3.40J / 22.71J
Modern Physical Metallurgy

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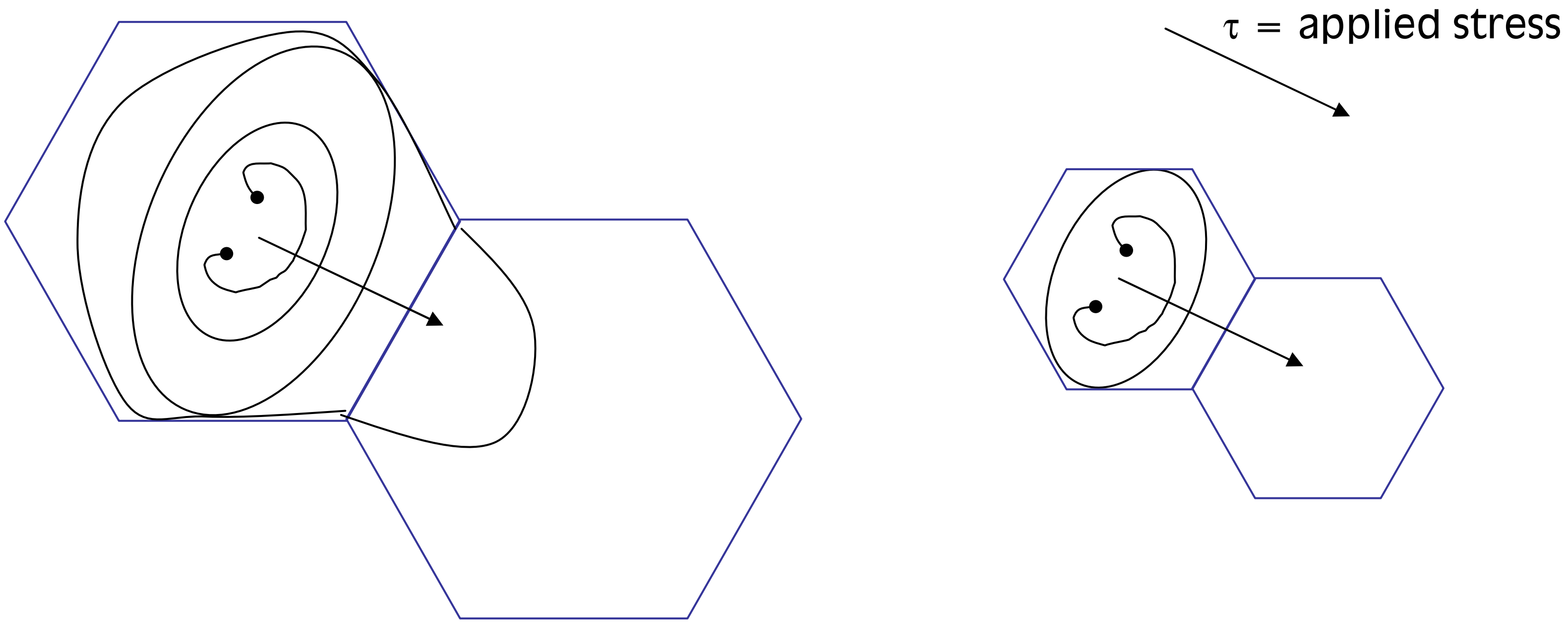
Lecture 12: Low energy defect surfaces

