# Lattice Defects and Mechanical Properties of Materials (latter half)

Prof. Masaharu KATO
Department of Materials Science and Engineering
kato@materia.titech.ac.jp

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## Chapter 1　Lattice Defects and Dislocations

### 1.1　Various lattice defects in crystals

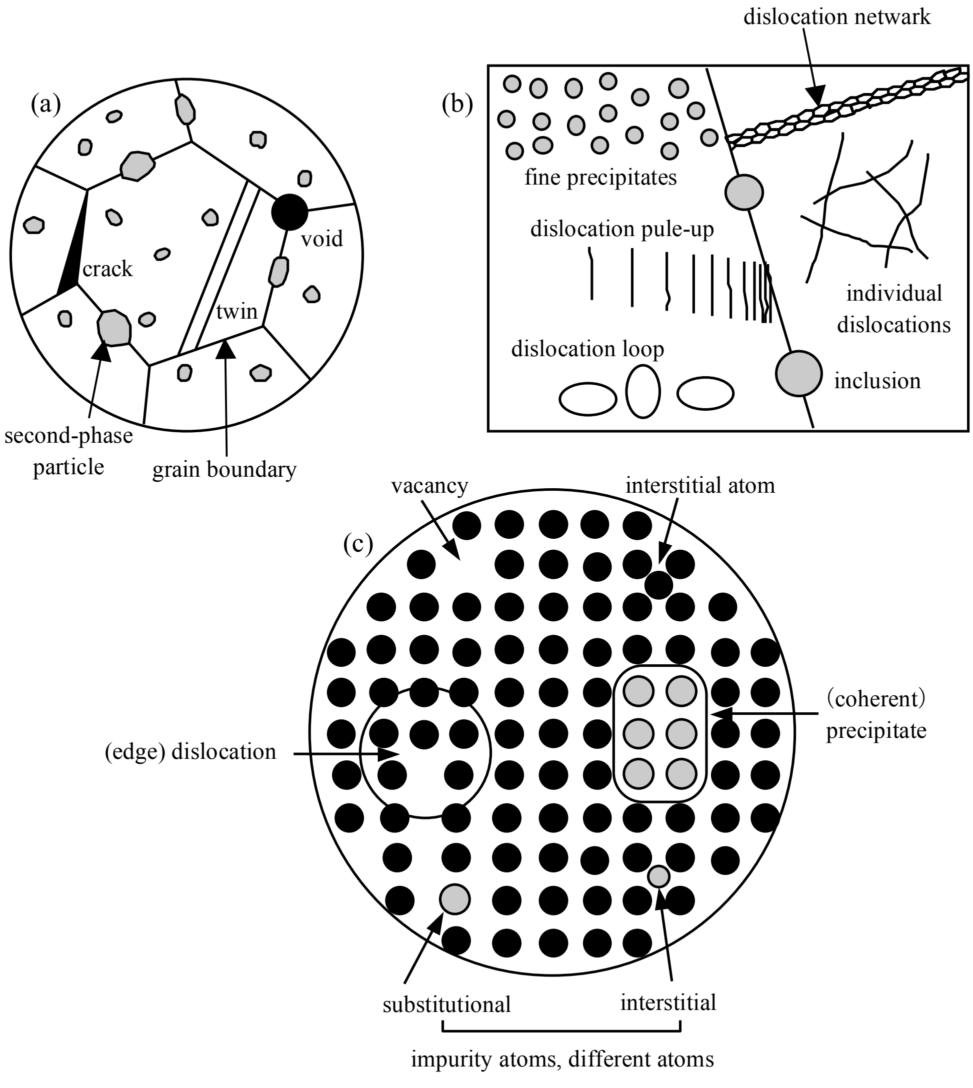


Fig. 1.1　Various defects,（a) optical microscopy（about x 50）,
(b) transmission electron microscopy（about x 50,000）,（c) atomic scale（about x 10,000,000）

・structure-sensitive properties: Young’s modulus, density, thermal expansion coefficient, etc.
・structure-insensitive properties: mechanical properties

0-D defects (point defects): vacancy, atom,
1-D defects (line defects): dislocation
2-D defects (plane defects): surface, grain boundary, domain boundary, twinning plane
3-D defects (bulk defects): $2^{nd}$-phase partilcle, void, crack

Among various lattice defects
→ Only the point defects are thermodynamically stable.

