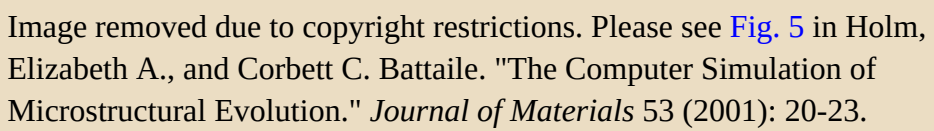
RECRYSTALLIZATION

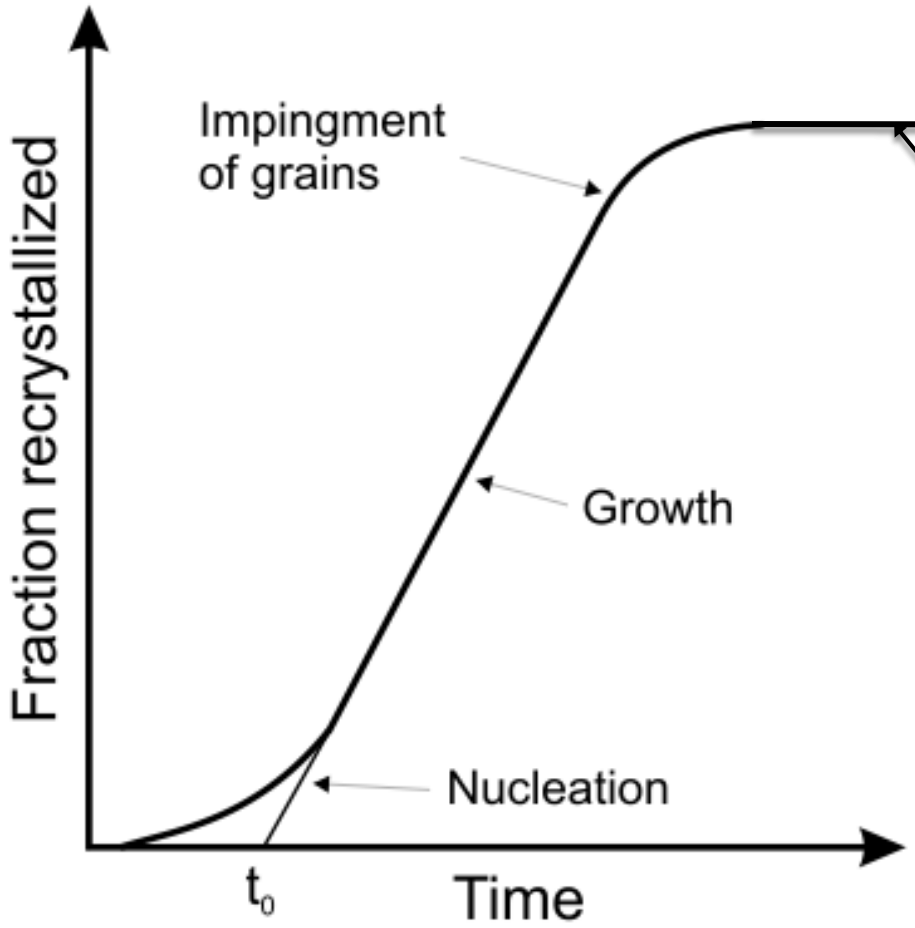


COURSE SUMMARY
10/19/09

Key concepts of recrystallization

- Recrystallisation diagram: nucleation, growth, impingement, conventional grain growth
- Nucleation mechanism
- Influence of temperature: T↗faster
- Influence of strain: ε↗faster + smaller grains
- Influence of grain size

“THE” DIAGRAM



4 zones on the curve

Conventional grain growth ~ $t^{1/2}$

http://en.wikipedia.org/wiki/File:RXkinetics.svg

“THE” DIAGRAM

Please see the video at Humphreys, John, and Ian Brough.
"Recrystallization of Aluminium in the SEM (low magnification)."
Recrystallization. University of Manchester, 2008.

DEFINITION

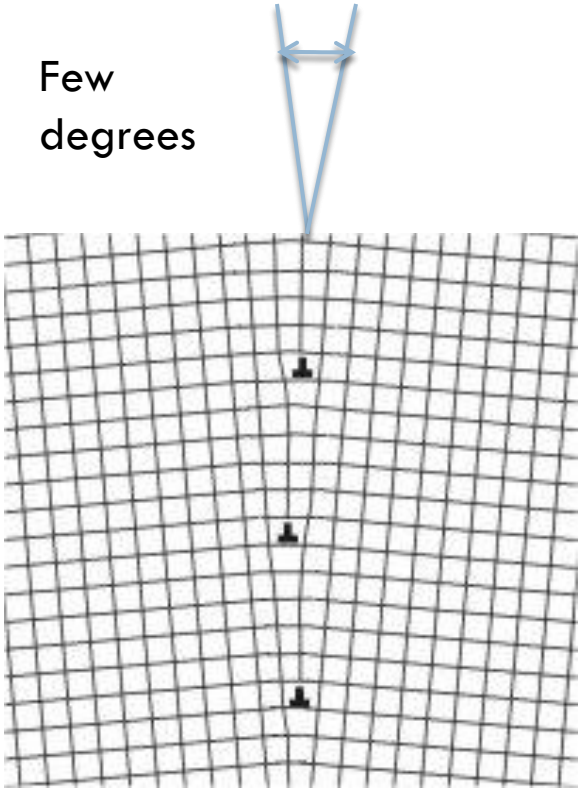
"Recrystalistation can be defined as the nucleation and growth of stress-free grains"

Elements of Metallurgy and Engineering Alloys, Flake C. Campbell

CLOSE UP ON POLIGONIZATION

- Because of temperature the dislocations are more mobile; they tend to pile up to lower the strain energy of the system
- The rearrangement of excess dislocations into low angle tilt boundaries (misorientation of a few degrees) is called polygonization. It leads to the formation of sub-grains

LOW ANGLE VS. HIGH ANGLE BOUNDARY



Courtesy of John Humphreys. Used with permission.

Image of a high-angle grain boundary removed due to copyright restrictions.

http://www.recrystallization.info/pictures/lagb.jpg

Poligonizationct'd

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Please see Fig. 8.13a in Campbell, F. C.
Elements of Metallurgy and Engineering Alloys.
Materials Park, OH: ASM International, 2008.

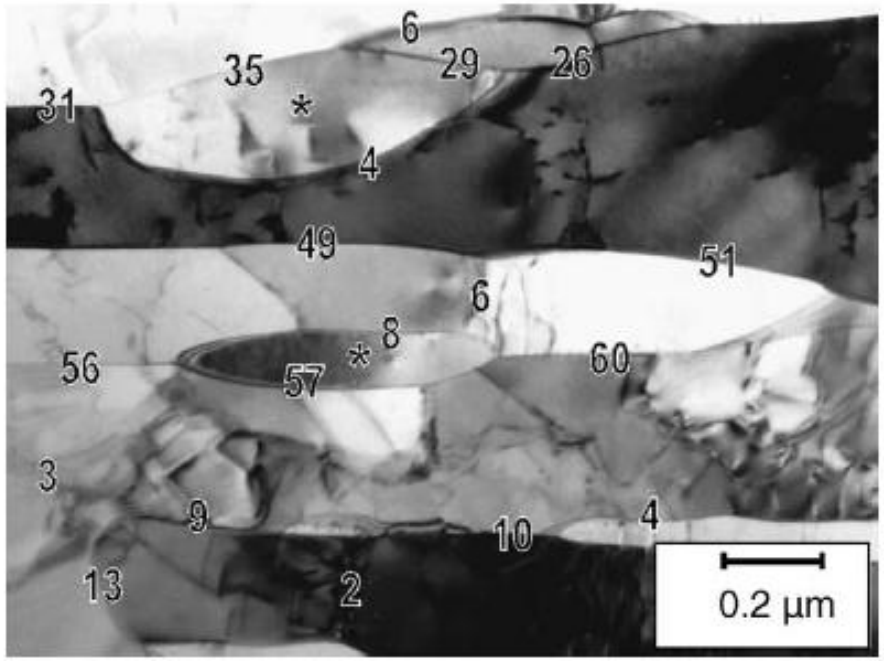


Fig. 11. Polygonization development during 2 min annealing at 625 °C of a ferritic stainless steel cold-worked to strain of 4.4. The picture represents the enlarged upper portion of Fig. 9a.The numbers indicate the (sub)boundary misorientations in degrees.

Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

Elements of Metallurgy and Engineering Alloys, Flake C. Campbell
Recovery and recrystallization in ferritic stainless steel after large strain deformation.
A. Belyakov, Y. Kimura and K. Tsuzaki

COARSENING

- Coarsening occurs after polygonization, where low angle boundaries recruit more dislocations while growing
- Fact: High angle boundaries are high energy and high mobility vs. low angle boundaries are low energy and low mobility

Mobility and grain boundaries

$1/t_{50} = A.\exp(-Q_{rex}/kT)$

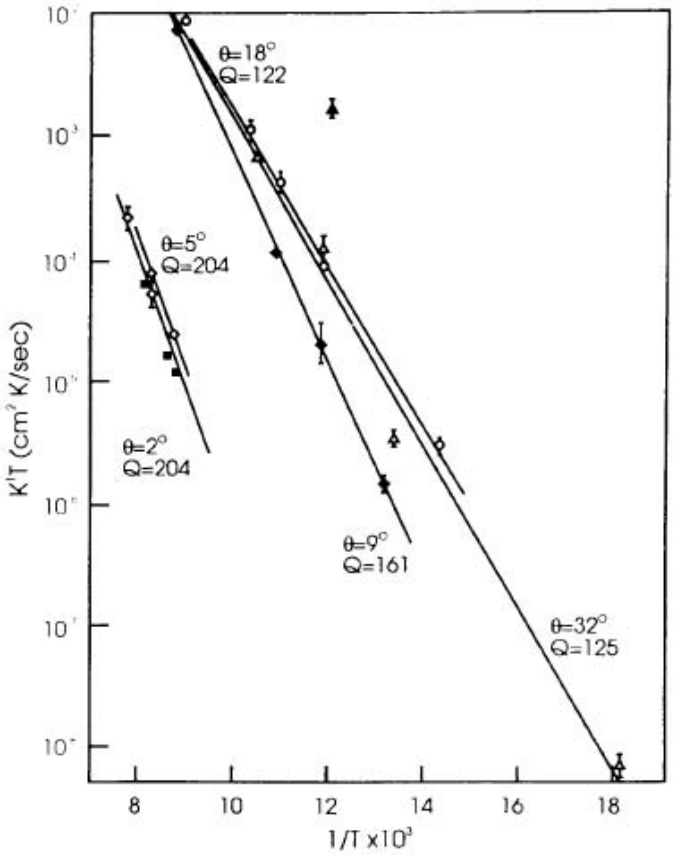
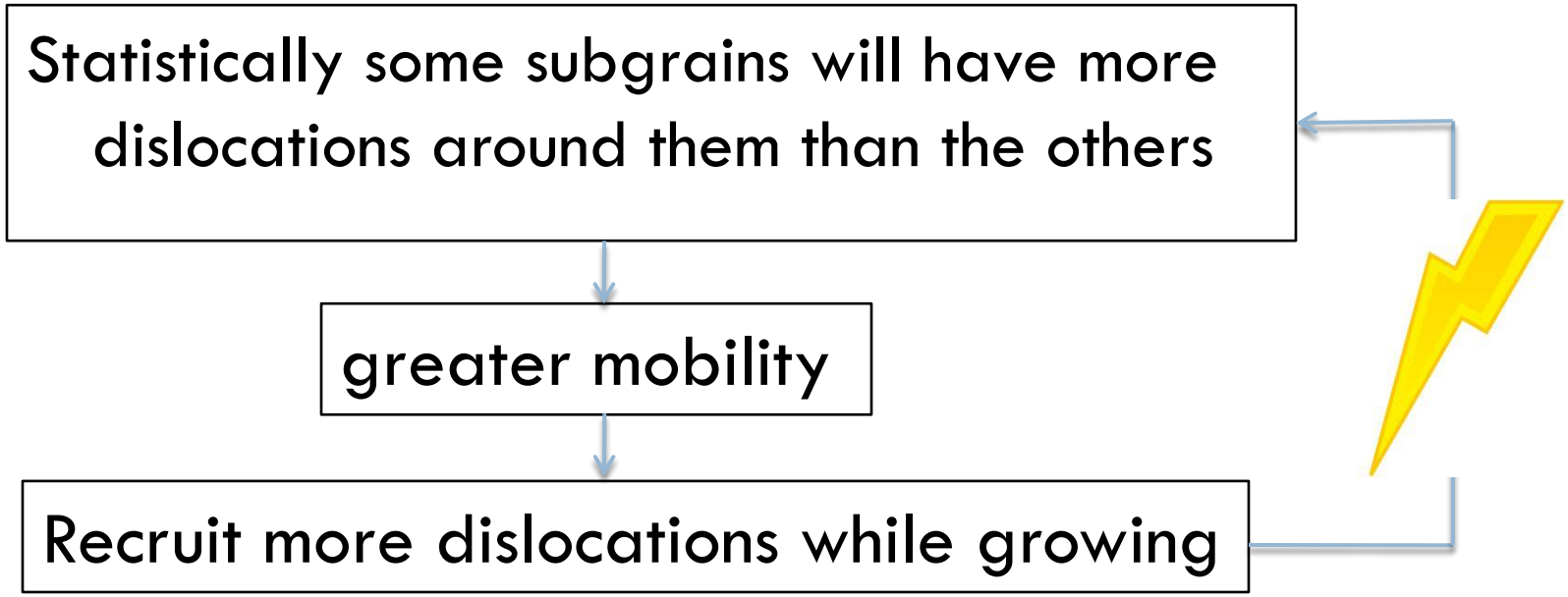


Fig. 2. The much lower mobility (K') and higher activation energy of low angle grain boundaries in high purity copper. From Humphreys and Hatherley [2] derived from the results of Viswanathan and Bauer.

Vicious cycle of growth

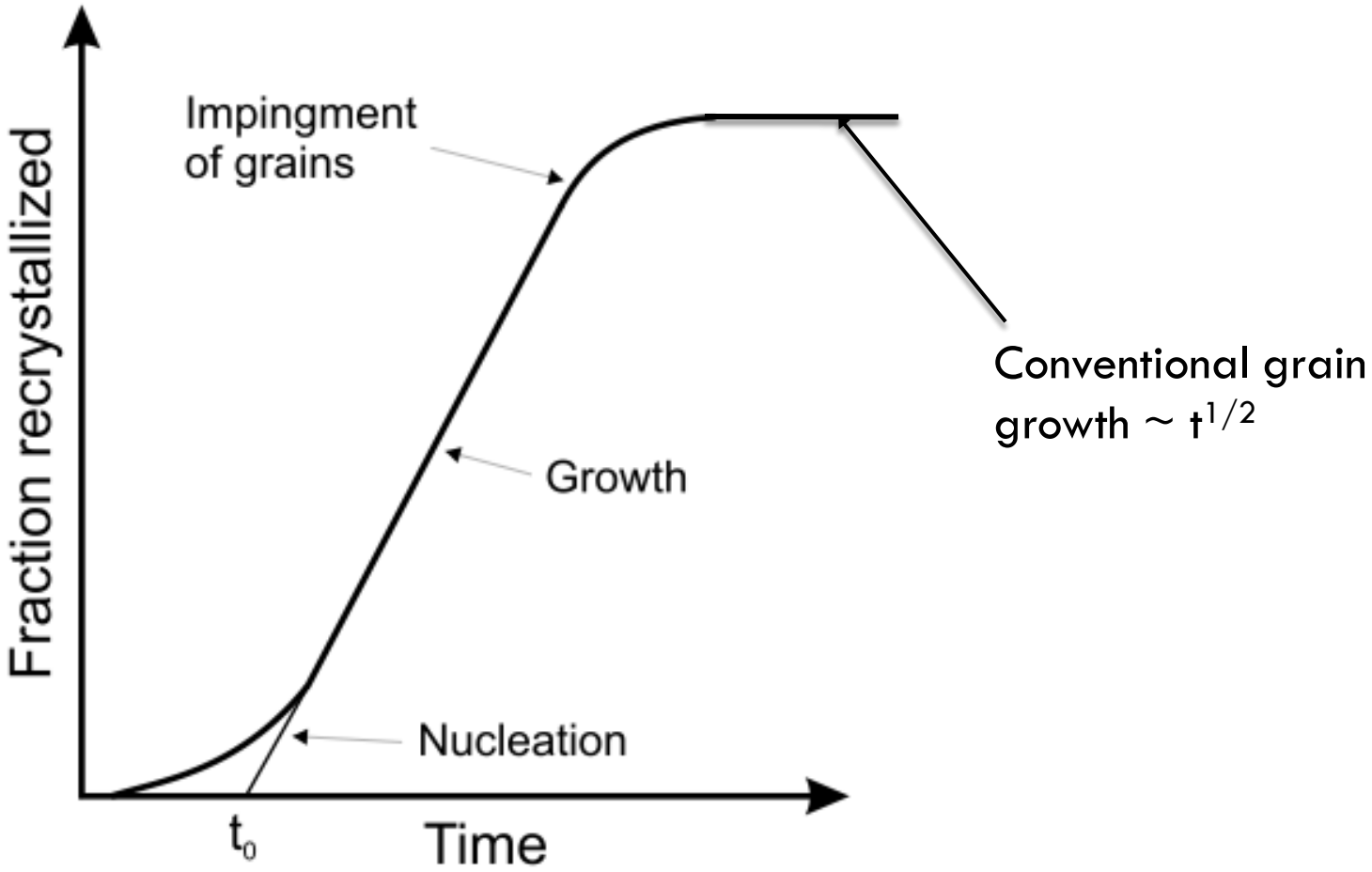


Impingement and classical growth

- Space is limited so at some point “lucky” nuclei get to touch each other and then prevent subsequent growth
- When the new grains are filling all the volume, the process of classical growth starts
- Reminder: $\sim t^{1/2}$

Driving force: minimization of interfacial energy

Again…



http://en.wikipedia.org/wiki/File:RXkinetics.svg

Variables influencing recrystallization

- **Temperature :**

High-purity copper (99.999%)

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Please see Fig. 8.16 in Campbell, F. C.
Elements of Metallurgy and Engineering Alloys.
Materials Park, OH: ASM International, 2008.

$$1/\tau = A \exp(-Q/RT)$$

Elements of metallurgy and engineering alloys, F.C Campbell

3.5 % silicon iron

1. Cold rolled 20%

2. Annealed 15 min, 500°C

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Please see Fig. 9.2 in Hull, Derek, and D. Bacon.
Introduction to Dislocations. Boston, MA: Butterworth-Heinemann, 2001.
or
Fig. 5a, 7, 9, 13a in Hu, Hsun.
"An Electron-Transmission Study of Rolled and Annealed Silicon-Iron Crystals with (112) [11-2] Orientation." *Transactions of the Metallurgical Society of AIME* 230 (April 1964): 572-580.

3. Annealed 15 min, 600°C

4. Annealed 30 min, 600°C

Introduction to dislocations, D Hull, Third Edition

