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Solute Segregation and Thermal Stability of Ultra-Fine-Grained Al-Mg

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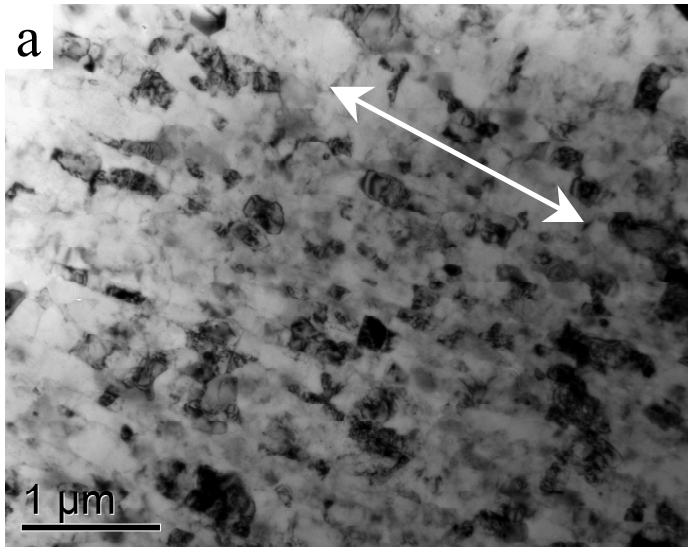
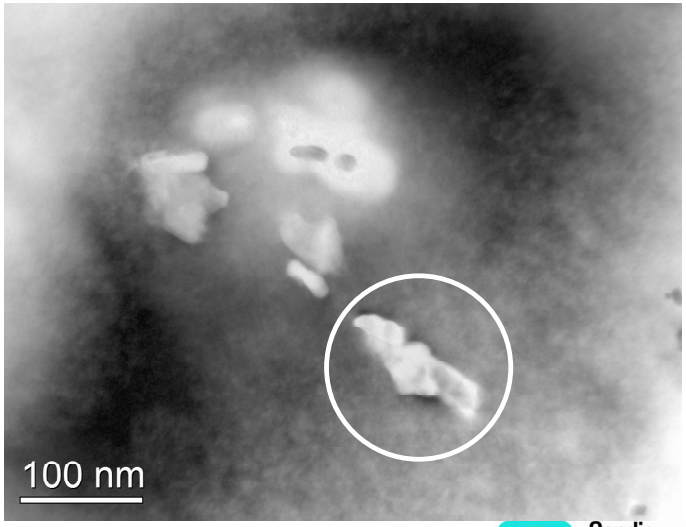
UFG Al-Mg: A Bulk Material with Properties that Arise from Nanometer-Scale Features

3.2 in.





San Marchi, Brown, Lucadamo, Karnesky, Yang (2008)

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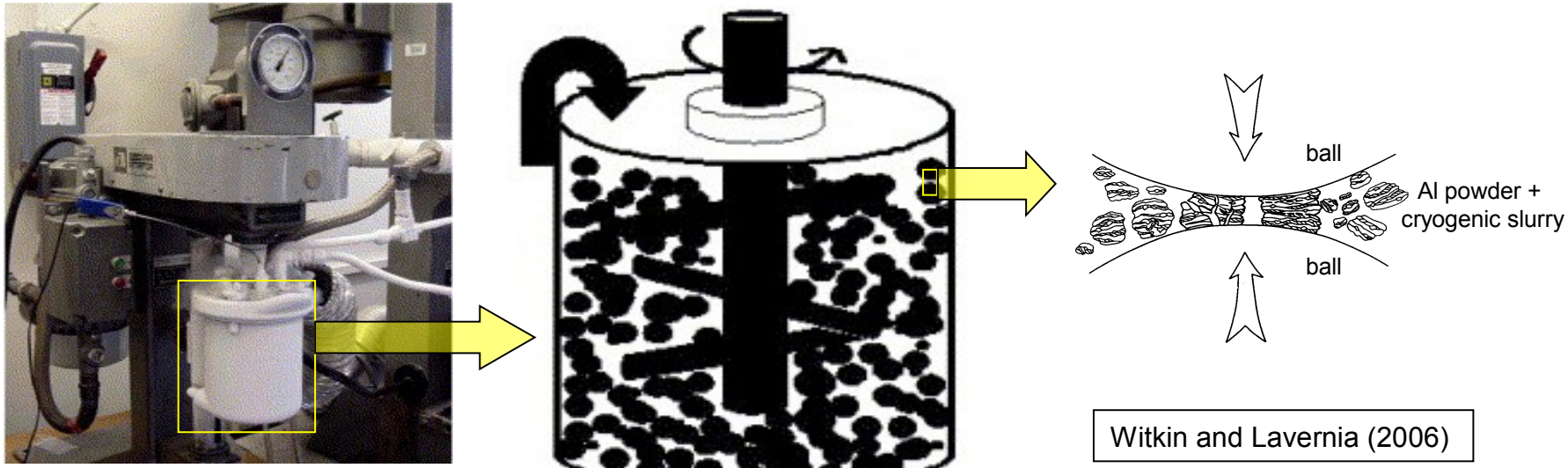
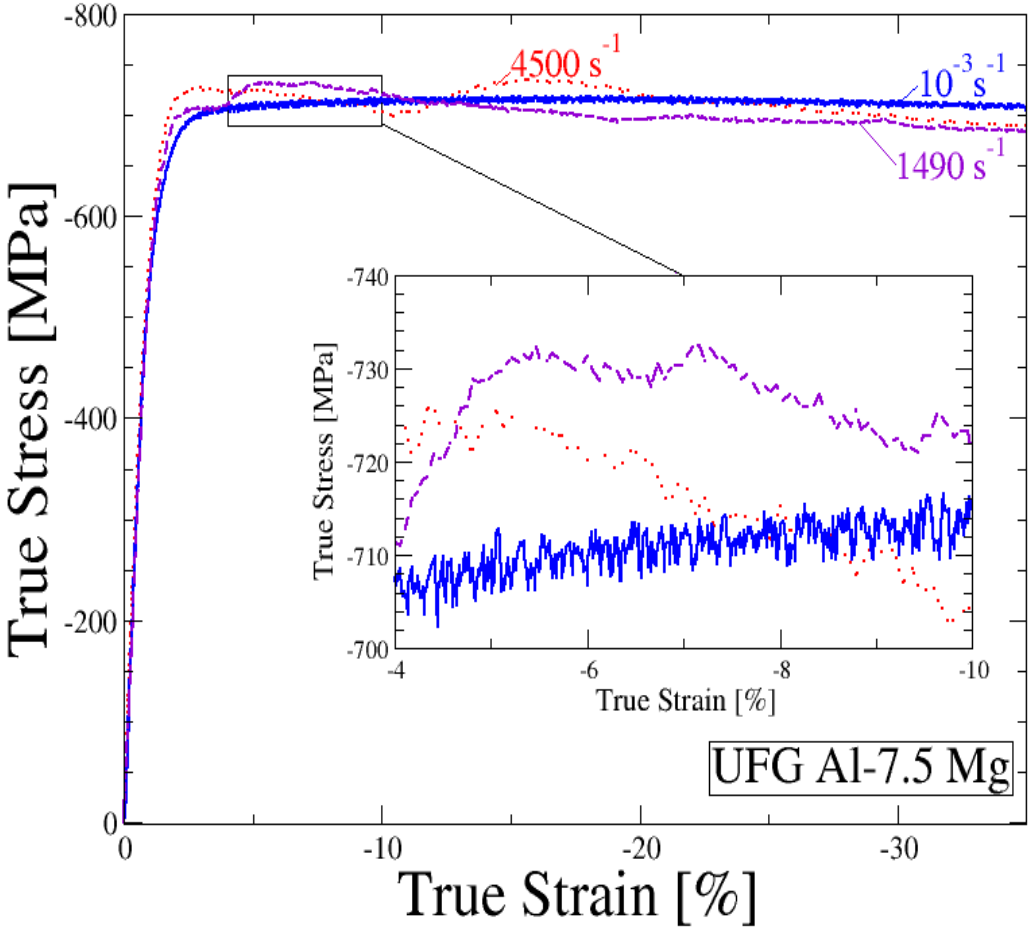
Processing of Cryomilled Al-Mg alloys and Grain Size