## 1.2 Elastic deformation and plastic deformation

### 1.2.1 stress-strain curve

uniaxial tensile test

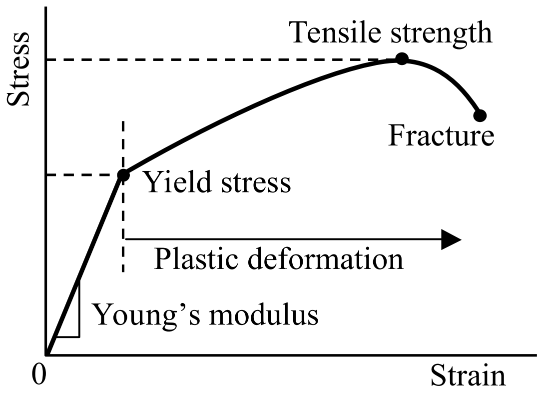


Fig. 1.2 Tensile stress-strain curve of a ductile material.

### 1.2.2 slip deformation of crystals

plastic deformation → shear deformation (slip deformation)

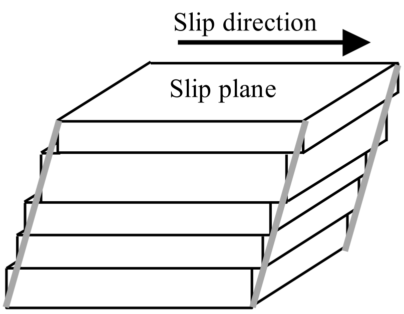


Fig. 1.3 Macroscopic plasitc deformation occurs by combination of slip.

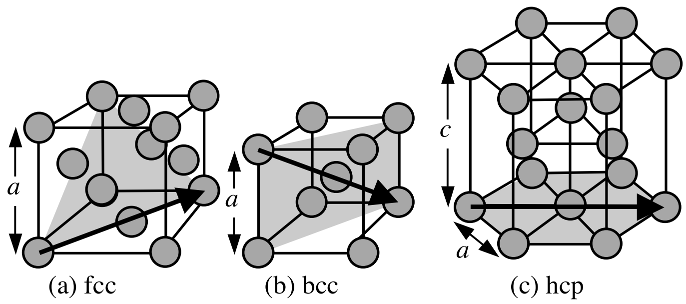


Fig. 1.4 Slip plane and slip direction for three crystals

Table 1.1 Typical slip systems

| Crystal | Slip plane | Slip direction |
|---|---|---|
| fcc | {111} | <110> |
| bcc | {110} | <111> |
| hcp | (0001) | $\langle 11\bar{2}0 \rangle$ |

slip plane + slip direction = slip system

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**Problem 1.1**
How many {111}<110> slip systems does an fcc crystal have?

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Schmid factor
to tell the most preferable slip plane (primary slip plane) among crystallographically equivalent slip systems

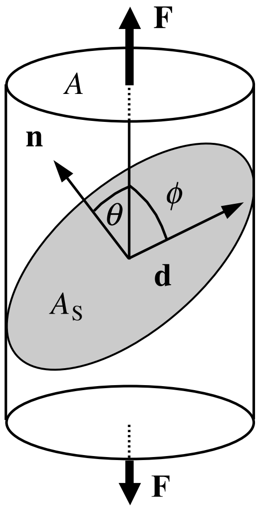


Fig. 1.5 Tensile deformation of a single crystal

$$\left\{ \begin{array}{l} \mathbf{F} : \text{tensile force}, \quad A : \text{specimen cross section}, \\ A_s : \text{slip plane area}, \quad \mathbf{n} : \text{slip plane normal}, \\ \theta : \text{angle between slip plane normal and force}, \\ \phi : \text{angle between slip direction } \mathbf{d} \text{ and force} \end{array} \right.$$

tensile stress $\sigma = F / A$
slip plane area $A_S = A / \cos\theta$
resolved shear stress

$$\tau = (F \cos\phi) / A_S = (F / A)\cos\theta\cos\phi = \sigma\cos\theta\cos\phi \qquad (1.1)$$

Schmid factor $\boxed{S_F = \cos\theta\cos\phi}$ (1.2)

critical resolved shear stress (CRSS)
The resolved shear stress above which plastic deformation of the crystal occurs.