Definition of a recrystallization temperature :

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Please see Fig. 8.15 in Campbell, F. C.
Elements of Metallurgy and Engineering Alloys.
Materials Park, OH: ASM International, 2008.

$$0.3\ T_m < Tr < O.5\ T_m$$

Elements of metallurgy and engineering alloys, F.C Campbell

□ Strain :

Aluminum

Alpha brass

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Please see Fig. 8.17 in Campbell, F. C.
Elements of Metallurgy and Engineering Alloys.
Materials Park, OH: ASM International, 2008.
Fig. 8.21 in Reed-Hill, Robert E., and Reza Abbaschian.
Physical Metallurgy Principles. Boston, MA: PWS Publishing, 1994.

ε ↗ , τ and Tr ↘

Existence of a criticalstrain

Elements of metallurgy and engineering alloys, F.C Campbell / Physical Metallurgy principles, Reed Hill, Third Edition

□ Initial grain size :

Dg ↗ , τ and Tr ↗

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The original grain size is determined by :

-The amount of cold work

- The working temperature

Elements of metallurgy and engineering alloys, F.C Campbell

□ Purity of the metal :

Aluminium, cold rolled 80%

Image removed due to copyright restrictions. Please see Fig. 8.23 in Reed-Hill, Robert E., and Reza Abbaschian. *Physical Metallurgy Principles*. Boston, MA: PWS Publishing, 1994.

Added Element (0.01 atomic percent)	Increase in recrystallization temperature (K) for pure copper
Ni	0
Co	15
Fe	15
Ag	80
Sn	180
Te	240

Physical Metallurgy principles, Reed Hill, Third Edition

QUESTIONS ?

3.40J / 22.71J / 3.14 Physical Metallurgy

Fall 2009