Atom-Probe Tomography as a Tool for Studying RF Cavity Materials for Particle Accelerators

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Problem

- How can atom-probe tomography help with the problem of breakdown in super-conducting rf cavities fabricated from Nb?

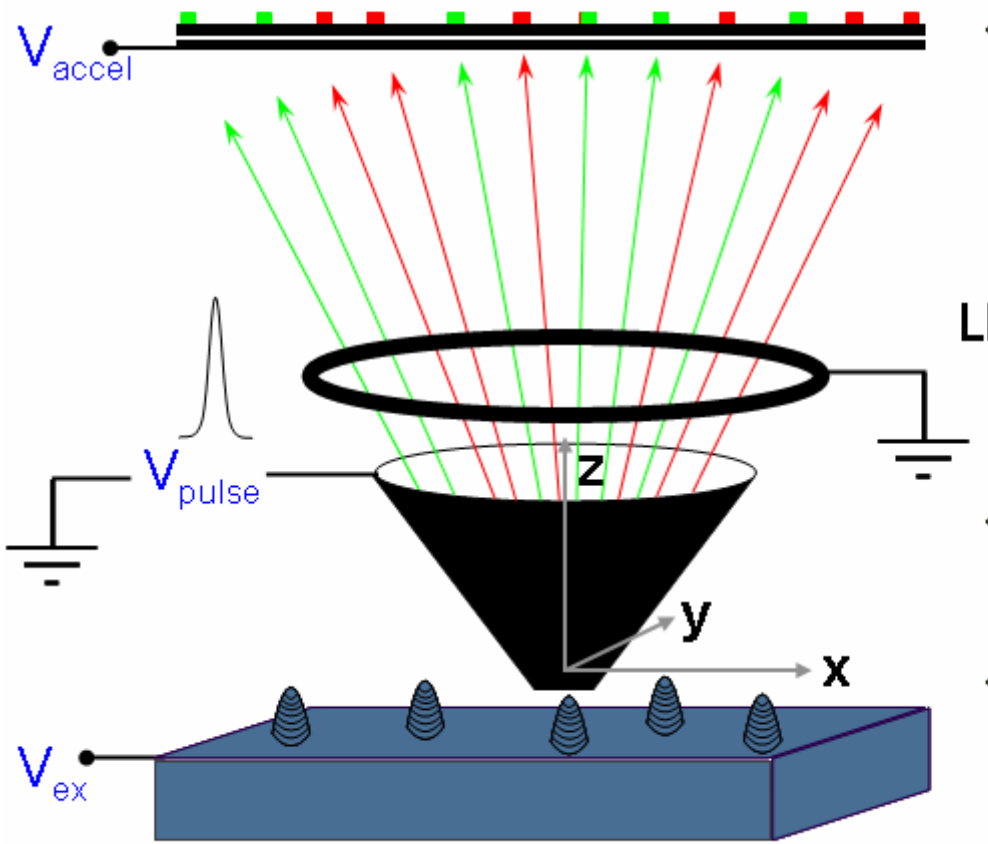
- Jim Norem (ANL) and co-workers have shown that current-field characteristics of Cu rf cavities obey Fowler-Nordheim law for electron field emission, which indicates the importance of sharp asperities in triggering breakdown.

The atom-probe microscope: time-of-flight (TOF) mass spectrometry of *single* atoms

- Due to the ability to control quantitatively the evaporation of atoms from a tip, atom-probe mass spectrometry is single-atom TOF mass spectrometry. The physical phenomenon of pulsed evaporation is accomplished with either electrical (nano- or picosecond) or laser (nano- or femtosecond) pulses

$$\frac{m}{n} = k\alpha(V_{\mathrm{dc}} + \beta V_{\mathrm{pulse}})\left(\frac{t + t_o}{d}\right)^2$$

LEAP microscope in scanning mode



SAP (Nishikawa et al. 1993) positionable funnel-shaped electrode for atom probe.

- Analyze microtips
  - Planar specimens
  - Multiple tips per specimen

LEAP (Kelly et al. 1994) adds post acceleration concepts with low voltage operation

- V_{ex} is small $\Rightarrow$ V_{pulse} is small
  - Much higher repetition rates
- V_{ex} small, V_{accel} large
  - Improve mass resolution
  - Larger field of view

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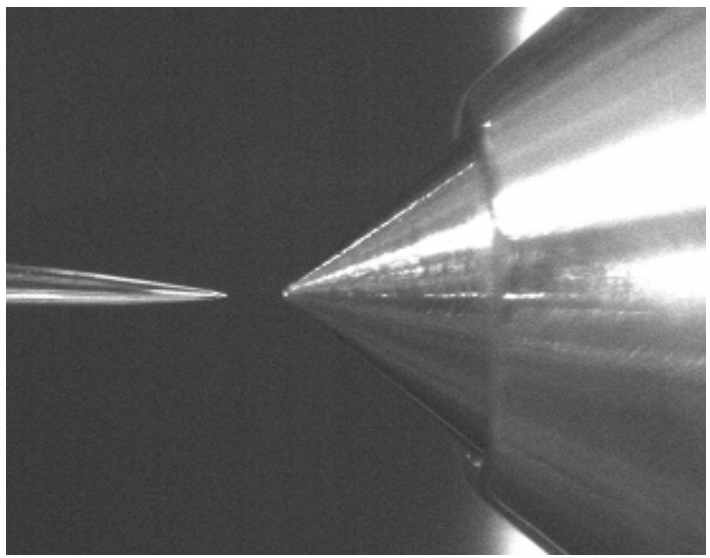
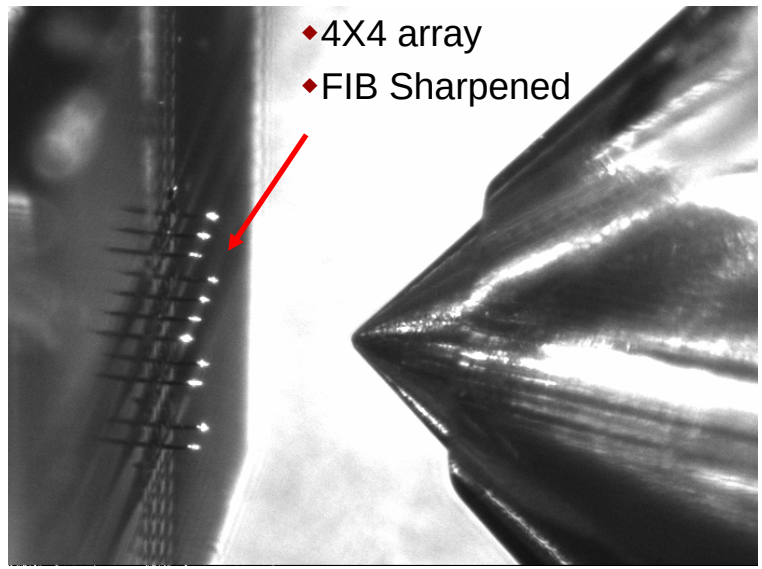
Local electrode in LEAP microscope for needle and scanning mode geometries

- Local electrode "localizes" field
  - both needles and microtips on wafers can be analyzed

Needle Geometry



Diced Microtip Geometry



Local-electrode atom-probe (LEAP) microscope

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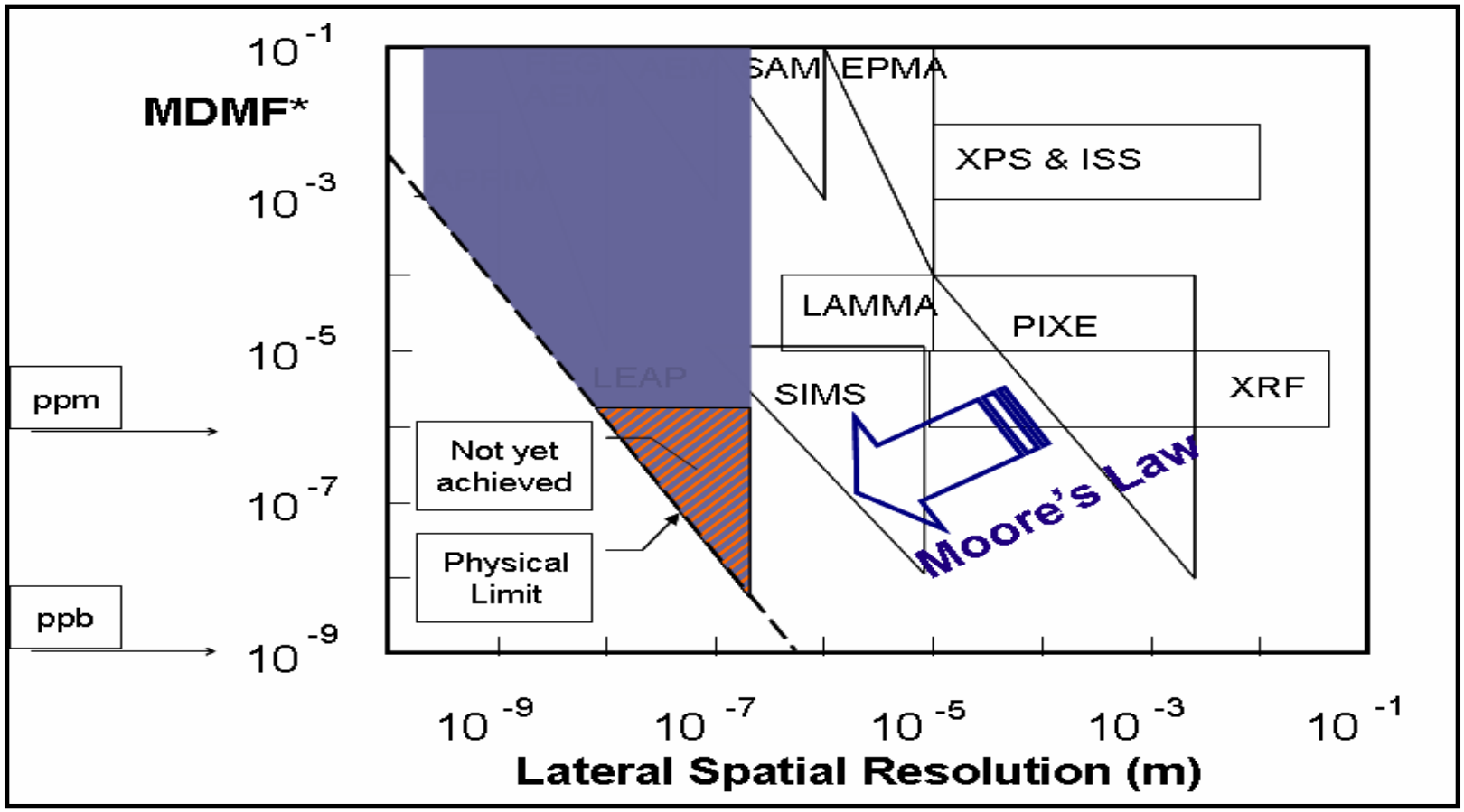
Minimum detectable mass fraction (MDMF) vs. lateral spatial resolution (meters) for different analytical techniques