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**Problem 1.2**
What is the maximum value of the Schmid factor?

**Problem 1.3**
For cubic crystals, it is known that the $(hkl)$ plane is perpendicular to the $[hkl]$ direction. Knowing this and using the dot product calculation of vectors, calculate the Schmid factor value for the $(1\bar{1}1)[011]$ slip system when an fcc single crystal is deformed in tension along the [213] direction.

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### 1.2.3 slip and dislocations

It is known theoretically that when slip occurs as if both the upper and lower halves of the crystal are rigid, the required CRSS is about $10^3$ to $10^4$ times larger than that observed experimentallly.

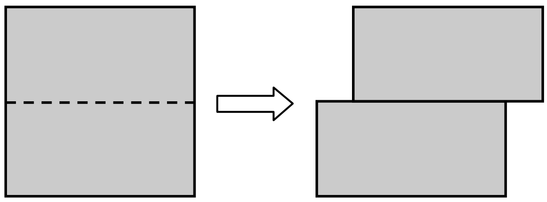

Fig. 1.6 Slip deformation as if crystals are rigid.

Taylor, Orowan, Polanyi (1934) → Dislocations
(Yamaguchi (1929))

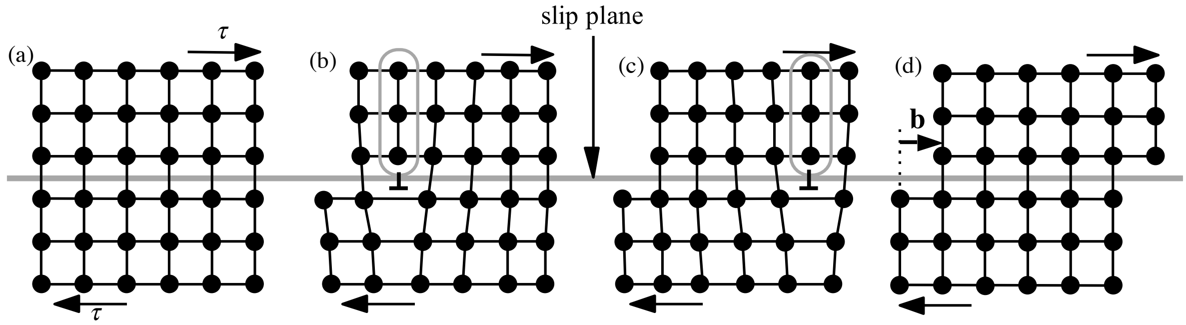


Fig.1.7 Motion of a dislocation under the shear stress $\tau$.

Dislocations → line defects
**b** : a vector expressing the amount of slip (shear) created by the motion of a dislocation

A dislocation (line) lies on a slip plane and is defined as a boundary between slipped and not yet slipped regions of the slip plane.

Dislocation density

$$\boxed{\rho \equiv \text{(total dislocation length in a unit volume)} \quad [\mathrm{m}^{-2}]} \qquad (1.3)$$

Consider a crystal of height $h$, width $w$ and thickness $l$.
When $n$ dislocations move from left to right as much as $w$, the amount of slip is $nb$. Therefore, the (engineering) shear strain $\gamma$ becomes $\gamma = nb/h$.
When $n$ dislocations move as much as $x$ instead, the resultant (engineering) shear strain will be

$\gamma = nb/h \times (x/w) = nbx/(hw)$.

From Eq. (1.2), we have

$\rho = nl / hwl = n / hw$ .

Finallly, we have

$$\boxed{\gamma = \rho b x} \qquad (1.4)$$

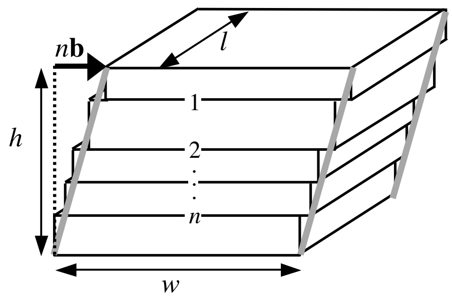


Fig. 1.8 Motion of a dislocation and the resultant shear deformation of a crystal.