Cryogenic Atom Probe Tomography: Expanding the Frontiers of Atomic-Scale Materials Characterization

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Atom probe tomography (APT) enables three-dimensional compositional analysis of materials with near-atomic resolution and, in principle, allows the detection of all elements, including hydrogen. However, accurate characterization of hydrogen and its isotopes using conventional APT remains challenging. During specimen preparation and transfer through ambient conditions, samples are highly susceptible to hydrogen contamination, while residual hydrogen in the analysis chamber contributes additional background signals. In addition, hydrogen exhibits extremely high mobility at room temperature and can rapidly diffuse out of the nanoscale needle-shaped APT specimens, making it difficult to preserve its intrinsic distribution within materials.

To address these challenges, cryogenic atom probe tomography (Cryo-APT) has recently been developed by integrating ultrahigh-vacuum and cryogenic specimen handling with the conventional APT workflow. In this approach, samples are maintained at liquid-nitrogen temperature under ultrahigh-vacuum conditions throughout preparation and transfer between the preparation chamber and the atom probe instrument. These conditions effectively suppress external hydrogen contamination and significantly reduce hydrogen diffusion within materials, enabling improved preservation of their original atomic distributions.

Initial applications of Cryo-APT have emerged in studies of hydrogen embrittlement in metallic systems as well as in surface processes such as oxidation and corrosion. Looking ahead, Cryo-APT is expected to provide unprecedented atomic-scale insights into hydrogen storage materials, surface catalysis, and emerging energy materials such as batteries, opening new opportunities for exploring hydrogen-related phenomena in materials at the true atomic scale.