Witkin and Lavernia (2006)

- Atomized (d=80 nm)
- Thermally degassed (d=280 nm)
- Cryomilled in LN_2 (d=30 nm)
- Thermally degassed (d=140 nm)
- Primary consolidation by HIP
- High-strain-rate extrusion (d=220 nm)

UFG Al-Mg as a Structural Material



- High strength
  - Grain Size
  - Oxides
  - Mg in Solid solution
- Impact resistant

San Marchi, Brown, Lucadamo, Karnesky, Yang (2008)

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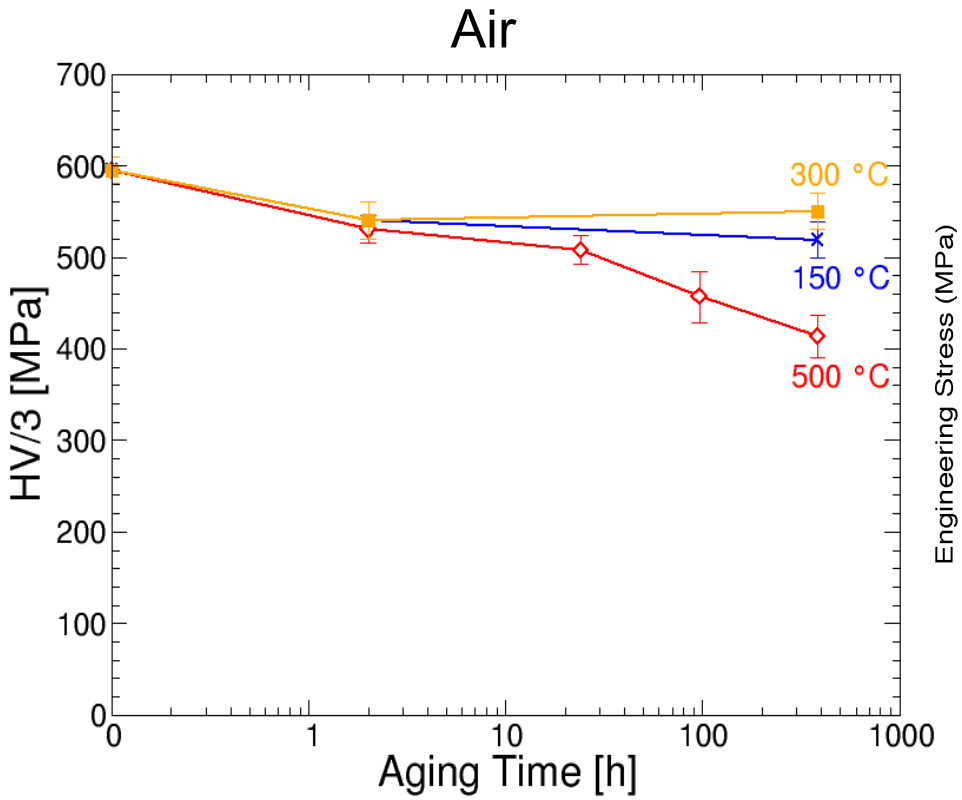
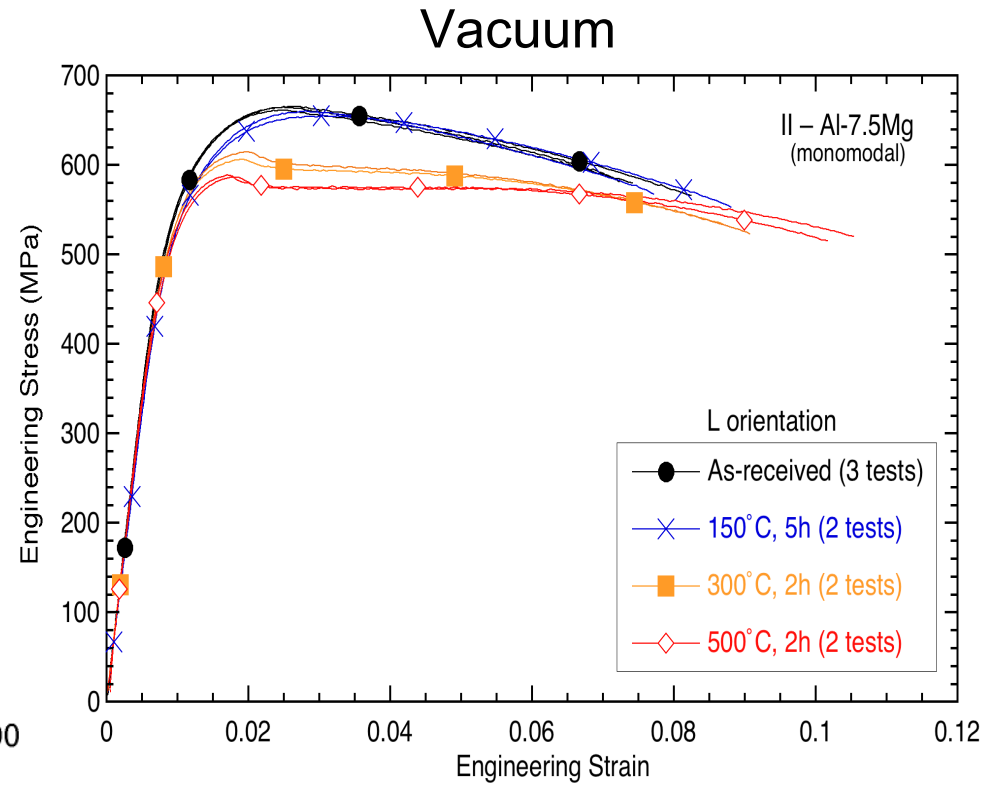
Strength is Retained on Aging