March 30, 2004

Review: Grain size & Mechanical effects

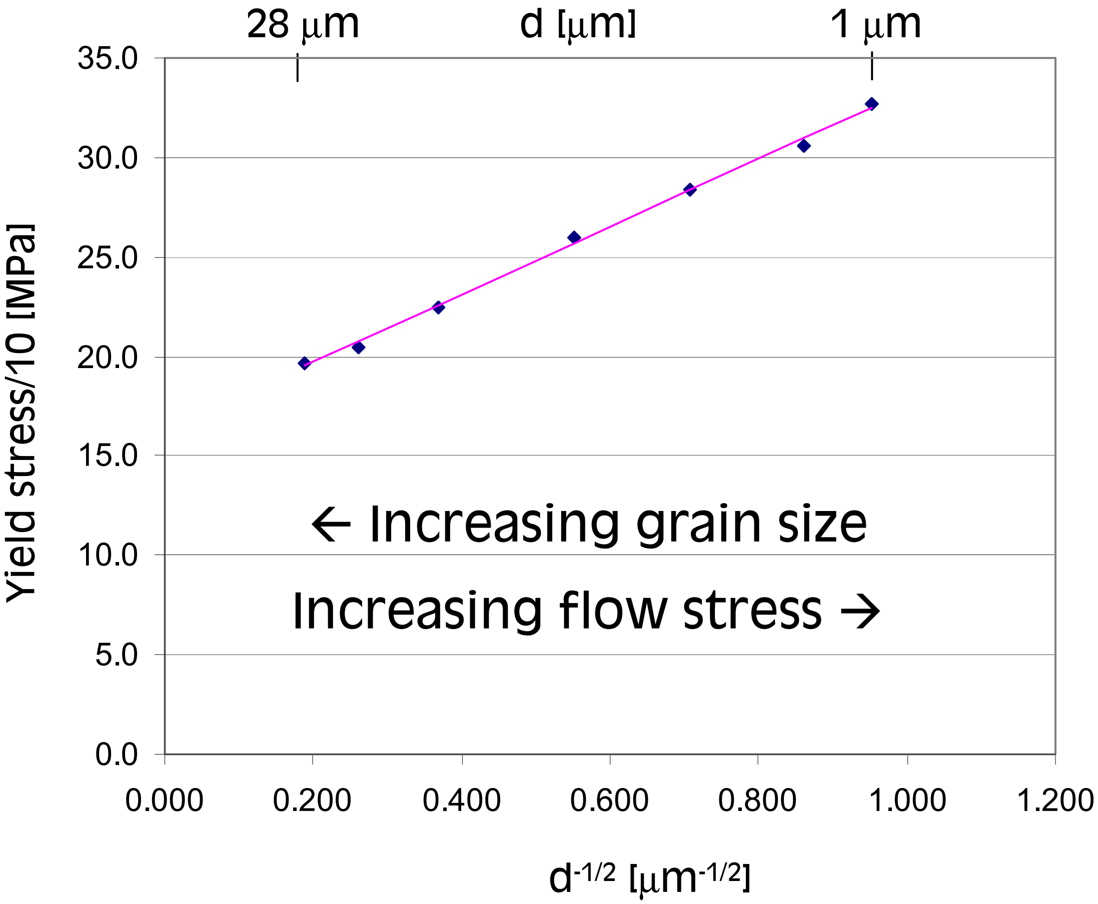
- GBs are obstacles for dislocation movement
- Plastic deformation proceeds by dislocation motion and multiplication
- If dislocations form or move inside grains, GB obstacles impede movement
- Dislocations will pileup at GB until generating sufficient stress to move through GB
- The larger the grain, the more dislocations pile-up, and the lower the applied stress to move dislocations



Thus, metals with large d yield under lower stress than metals with small d.

Review: Grain size & Mechanical effects

- Hall-Petch relation: $\sigma_y = \sigma_0 + kd^{-1/2}$ (EO Hall, 1951; NJ Petch, 1953)



Experimental data
G.W. Brandie, 2003; Chemical Engineering, Queens College
Samples = steel

Review: Grain size & Mechanical effects

Reducing grain size
strengthens material to a
point, but…

the density of defects
at the GB ultimately weakens
the metal when the grain
size approaches the GB
thickness.

(Image removed due to copyright considerations.)

