Plasticity

Lecture for “Mechanical Engineering” and “Materials Science and Engineering”
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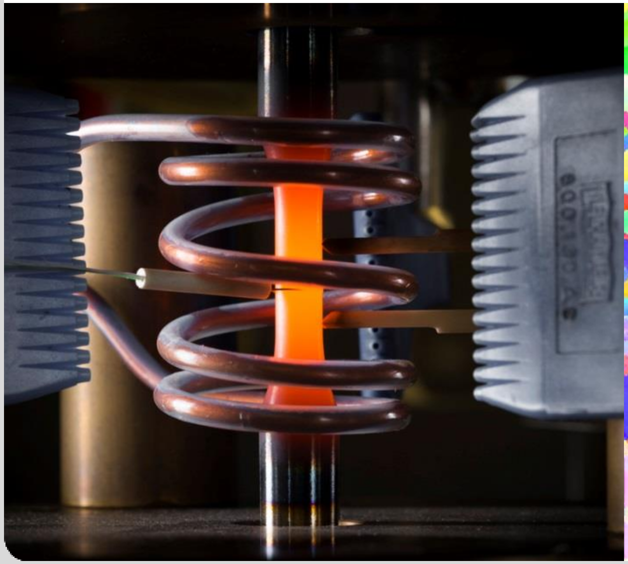
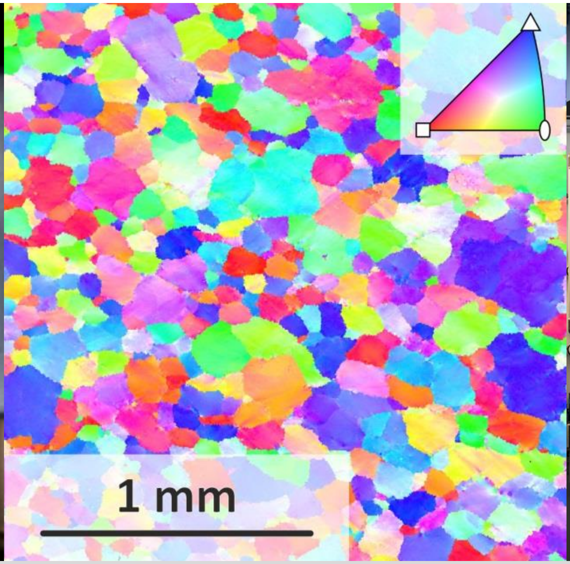
Institute for Applied Materials (IAM-WK)





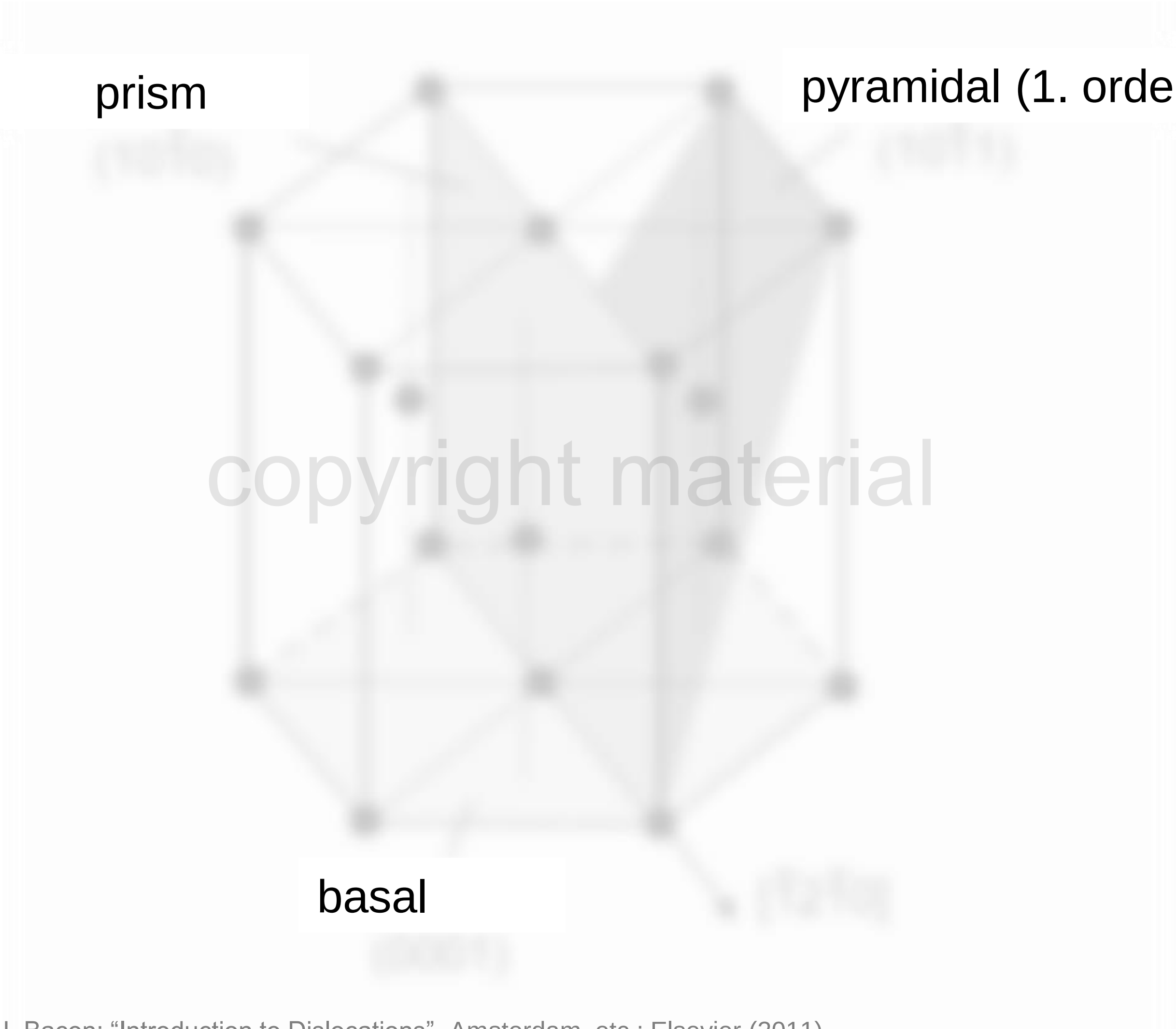
Topics

- Dislocations in Metals and Alloys: A3, hcp
  - Basal glide and prism glide
  - Potential stacking faults

Strukturbericht designation A3

- In hcp metals and alloys, **the c/a determines potentially preferred nearest neighbor bonds. Only for ideal packing $c/a = \sqrt{\frac{8}{3}} \approx 1.633$, all bonds are equal**. In all other cases, directional bonds are observed. This causes deviations from the expectations by the Peierls-Nabarro equation.
- Close-to-ideal metals and alloys, like Mg or Co, exhibit **basal glide:** $(0001)\frac{1}{3}\langle 11\bar{2}0\rangle$.
- There is a vast variety of reports on additional slip planes and slip direction (most notably $a + c = \frac{1}{3}\langle 11\bar{2}3\rangle$) in literature depending on the conditions of plastic deformation. Most of the slip systems are categorized by the prism plane or the type and order of the pyramidal planes.

Strukturbericht designation A3



D. Hull, D. J. Bacon: “Introduction to Dislocations”, Amsterdam, etc.: Elsevier (2011)

Strukturbericht designation A3

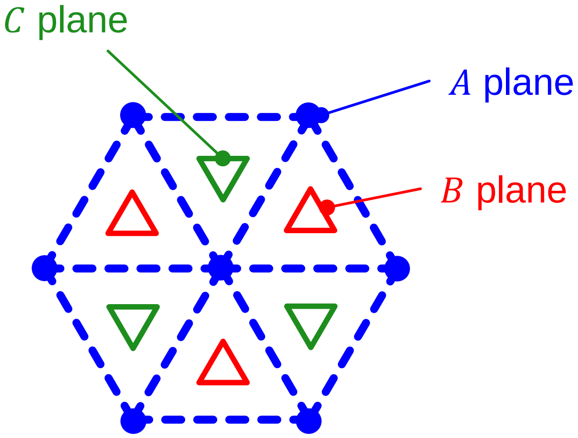
- The critical stress for basal glide is usually small (Be, Mg, Zn, Cd): ~ 1 MPa. Prism planes are more difficult to activate (Ti, Zr): ~ 10 MPa.

metal	Be	Ti	Zr	Mg	Co	Zn	Cd
c/a	1.568	1.587	1.593	1.623	1.628	1.856	1.866
slip plane	basal	prism	prism	basal	basal	basal	basal

- This cannot be rationalized by the Peierls-Nabarro equation: lattice plane distance $\frac{c}{2}$ vs. $\frac{\sqrt{3}\,a}{6}$ or atomic packing factor $\frac{4}{\sqrt{3}}\,\frac{1}{a^2}$ vs. $\frac{1}{c\,a}$.

Stacking faults

- The assessment of stacking faults is similar to the treatment of fcc A1 metals and alloys:



perfect stacking	intr. SF (1)			intr. SF (2)	extr. SF
B	B		C	C	B
A	A		B	B	A
B	B		C	C	B
A	A		B	B	A
B	B		C	C	C
A	B	→	B	A	B
B	A		A	B	A
A	B		B	A	B
B	A		A	B	A
A	B		B	A	B
B	A		A	B	A
A	B		B	A	B
	unstable				

single layer with wrong NN environment

two layers of wrong stacking

three layers of wrong stacking

$$3\,\gamma_{iSF1} \approx \frac{3}{2}\gamma_{iSF2} \approx \gamma_{eSF}$$

Stacking faults

- Hence, a dissociation of the dislocations in the basal plane is reasonable: $\frac{1}{3}[11\bar{2}0] \rightarrow \frac{1}{3}[10\bar{1}0] + \frac{1}{3}[01\bar{1}0]$ on (0001) and an intr. SF (2) is formed. The Burgers vectors are a^2 to $2\frac{a^2}{3}$ after dissociation.
- The dissociation distributes the disregistry by the dislocation within the slip plane and rather small on-set stresses for dislocation motion are observed.
- Computer simulations indicate also other metastable stacking faults with for example $\frac{1}{6}[11\bar{2}\ (0 \ldots 0.6)]$. This stacking fault might contribute to a distribution of disregistry within the prism plane.

Stacking faults

- In case γ_{iSF2} is small in comparison to the stacking fault energy in the prism plane (for example in Mg), dissociation within the basal plane occurs and cross-slip to the prism plane is prevented.
- In Zr and Ti, both defect energies are assumed to be similar and a cross-slip/dissociation into the prism plane is possible. The critical stress to move the dislocation is larger since constriction to a glissile dislocation is necessary.

dissociation of edge dislocation

dissociation of screw dislocations

D. Hull, D. J. Bacon: “Introduction to Dislocations”, Amsterdam, etc.: Elsevier (2011)

Consequences

- There are **only two independent slip systems for basal slip** with $(0001)\frac{1}{3}\langle 11\bar{2}0\rangle$!
- There are **three prism planes $\{1\bar{1}00\}$ one Burgers vector of $\frac{1}{3}\langle 11\bar{2}0\rangle$** each. **Only two of them are independent!**
- **For a single set of slip systems, v.-Mises criterion is not fulfilled!**
- Anyway, **Ti, Zr or Zn with low interstitial impurity contents** (e.g. Ti Grade 1) **exhibit very good deformability at RT**. This is related to the **activation of additional slip and deformation twinning systems** (depending on the load conditions).

Summary

- The treatment of the **dissociation of dislocations in A3** metals and alloys is **similar to the treatment in A1 metals and alloys**.
- Additional **directional bonds** have to be considered when **non-ideal** c/a ratios occur.
- **Basal and prism planes are usually observed as slip planes.** Depending on the deformation conditions, a huge variety of **additional slip and deformation twinning systems** can be activated.