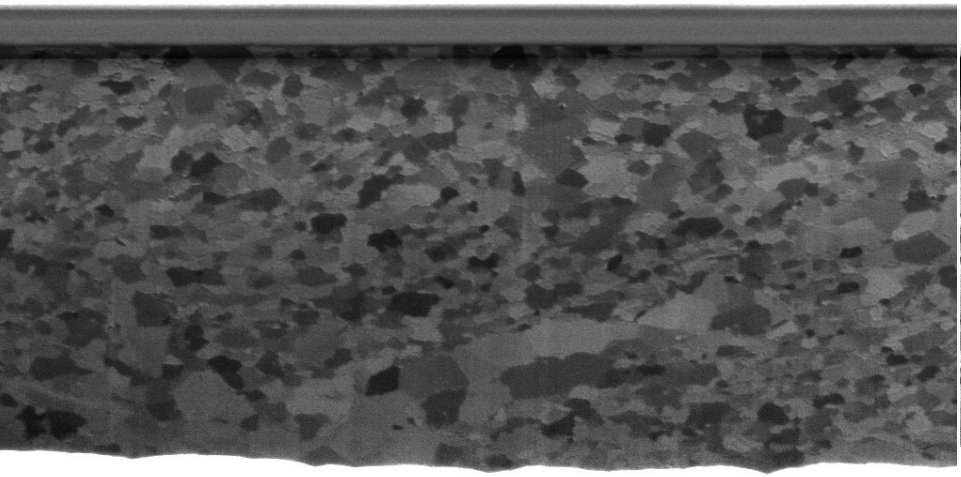


- Initial recovery after 2 h of aging at all temperatures
- Strength retained for up to 16 days at 300 °C
- Strength decreases with aging time at 500 °C

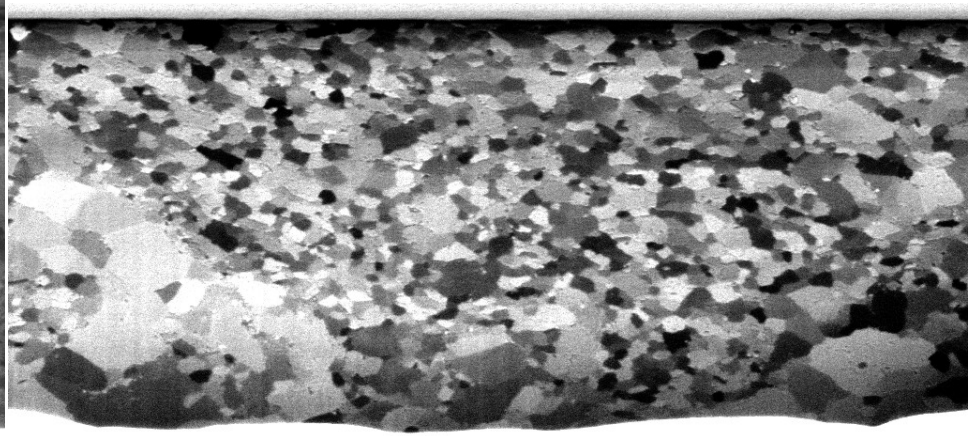
San Marchi, Brown, Lucadamo, Karnesky, Yang (2008)

Grain Size Stability at 500 ºC

2 h



16 d



- XRD suggests there is no change in d
- FIB shows that there are fine grained regions that have the same d, but an increase of coarse graining

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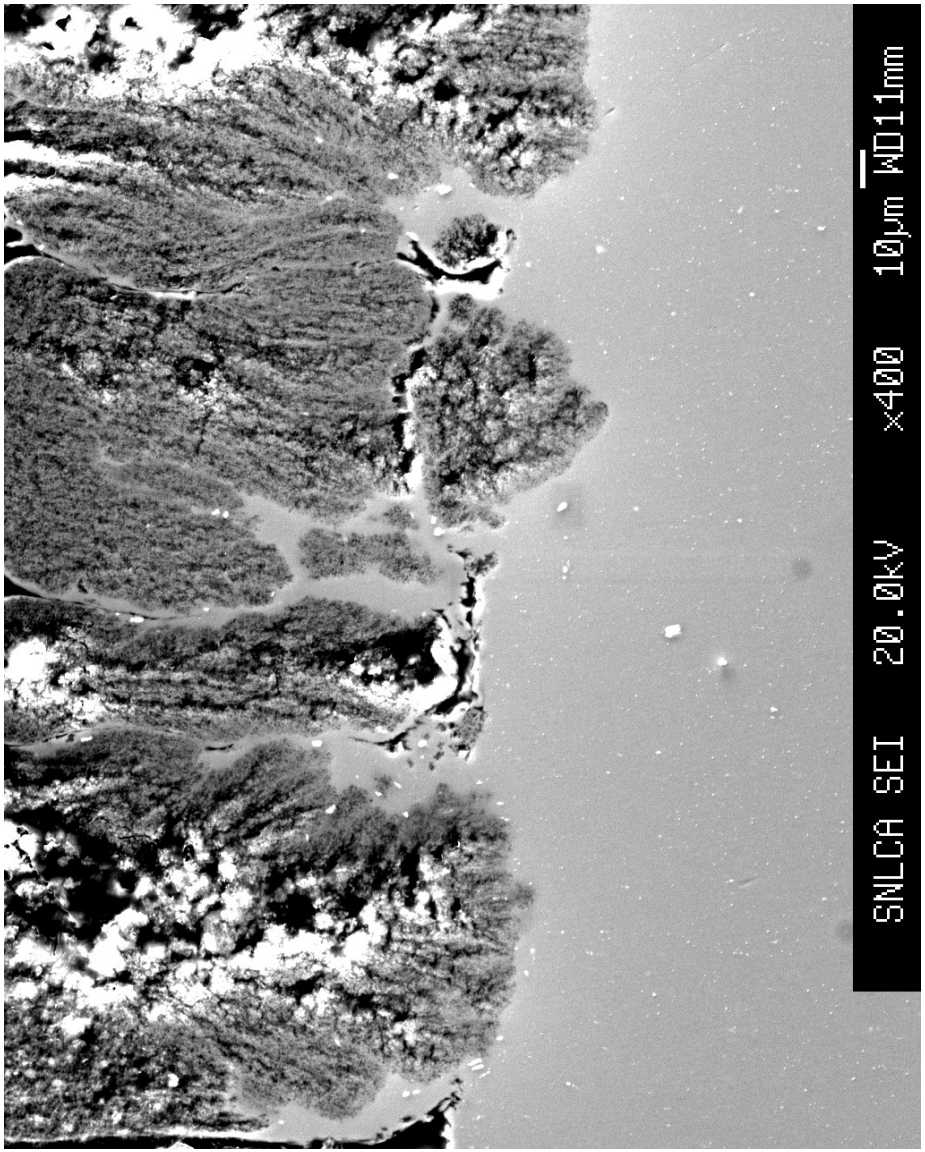
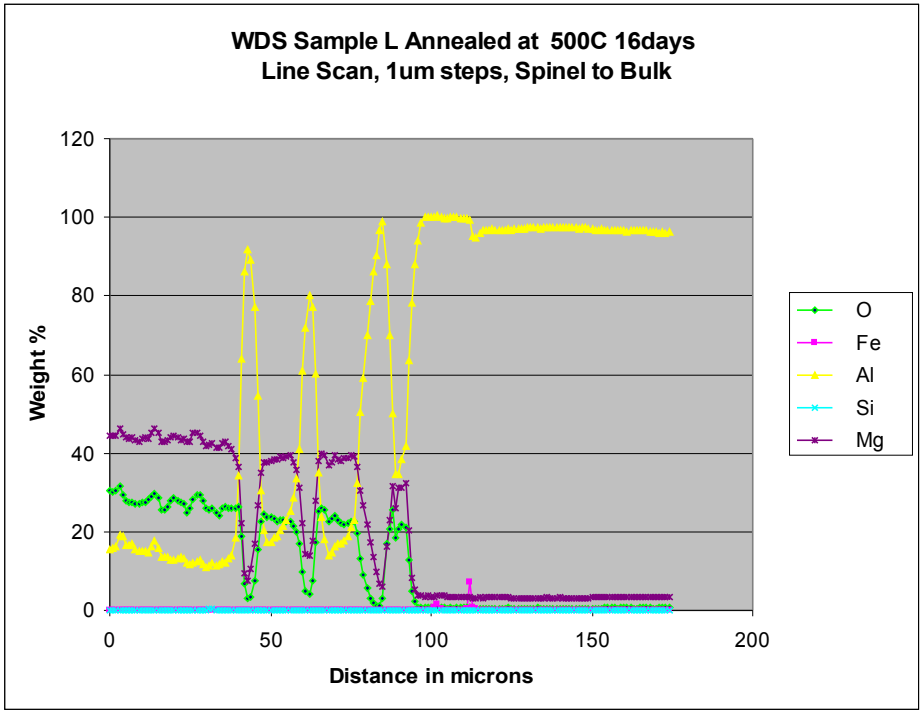
Mg Migration and Oxidation at 500 ºC





- Documented in CG alloys & Mg migration also seen in vacuum

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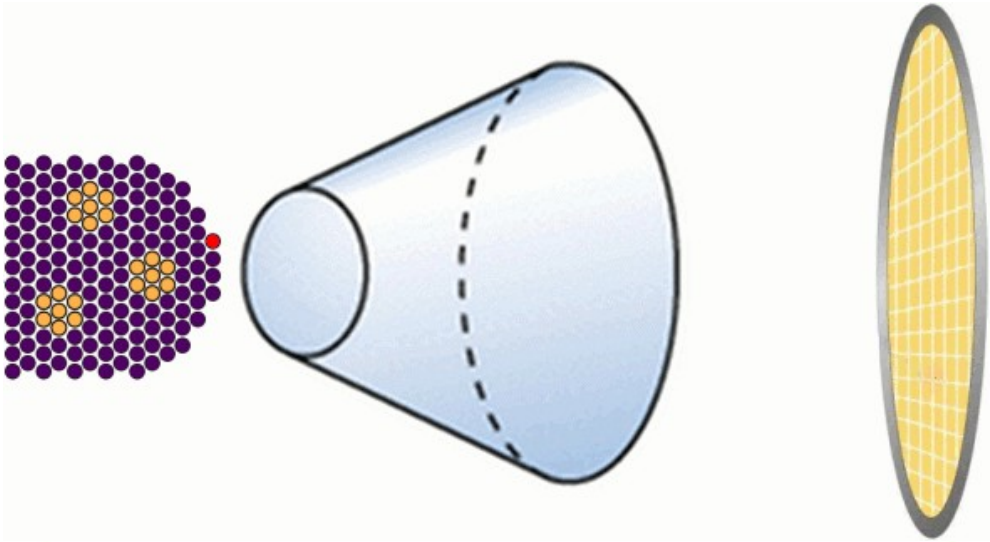
Local-Electrode Atom-Probe (LEAP) Tomography

Compositional and structural analysis at the atomic scale

- Pulse encodes z
- Area detector gives (x,y)
- TOF encodes mass/charge



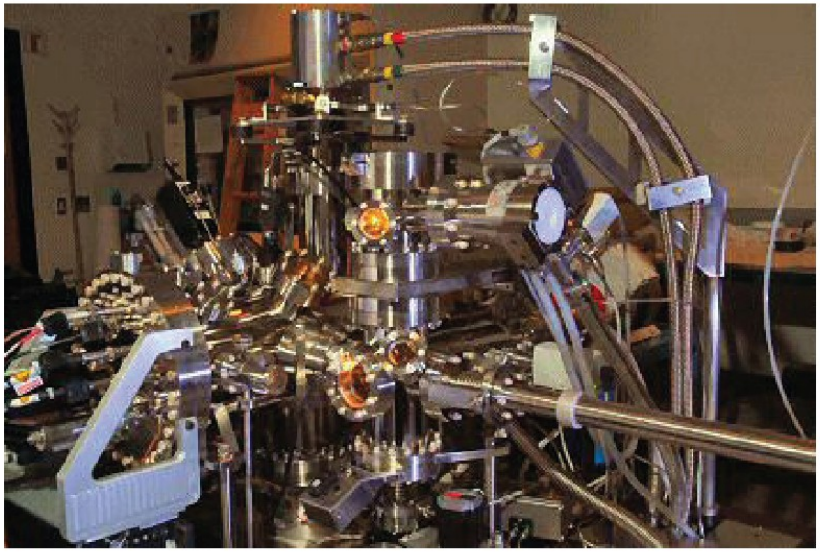
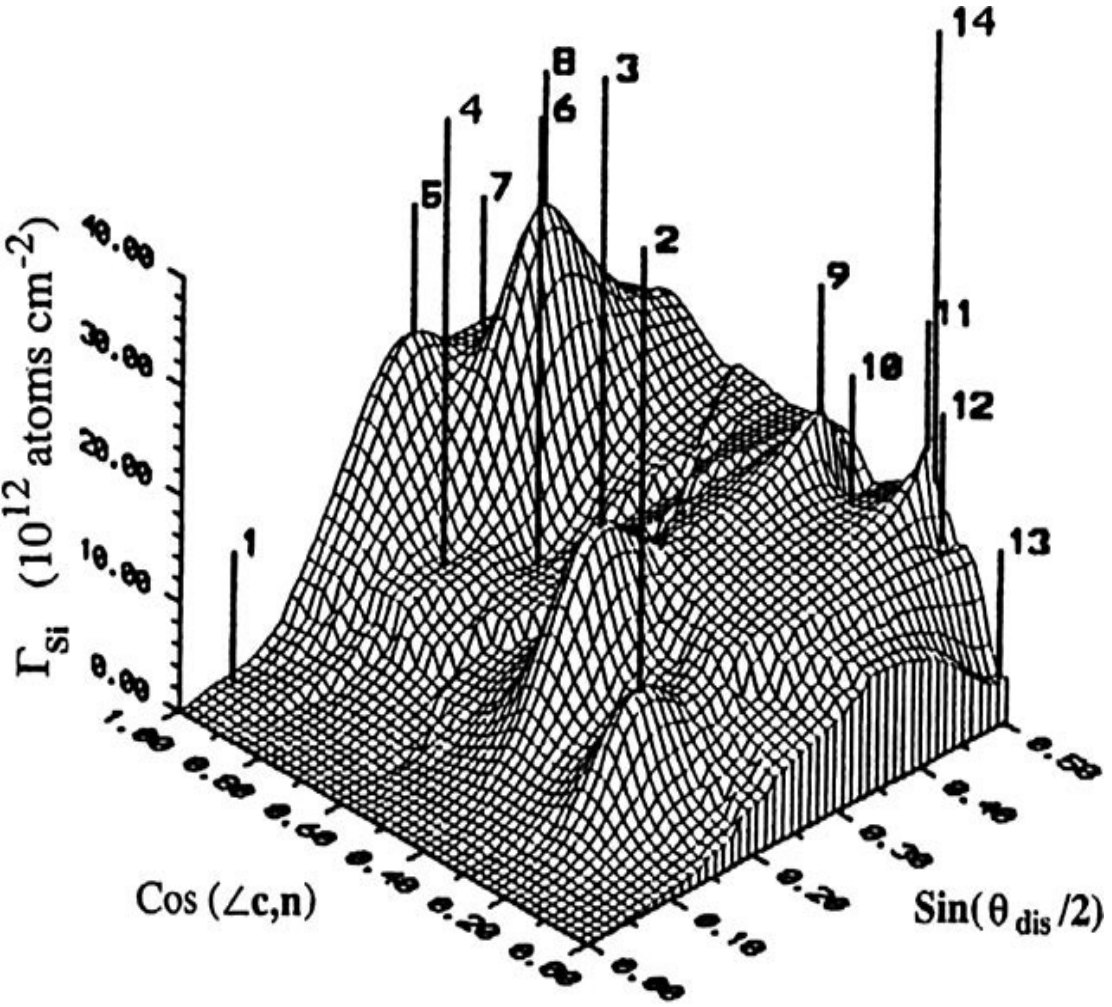


Photo courtesy of R.P. Koll

Instrument capability

- 10^6–10^7 nm^3 analysis volume
- 3×10^{-11}–10^{-10} torr UHV
- 20–100 K specimen temp.
- 200 kHz electrical pulsing

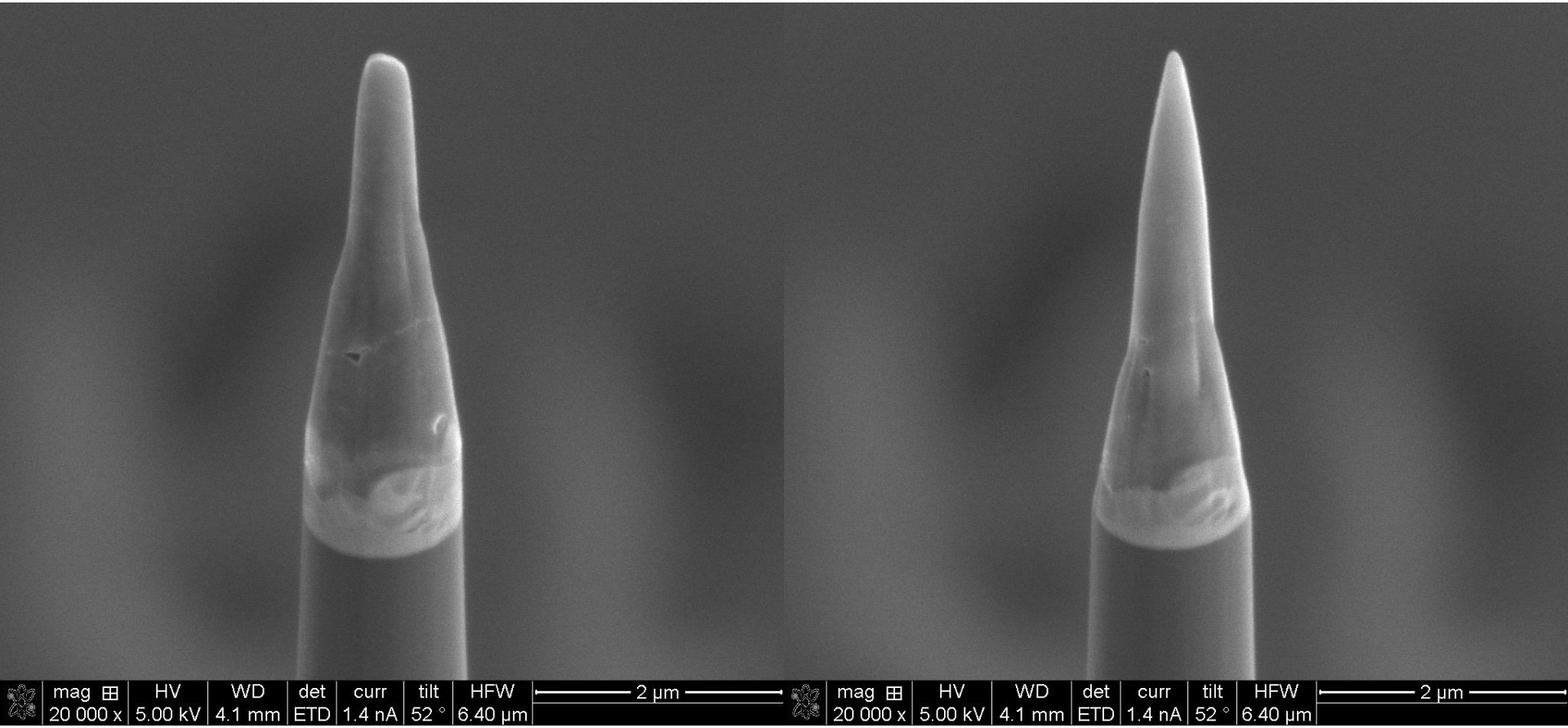
A Note on GB Segregation



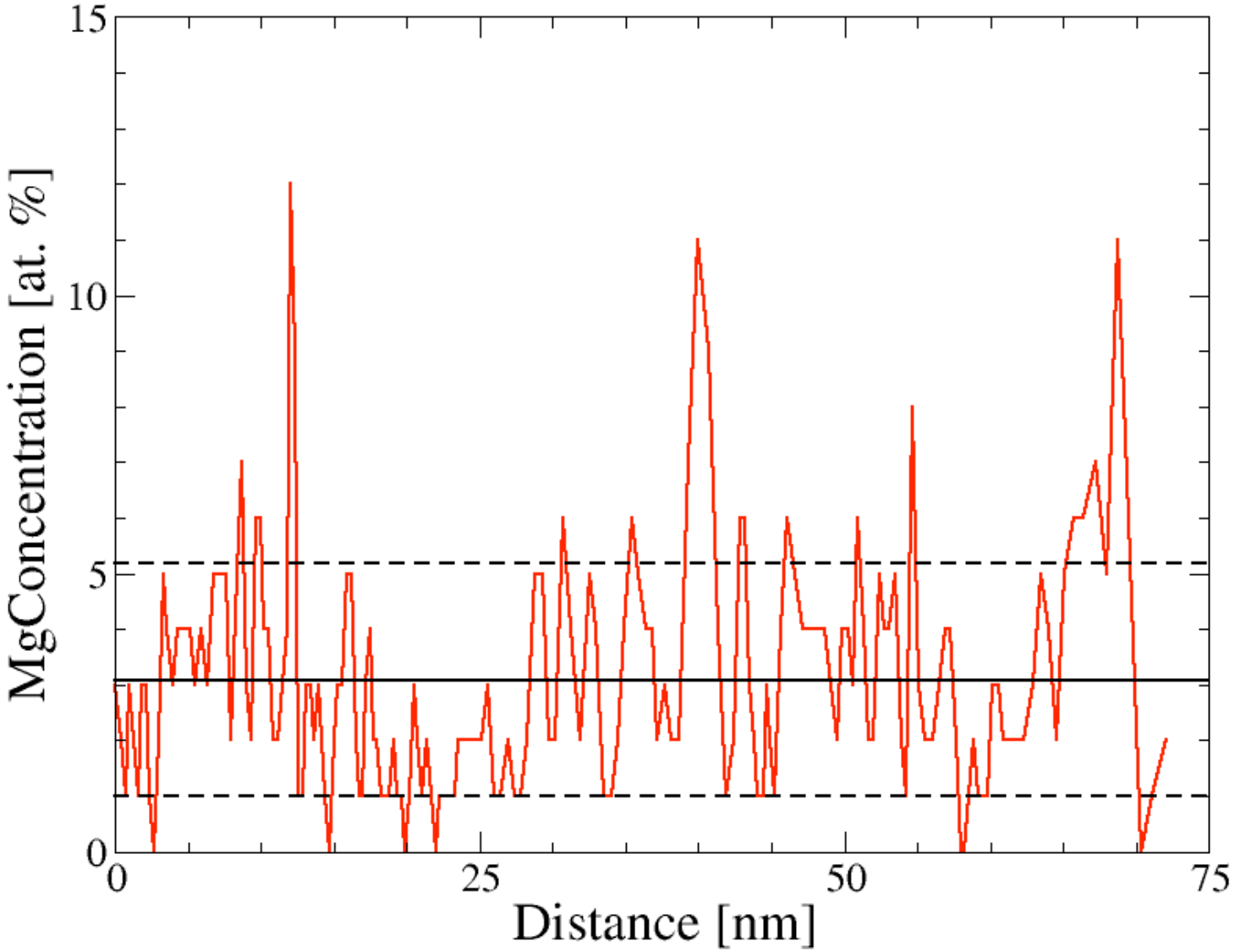
- Complex function of GB's 5 DOF
- Possible to perform TEM on APT tip in CG specimens
- Hard in NC specimens
  - MANY GBs

Krakauer and Seidman (1998)

Tips of Powders made by FIB



LEAP Tomography of Undegassed Powder



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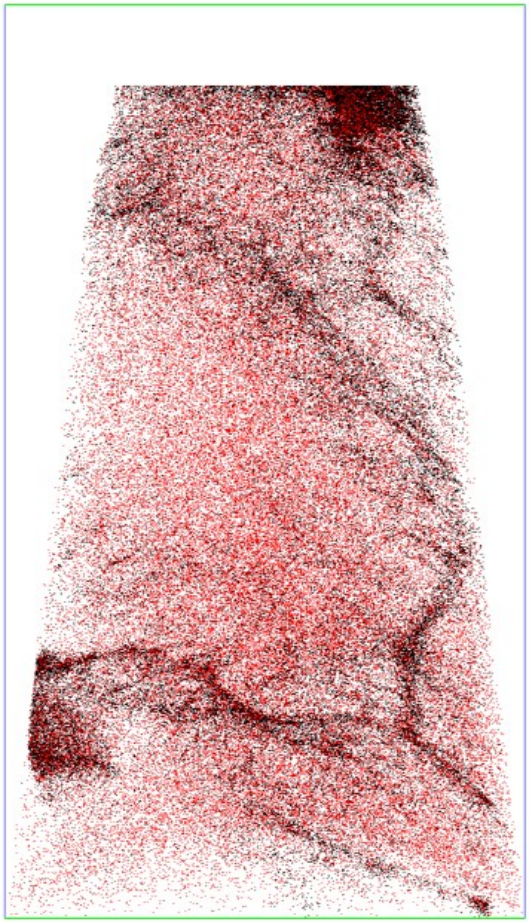
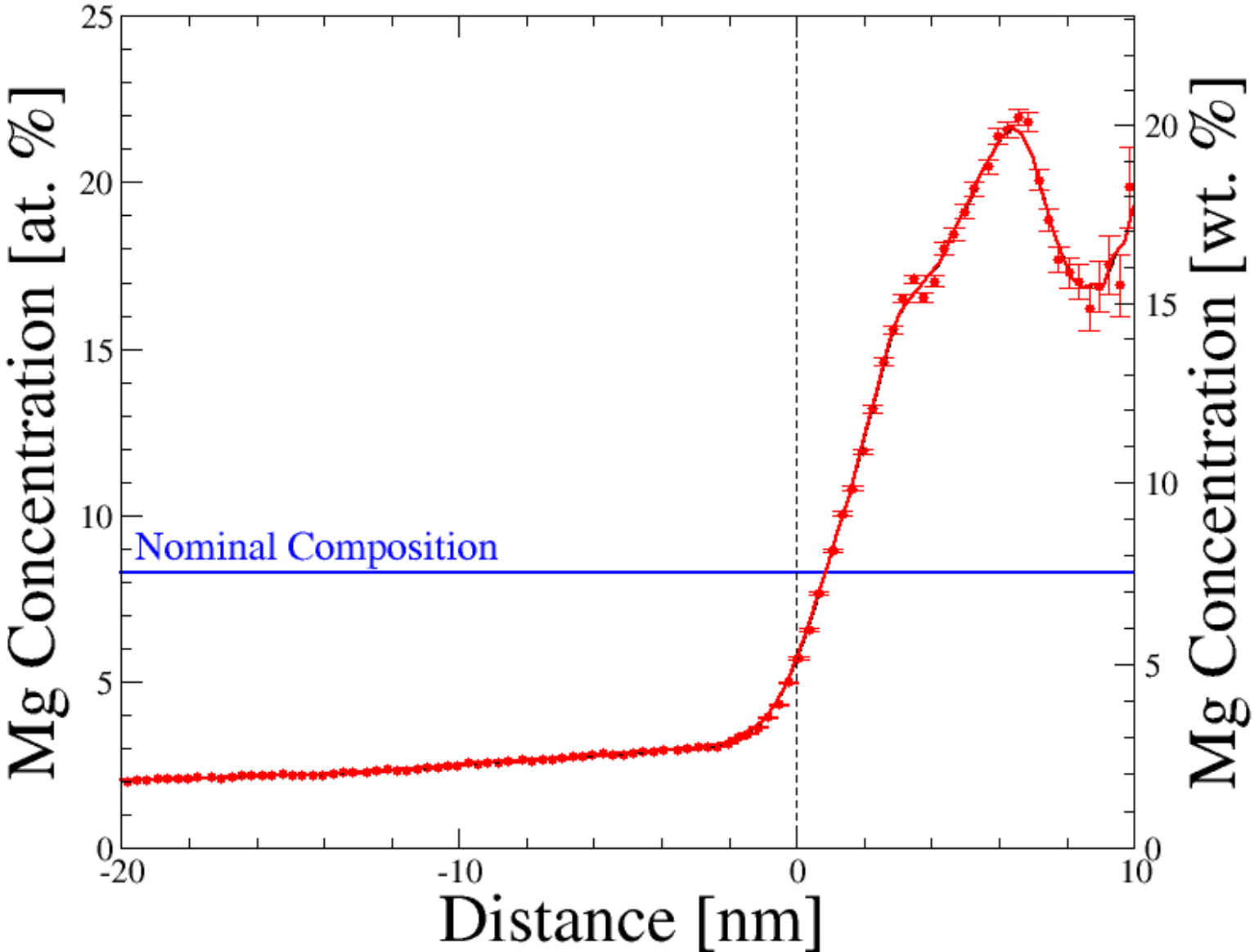
LEAP Tomographic Reconstruction of Degassed Powder



