ENGINEERING

Basics of Dislocations in High Purity Niobium

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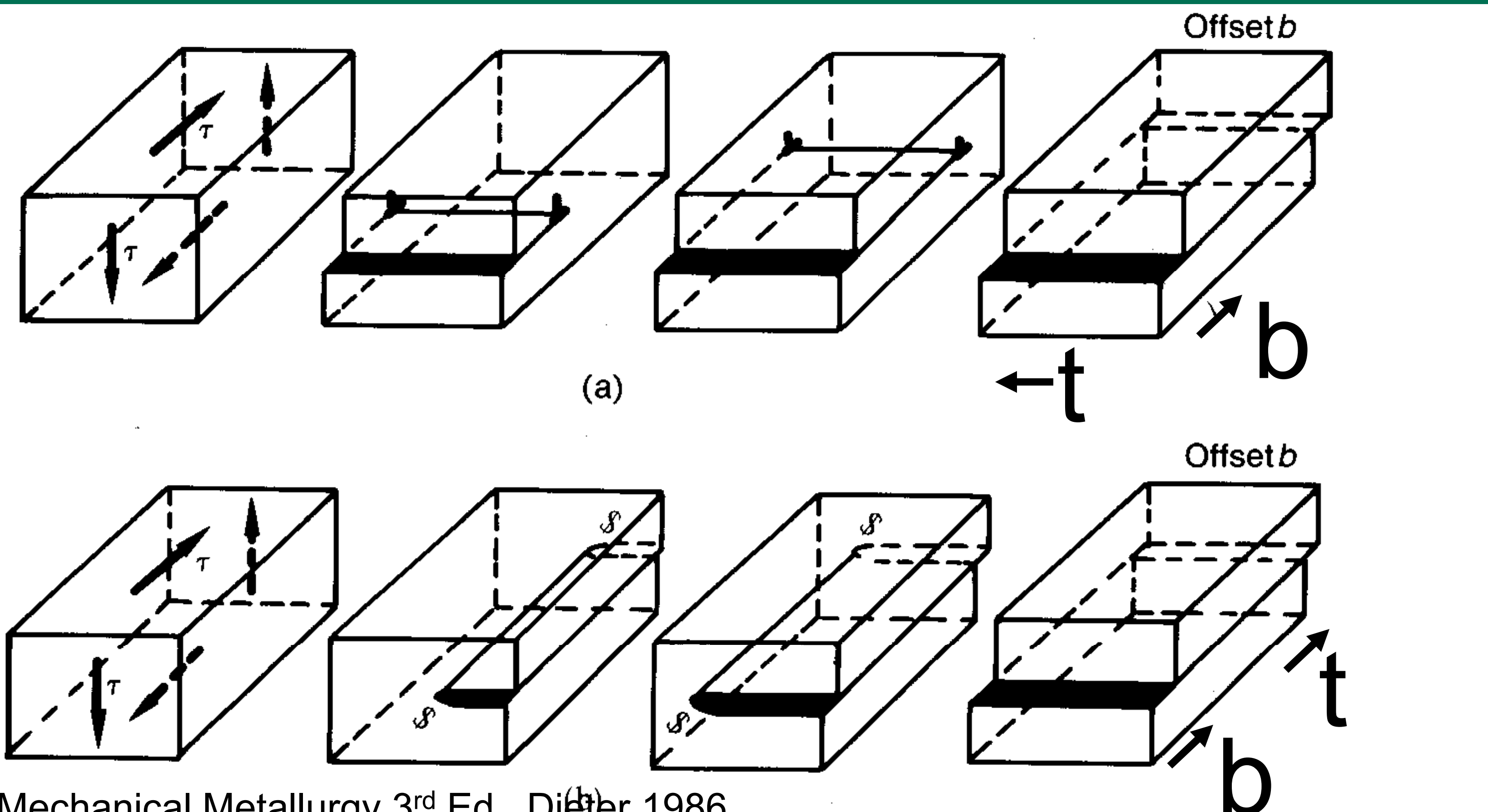
Dislocation substructure, recrystallization, and texture are important for SRF community

- Polycrystalline Nb
  - Would like to determine textures best suited for given forming process (e.g. hydroforming)
  - Need accurate crystal plasticity model
- Large grain/Single crystal Nb
  - Tubes (welded or seamless) for hydroforming
  - Will deform differently in different crystal directions
  - Relating dislocation substructures to recrystallized grain orientations would aid design of desired textures
- Electric/Superconducting properties
  - Romanenko’s thesis on high-field Q-slope correlates hot spots to higher local misorientation of lattice (higher dislocation density)
  - Phonon scattering due to dislocation lines parallel to phonon travel