Low energy defect surfaces

Examples

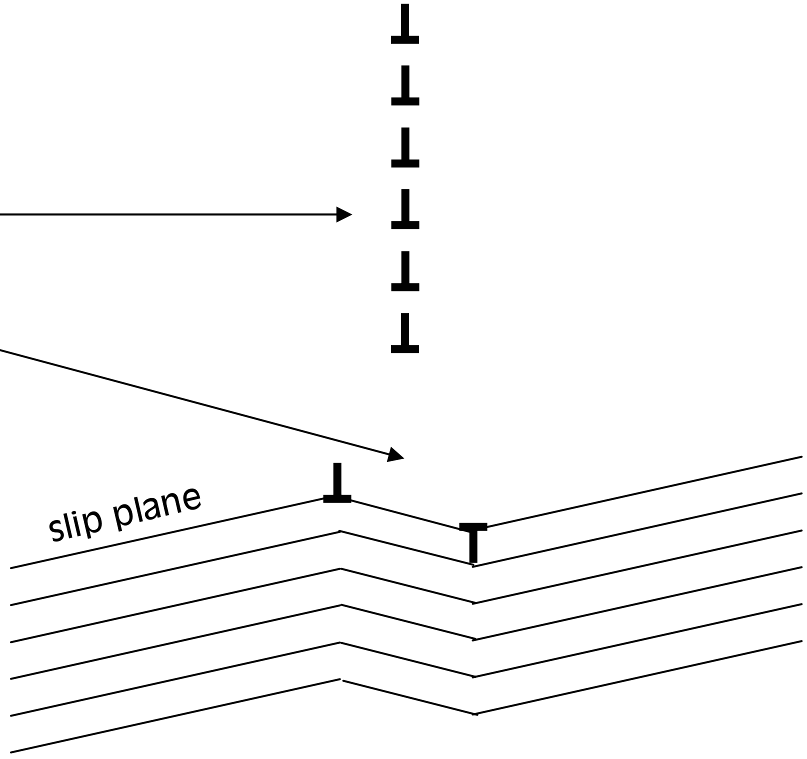
Importance

LEDS

LEDS: Low Energy Dislocation Structure

Examples:

- Real ones:
    - Tilt boundary
    - Kink band array

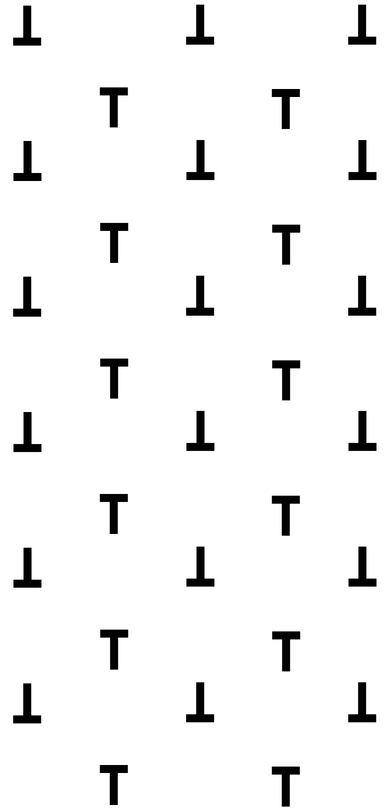


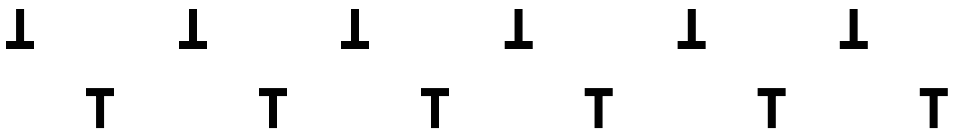
LEDS

LEDS: Low Energy Dislocation Structure

Examples:

- Imagined ones:
  -
  -

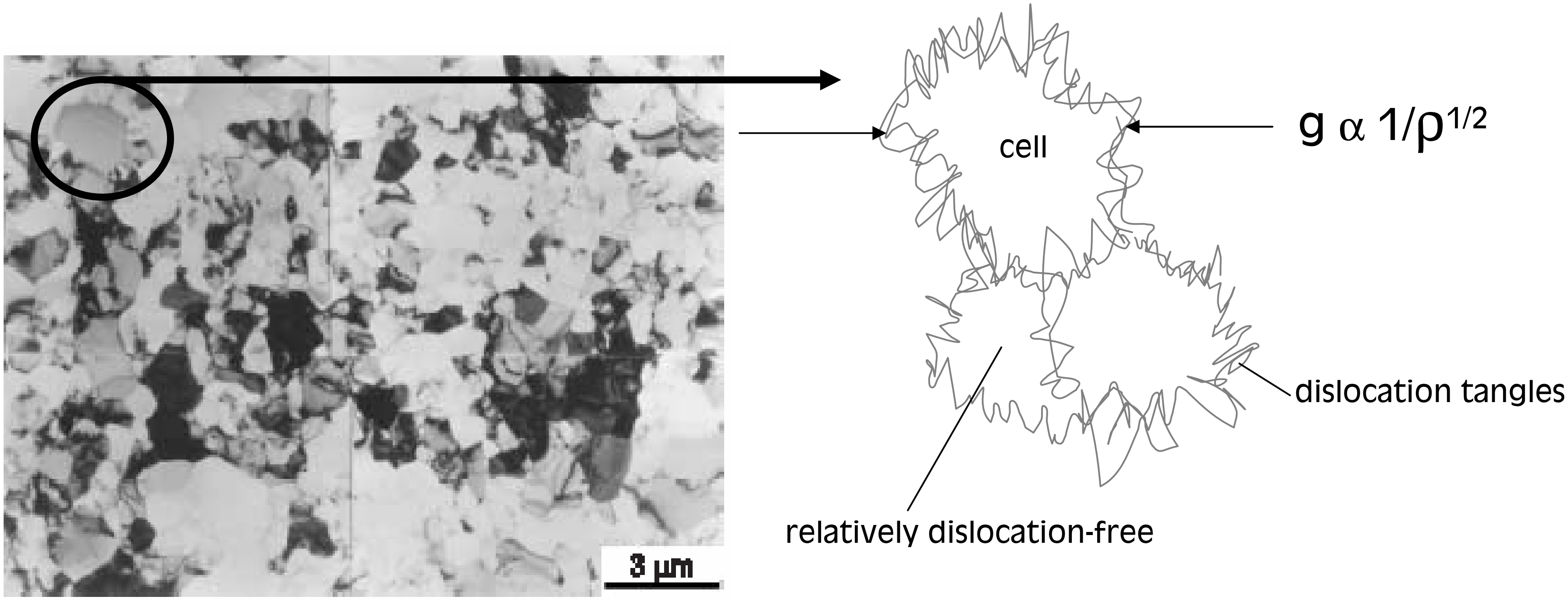




Dislocation Cell Structures

LEDS:

Dislocation cell structures:



Dislocation Cell Structures: Production of nanocrystalline metals

“On the basis of a study on the microstructures of ballmilled Ru and AlRu, the formation of [a nanocrystalline] structure is thought to evolve from the development of dislocation cell structures within shear bands;[15] then, the dislocation cells transform into low-angle grain boundaries and finally form nc grains surrounded by high-angle boundaries *via* grain rotation.[16]

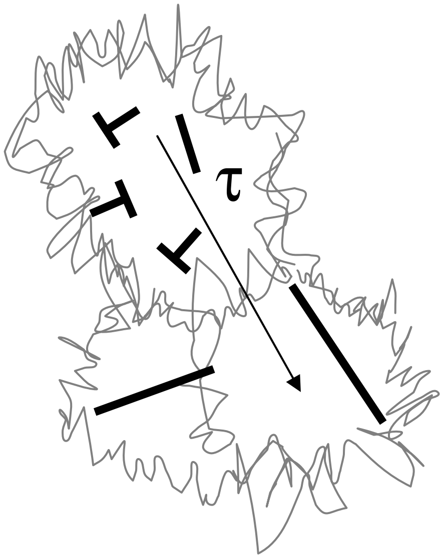
More recently, Fecht[13] has proposed that the grain size refinement includes three stages: (1) localized deformation in shear bands consisting of high density dislocation array; (2) dislocation annihilation and recombination that lead to small-angle grain boundaries separating the individual grains; and (3) development of completely random misorientations between neighboring grains.”

YUWEI XUN, ENRIQUE J. LAVERNIA, and FARGHALLI A. MOHAMED
Synthesis of Nanocrystalline Zn-22 Pct Al Using Cryomilling
METALLURGICAL AND MATERIALS TRANSACTIONS A VOLUME 35A, FEBRUARY 2004—573

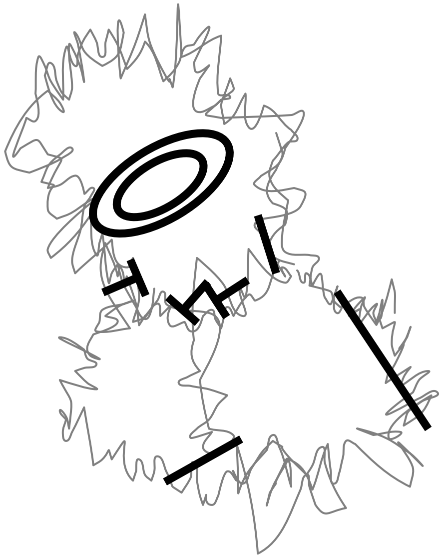
Dislocation Cell Structures:

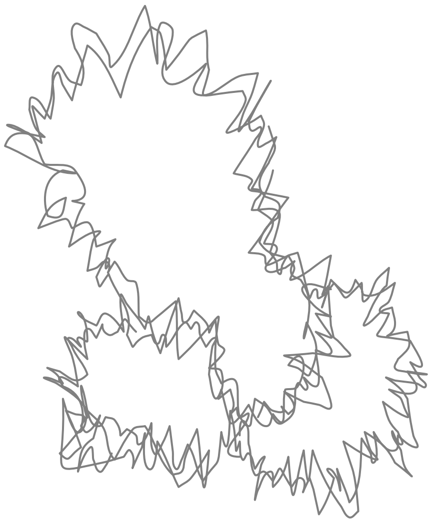
Dynamic recovery and work softening

Dislocation cells form under applied stress/plastic deformation



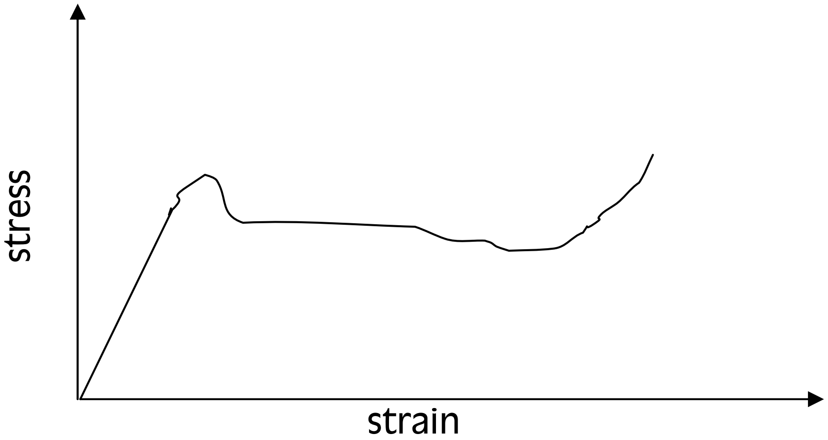
1.