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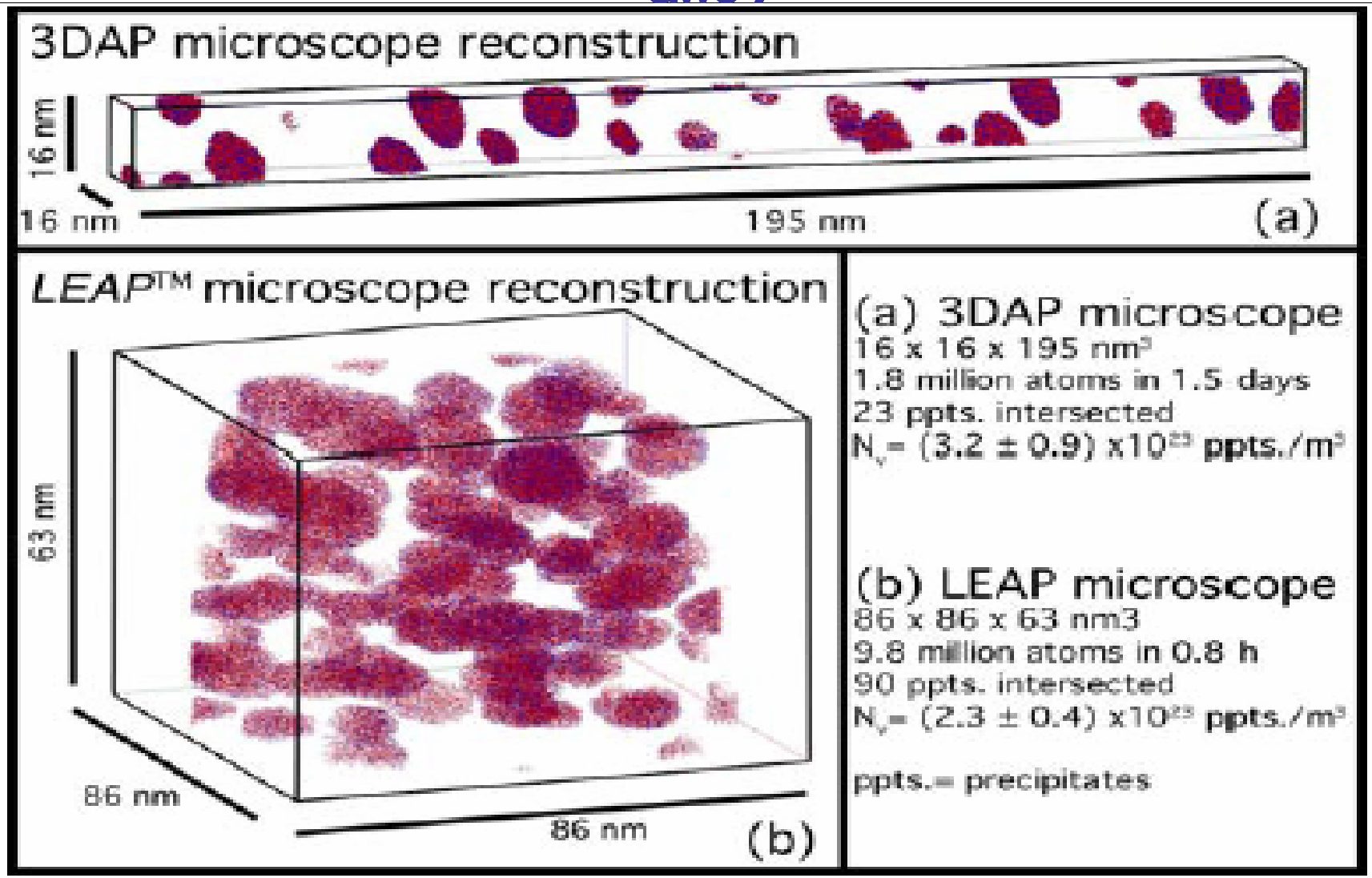
3D reconstructions of γ'-precipitates in a Ni-Al-Cr alloy



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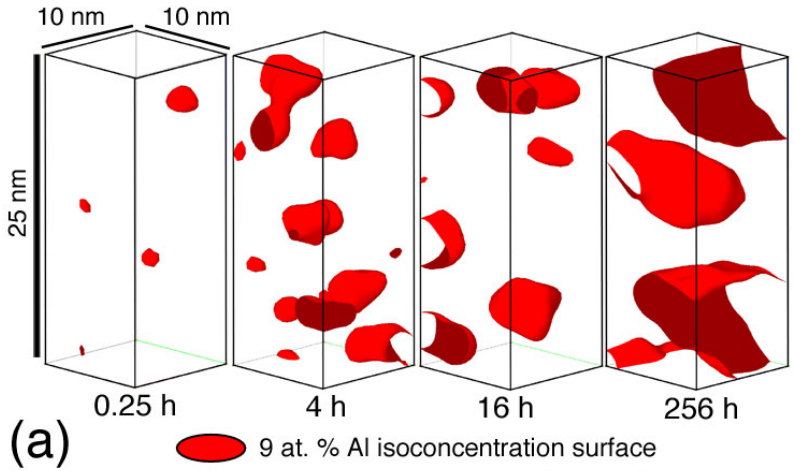
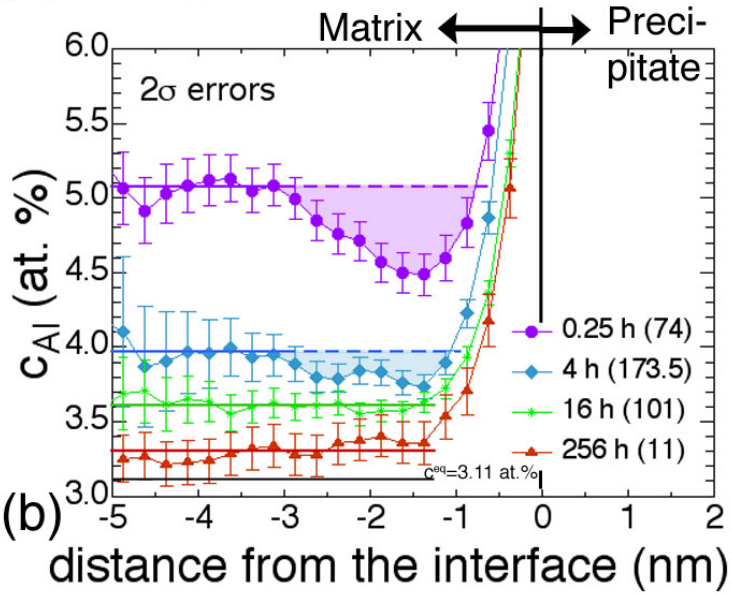
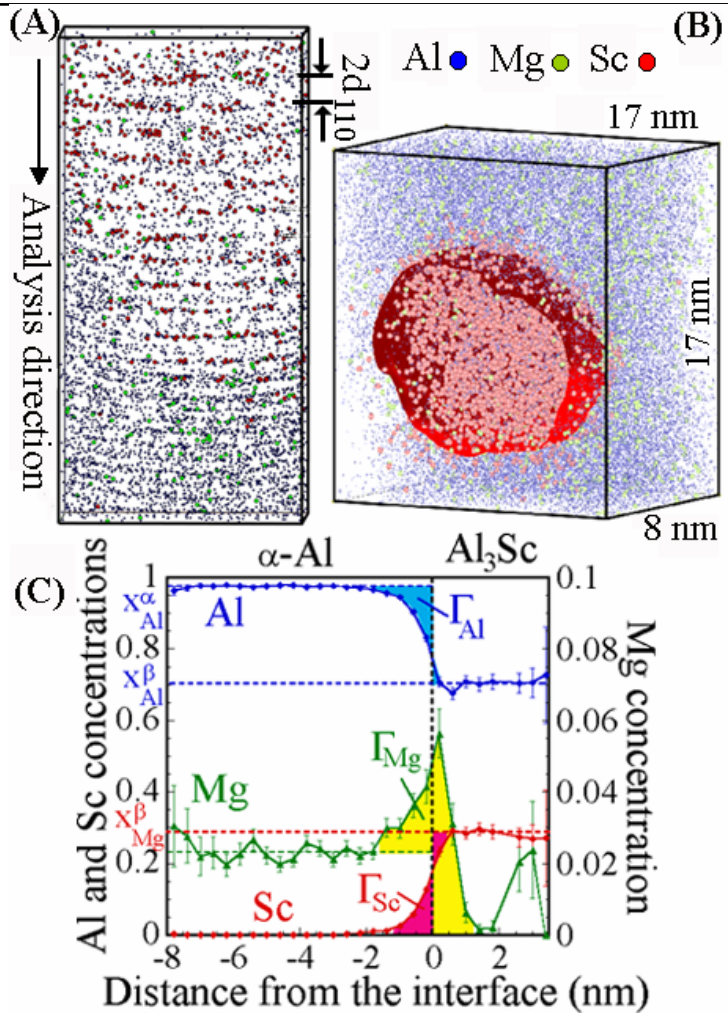
Isoconcentration surfaces & concentration profiles associated with γ'-precipitates in Ni-Al-Cr aged at 873 K.





