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Atomic-Scale Quantitative Three-Dimensional Characterization with a Local Electrode Atom Probe

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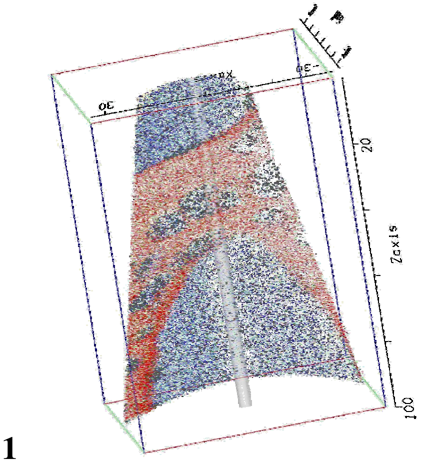
The Local Electrode Atom Probe (*LEAP*®) is an innovative three-dimensional atom probe microscope developed at Imago Scientific Instruments that combines quantitative 3-D atomic-scale imaging with high analytical sensitivity [1,2]. This technique, known as atom probe tomography, is the highest spatial resolution three-dimensional analytical technique available. It operates by taking specimens apart one atom at a time. Individual specimen atoms are ionized from the surface of a sharp specimen by a rapidly-pulsed electric field, and are then accelerated to a position-sensitive detector. The location where each ionized atom excites this detector directly maps to its original specimen position by projection microscopy, while time-of-flight measurement determines elemental identity. The LEAP microscope provides 3-D images with a nominal magnification of one million times with ~0.5 nm lateral resolution and 0.2 nm axial resolution, in combination with single atom analysis of elemental composition. This technique has applications in a wide spectrum of materials characterization tasks at the nanometer scale and several illustrative examples are shown below.

Fig. 1 shows an image of Alloy 718 where the two predominant phases are visible as revealed by the Cr-enriched and Nb-enriched phases. Aluminum is segregated to the interfaces between the two phases which has implications for phase stability at high temperatures. An atom map of an ultra-shallow junction in Si (red dots) – 6 keV As implant (blue spheres) and annealed at 1050^{o}C for 30 seconds - is shown in Fig. 2. There is no other technique that can provide this critical information to the semiconductor industry for developing and monitoring production of dopant implant regimens. Another important application for the semiconductor industry is the distribution of B atoms in a heavily B-doped polycrystalline-Si sample, Fig. 3. The B has clearly segregated to the grain boundaries, giving a distinct visualization of the grains. Clusters of B are found at grain boundary triple points in the polysilicon. The cluster indicated contains 264 B atoms and has a peak concentration of ~ $3\times10^{21}/cm^3$. Fig. 4 shows an advanced giant magneto-resistive spin valve stack with an oxidized region contained within a thin CoFe soft magnetic reference layer. The extent and location of oxidation is quantified on the atomic scale.

These examples illustrate several ways that atom probe tomography provides information which is not available by any other means. Furthermore, this novel information is often crucial to the materials research and development program utilizing it.

References

[1] T. F. Kelly and D. J. Larson, "Local Electrode Atom Probes (Review)," *Materials Characterization,* **44**, (2000) 59-85.
[2] T. F. Kelly et al., "First Data from a Commercial Local Electrode Atom Probe." *Microscopy and Microanalysis,* **10(3)** (2004) 373-386.
[3] We gratefully acknowledge the many other Imago employees who enabled this work. This material is based upon work supported by the National Science Foundation under Grant No. 0216620.



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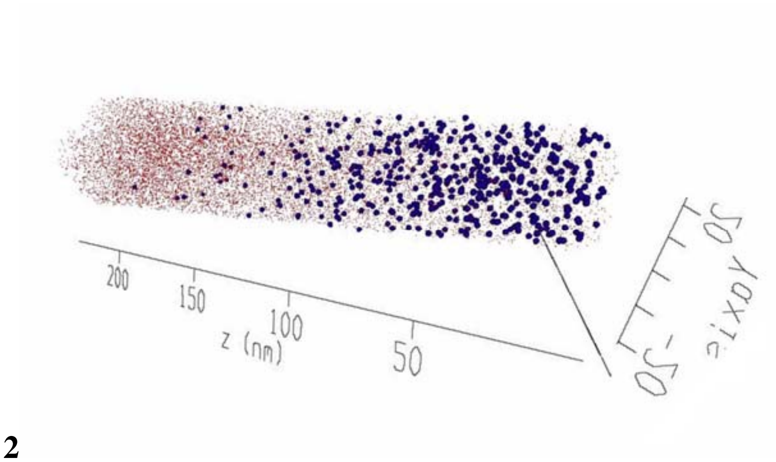