Difference between screw and edge dislocations

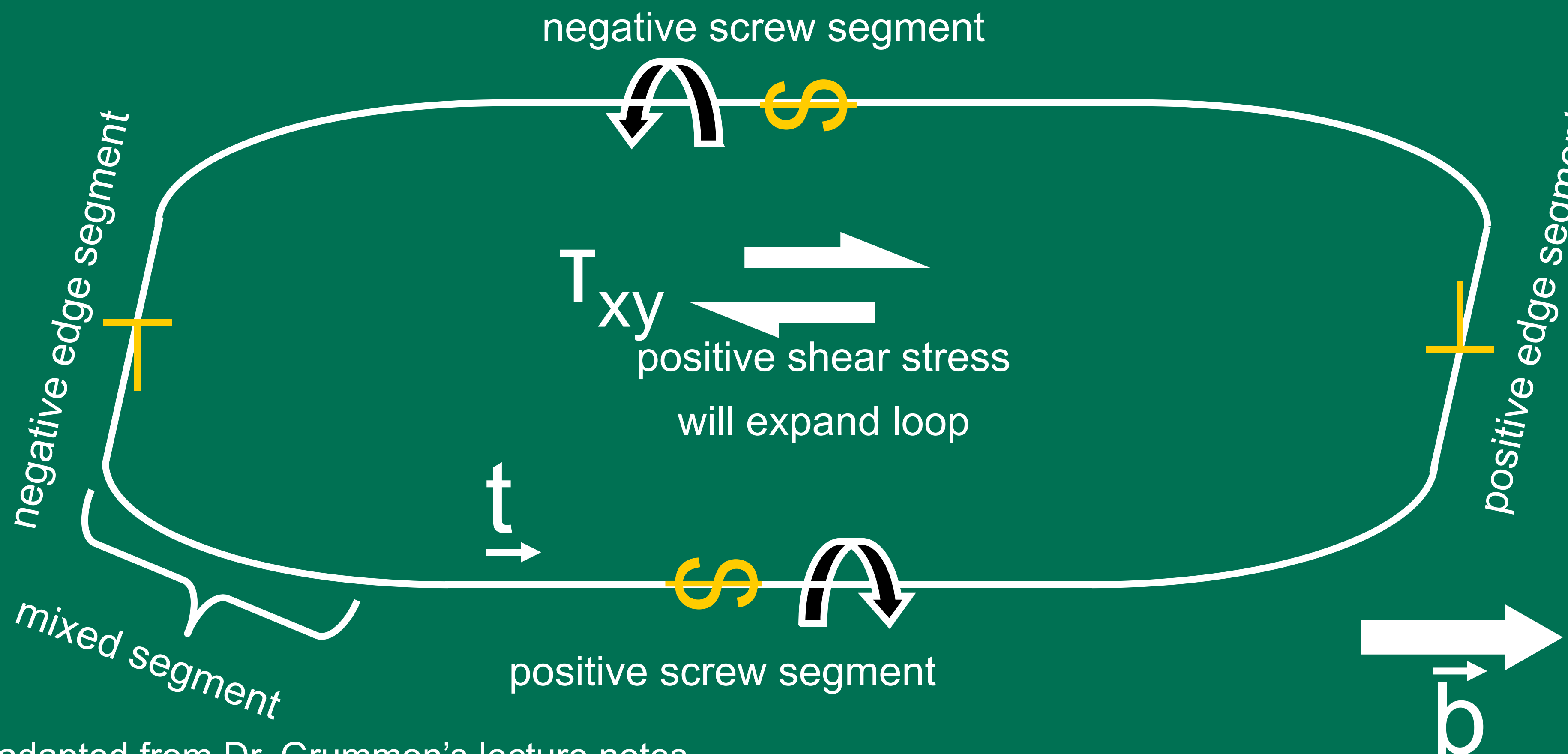
- Line defect in crystal lattice, burgers vector (b) and line direction (t)
- Edge has well defined slip plane (b x t = n), Screw does not (b || t)
- Sufficient shear stress resolved on slip plane and in burgers vector direction→ glide



Mechanical Metallurgy 3rd Ed., Dieter 1986

Glide loops develop inside a crystal and expand into space, and terminate against a grain boundary

- Dislocation terminates on itself



adapted from Dr. Grummon’s lecture notes

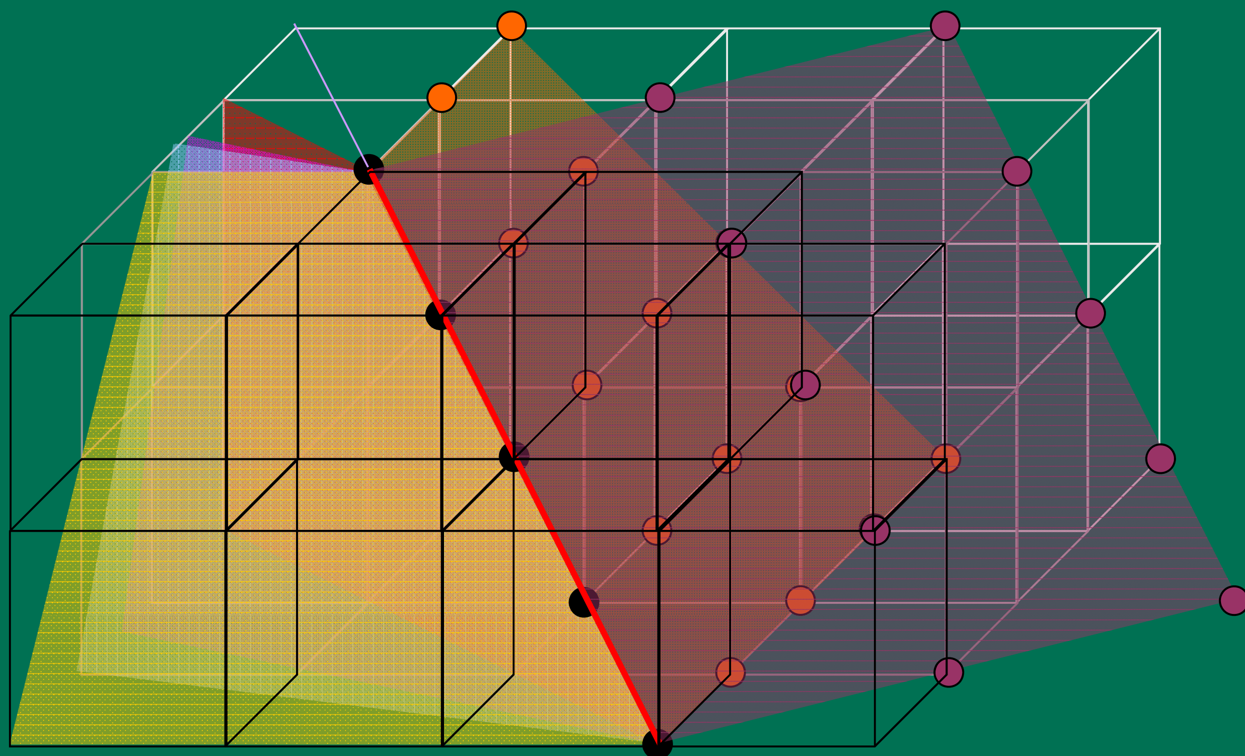
High purity BCC Slip Systems

Slip is expected to be easiest (lowest CRSS*) on

{110} planes, which have highest planar density,

and {112}

{123} at large strain



6 of the 48 available are illustrated and listed:

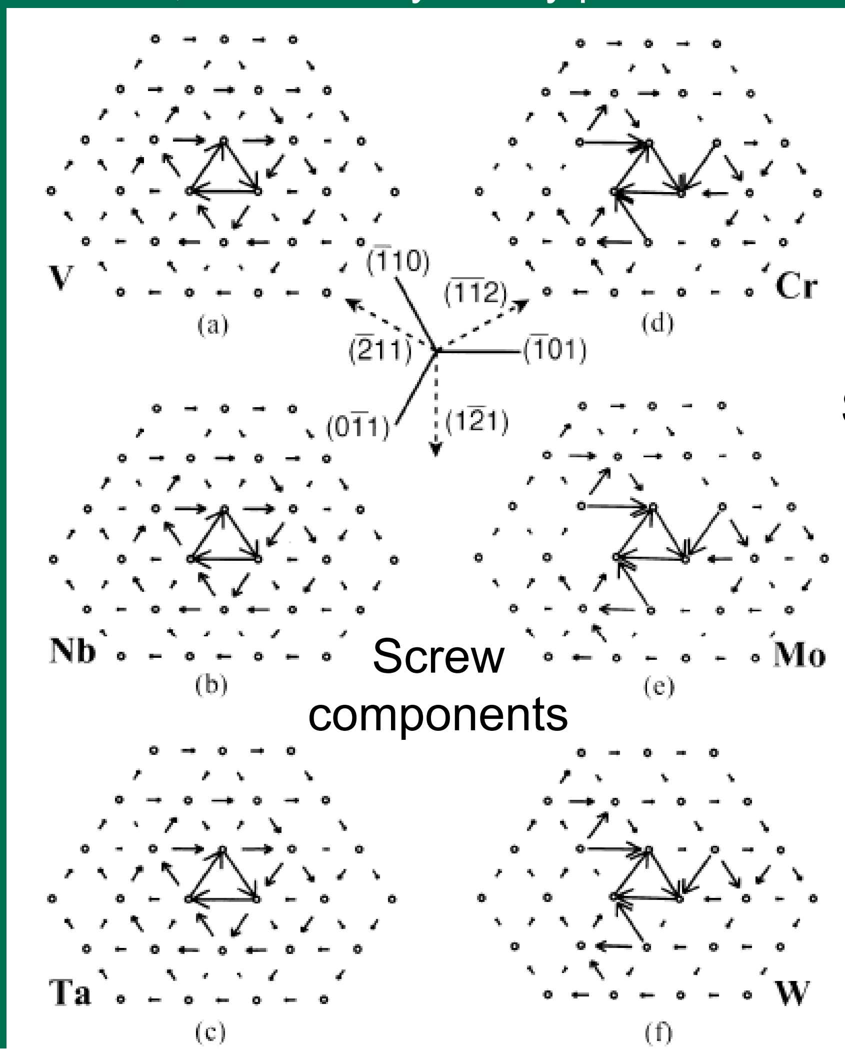
[-1 1 1] (1 1 0)	[-1 1 1] (1 -1 2)
[-1 1 1] (1 0 1)	[-1 1 1] (-1 -2 1)
[-1 1 1] (0 -1 1)	[-1 1 1] (2 1 1)

* Critical Resolved Shear Stress

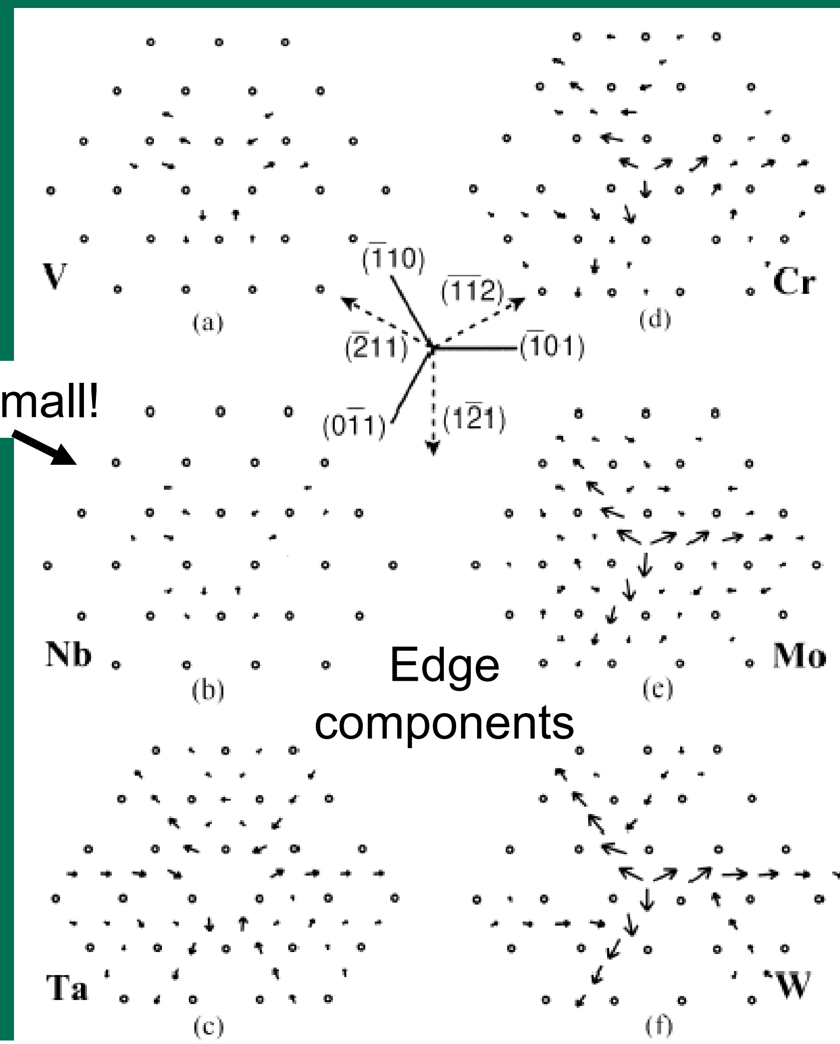
DUESBERY and VITEK: OVERVIEW No. 128
Acta mater. Vol. 46, No. 5, pp. 1481–1492, 1998

Screw Dislocations in BCC

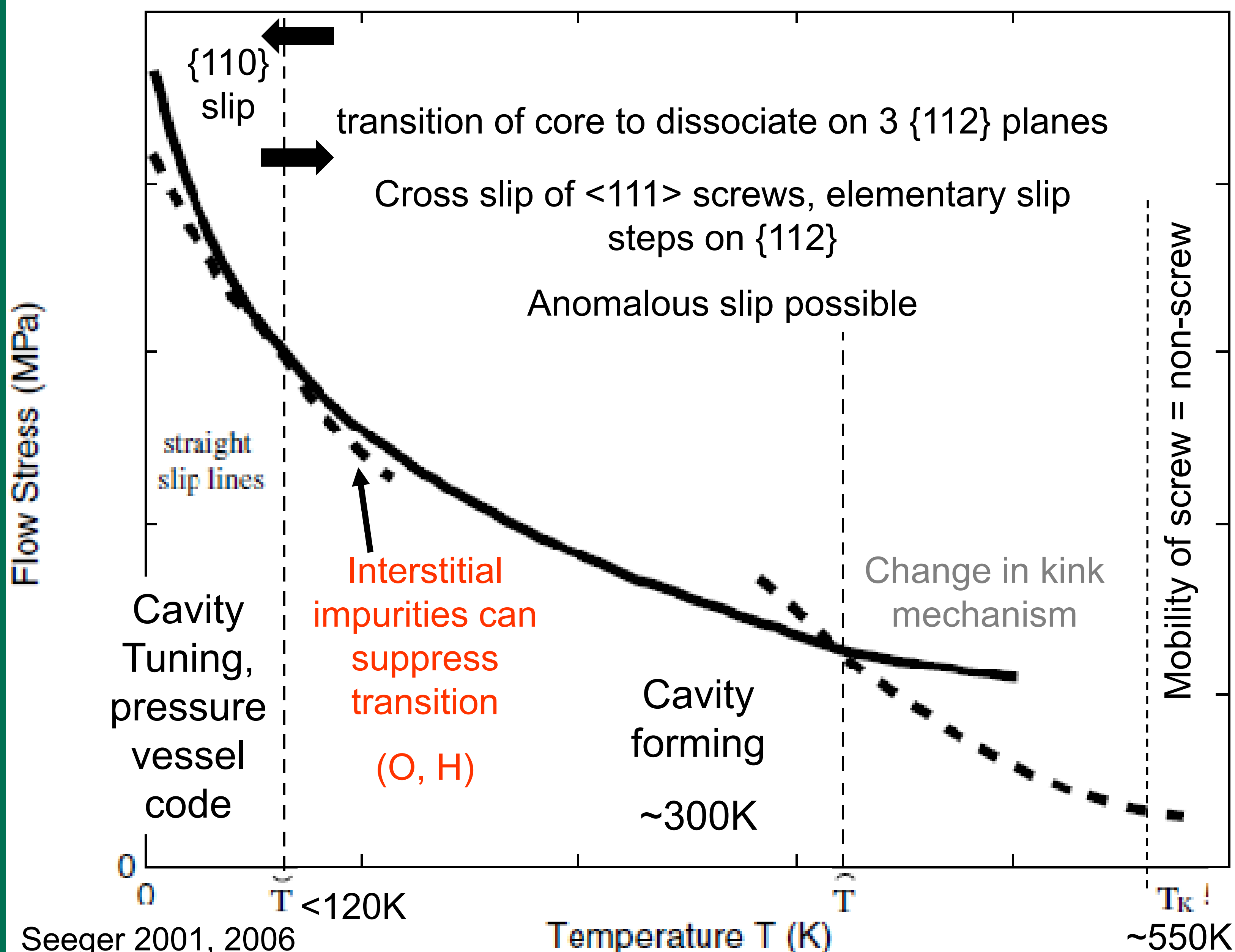
- Core dissociates in 3D on three symmetric {110} planes < Ť
- Non-glide shear stresses interact with edge components → CRSS varies with orientation
- Edge components small in Nb, dependence of CRSS on crystal orientation is small
  - In FCC, core already moslty planer



Small!



Favored slip planes change with T & purity

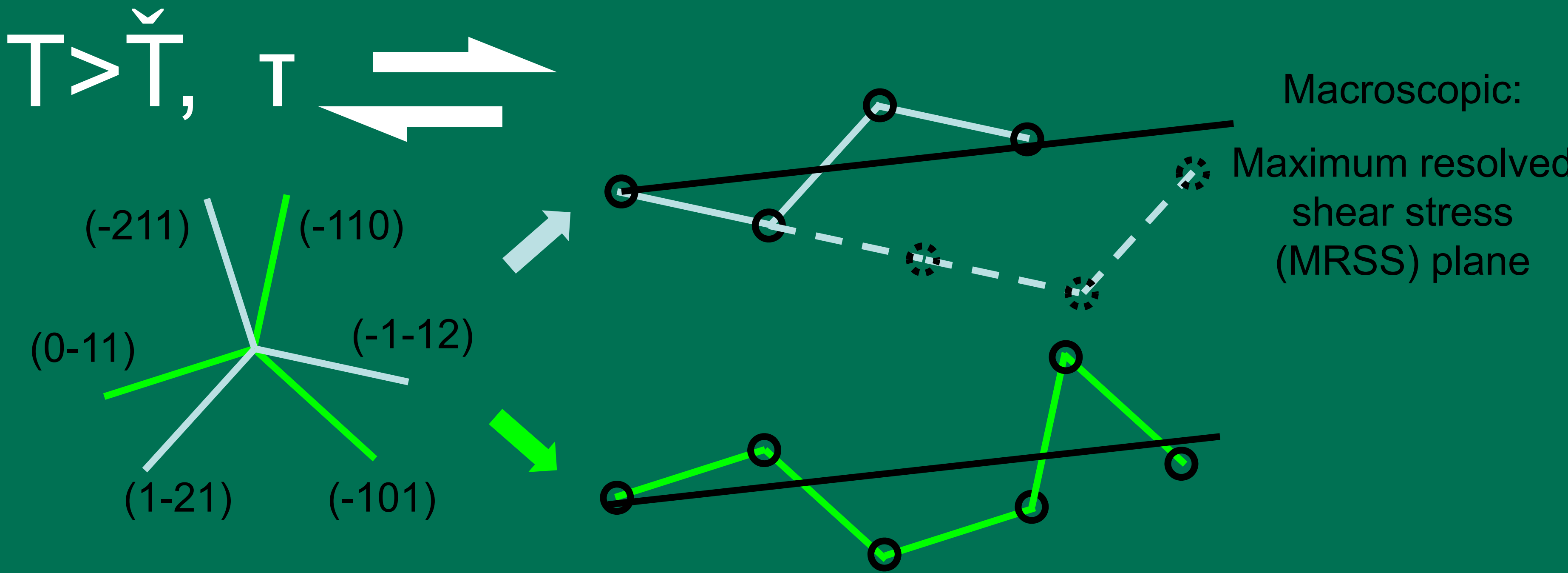


Seeger 2001, 2006

Possible issue of hydrogen contamination

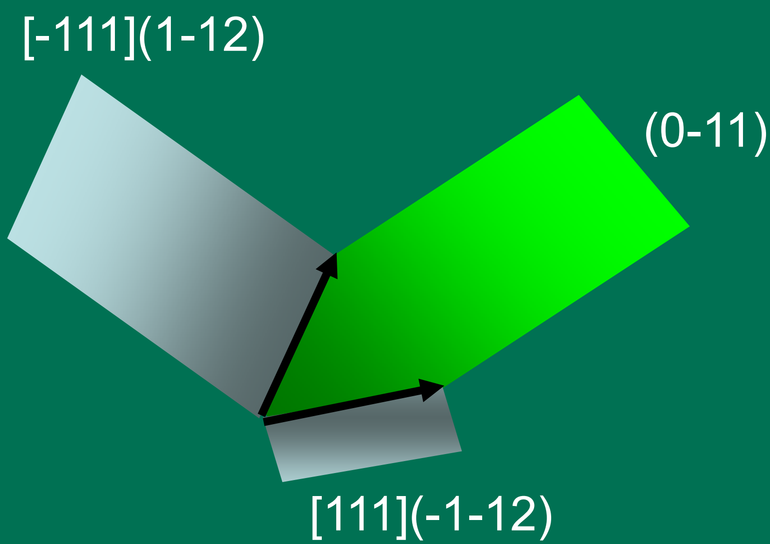
- Hydrogen penetration during
  - Deformation (thin oxide cracks)
    - Rough calculation: H may move 4mm in 5min at RT in Nb
    - How much of an effect?
  - Etching/Electropolishing
    - Not usually done before forming, sometimes remove Fe
- Stabilizes {110} dissociation
  - Promotes Slip on {110}
  - Dislocations, vacancies trap H
- Include in CPFE modeling of forming process

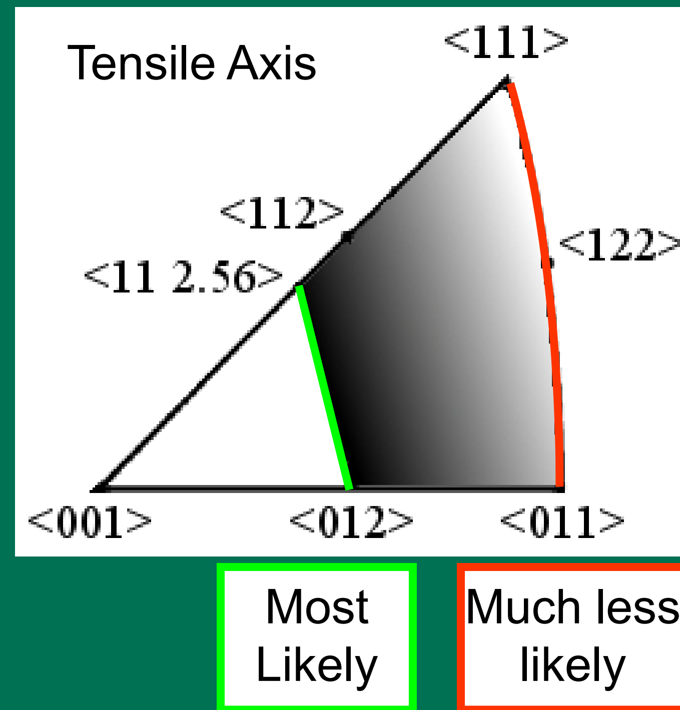
Can we tell from slip traces?



- Complication: The distance between cross-slip events is unknown

Anomalous Slip





- Highest shear stress on two intersecting, equally active {112} planes
- Cross-slip to mutual {110} plane
  - of ~half the resolved shear stress on {112}
- Maintains lower free energy

To avoid:

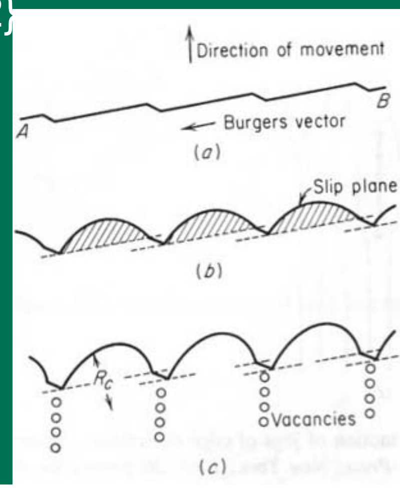
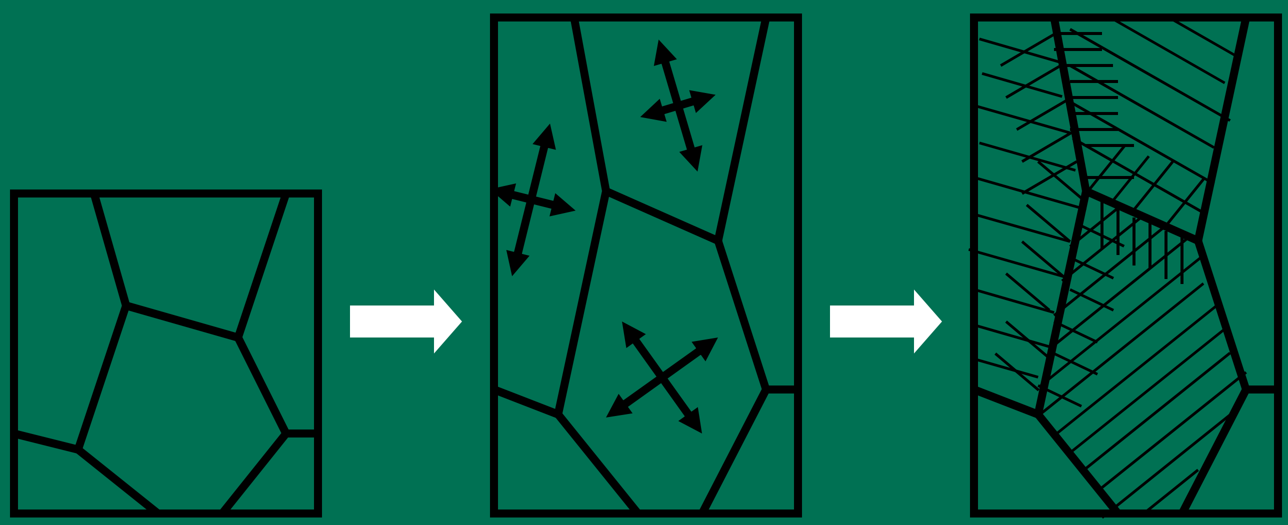


Figure 5-24 Movement of jogged screw dislocation. (*a*) Straight dislocation under zero stress; (*b*) dislocation bowed out in slip plane between the jogs due to applied shear stress; (*c*) movement of dislocation leaving trails of vacancies behind the jogs. *(From D. Hull, "Introduction to Dislocations," p. 136, Pergamon Press, New York, 1965. By permission of the publishers.)*

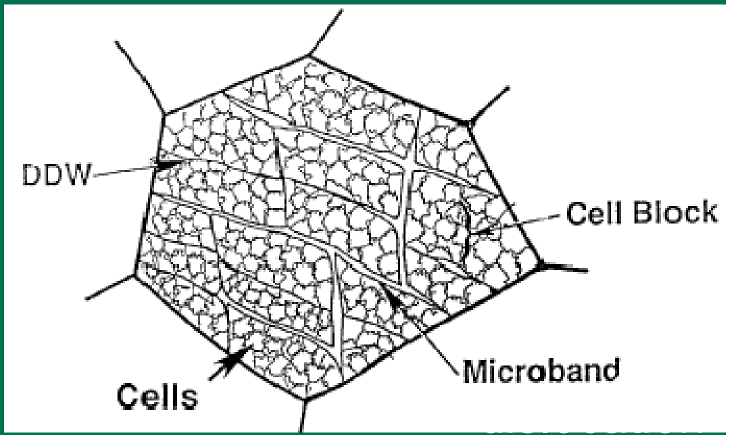
5 independent slip systems needed for arbitrary shape change (Von Mises)

- Taylor model often used for polycrystals
  - Strain of each grain same as that of aggregate
  - Different stress states in each grain
  - maintains grain boundary cohesion
  - Refined methods for selecting the 5 systems



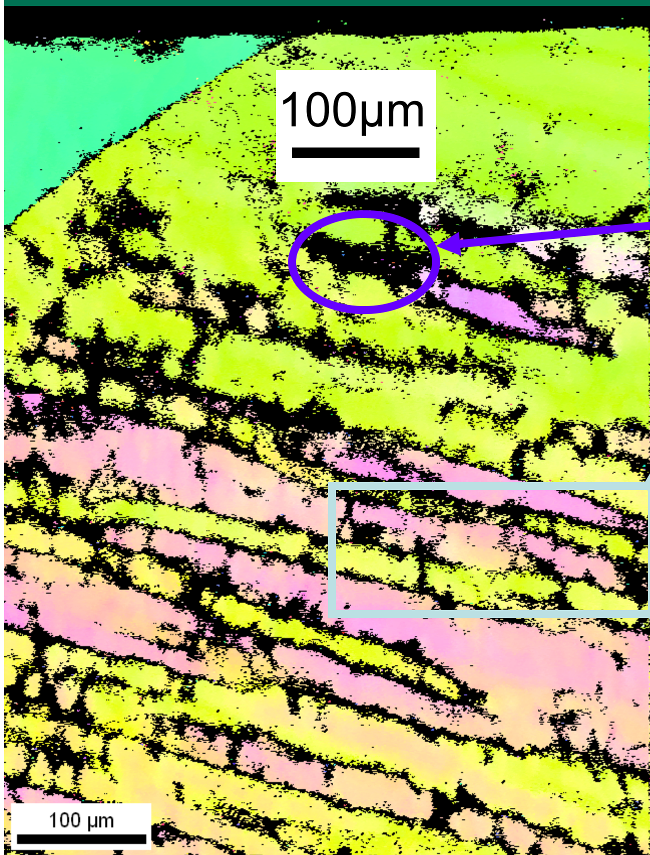
Dislocation structures

- Grains divide into
  - Cell Blocks (CBs) bounded by long flat boundaries
  - Microbands (MBs)- double walled, small strains
  - Dense Dislocation Walls (DDWs)- single walled, small strains
  - Lamellar boundaries (LBs)- appear at large strains, form very flat CBs, replace MBs and DDWs
  - All the above are considered geometrically necessary boundaries (GNBs)
    - Separate regions that deformed differently
    - Arranged in parallel families
    - Special macroscopic orientation relative deformation axis
    - Increasing strain- increase in misorientation angle and decrease in spacing, much more rapidly than IDBs
  - Cells within CBs (SSDs)
    - Equiaxed, bounded by incidental boundaries (IDBs)
    - Low misorientation angles

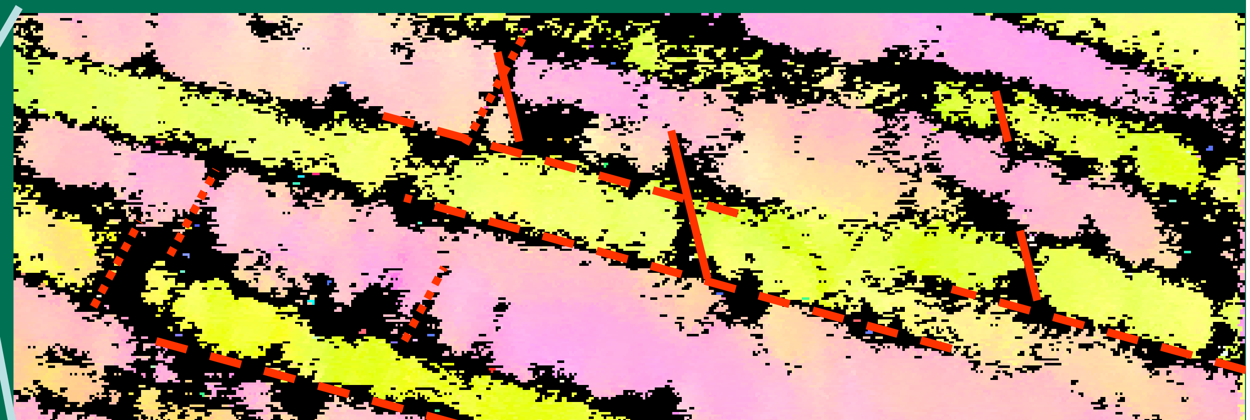


Doherty et al, Mat Sci Eng A238 (1997) 219-274

Shear bands at grain boundaries



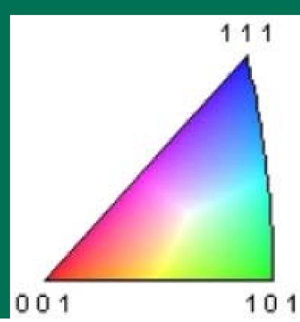
Dislocation substructures much larger than the coherence length are commonly observed



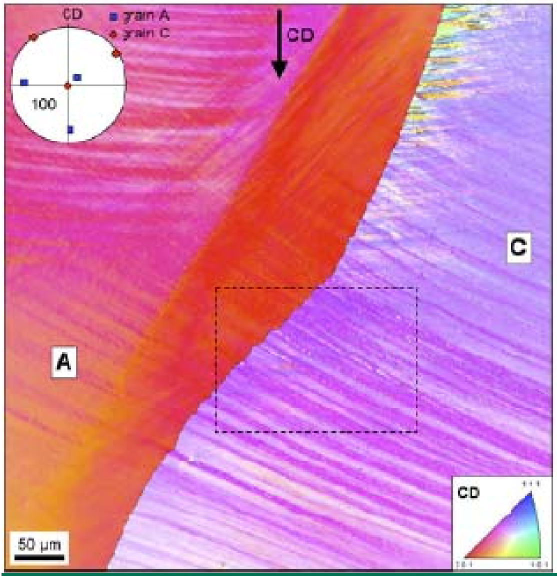
Evidence for multiple slip planes

Crystal directions || rolling direction

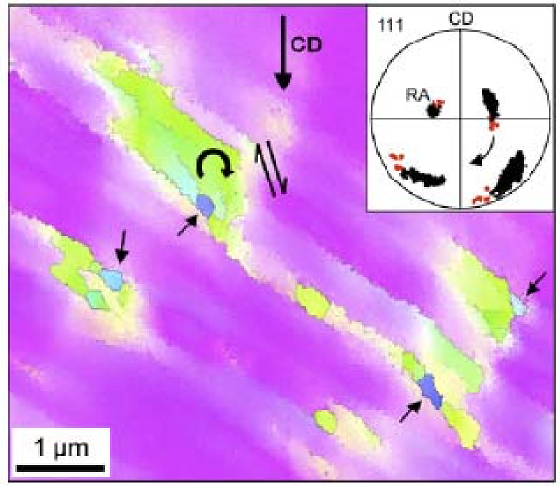
Bicrystal rolled 40%



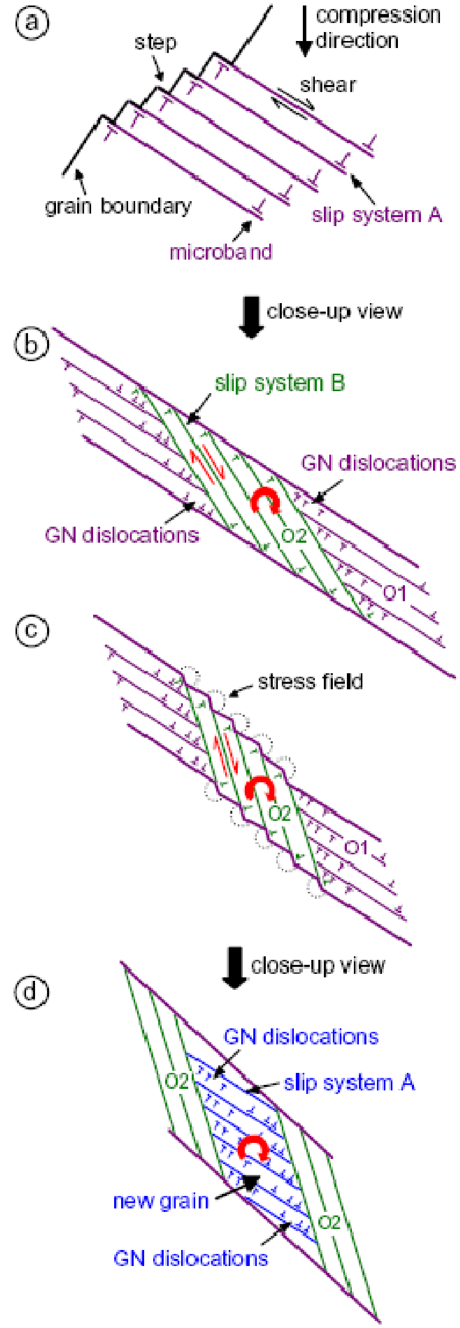
Example of possible embryos/nuclei in Fe- 3wt% Si



Microshear bands at grain boundary. EBSD step size 1.4 µm.