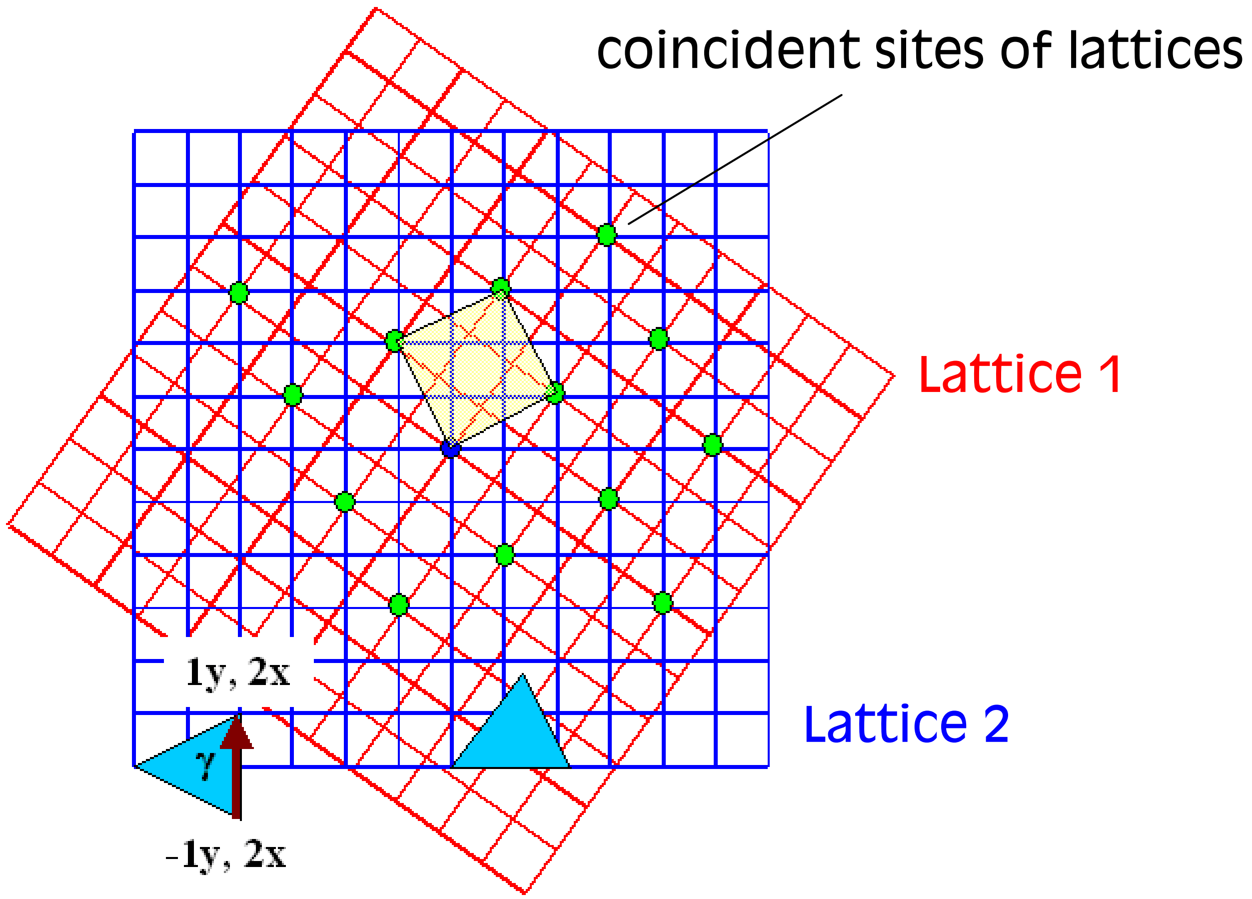


3.

2.



Coincident Site Lattices

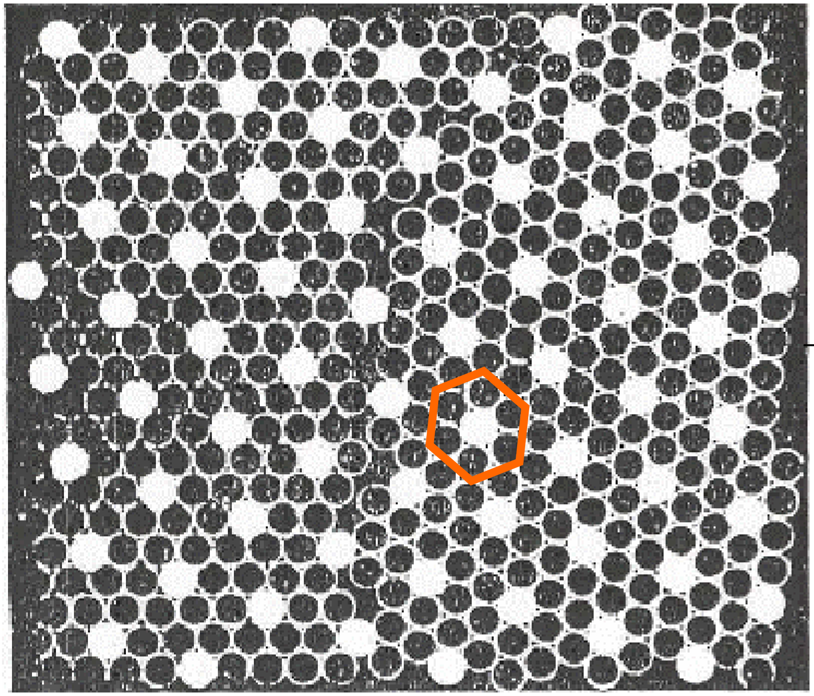


coincident sites of lattices

Lattice 1

Lattice 2

Coincident Site Lattices



bubble raft {111}: white = coincident site

Coincident Site Lattices: Applications

CSLs of large Σ have special properties. Why?

T. Watanabe (1980s)

Examples:

1. Pb electrodes:

Lifetime in batteries limited by
corrosion and cracking.

Improved via GBE of 67%CSLs

Images: After 40 +/- cycles

CSL: $3 < \Sigma < 29$

Coincident Site Lattices: Applications

Examples:

2. Ni alloy creep:

Inconel deforms under constant stress, temp

By adding large fraction of CSLs, creep resistance dramatically enhanced

Mechanism: Dislocations trapped at CSLs, and cannot move to facilitate creep.

**CSLs are efficient dislocation obstacles, even at elevated temp (tangles).

(Image removed due to copyright considerations.)

Coincident Site Lattices: Curiosities

1. Σ only odd integers, never even
2. $\Sigma <$ 29
3. Low Σ boundaries have lower energy than random boundaries BUT energy does not scale with Σ: