

Atom Probe Tomography and the Local Electrode Atom Probe

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The introduction of the local electrode atom probe has made dramatic, orders of magnitude improvements in the data acquisition rate and the size of the analyzed volume compared to the previous types of three-dimensional atom probes. The local electrode (or scanning) atom probe was initially envisaged by Nishikawa for the analysis of planar specimens [1,2]. The original intention was for the characterization of naturally occurring protrusions or microtips fabricated from the surface layers of a specimen by focused ion beam techniques. However, the instrument may also be applied to traditional needle-shaped field ion microscopy specimens.

In atom probe tomography, three-dimensional images of the internal structures of the specimen are generated from many slices, each containing a few atoms [3]. The atomic coordinates and the mass-to-charge ratio are determined for each ion collected in a time-of-flight mass spectrometer that is equipped with a position-sensitive single-atom detector, Fig. 1. A high voltage pulse is repetitively applied to a field-defining counter electrode in front of the cryogenically cooled specimen to field evaporate ions from the surface of the specimen. The major difference between the local electrode atom probe and previous three-dimensional atom probes is the diameter of the aperture in the counter electrode and its proximity to the apex of the needle-shaped specimen. In a conventional three-dimensional atom probe, a 5-10 mm diameter aperture is typically placed 4-10 mm in front of the specimen. In the local electrode atom probe, a 20-50 μm diameter aperture is typically positioned approximately one aperture diameter in front of the specimen. In order to accurately align the specimen to the aperture in the funnel-shaped electrode, the specimen is mounted on a three axis nanopositioning stage. This stage may also be used to scan across the surface of planar specimen to locate microtips, etc. The advantage of this local electrode configuration is that a significantly lower voltage is required to produce the field strength required to field evaporate ions from the specimen. For example compared to the conventional three-dimensional atom probe, only $\sim 50\%$ of the voltage is required for a 30 μm aperture positioned $\sim 10 \mu\text{m}$ in front of the apex of the specimen. As the voltages are lower, it is economical to build voltage pulsers that can operate at orders of magnitude faster pulse repetition rates of up to 200 kHz. These pulsers coupled with crossed delay line detectors enable significantly faster data acquisition rates to be achieved. Due to the close proximity of the local electrode to the specimen, the transit times of the ions to the electrode and the field free region of the mass spectrometer are considerably shortened, thereby eliminating the major source of the energy deficits that degrade the mass resolution. As energy-compensating lenses are not necessary, a larger field of view of the specimen may be analyzed. This new design results in data sets containing up to 10^8 atoms. Examples of the fine scale decomposition that occurred in a bulk metallic glass and a nickel base superalloy are shown in Figs. 2 and 3, respectively [4].

- [1] O. Nishikawa and M. Kimoto, *Appl. Surf. Sci.*, **74/75** (1994) 424.
- [2] T.F. Kelly and D.J. Larson, *Mater. Characterization*, **44** (2000) 59.
- [3] M.K. Miller, **Atom probe tomography**, Kluwer Academic/Plenum Press, New York, 2000.
- [4] Research at the Oak Ridge National Laboratory SHaRE Collaborative Research Center was sponsored by the Division of Materials Sciences and Engineering, U.S. Department of Energy, under contract DE-AC05-00OR22725 with UT-Battelle, LLC.

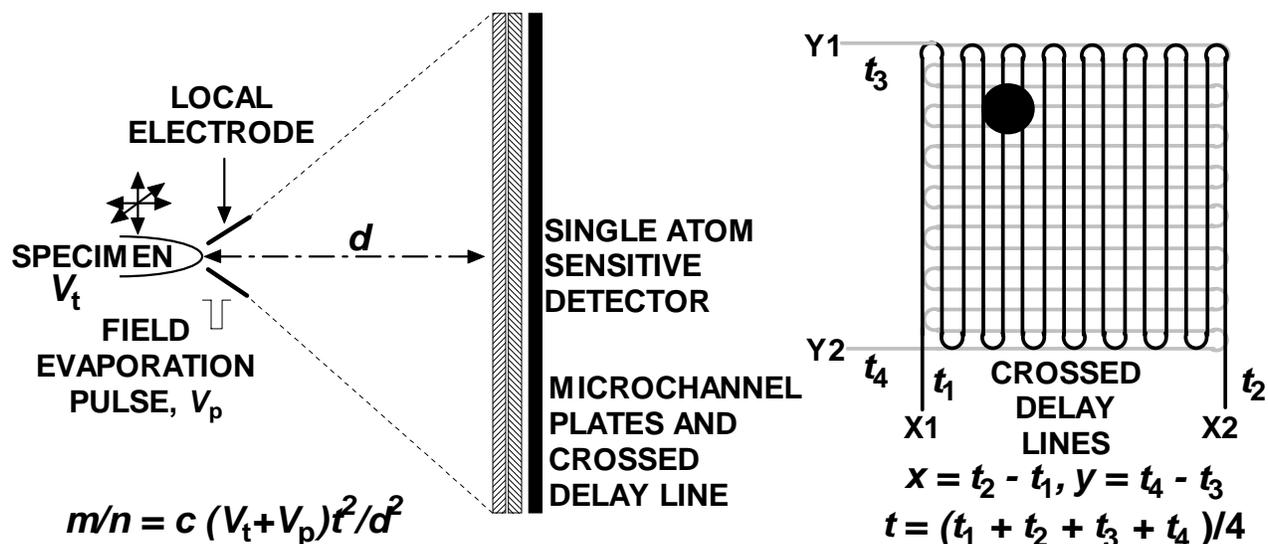


Fig. 1 The local electrode atom probe features a funnel-shaped counter electrode positioned in close proximity to the specimen. Atoms are removed from the specimen by the application of a high voltage pulse to the local electrode and are analyzed in the time-of-flight mass spectrometer.

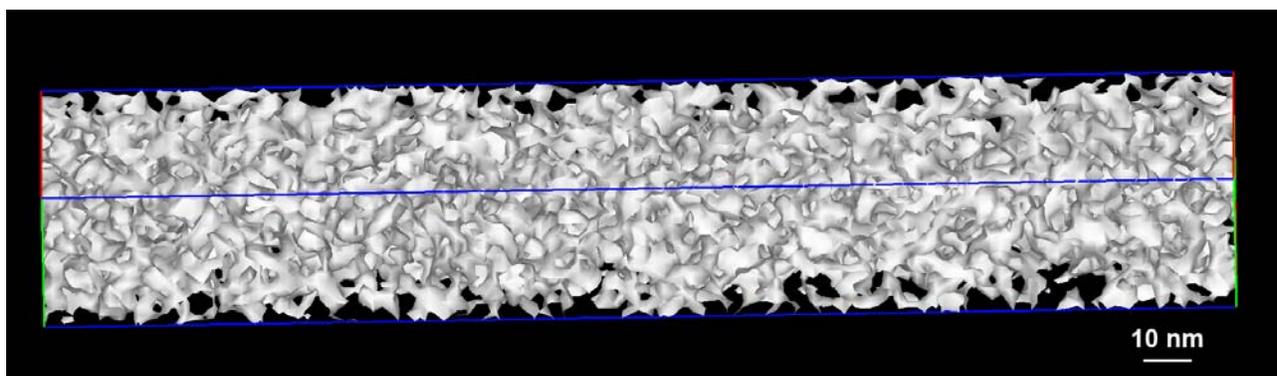


Fig. 2 Phosphorus isoconcentration surface in a $\text{Pd}_{40}\text{Ni}_{40}\text{P}_{20}$ bulk metallic glass showing a fine-scale isotropic interconnected network structure of two amorphous phases after annealing for 80 min at 340°C . Specimen courtesy Dr. R. B. Schwarz, Los Alamos National Laboratory.

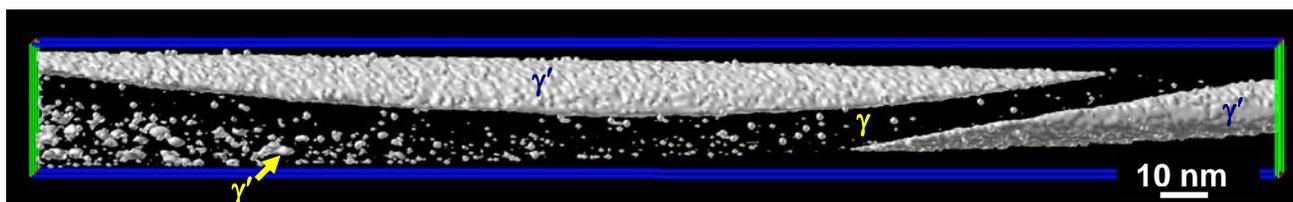


FIG. 3. Aluminum isoconcentration surface of a CMSX4 nickel based superalloy. A zone that is depleted in small γ' precipitates is evident in the γ matrix phase adjacent to the primary γ' precipitates. Specimen courtesy Prof. R. Reed, University of British Columbia.