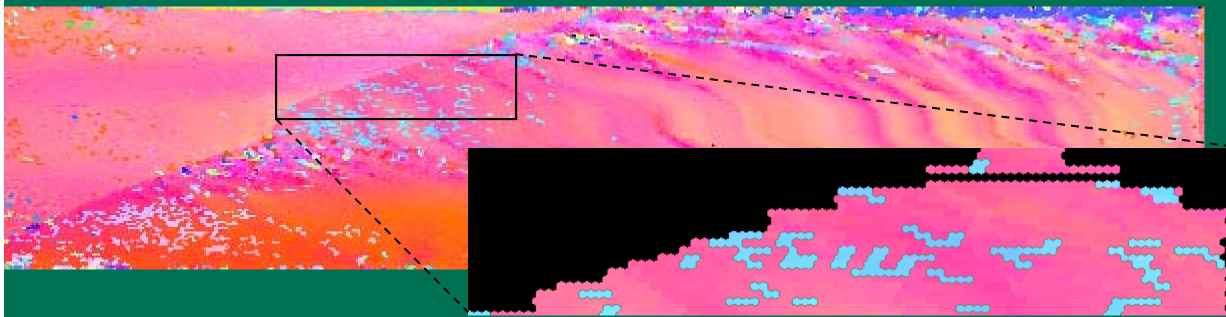
Lattice rotations about ~{111} of possible embryos, black lines >15° misorientation



Intersecting slip systems lead to local rotation about a {111} axis and make possible embryos within microshear bands

Dorner et al. *Scripta Mat.*, 57, 2007

Rolled to 71%, **no heat treatment**



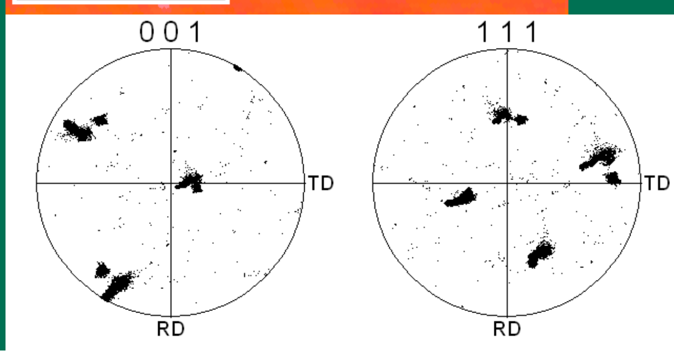
2micron step

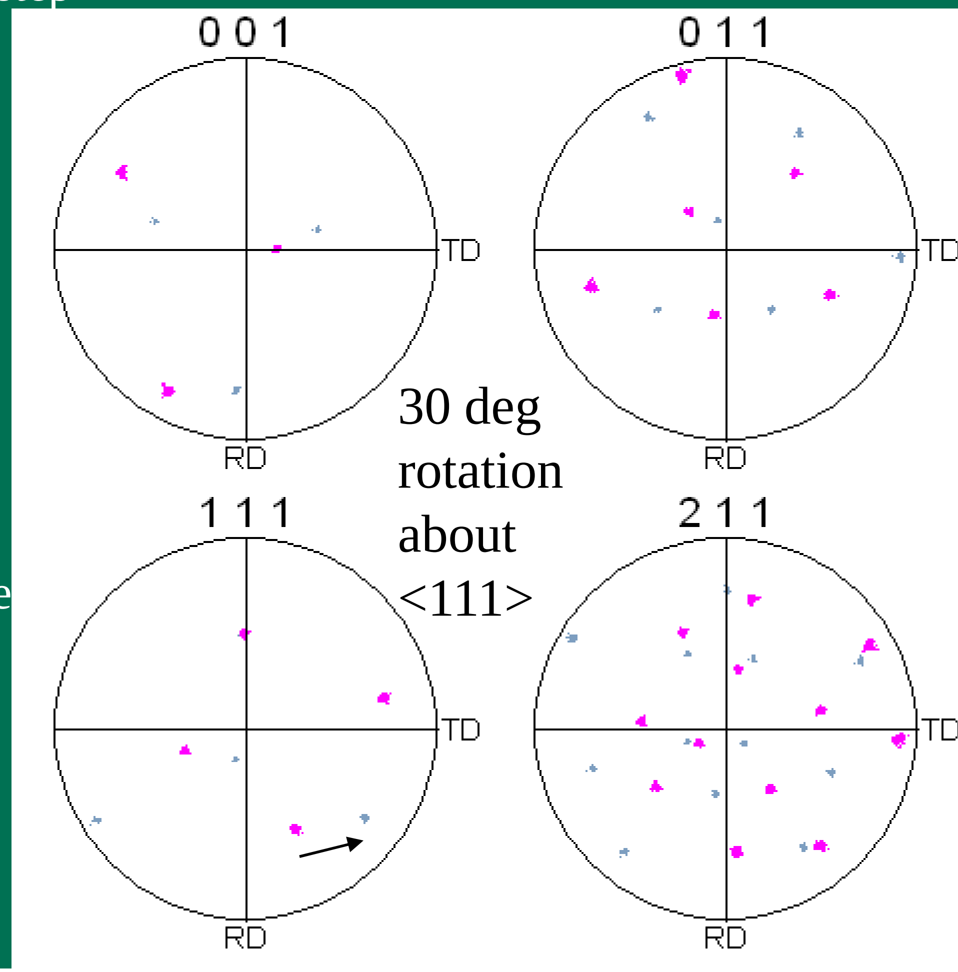
Sample 6

Near top shows development of measurable new orientations (blue) in right grain, ***only due to strain***

As-rolled to 70% reduction near bottom – shows lesser development of new orientations in right grain

10micron ste





30 deg rotation about <111>

Summary

- Complex dislocation behavior most important for initial production of polycrystalline Nb sheet
  - Screw dislocation behavior controls plastic deformation behavior in sxl/large grain Nb
  - Awareness so can control deformation texture and therefore Rx texture
  - Need to incorporate screw behavior into crystal plasticity model
    - Others have done this, evaluate best method to use
- Complex BCC slip less of an issue in polycrystal
  - Closer to random texture more isotropic
  - Strong textures may be more affected
- Provocative questions
  - After Rx, why not leave the sheet alone?
  - After 800C Bake, why more EP?
    - Can we put furnace in Clean room?

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