Westfälische Wilhelms-Universität Münster

Short-Circuit Diffusion in Recrystallizing Microstructure: Diffusion Properties of a Recrystallization Front

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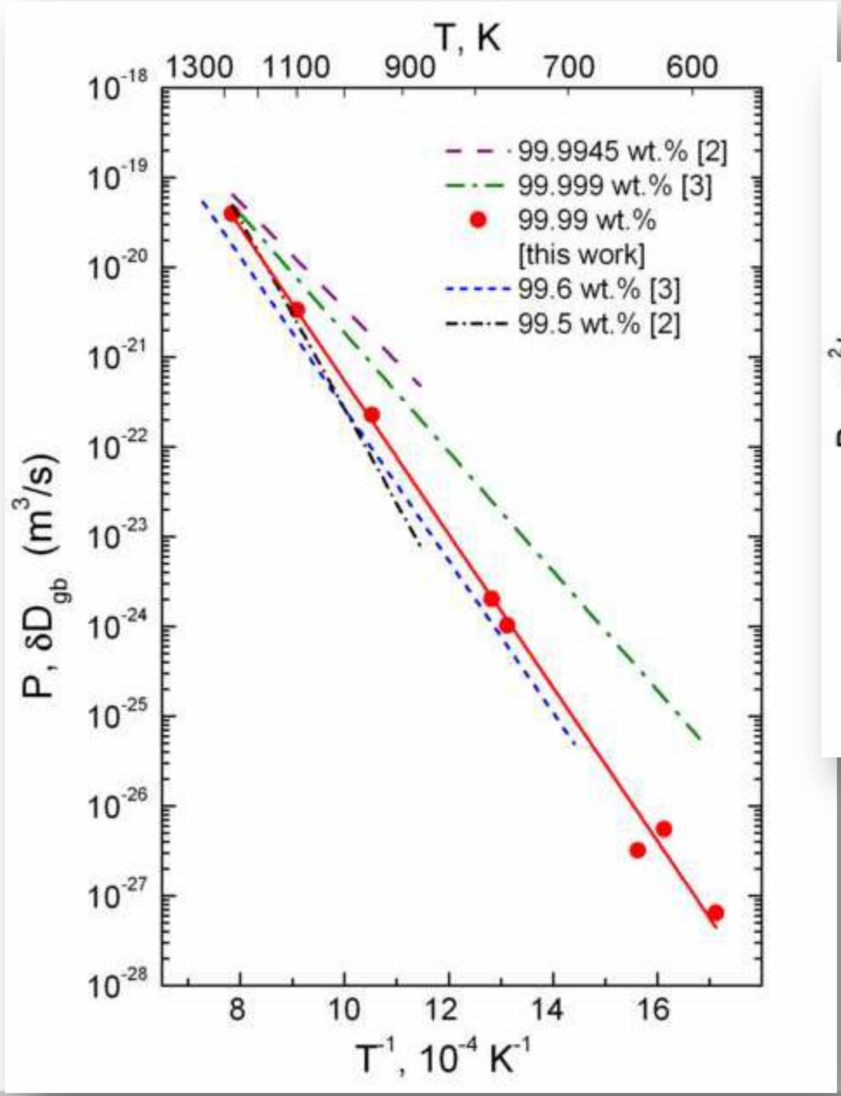
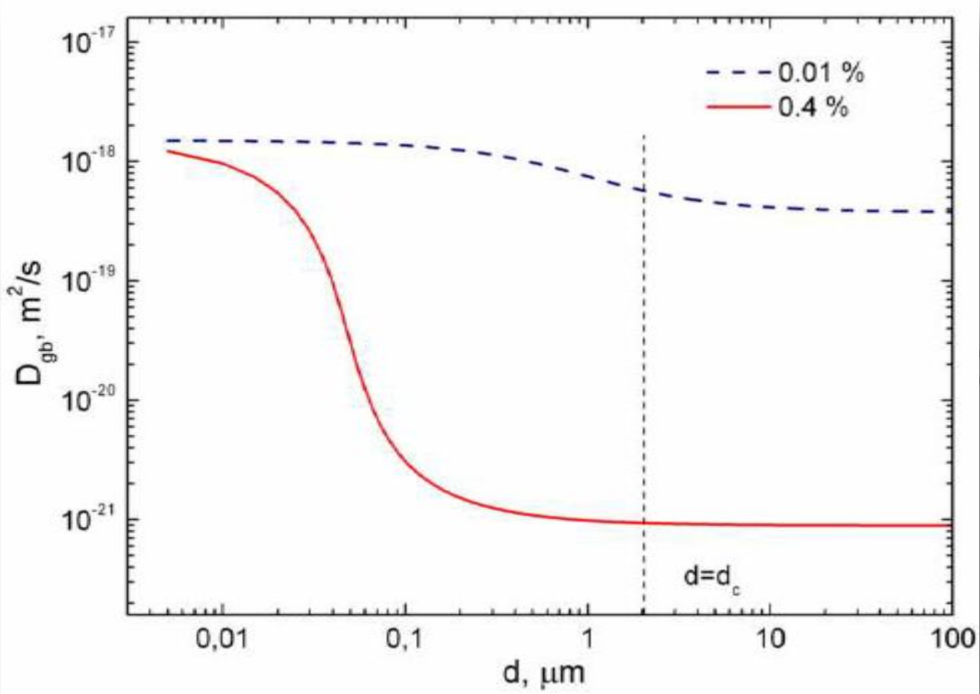
OUTLINE

- Types of interfaces in recrystallizing material
- “Recrystallization front”
- Diffusion properties of stationary boundaries
- Diffusion enhancement in moving boundary

GB diffusion in coarse-grained Ni

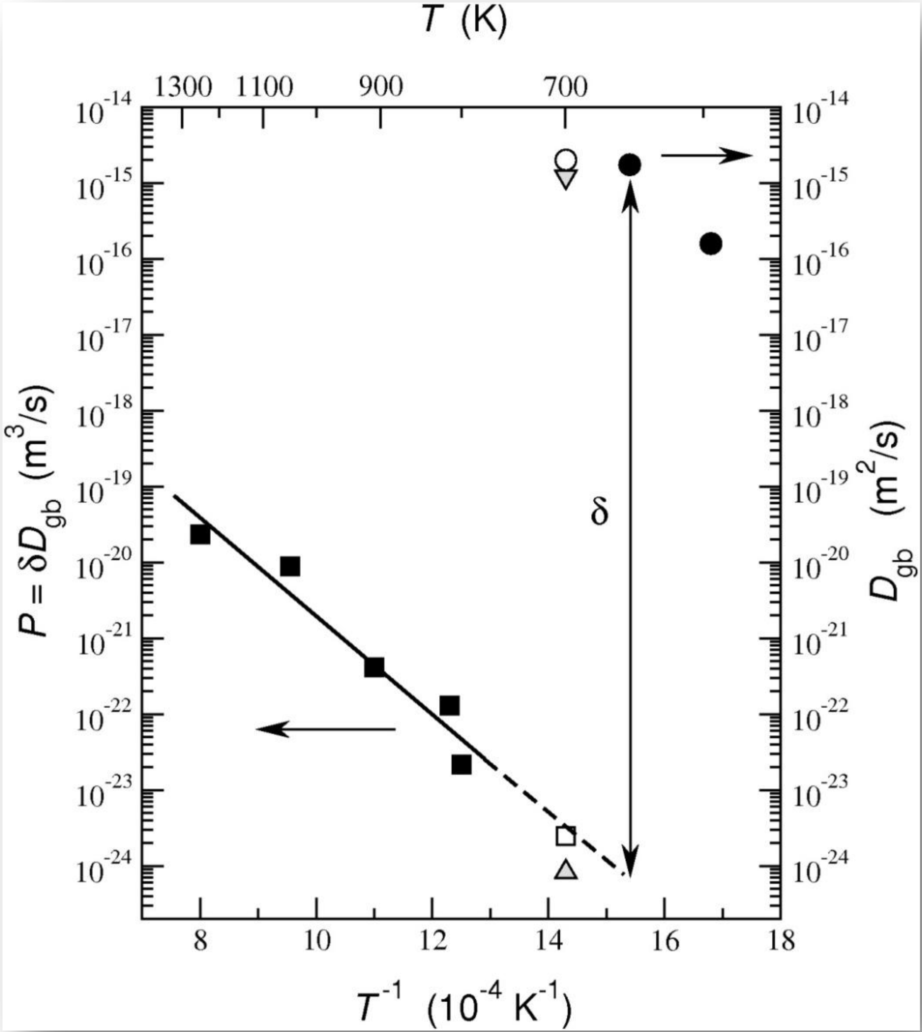




Effect of grain size and purity on GB diffusion

Prokoshkina, Esin, Wilde, S.D., Acta Mater (2013)

Grain boundary width



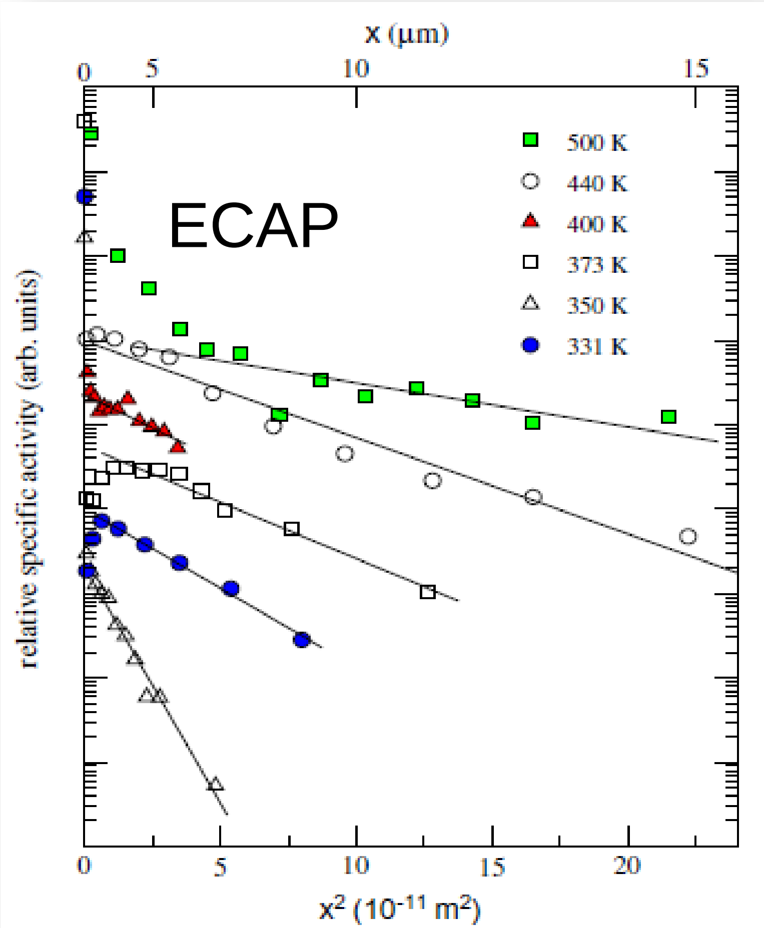
Material	Tracer	δ (nm)
Ni (5N, 4N)	^{63}Ni	0.54±0.1
NiO	^{63}Ni	0.7*
Ag	^{110m}Ag	0.43±0.27**
Ag	^{110m}Ag	0.5***
γ-FeNi	^{59}Fe	0.5
γ-FeNi	^{63}Ni	0.55±0.43
α-Fe	^{59}Fe	0.5****
α-Ti	^{44}Ti, ^{57}Co	0.5
Ag	^{110m}Ag	0.5

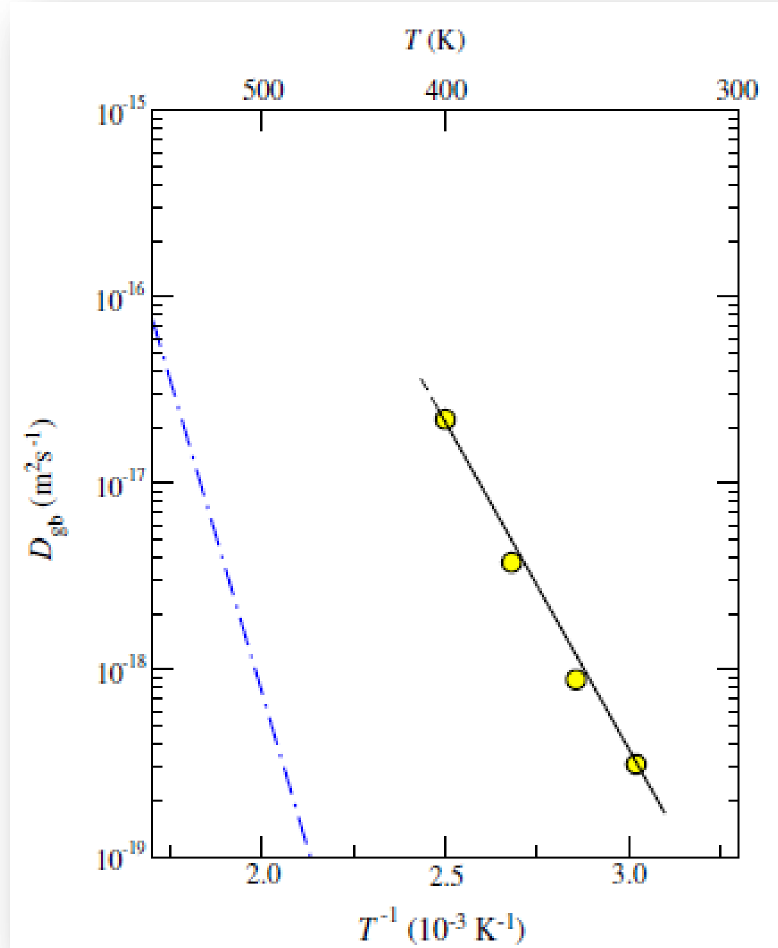
* Atkinson&Taylor, 1981
** Sommer & Herzig, 1992
*** Bernardini et al, 1992
**** Iijima et al., 2007
Divinski et al, 2003, 2004, 2009, 2010, 2013

Types of short-circuit paths in deformed polycrystal

- Dislocations
- Dislocation walls, low-angle grain boundaries
- High-angle grain boundaries
  - General (random)
  - Special (sigma), twin boundaries
- **Deformation-modified interfaces**
  (higher energy, higher coefficient of self-diffusion, strain fields)

GB diffusion in SPD Ni (99.6 wt.%)





Deformation-induced enhancement of GB diffusion in SPD Ni

Divinski, Reglitz, Wilde, Acta Mater (2011)

Types of short-circuit paths in a polycrystal

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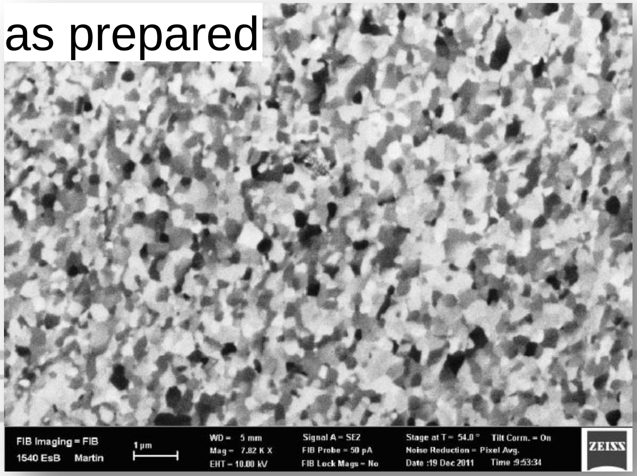
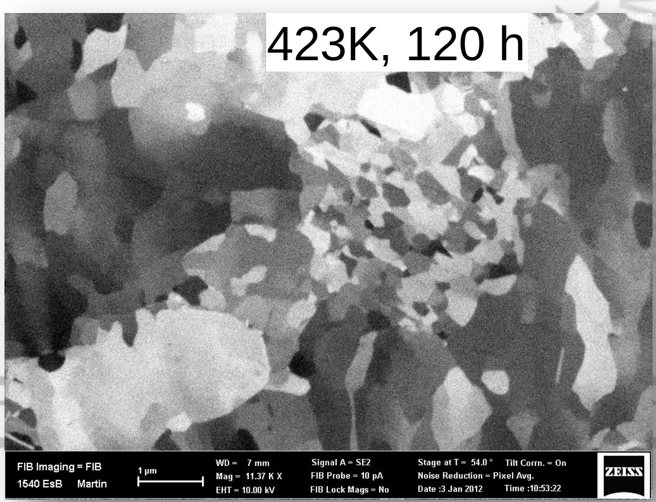
heterogenous recrystallization

- Boundaries between newly appeared grains
- Boundaries between new and old (deformed) grains

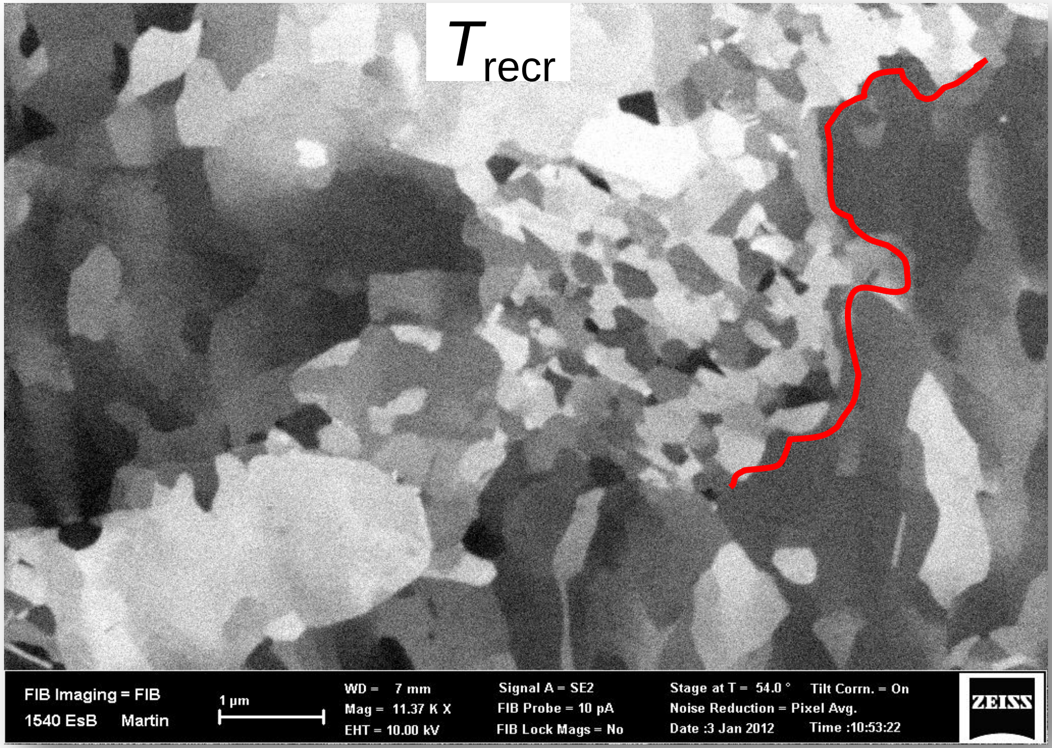


Deformed Ni



Properties of the recrystallization front

Two strategies

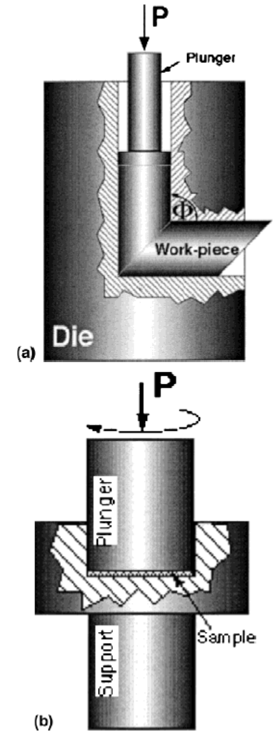


Diffusion experiments at $T < T_{recr}$
$\Rightarrow$ stationary recrystallization front

Diffusion experiments at $T = T_{recr}$
$\Rightarrow$ mobile recrystallization front

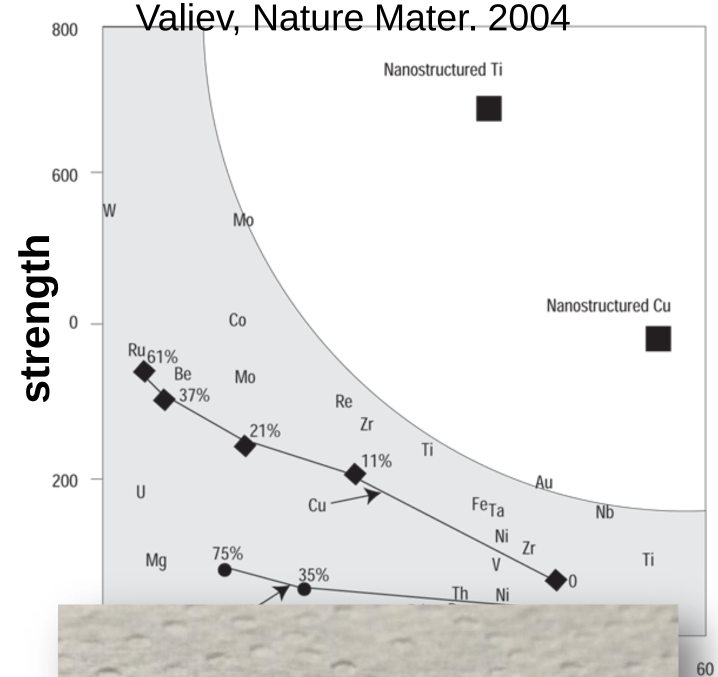
Short-circuit diffusion in deformed materials

- Rolling to 80%
- High-pressure torsion
- Radiotracer diffusion as a unique and sensitive probe for detecting changes of the interface structure

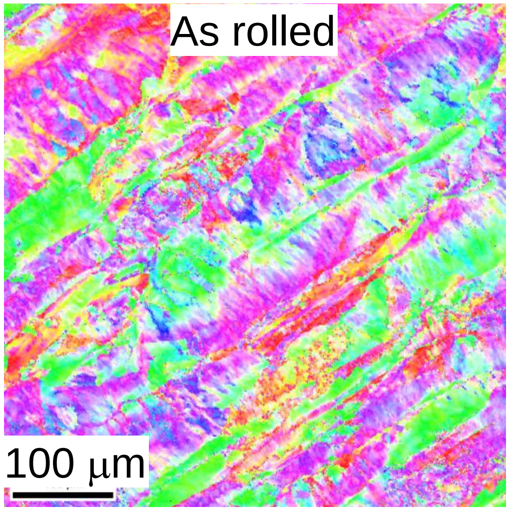


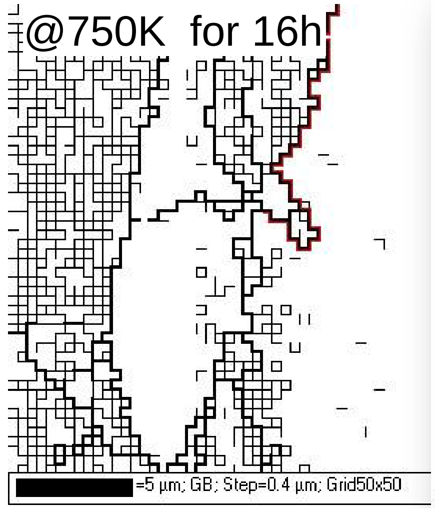
R.Z. Valiev, et al.,
J. Mater. Res., 2002

Valiev, Nature Mater. 2004

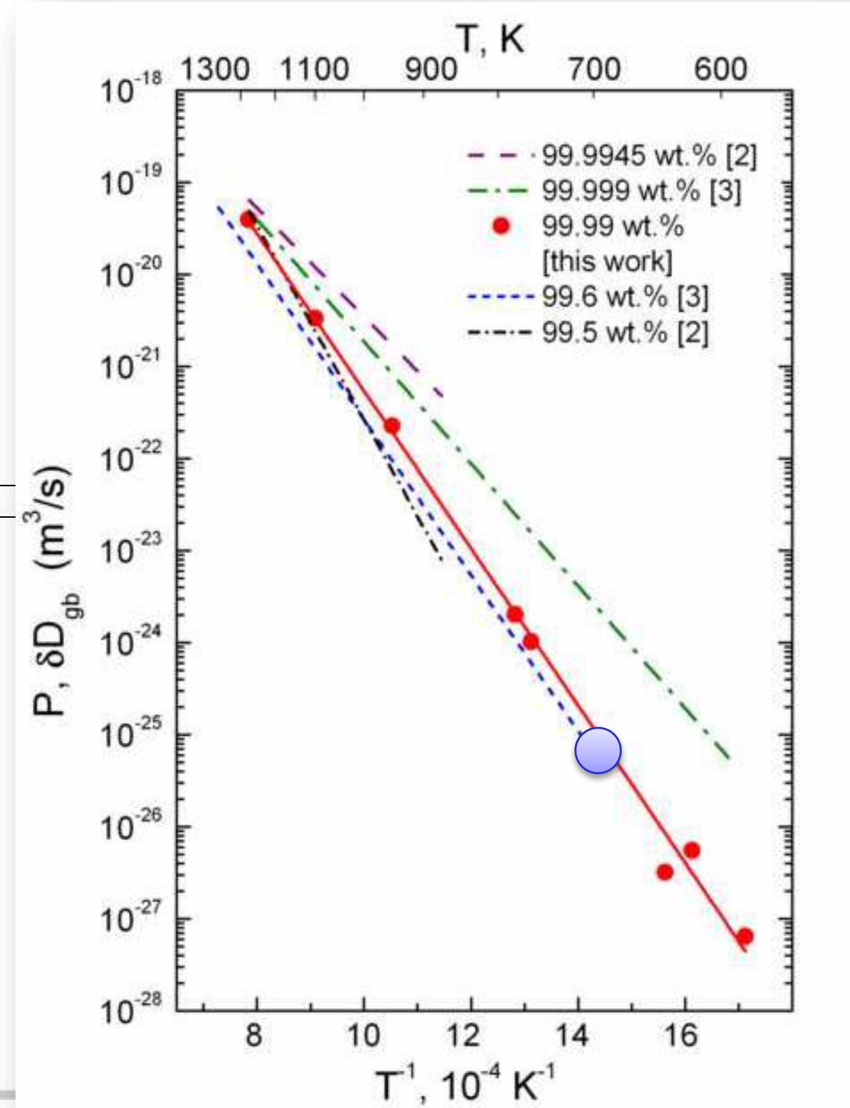


Partially recrystallized rolled Ni (99.6wt%)

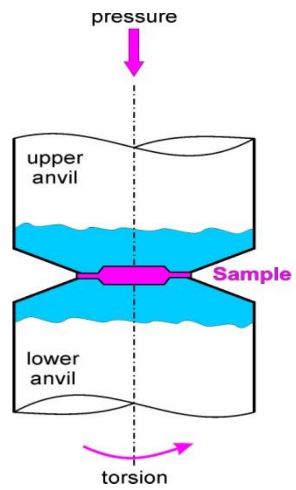


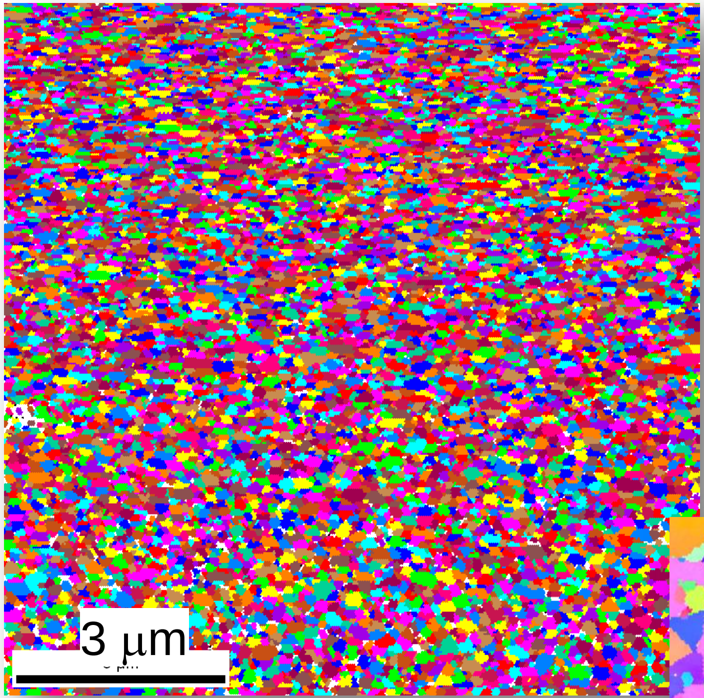


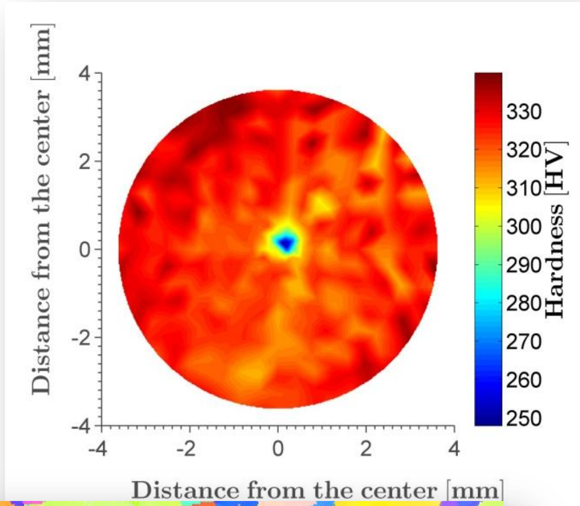
- no measurable diffusion enhancement at T ≤ 700 K
- **Kinetic properties of stable recrystallization front correspond to those of general high-angle GBs**

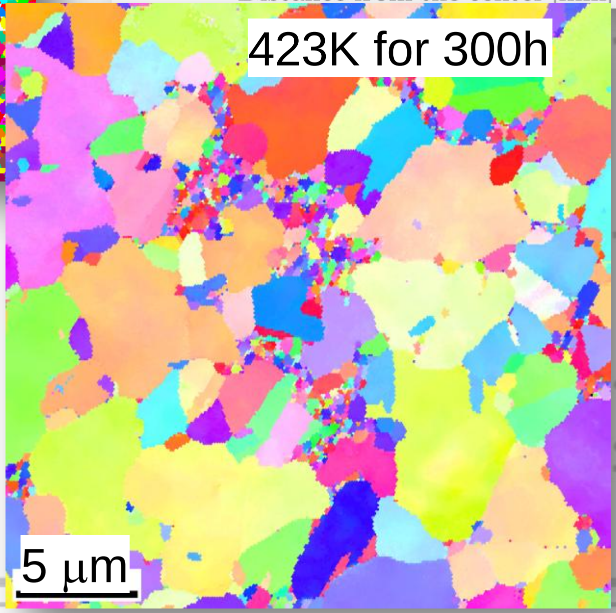


Diffusion and recrystallization in HPT Ni (99.99wt.%)





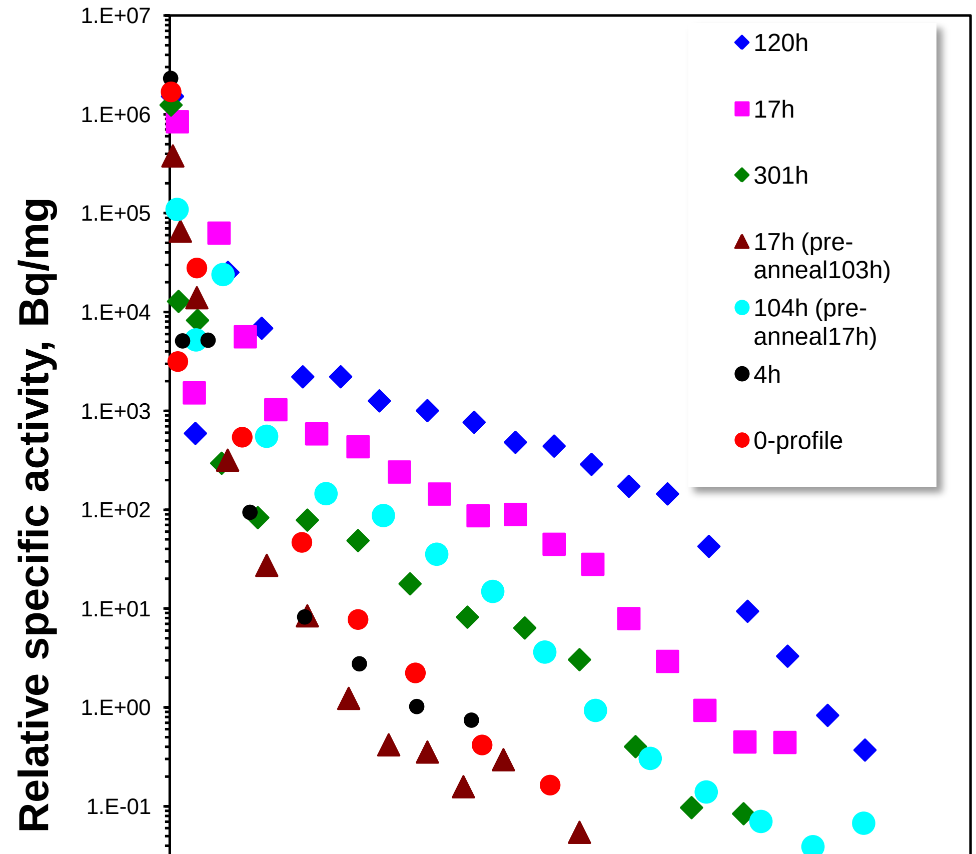




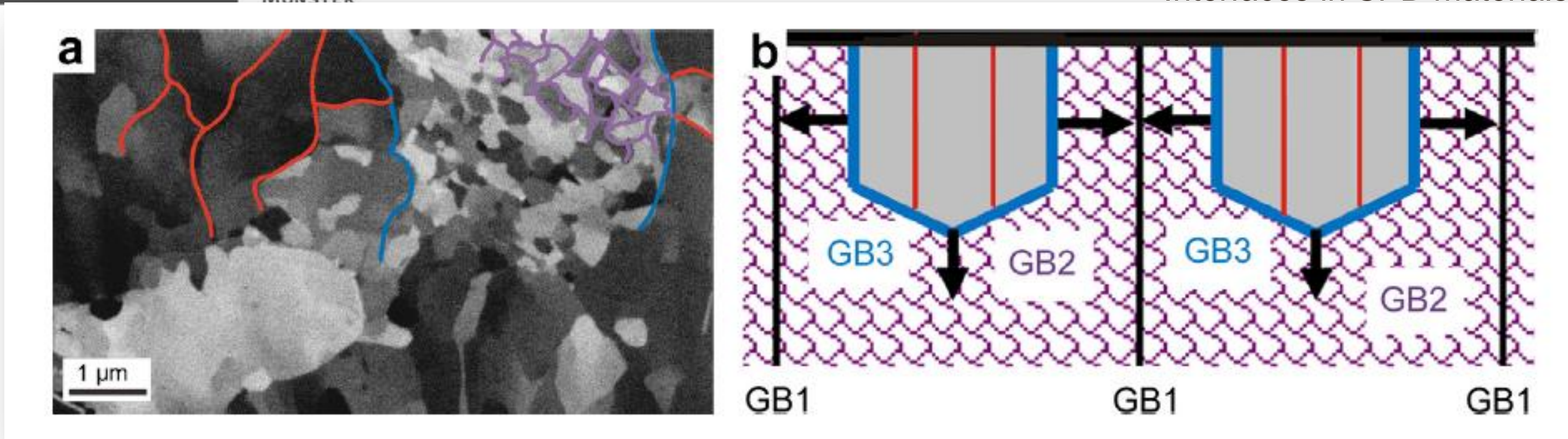
- 4N Ni is less stable against recrystallization / grain growth as 2N6 Ni
- Pronounced recrystallization at 423 K

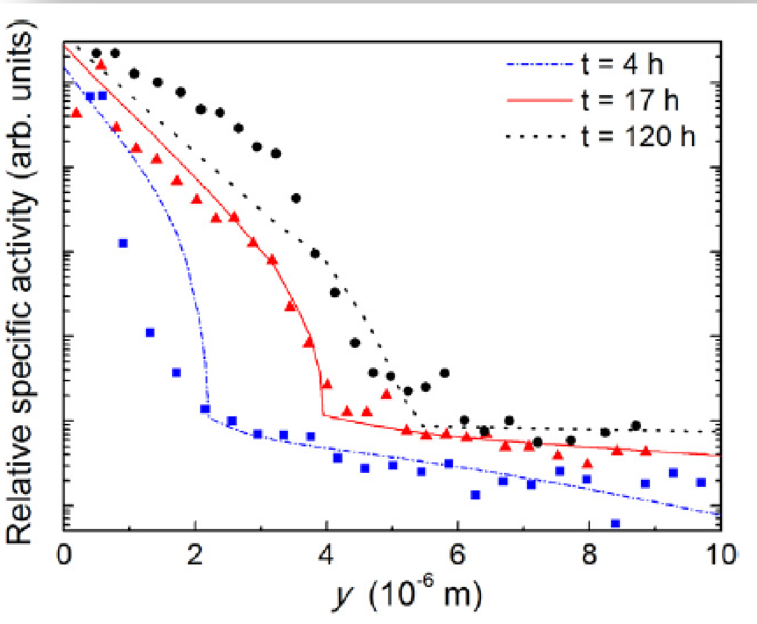
Diffusion in HPT Ni (99.99 wt.%)

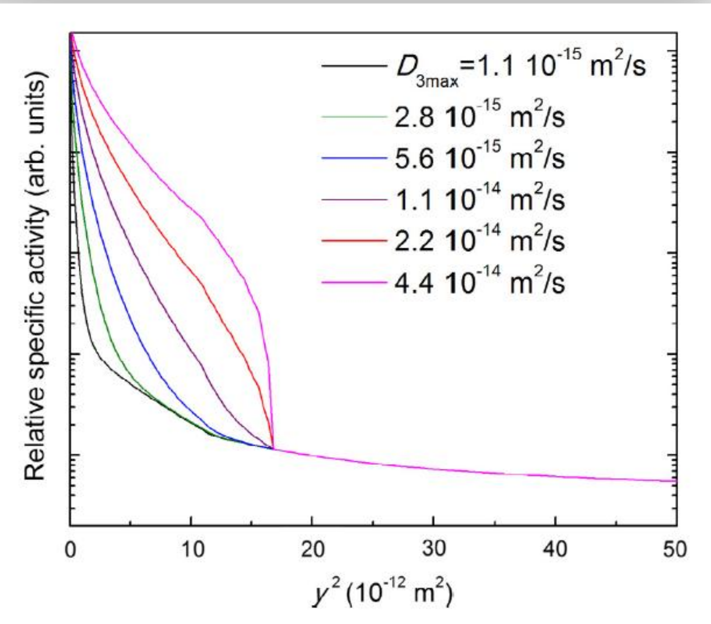
- **Diffusion component associated with deformation-induced state of GBs**
- **Diffusion component associated with new grain boundaries:**
- Diffusion depths grow first
  0h = 4h < 17h < 120h
  and then decreases
  120h > 301h
- Characteristic “kink” in the profiles measured for 17 and 120h
- No measurable diffusion after 104h pre-annelaing



- New GBs correspond to relaxed high-angle GBs
- **moving recrystallization front** reveals enhanced diffusivity
- stationary recrystallization front does not







Prokoshkina, et al, Acta Mater (2014)

Diffusion in SPD materials

Nickel:

- Deformation-induced diffusion enhancement
- Recrystallization:
  - intricate interplay of grain growth and purity on diffusivity of new GBs
  - Stationary recrystallization front reveals no measurable diffusion enhancement
  - Mobile recrystallization front represents a fast-diffusion path

Copper

- Enhanced GB diffusion in fully recrystallized microstructure at T<500K
- „normal" GB diffusion in microstructures recrystallized at T>600 K

Silver

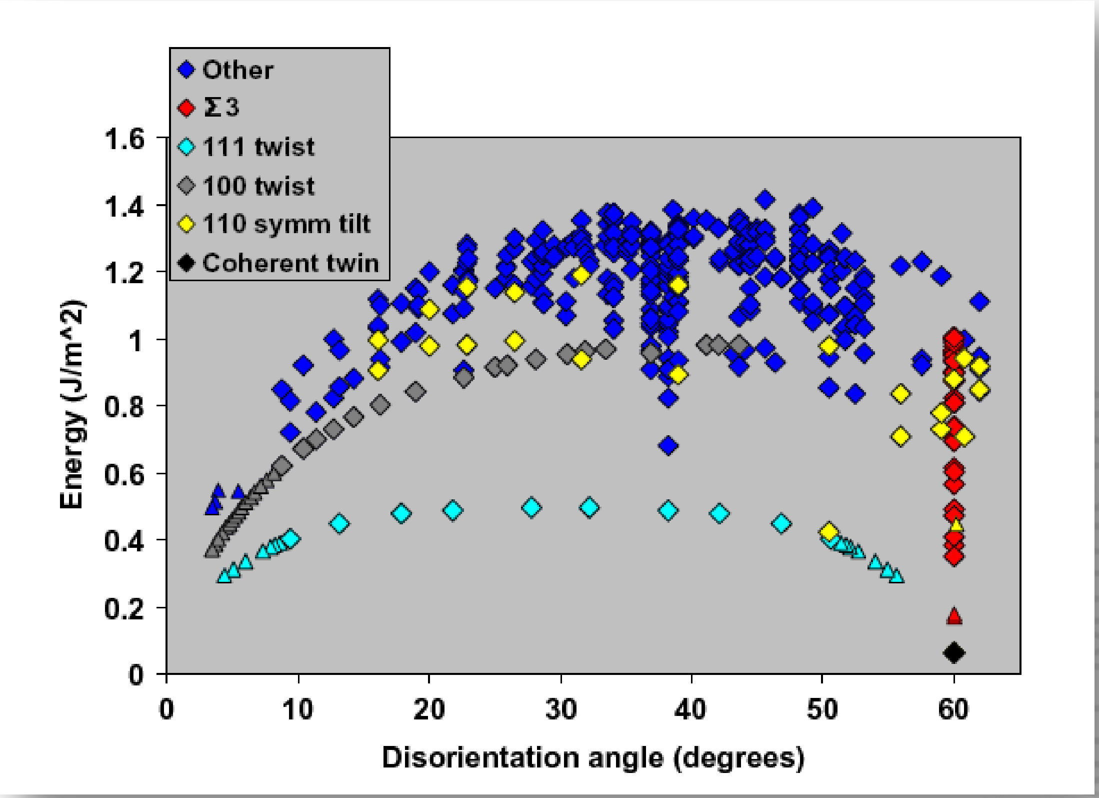
- Enhanced GB diffusion in dynamically recrystallized microstructure
- „Normal" GB diffusion after recrystallization at T > 500 K

Effect of free volume redistribution/annihilation

$\Rightarrow$ formation of voids and interconnected porosity

Energy of high-angle GBs

- Many „high energy” grain boundaries
- „constrained“ recrystallisation at low temperature creates a high fraction of „high energy” grain boundaries



E. A. Holm et al., Acta Mater., 57, 3694-3703 (2009)

⇒ Ostwald step rule