Segregation of Mg at coherent (no misfit dislocations) Al_3Sc ($L1_2$) precipitates in α-Al matrix – E. Marquis, D. N. Seidman et al. Phys. Rev. Lett. 2003



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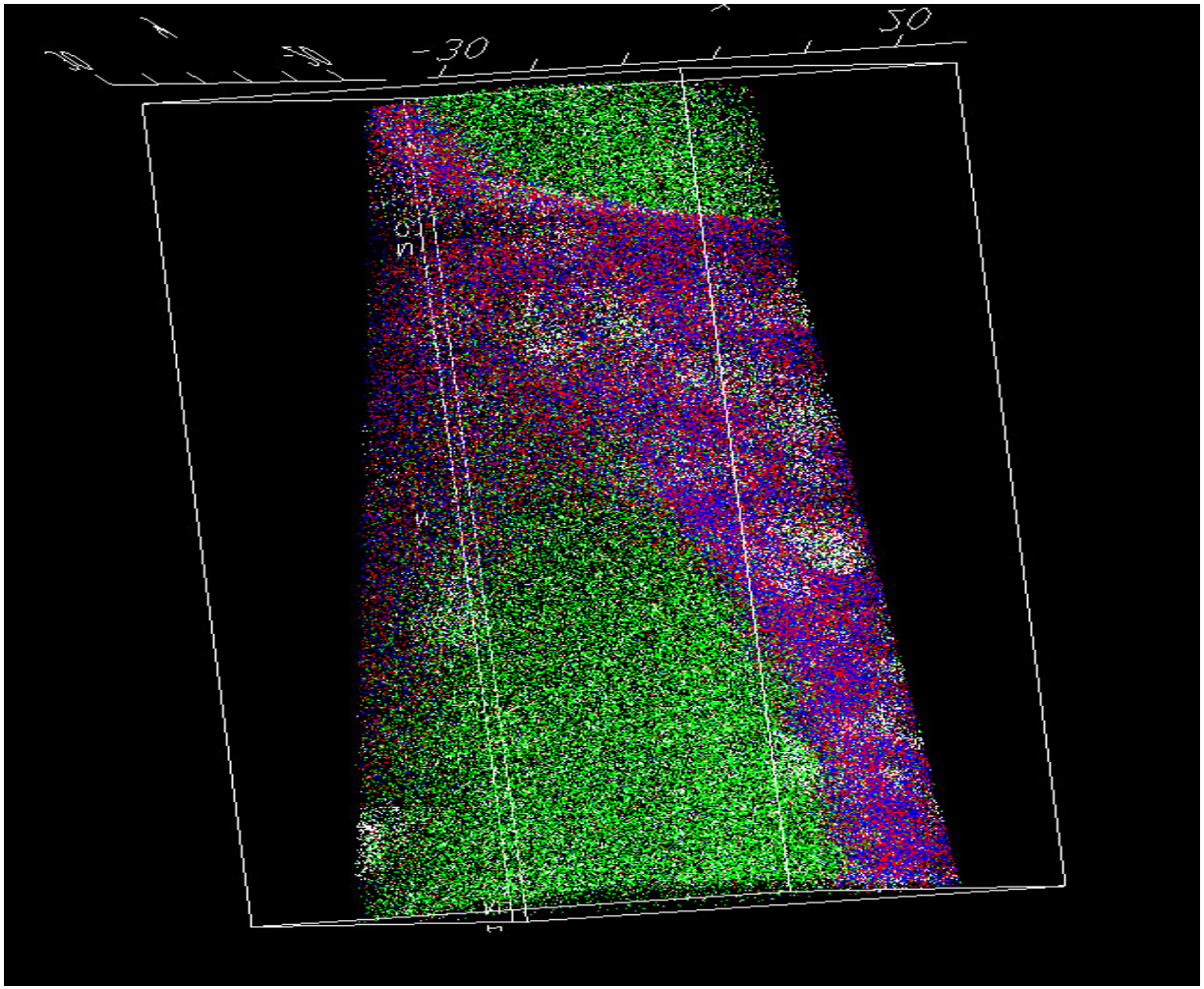
Aged Superalloy 718 analyzed by LEAP microscope

ca. 10^7 atoms in a volume that has a 40 nm^2 cross-section and depth of 120 nm



Each spot corresponds to a single atom.

