Abstract & Bio
Three-Dimensional Quantitative Analyses of Material Microstructures by Atom-Probe Tomography

Keith E. Knipling
U. S. Naval Research Laboratory, Washington, DC 20375

Atom-probe tomography (APT) produces three-dimensional compositional images at the atomic scale with high (10 atomic parts per million) analytical sensitivity. Recent advances in the technique, particularly with the development of the local electrode atom probe (LEAP), have increased the analysis volumes by several orders of magnitude. In this talk, I present two examples where the wide field-of-view of modern atom-probes enables detailed structural analysis, on the order of tens of nanometers, in addition to the subnanometer compositional information normally associated with APT.

Conventionally solidified Al-Sc alloys, strengthened by Al₃Sc (L1₂ structure) precipitates, exhibit impressive coarsening and creep resistance up to 300°C, which can be improved to 400°C with ternary additions of Zr. Zirconium has a much smaller diffusivity than Sc, forming nanoscale Al₃(Sc₁₋ₓZrx) precipitates with Sc-rich cores that are enveloped in a ~1 nm thick Zr-enriched shell. The slower-diffusing Zr atoms limit coarsening, and, because they substitute for Sc in the precipitates, also reduce the relatively high cost of Sc additions. The compositions, radii, volume fractions, and number densities of the Al₃(Sc₁₋ₓZrx) precipitates are measured using APT, and this information is used to quantify the strengthening increments observed.

Finemet, Fe₇₃.₅Si₁₃.₅B₇Nb₅Cu₁, is a nanocrystalline soft magnetic material possessing a unique combination of large magnetization, high permeability, and low coercivity and core loss, which results from nanoscale ferromagnetic grains that are exchange-coupled through a surrounding amorphous matrix. Prepared by partially devitrifying melt-spun amorphous precursors, the microstructure consists of a large volume fraction (~70 vol.%) of ~10 nm diameter randomly oriented Fe-Si grains embedded in a residual B- and Nb-rich amorphous matrix. A small volume fraction (~1 vol.%) of ~5 nm diameter Cu precipitates is also present, which act as heterogeneous nucleation sites for the Fe-Si crystallites during devitrification. Substituting Al for Fe is expected to decrease the magnetocrystalline anisotropy of the nanocrystals, further reducing the coercivity and core losses. Using APT, the phase compositions are measured in a series of (Fe₁₋ₓSiₓAlₓ)₈₇B₇Nb₅Cu₁ alloys. A significant amount of Al is scavenged by the Cu precipitates, limiting the amount available for incorporation into the Fe-Si crystallites.

Keith Knipling earned his B.S. and M.S. degrees from Virginia Tech, and his Ph.D. from Northwestern University, all in Materials Science and Engineering. His Ph.D. research, under the guidance of Profs. David Seidman and David Dunand, was toward developing new precipitation-strengthened aluminum alloys for high-temperature applications. In the Fall of 2006, Dr. Knipling came to the U.S. Naval Research Laboratory (NRL) as a National Research Council Fellow. Supervised by Dr. Richard Fonda, his research studied the microstructures and crystallographic textures that develop during friction stir welding of aluminum, steel, and titanium alloys. Currently a staff scientist at NRL, Dr. Knipling has continued his interests in understanding the deformation mechanisms occurring during friction stir welding. Another area of research is developing new, more energy efficient soft magnetic alloys. Dr. Knipling has published 23 peer-reviewed articles in the scientific literature, primarily in physical metallurgy. He is the recipient of two NRL Alan Berman Publication Awards (2008, 2009), and was a 2012 recipient of the Presidential Early Career Award for Scientists and Engineers (PECASE).