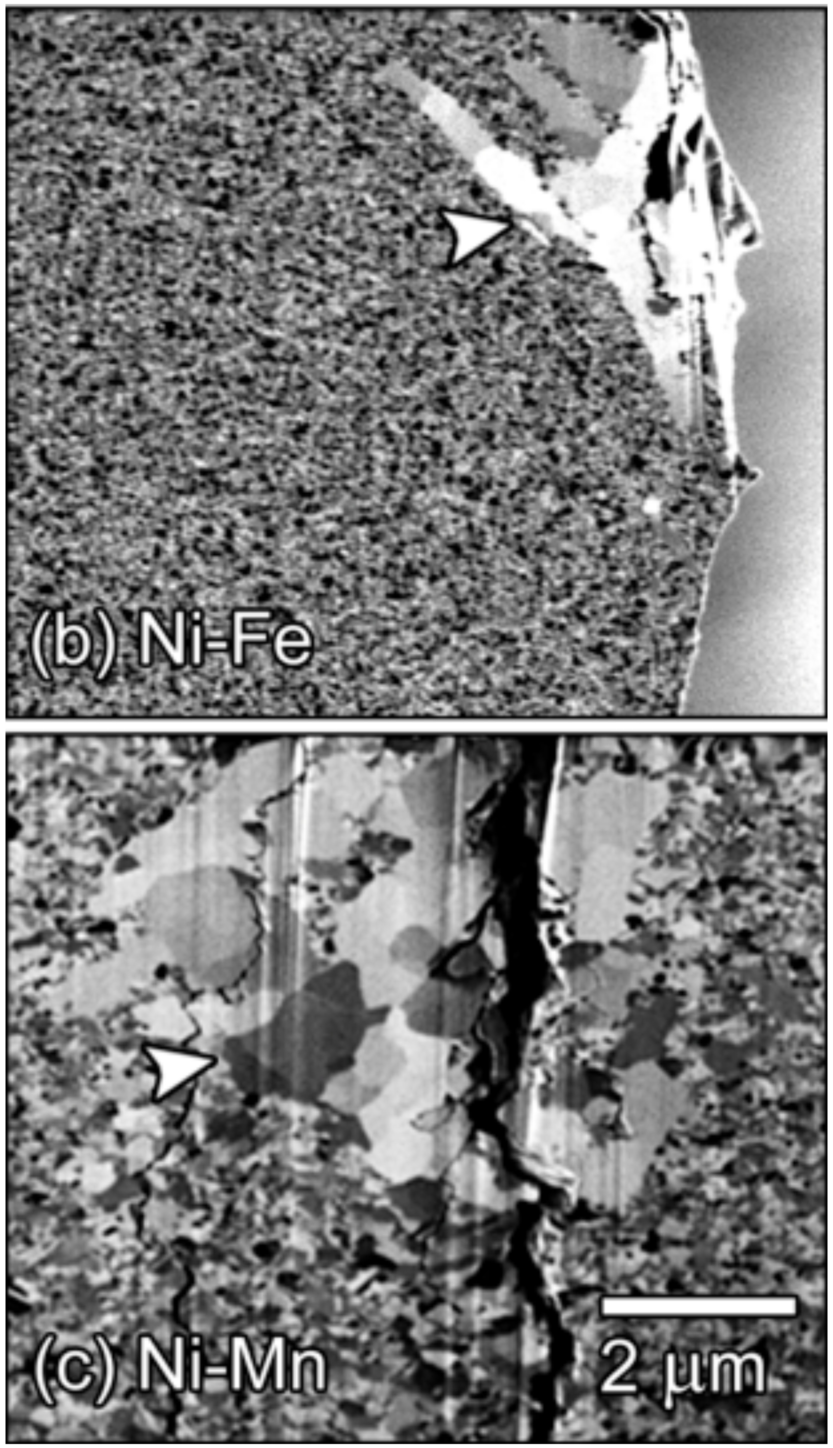
SAND2012-1412C

The Enhancement of Grain Growth in Copper During Microindentation at Low Temperatures

Corbett Battaile,
Henry Padilla, Garritt Tucker,
Brad Boyce, Stephen Foiles, Elizabeth Holm
Sandia National Laboratories
Albuquerque NM 87185

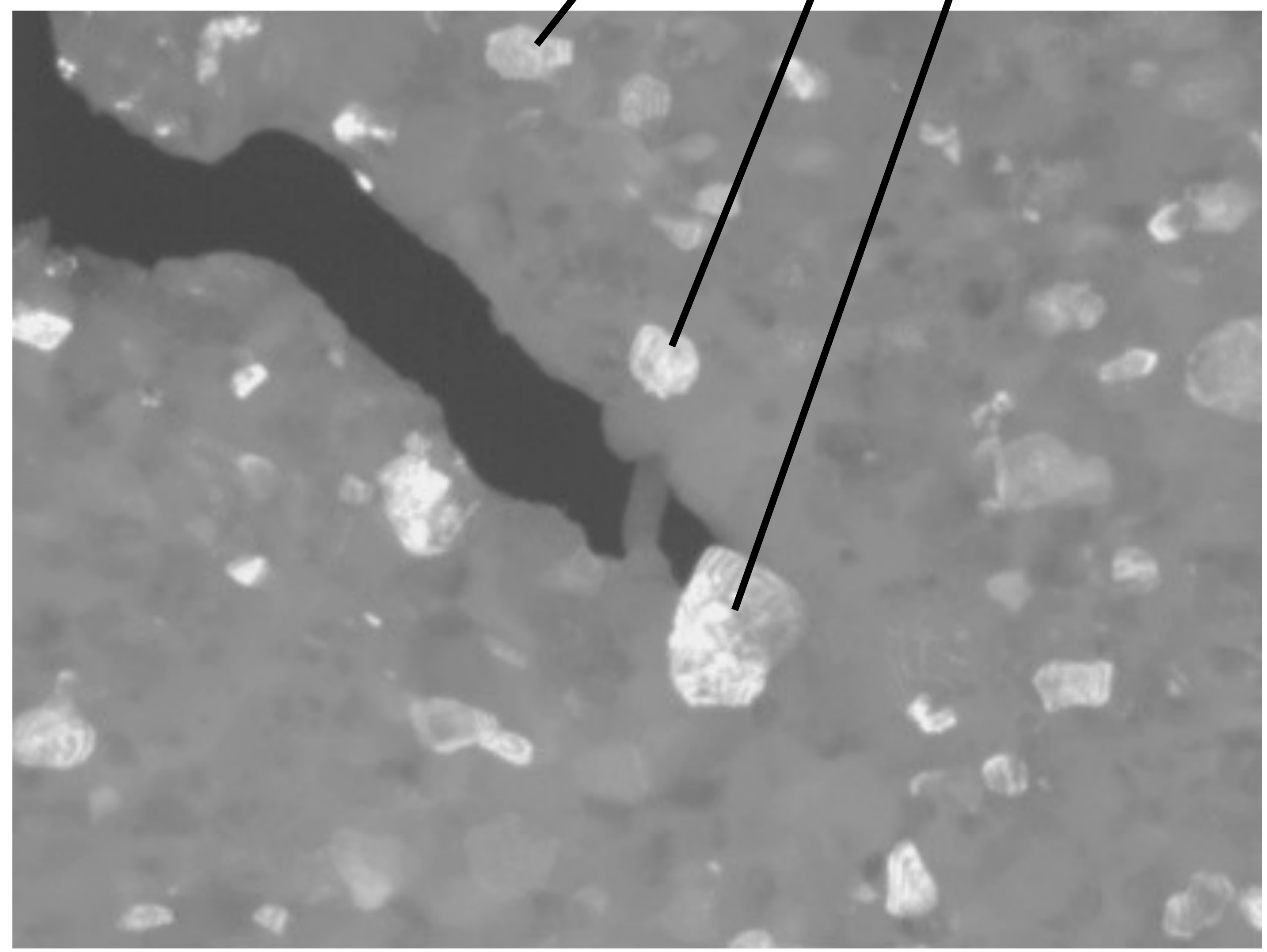
Introduction: Why do we care?

Deformation can have a profound impact on grain growth.



Grains coarsening near fatigue cracks[1] in Ni alloys

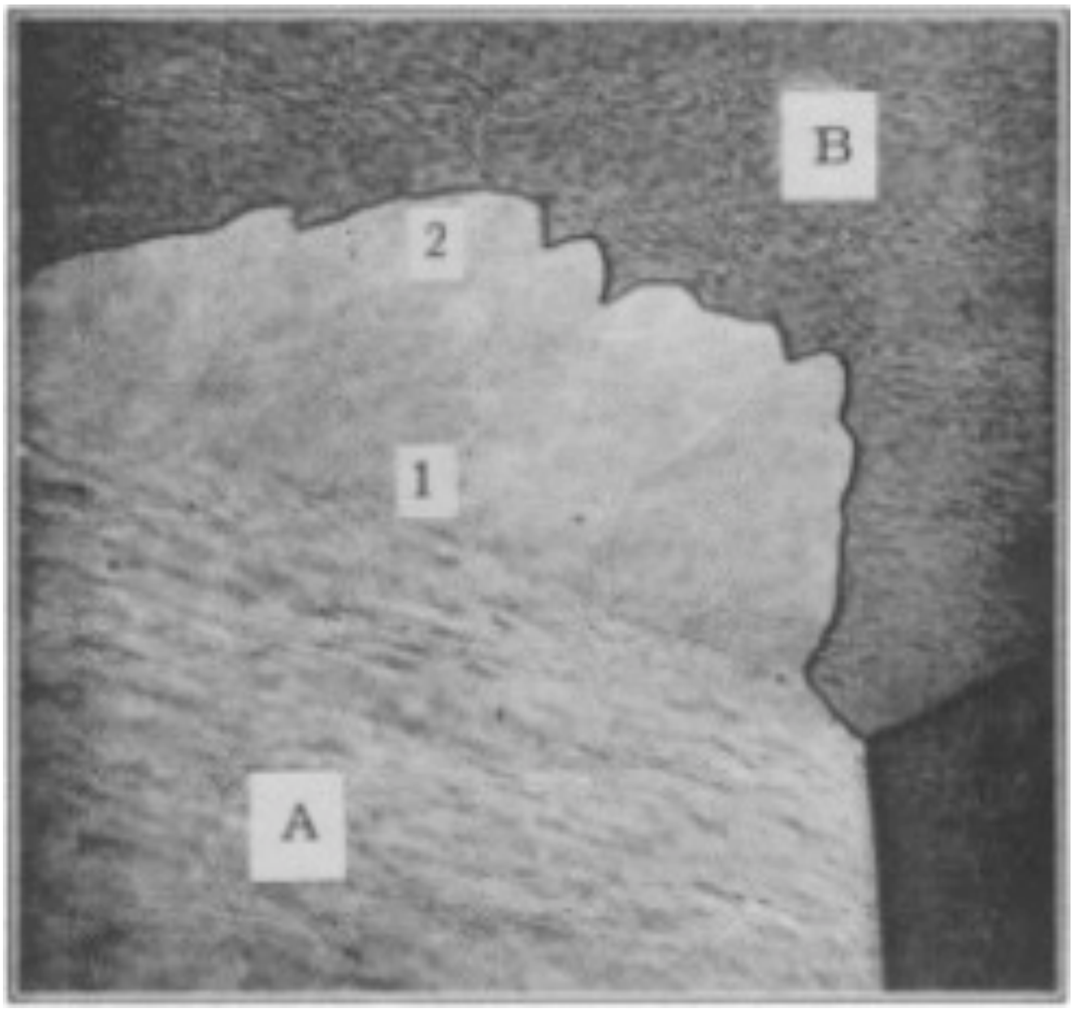
Grains coarsening in the stress field generated by an advancing crack[2] in Al