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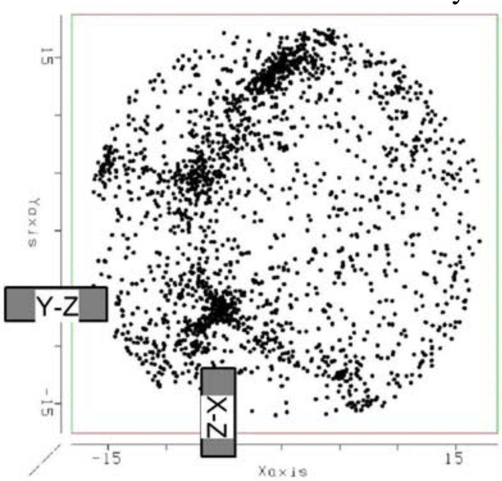
Fig. 1. LEAP image of Alloy 718 which shows Al (black), Cr (red), and Nb (blue). Volume is ~60 by ~60 by ~100 nm (data courtesy of M. K. Miller, Oak Ridge National Laboratory).

Fig. 2. Atom map of As (large spheres) implanted into Si (red dots). Only 0.2% of the Si atoms are shown for visualization clarity. The ion entry surface is close to z = 0 nm.



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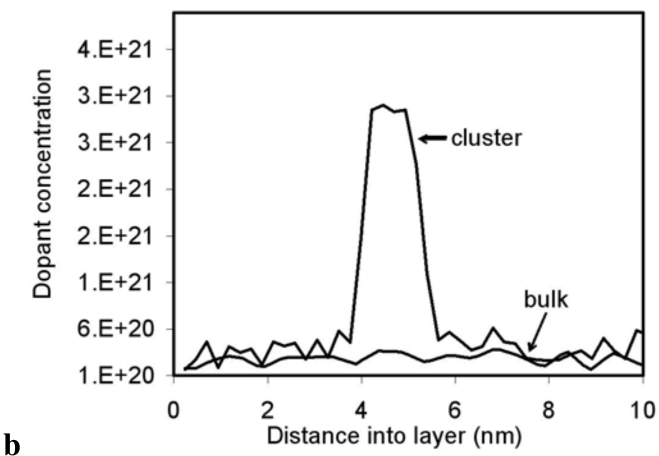
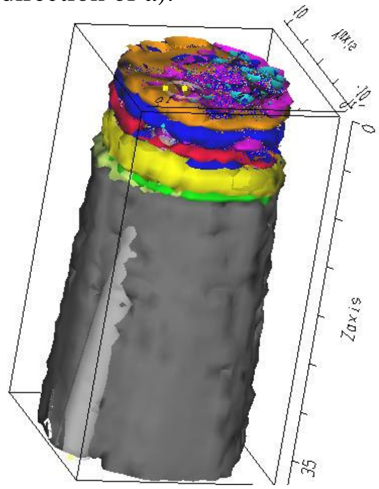


b

Fig. 3. a) Atom map of B in polysilicon. The axes are labeled in nm. b) Composition profile of B in the Z direction of a).



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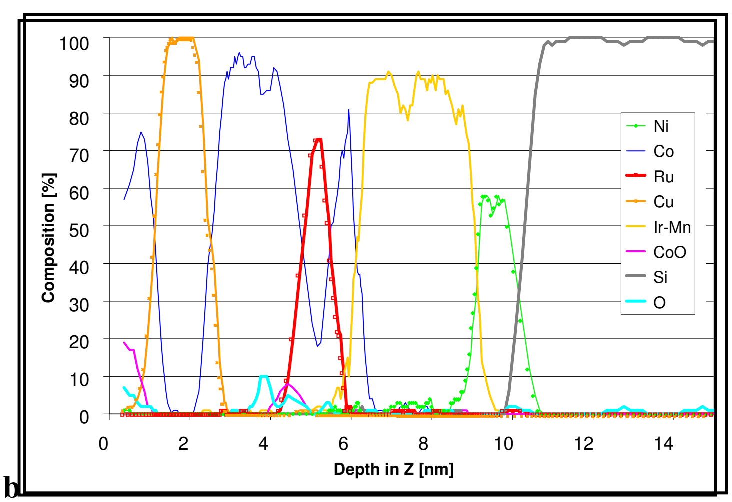

b

Fig. 4. a) Isoconcentration surfaces for a multilayered spin valve structure. b) Composition profile along the top-most section of the light gray cylinder shown in a).

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