Color Code

Ni- green

Al – grey

Ti – blue

Cr – Red

Nb – purple

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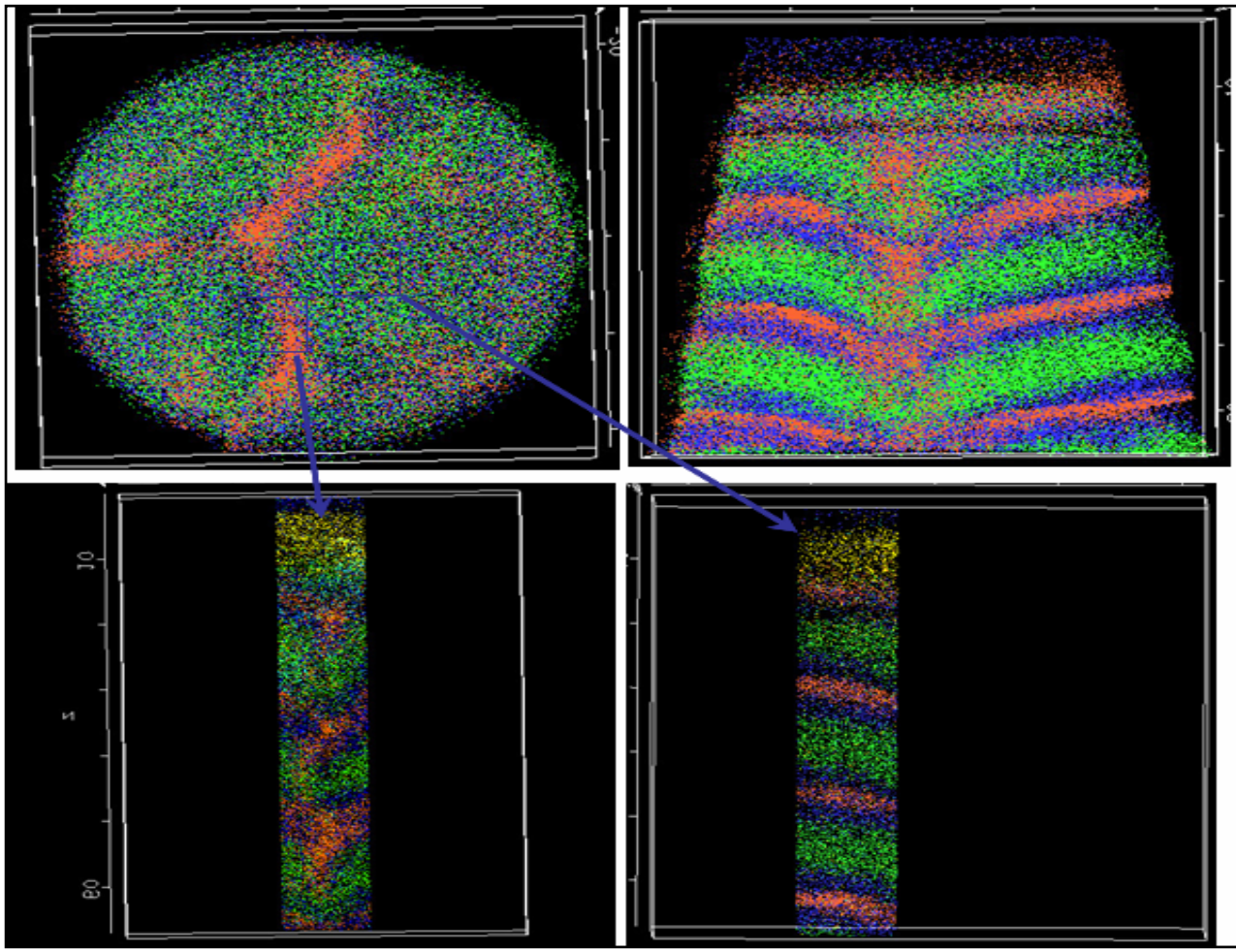
Benefit of wide field-of-view (FOV) in LEAP microscope



