces defects. And deformation is the motion of defects, or dislocation motion. The more defects there are, the harder it is for these defects to move. A cold-worked material is harder and stronger.

**Three stages of annealing**

* **Purpose:** to remove damage from cold work

1. **Recovery**

* Annihilation of point defects
* Dislocation **polyganization** (subgrain boundaries)
  + because of low temperature of the dislocations are more mobile, they tend to pile up to lower the strain energy of the system
  + the arrangement of excess dislocations into low angle tilt boundaries (misorientations of a few degrees).
  + leads to the formation of sub-grains
* Driven by reduction in strain energy

1. **Recrystallization**
   * Driven by reduction in strain energy
   * Crystallization reaction of new strain-free grains that consume the little heavily dislocated grains behind them



1. **Grain growth**

* Driven by reduction in surface energy

Strength on a microstructural scale is resistance to the nucleation and migration (slip) of dislocations. Grain boundaries act as barriers to dislocation motion by disrupting the continuity of slip planes; the more grain boundaries appearing in the path of mobile dislocations, the greater the number of impediments to their motion. Consequently, fine grained microstructures with their higher density of grain boundaries resist dislocation motion more than coarse grain microstructures.

**Diffusion phenomenon, two types – interdiffusion and self-diffusion**

|  |  |
| --- | --- |
| **Inter-diffusion** | **Self-diffusion** |
| Substitutional diffusion | Interstitial diffusion    Interstitial atoms are smaller and more mobile. More empty positions than vacancies |
| **Arrhenius equation**  Fick’s law |  |

**Volume defects**

Inclusions- MnS in steel

Dispersed particles- Al2O3 in Al

Voids and cracks

**Creep deformation**

|  |  |
| --- | --- |
| File:3StageCreep.svg | **Primary**- the strain rate is relatively high, but slows with increasing time due to work hardening.  **Secondary**- the strain rate reaches a minimum and becomes near constant, due to the balance between work hardening and annealing.  **Tertiary**- the production of dislocations is too significant. The strain rate increases exponentially because of necking.  Grain boundary sliding will be aggravated by more grain boundaries, offering a larger interfacial area over which sliding can occur. Since small grained materials have larger grain boundary area, they are more likely to suffer creep. Therefore it is more desirable to design creep-resistant ceramics having larger grains. |

**Phases and components**

**Phase**- physically distinct, homogeneous, body of matter with definable boundaries

**Component**- distinct chemical constituent form which phases are formed

**Degrees of freedom**- independent variables available to a system; if varied, cause phase changes

**Gibbs Phase Rule**, F = C – P + 2

|  |  |
| --- | --- |
| Binary isomorphous system    Solids dissolve solids  Substitutional and interstitial  Depend “in part” on Hume-Rothery rules | **Hume-Rothery rules**  Atomic size effect (<= 15% difference in atomic radii)  Structure effect (same Bravais lattice, same crystal structure)  Electronegativity effect (attraction for electrons)  Valency effect (same oxidation state)  http://upload.wikimedia.org/wikipedia/commons/thumb/8/8e/Lever_rule.svg/400px-Lever_rule.svg.png |