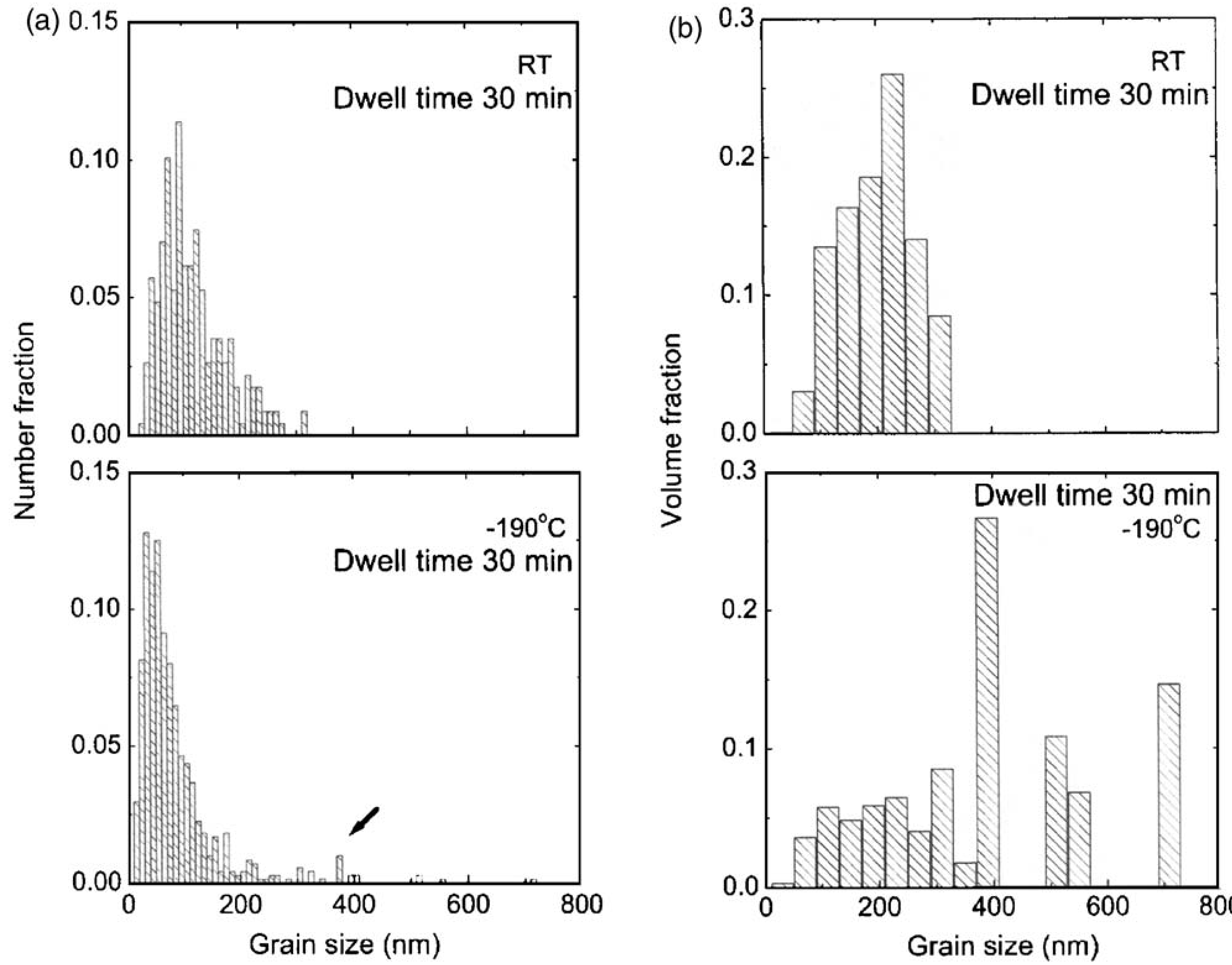
1) Boyce and Padilla, *Met. Trans. A* **42** (2011) 1793.
2) Legros, Gianola, and Hemker, *Acta Mater.* **56** (2008) 3380.

Introduction: Why do we care?

Deformation can have a profound impact on grain growth.



Strain-induced boundary migration[3]
in deformed Al



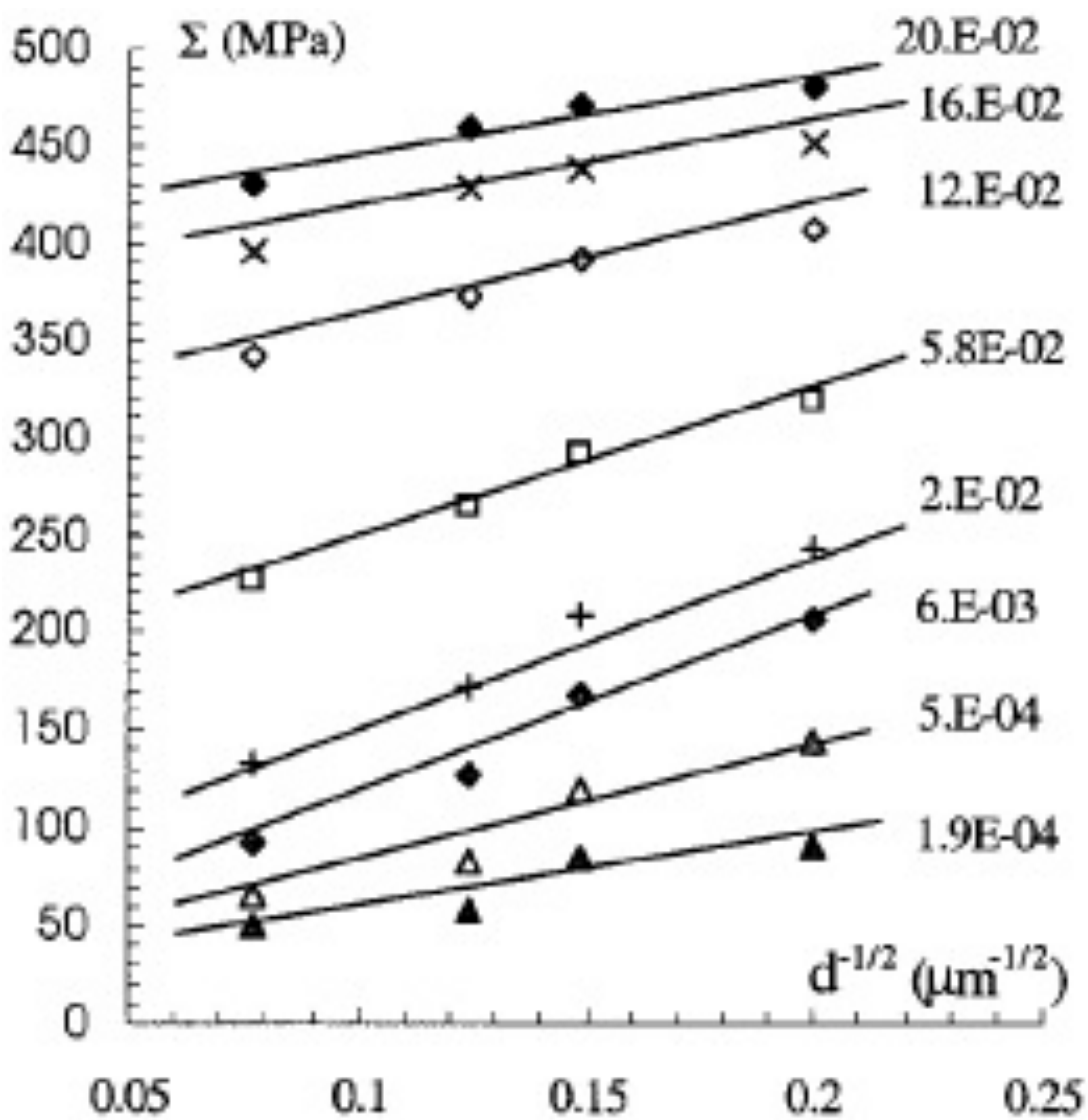
Low-temperature enhancement of grain growth[4]
in indented nanocrystalline Cu

3) Beck and Sperry, *J. Appl. Phys.* **21** (1950) 150.

4) Zhang, Weertman, and Eastman, *Appl. Phys. Lett.* **87** (2005) 061921.

Introduction: Why does grain size matter?

Grain size can have a profound effect on properties.



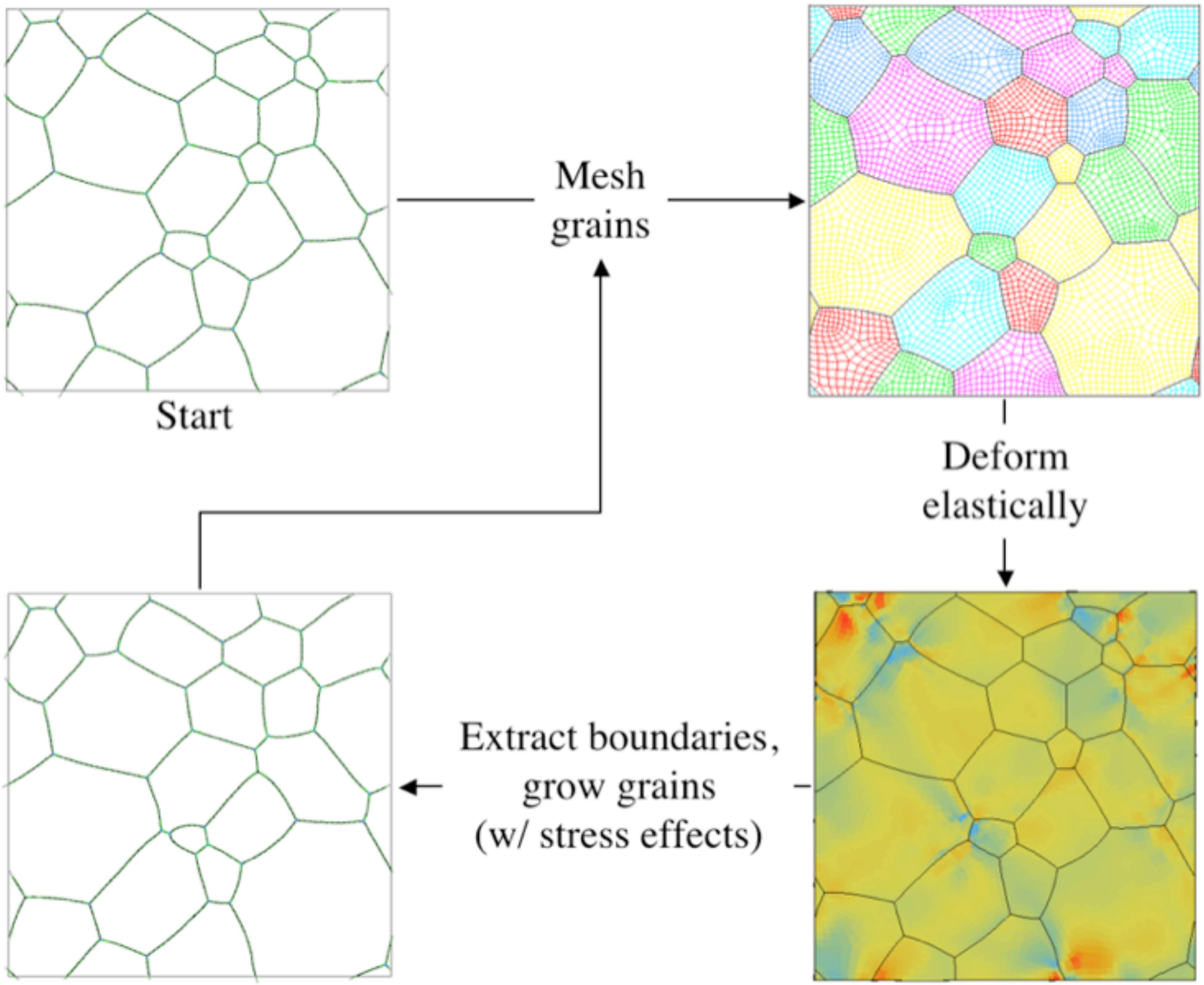
Hall Petch effect[5] in Ni

In addition, nanocrystalline metals can be highly unstable even at low temperatures, such that their micro-structures evolve far from the initial and intended state.

5) Feaugas and Haddou, *Met. Trans.* **34A** (2003) 2329.

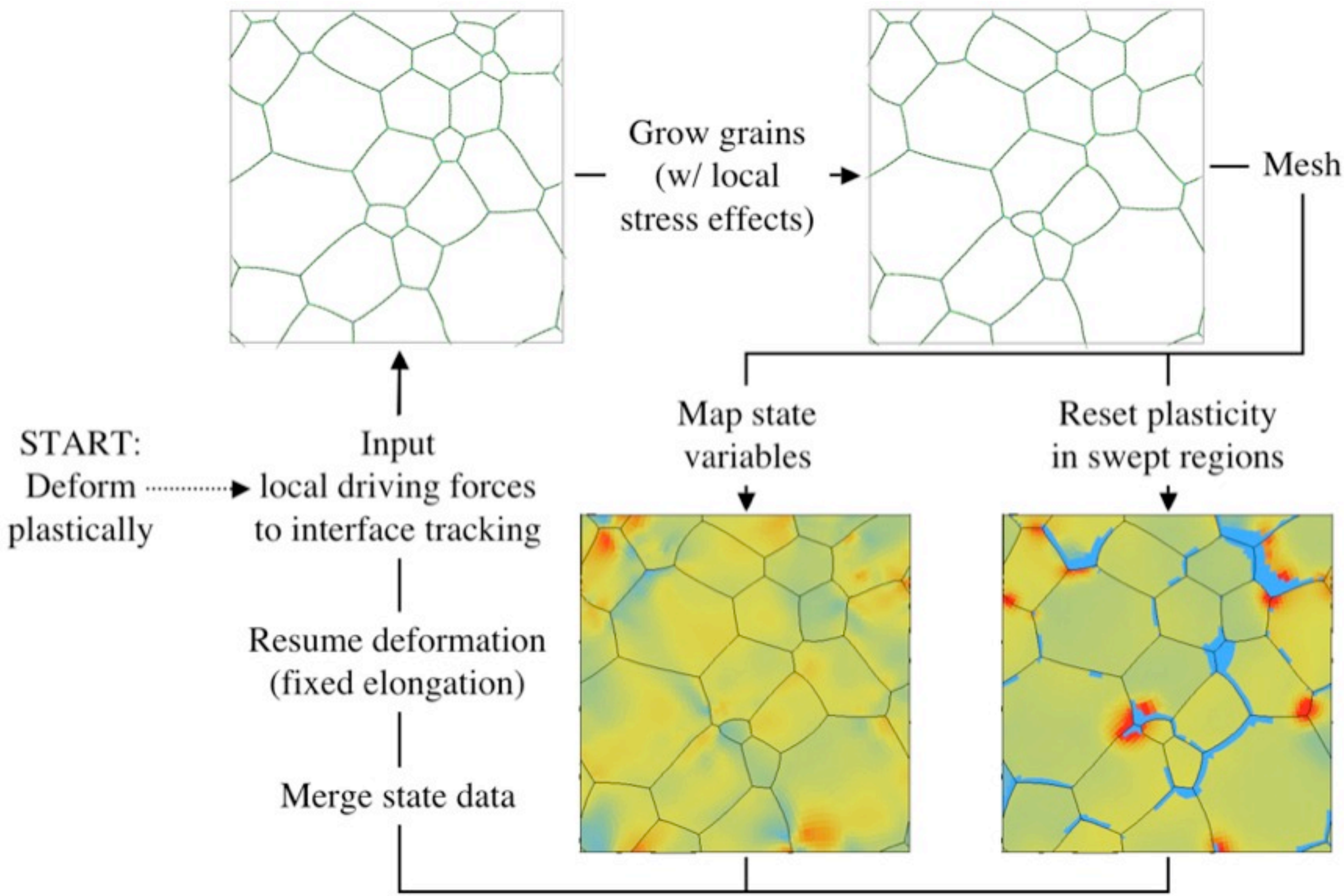
Background: Grain growth during elastic loading

Our earlier work examined this interaction via simulations.



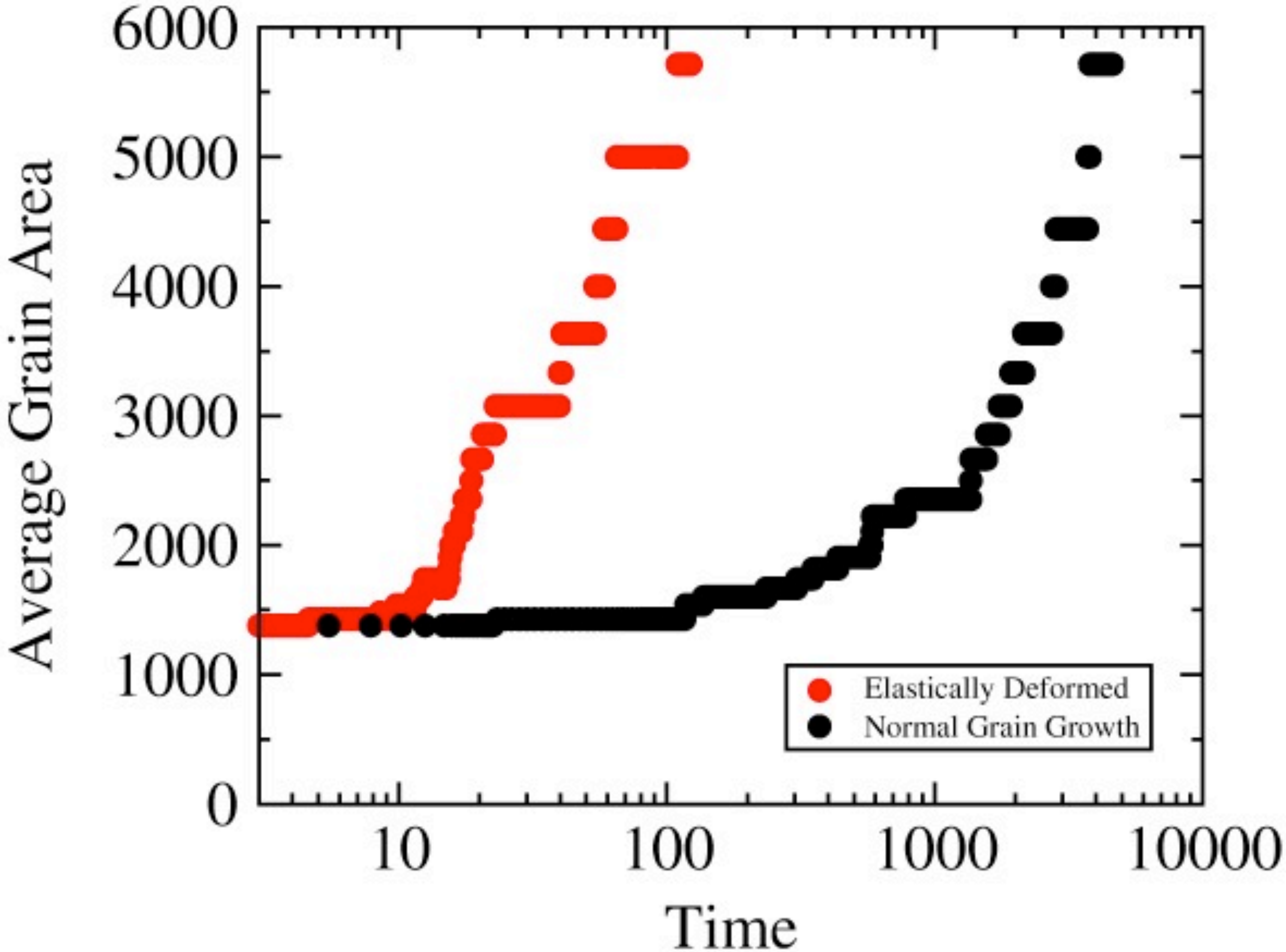
Background: Grain growth during plastic loading

The approach that includes plasticity
is similar but more complicated.



Background: Deformation accelerates grain growth

When plasticity is operative (black), grains grow much more slowly than when only elasticity was allowed (red).



Overview

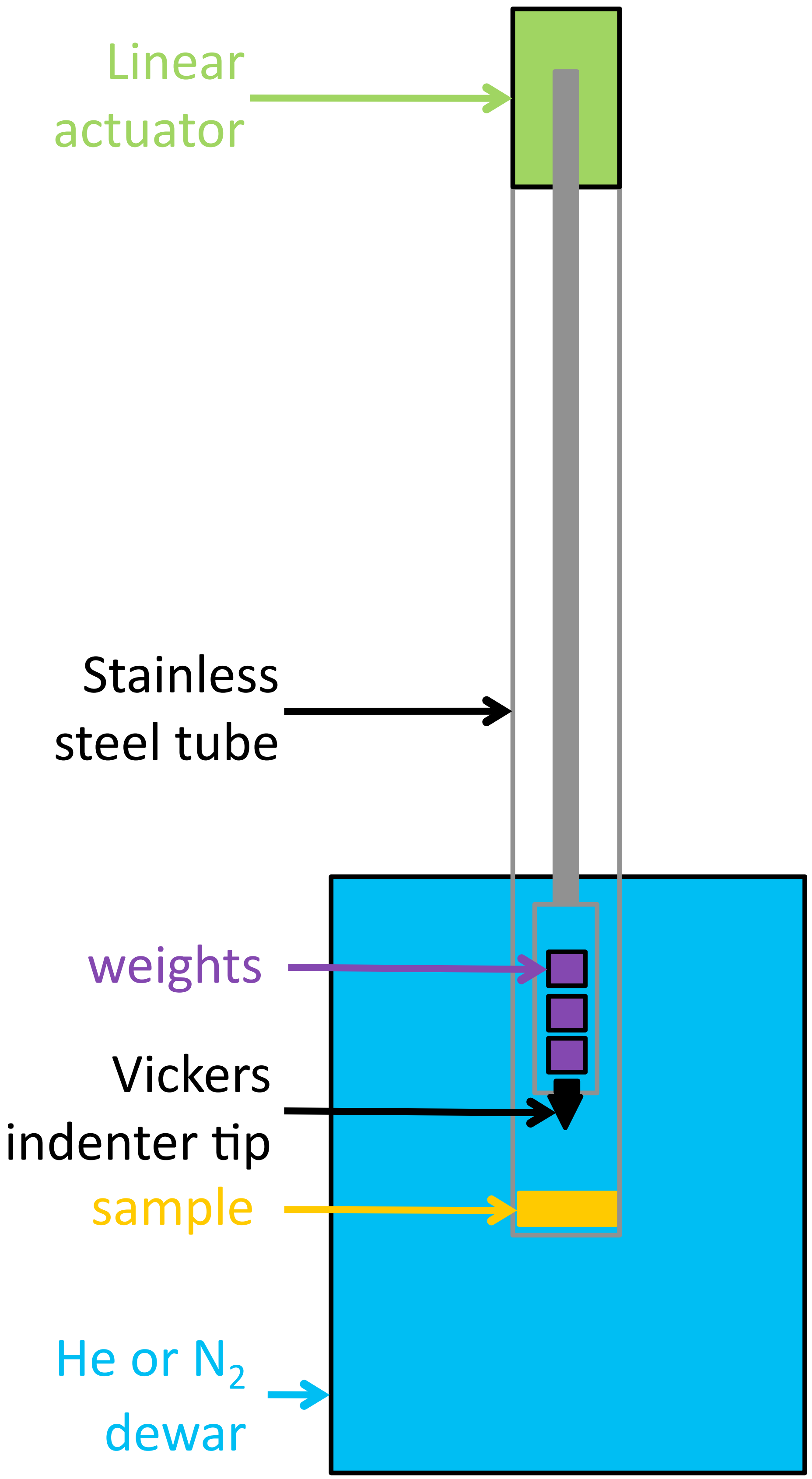
- Mesoscale simulations suggest that the suppression of plasticity can lead to accelerated grain growth.

- Experiments indicate that indentation at low T leads to accelerated grain growth.

- One would expect plasticity to be suppressed at low T.

- This work aims to examine this phenomenon in more detail, with the hope of better understanding and controlling the stability of nanocrystalline metals.

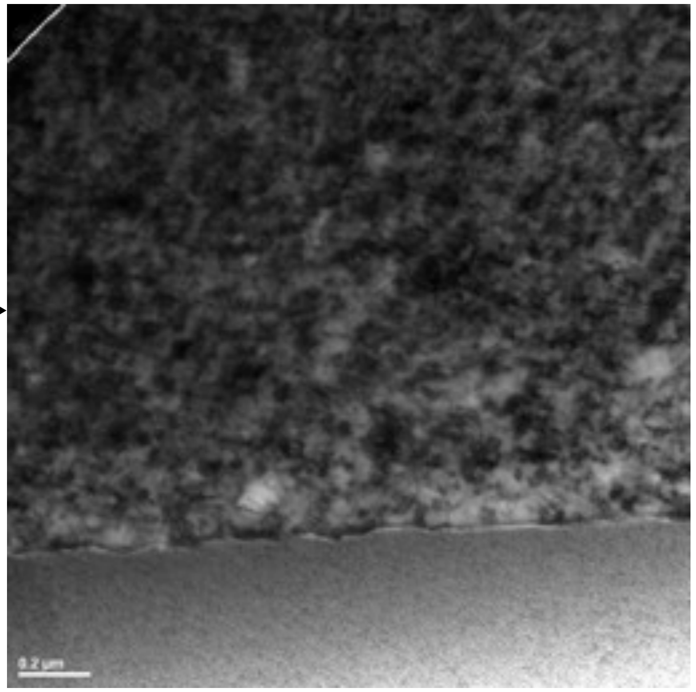
Experimental Method

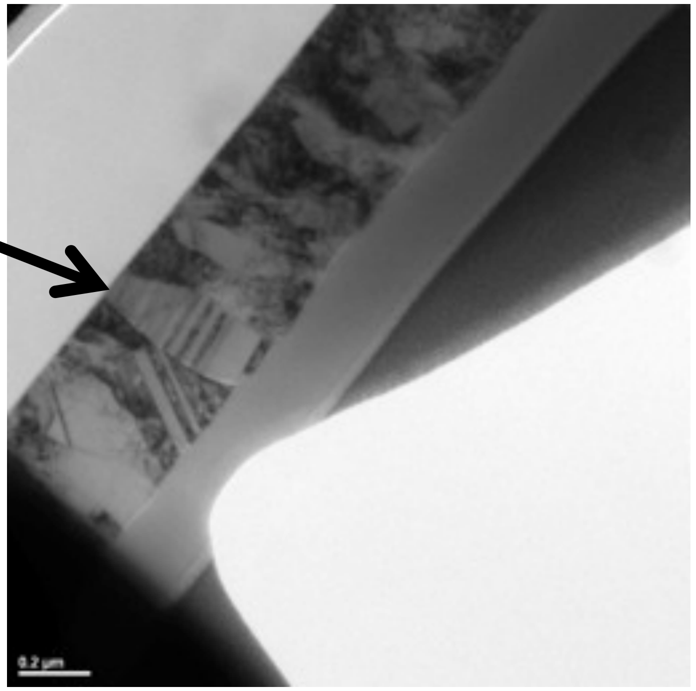


- Samples were submerged for ten minutes in liquid He, liquid N_2, or left in air, to achieved thermal equilibrium.
- The indenter tip was lowered using a linear actuator (0.1 mm/s).
- Indentation dwell times were typically 10 or 600 seconds.
- After indentation, samples were removed and allowed to reach room temperature before characterization was performed.

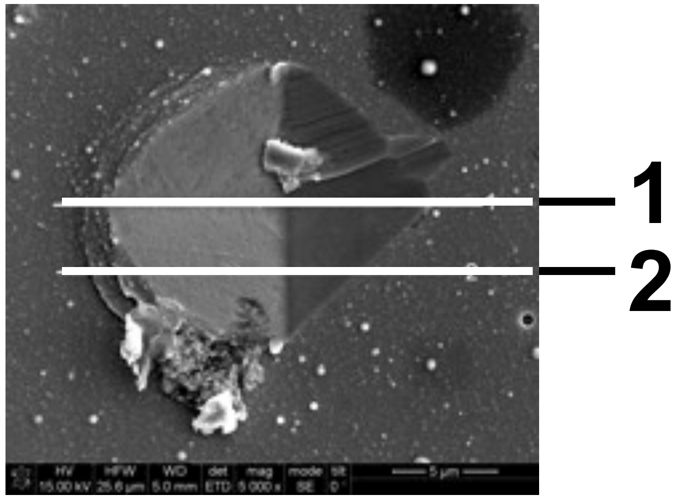
Thin Film Deposition Processing

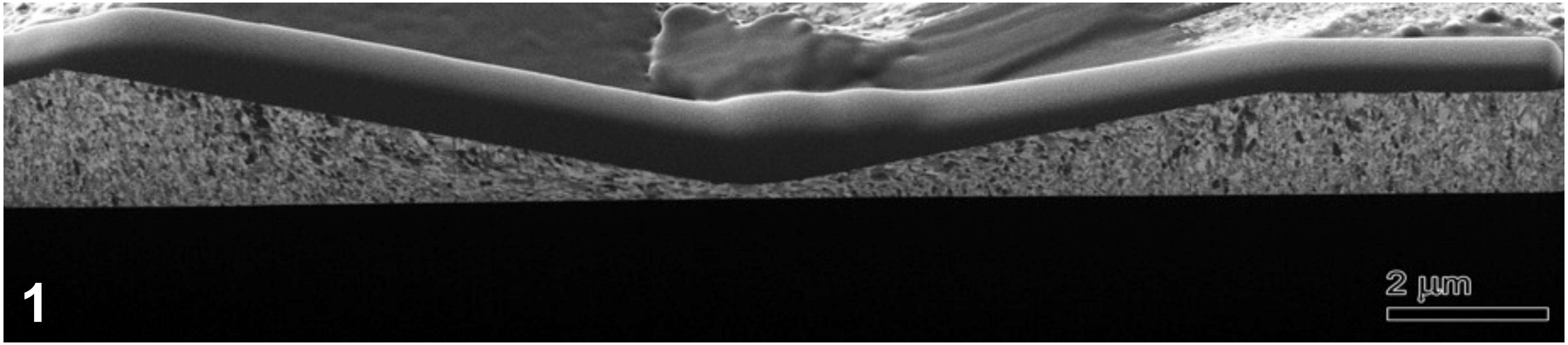
- Copper films deposited on silicon substrates
- Three types of copper deposited by ion and laser ablation of targets
  - Repetitive High-Energy Pulsed Power
    - Untwinned microstructure
    - ~1.5 μm thick
    - ~50 nm equiaxed grains
  - Pulsed Laser Deposition
    - Nanotwinned microstructure (or untwinned if done at low T)
    - ~500 nm thick
    - Columnar grains, ~5 nm twins

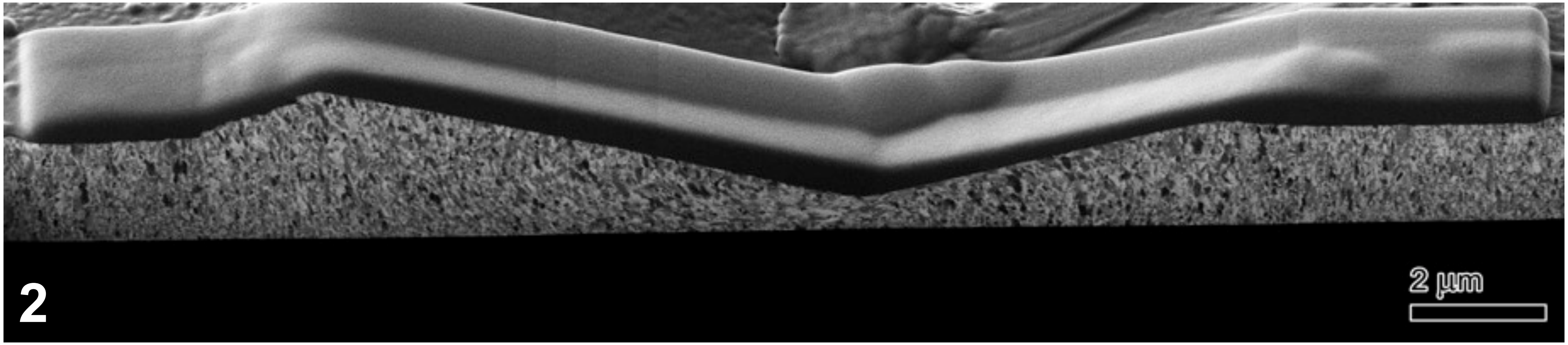




Untwinned RHEPP Cu Indented in Air

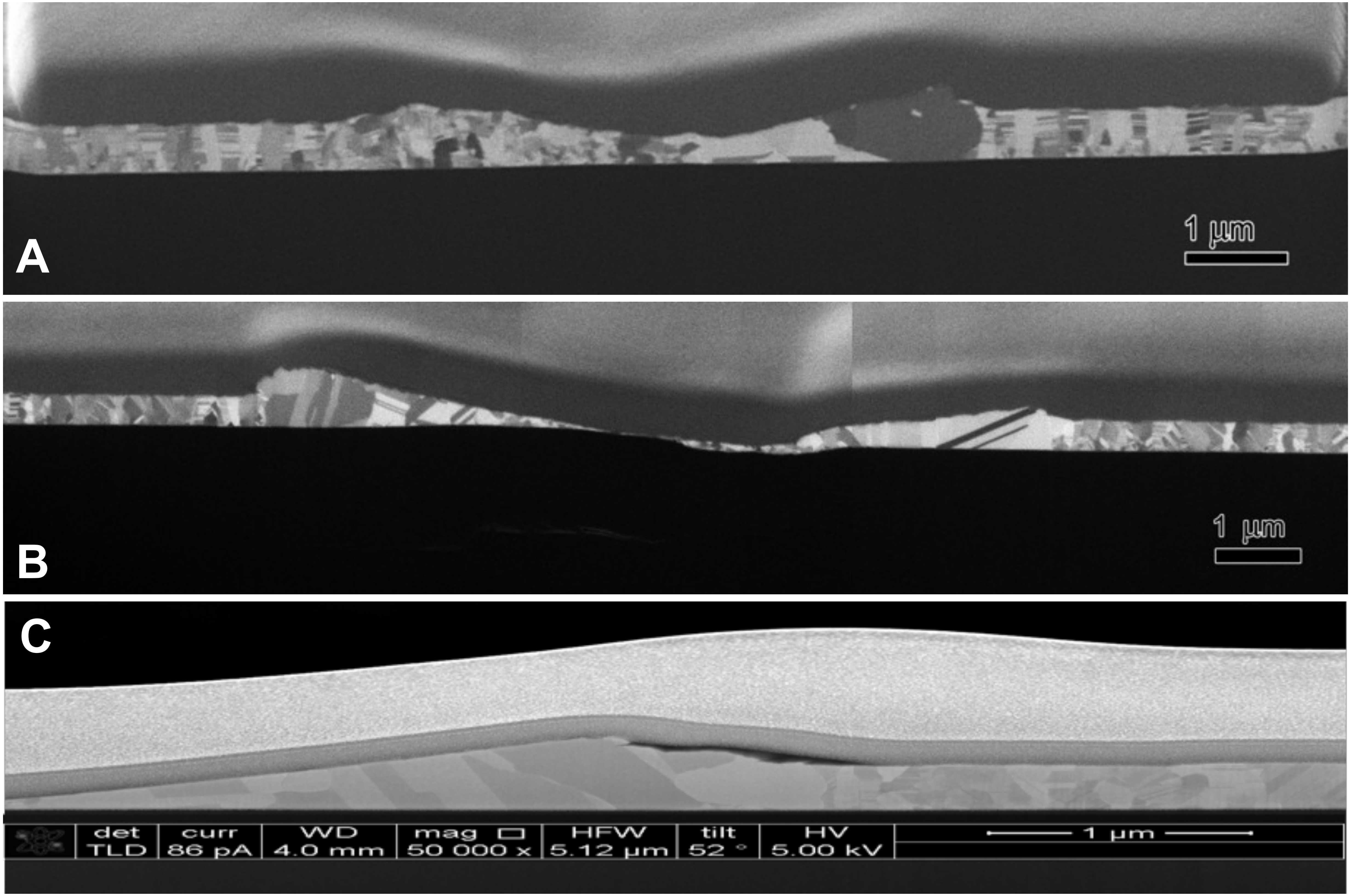






Untwinned copper shows only moderate grain growth.

Nanotwinned PLD Cu, in He (A,B) and N_2 (C)



Nanotwinned copper shows **extensive** grain growth.

Experimental Text Matrix

Indentation at low temperatures appears to promote grain growth in nanotwinned copper, but NOT in untwinned copper.

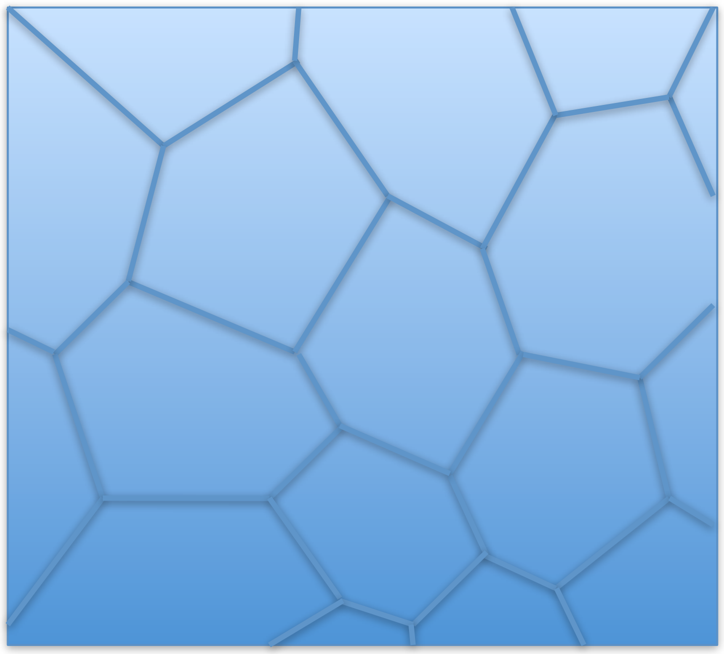
	RHEPP Untwinned			PLD Untwinned			PLD Nanotwinned		
	9.5 g	21 g	55 g	9.5 g	21 g	55 g	9.5 g	21 g	55 g
Air	?	Y?	?	?	?	?	?	N	N
N_2	?	N	N	?	N	?	Y	Y	?
He	N	?	N	?	N	N	Y	Y	Y?

Y – accelerated coarsening

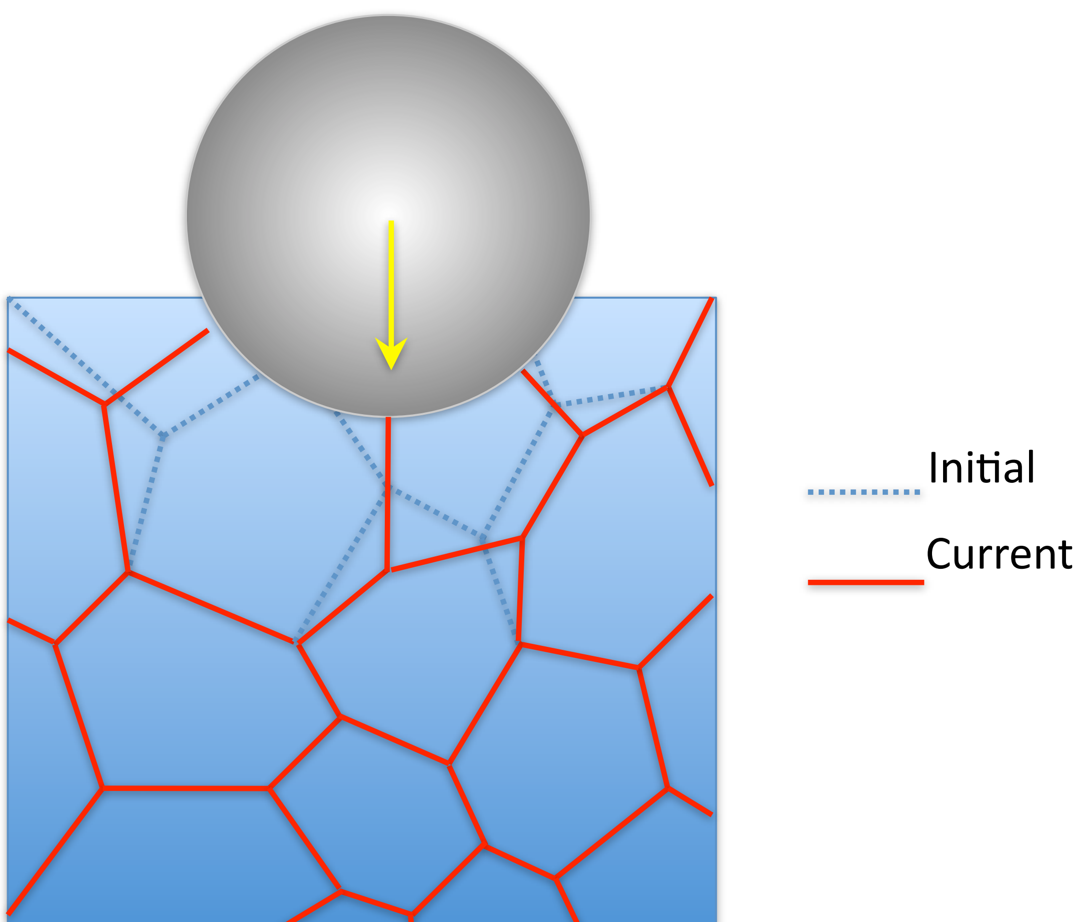
N – no noticeable coarsening

? – results inconclusive or no data (yet)

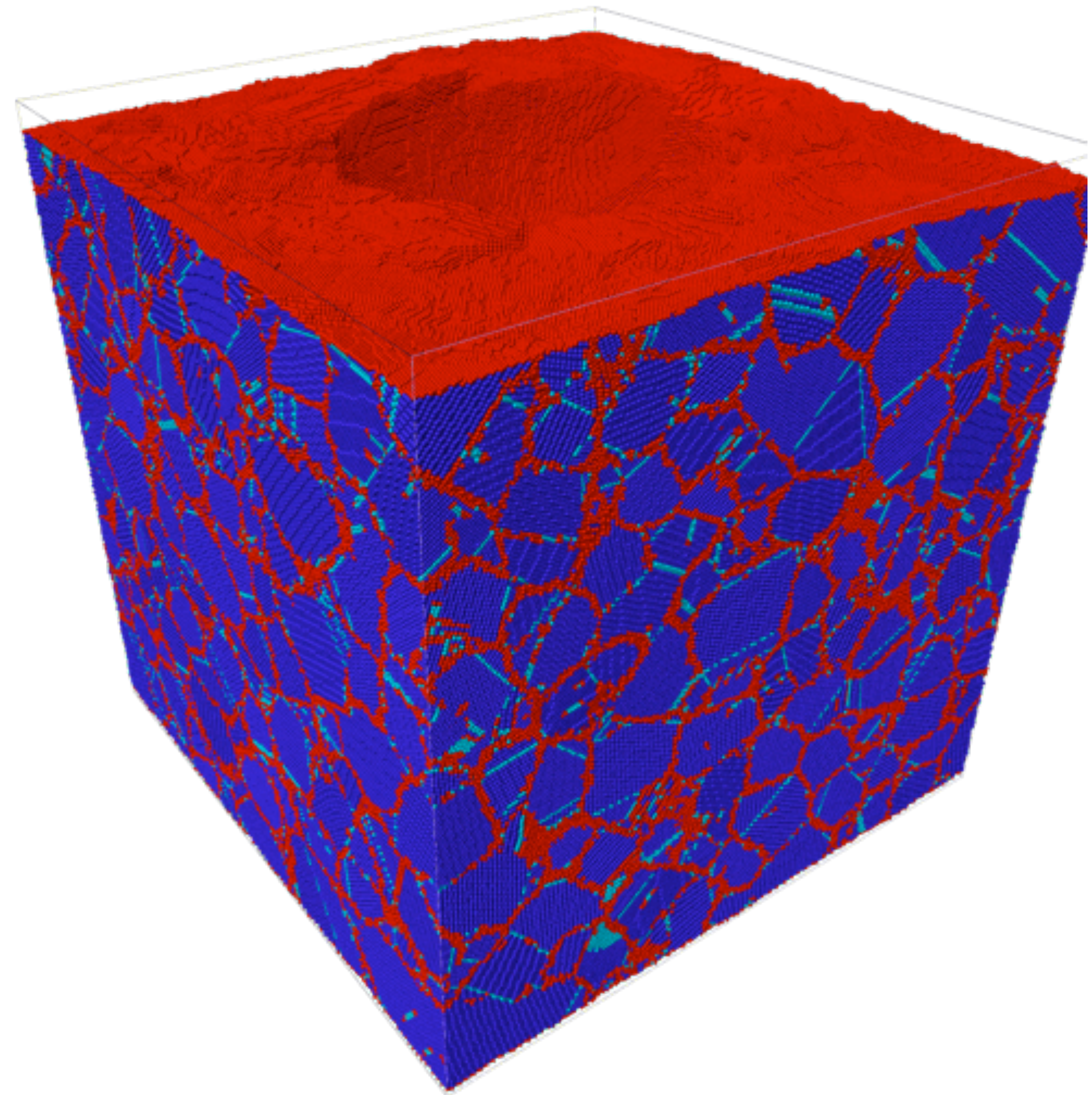
MD Simulations of Nanoindentation



Initial Configuration



Deformed Configuration



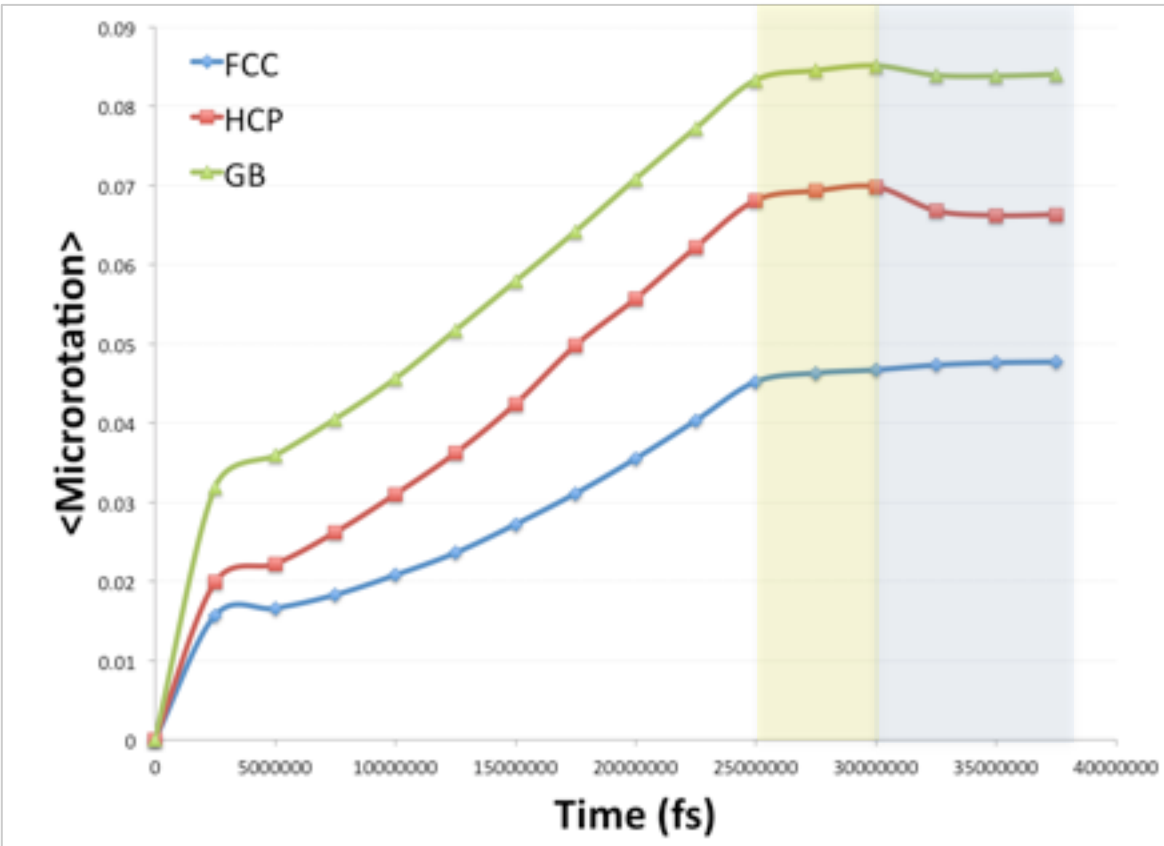
Common Neighbor Analysis (CNA)

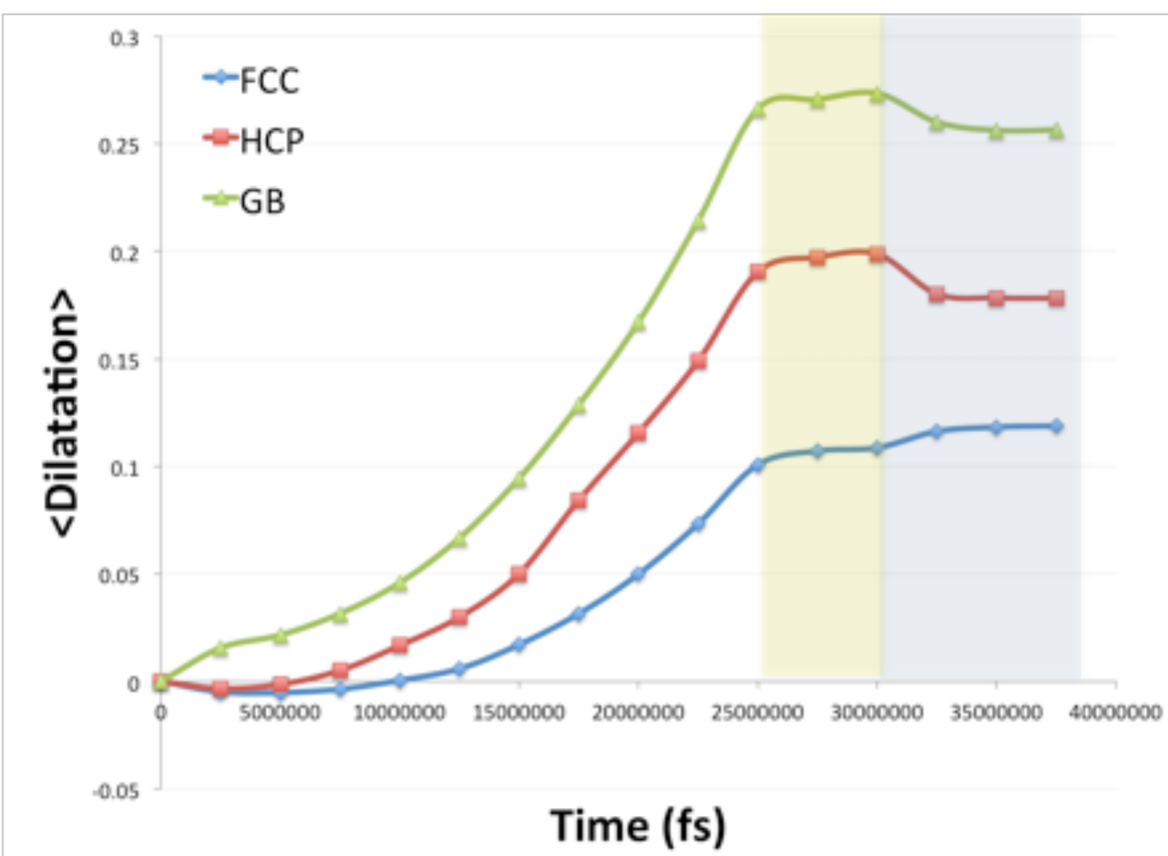
- FCC – lattice atoms
- HCP – stacking faults and twin boundaries
- Other – GBs and dislocations

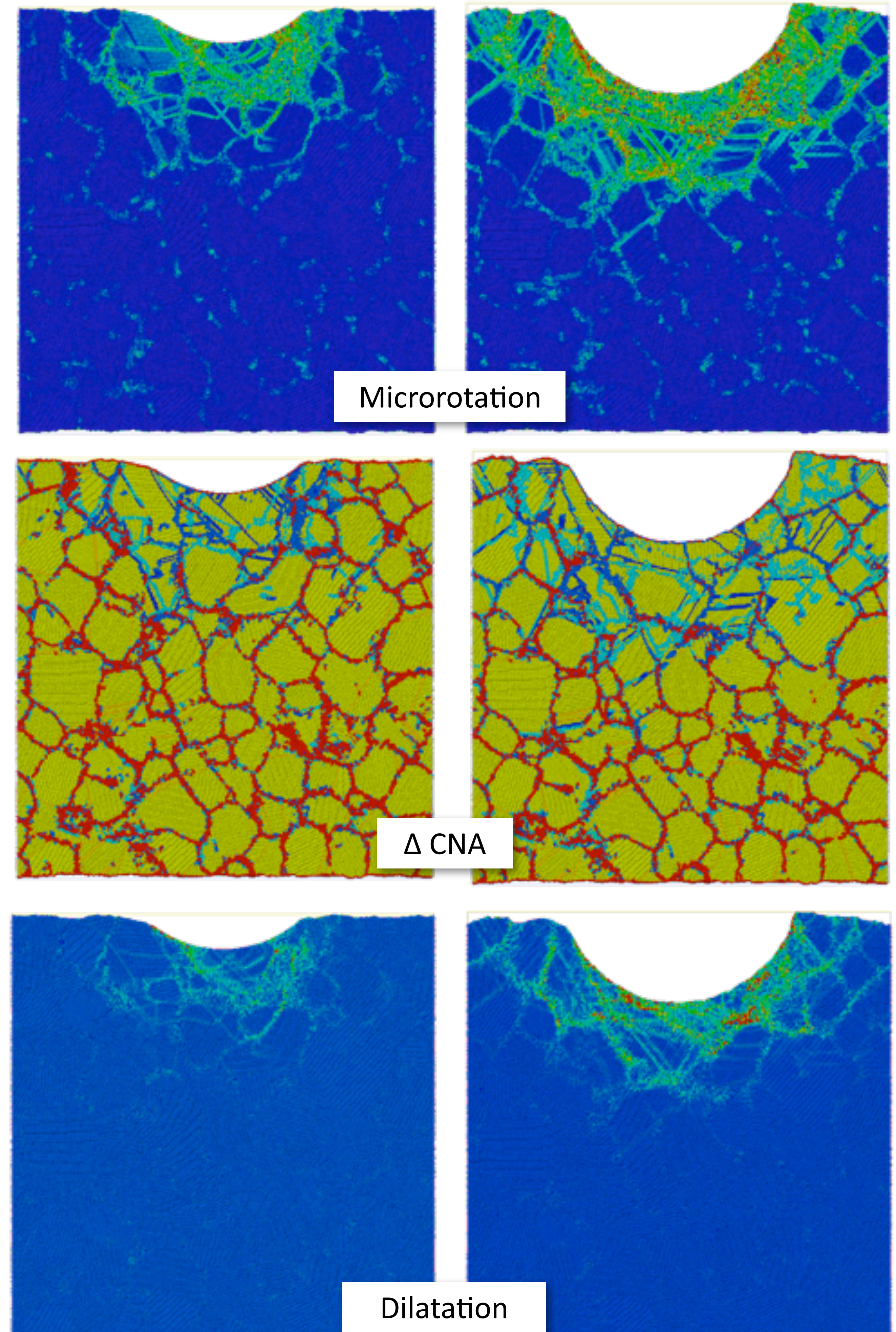
Constant Velocity:

- 20 cm/s
- 1 m/s
- 5 m/s

MD Simulations

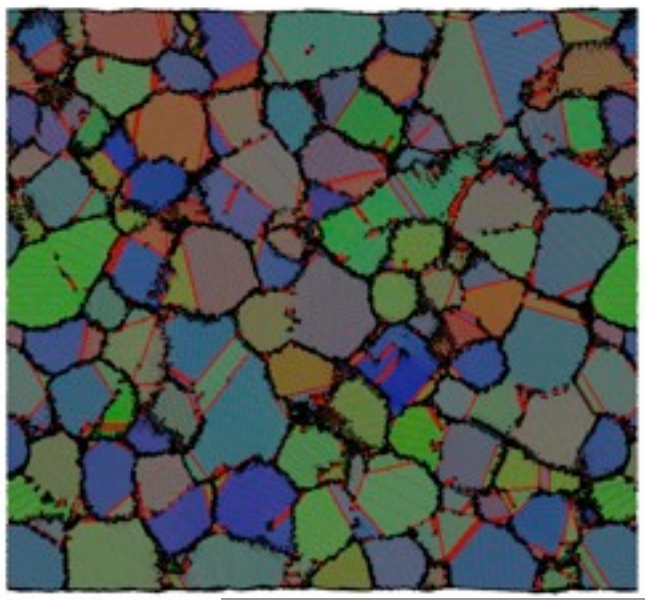




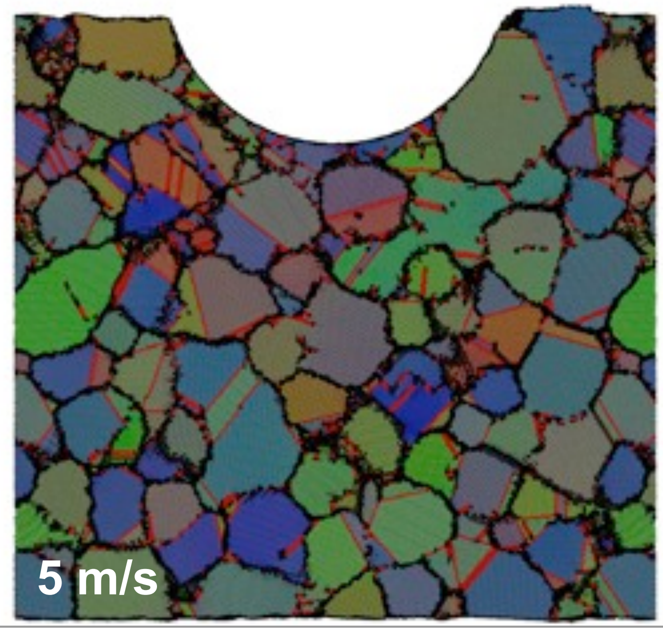


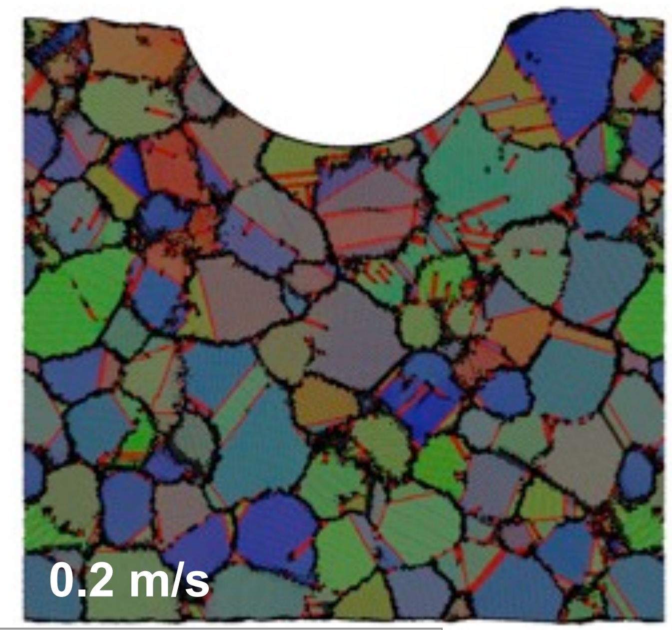
MD Simulations of Nanoindentation

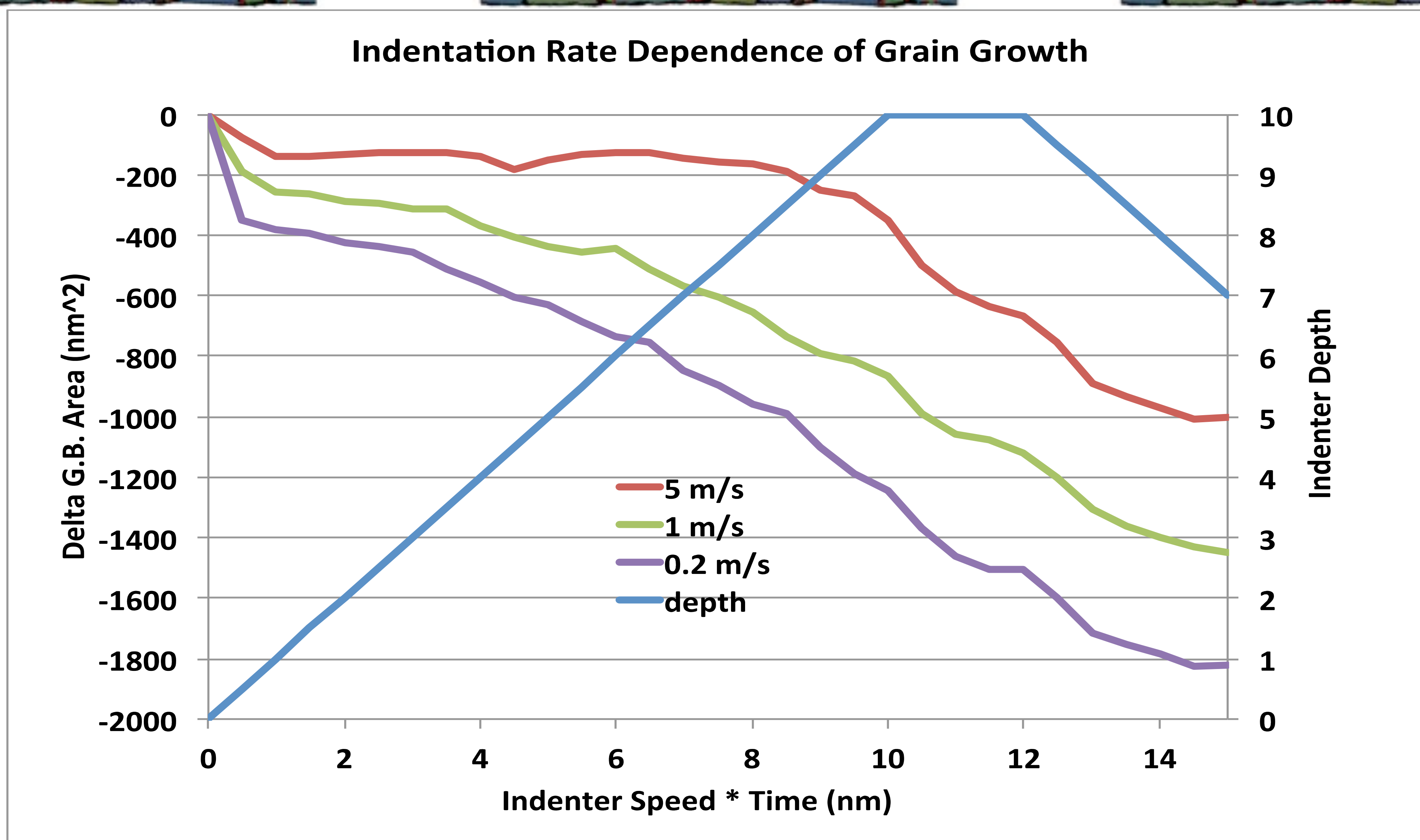
Initial Condition



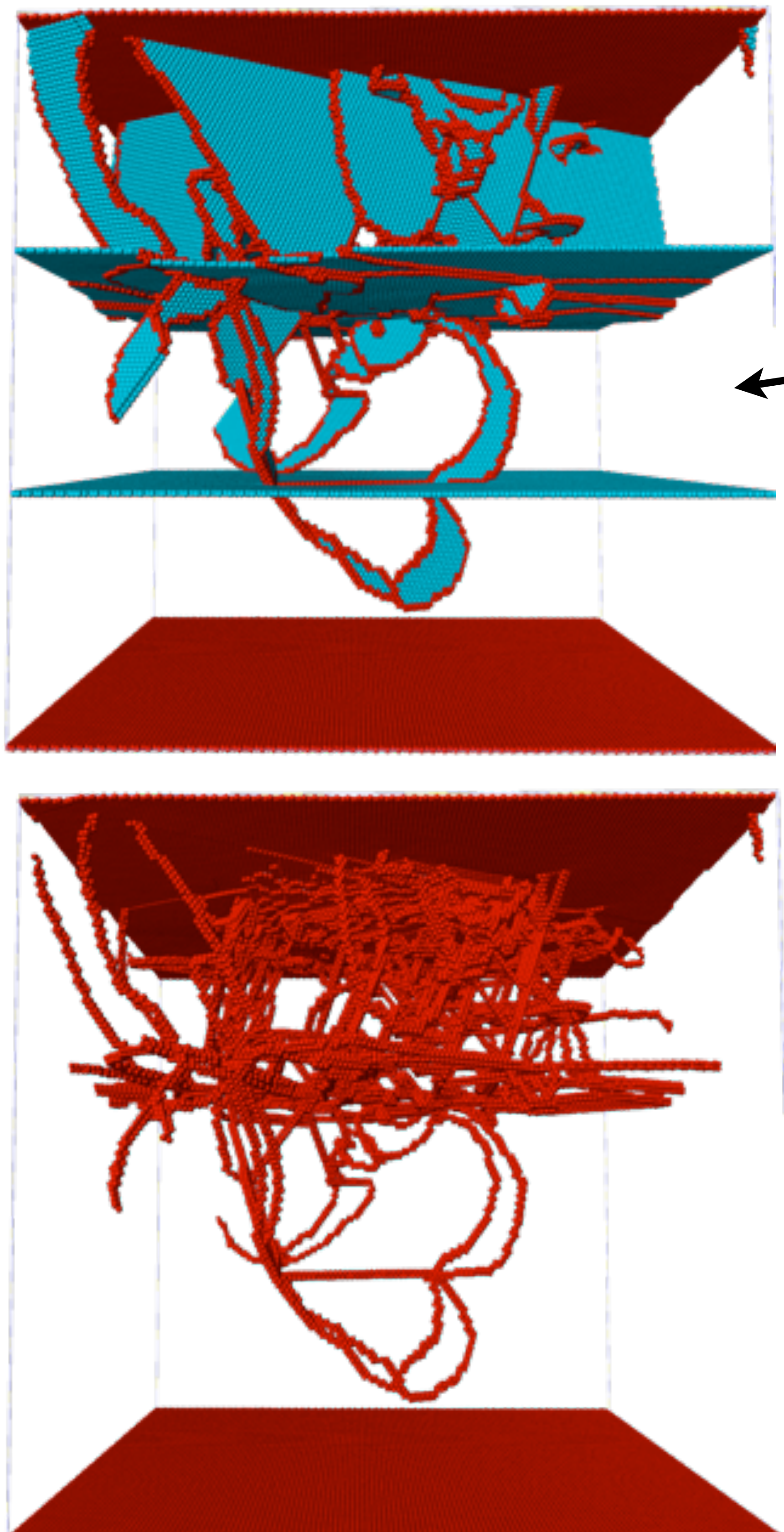
Snapshots at 10 nm depth



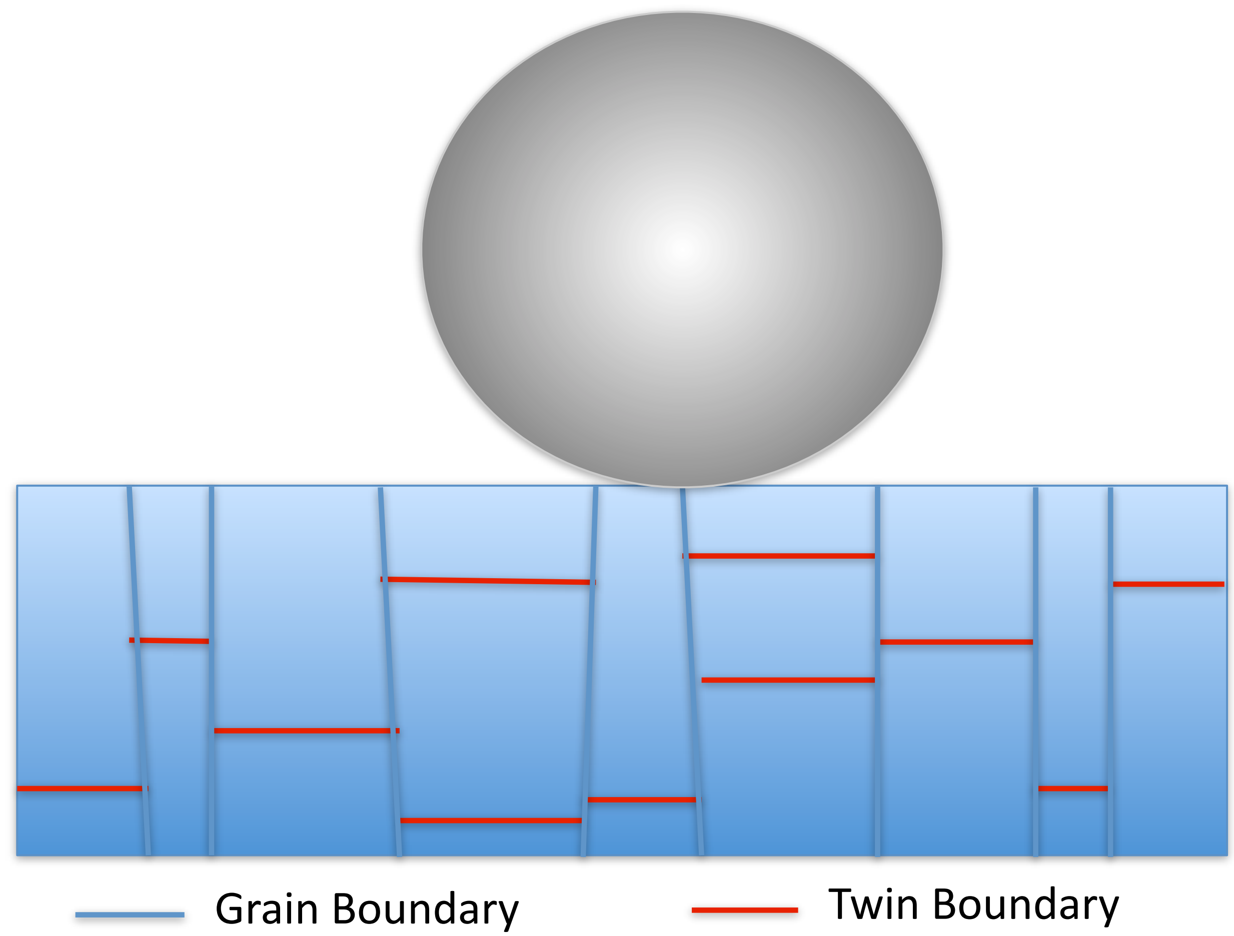




MD Simulations of Nanoindentation: Ongoing Work



Indentation into twinned mono- and poly-crystalline films.



Conclusions

- Mesoscale simulations suggest that the suppression of plasticity can lead to accelerated grain growth.
- Experiments indicate that indentation at low T leads to accelerated grain growth.
- Nanotwins appear to be crucial in governing grain growth during / after microindentation.
- Molecular dynamics simulations show grain growth in nanocrystalline material at room temperature, and are being used to elucidate mechanisms.