- Cu/CoFe/NiFe multilayer

Cu

Co

Ni

Wide FOV gives a more complete picture

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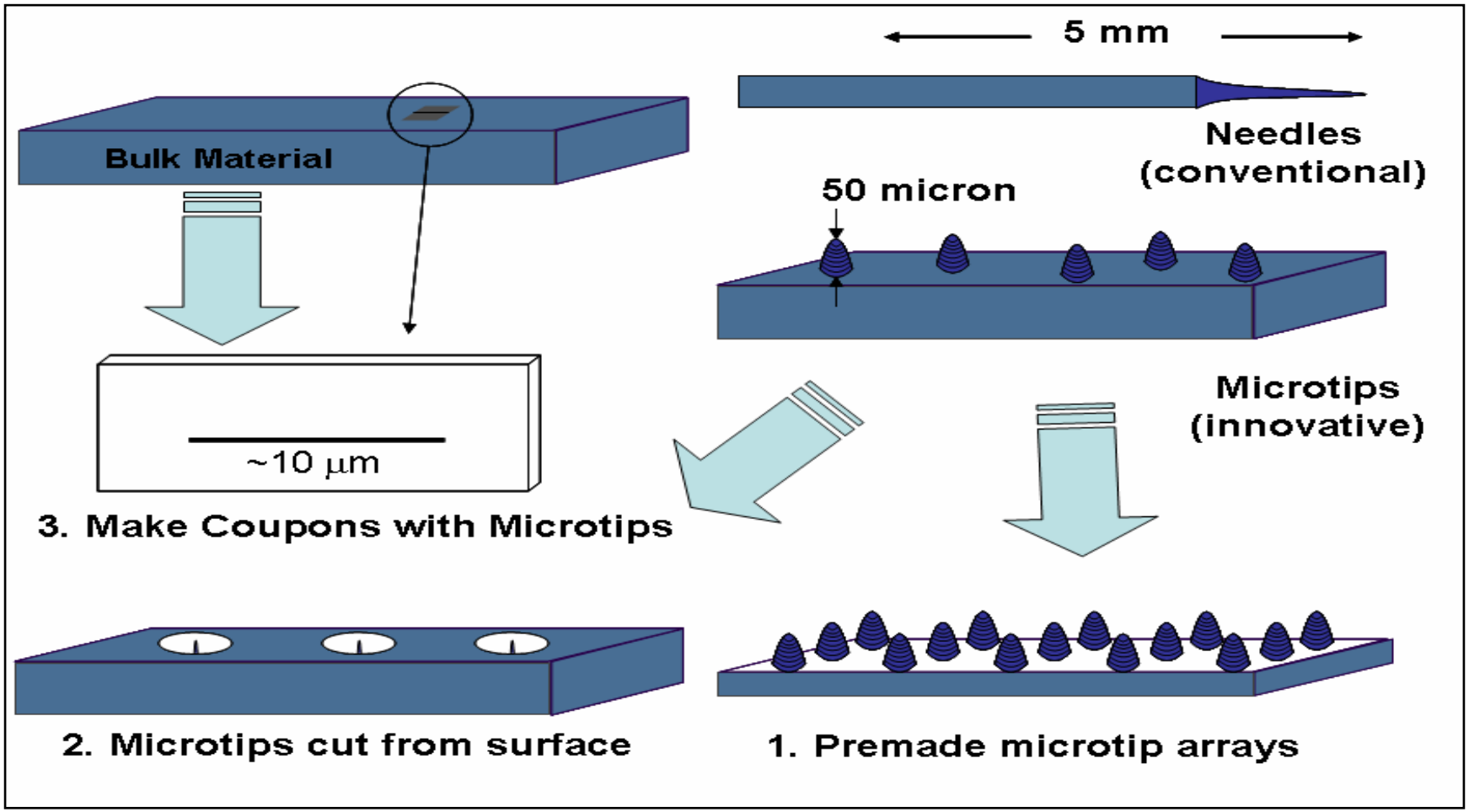
Specimen Preparation Techniques



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Conclusions

- Characterization of the near surface regions of RF cavity materials by local-electrode atom-probe microscopy is feasible with subnanoscale resolution for chemistry.

- The primary work will be to prepare LEAP specimens that allow us to analyze the first 200 nm, which preserves the original state of the material.