- 60M ions
- Different Gbs show different Mg segregation (red)
- All grains show same solute content

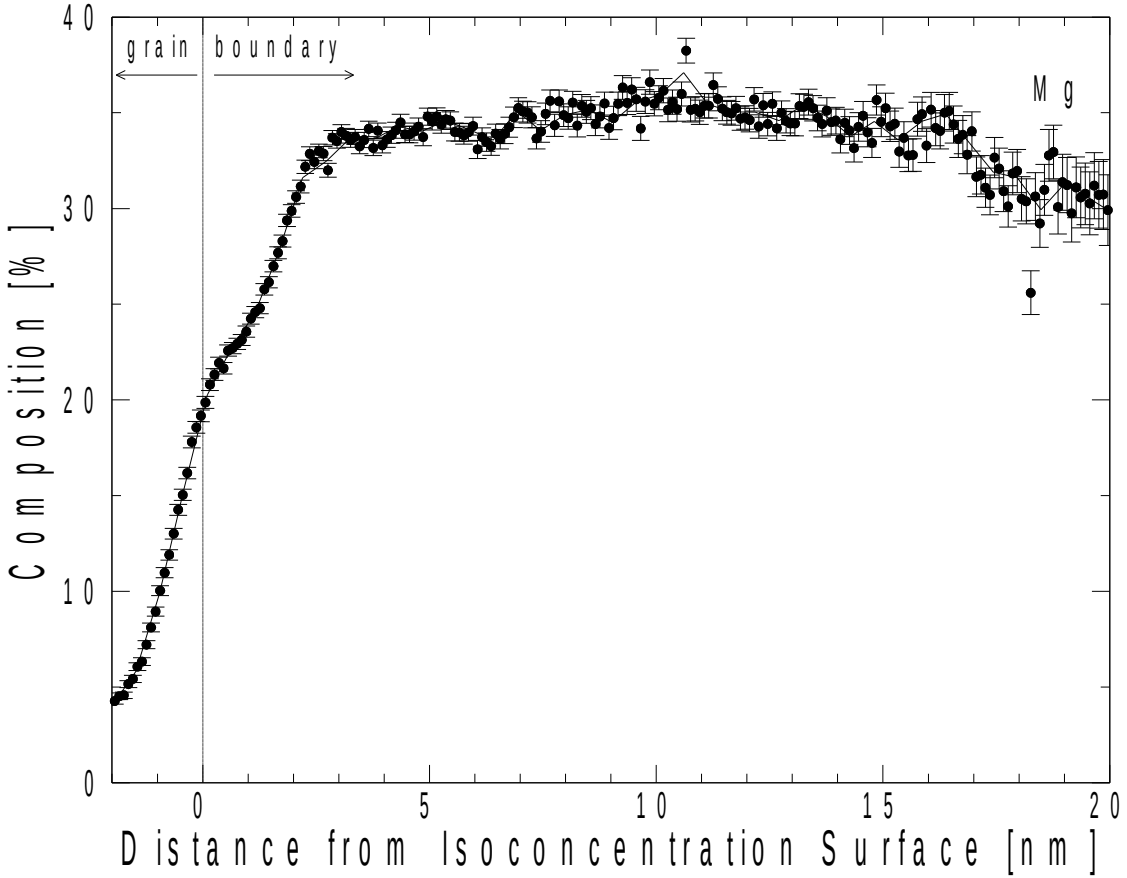
GB segregation of Mg



LEAP Tomography of Consolidation

- 11M ion dataset
- Mg segregation at GB
- Large MgO at GB (should pin grains)

Mg Segregation at GB



- Large segregation
- Detrimental to:
  - Solid solution strengthening
  - Fracture toughness
  - Permeability
- May promote beneficial oxide

LEAP Tomography of Aged Consolidation

Summary

- UFG Al-Mg exhibits
  - Outstanding mechanical strength
  - Reasonable thermal stability
  - Mg segregation to GBs, first reported here, may contribute to this stability
- On thermal aging,
  - Relaxation occurs
  - Mg may migrate through GBs to surface
  - Grains may grow

Acknowledgements

- UC Davis for materials
- NUCAPT (especially Dr. Dieter Isheim) for FIB preparation of powders
- J. Chames, M. Clift, R. Nishimoto, A. Gardea (Sandia)