

3-D Atom Probe Applications: Past, Present and Future

G.D.W. Smith and A. Cerezo

Department of Materials, Oxford University, Parks Road, Oxford OX1 3PH, United Kingdom, and Oxford nanoScience, 4-6 Carters Lane, Kiln Farm, Milton Keynes, MK11 3ER, United Kingdom.

The three-dimensional atom probe has changed the way that we carry out materials research. For the first time, it has become possible to study the 3-D atomic scale chemistry of a solid specimen, and not only its 3-D structural configuration. By combining field ion microscopy with state-of-the-art, nanosecond resolution, time-of-flight mass spectrometry and position-sensitive detection, the location and identity of an individual atom can be established. The pulsed field evaporation process is then iterated millions of times, to build up a comprehensive 3-D image of the specimen [1-3].

The initial applications of the 3-D atom probe were largely in the metallurgical area, and involved studies of the role of alloy elements on phase transformations, phase stability and heat treatment procedures in steels, and in alloys based on aluminium, titanium or nickel. This work has been comprehensively reviewed by several authors [2-4]. New and important data was obtained regarding the effect of individual alloy additions on the processes of nucleation, growth and coarsening of particles, on the mechanisms and kinetics of spinodal decomposition, and on the atomic-scale processes involved in grain boundary segregation. However, the outcomes were unexpectedly significant in at least two respects. Rapid developments took place in the 3-D atomistic computer modelling of materials, in parallel with the development of the 3-D atom probe, and these led to new and highly important synergies between theory and experiment (see for example [5, 6]). As a result, the 3-D atom probe can now legitimately be regarded as a tool to aid the design of new materials, as well as a means to analyse existing ones. Also, the 3-D atom probe turned out to have remarkably direct applications to the study of real engineering materials, not just to model alloys prepared in the laboratory. As a consequence, the technique became significant for the study of some critical engineering problems, for example in assessing the structural integrity and safe operating lifetime of electrical power generating plant [2, 3].

A number of further areas of application of the 3-D atom probe have emerged. New specimen preparation methods, and new instrument geometries, have facilitated the study of multilayer thin films. There have been a number of important studies of thin film nanostructures used for information storage and retrieval and these are the subject of an excellent review by Larson et al. [7].

The incorporation of pulsed laser field evaporation methods has enabled the technique to be applied to less conducting materials, and valuable work has been carried out on III-V semiconductor multi-quantum well structures [8]. The main limitation of the initial laser probe work was the restriction on the pulse repetition rate. However, a new generation of lasers is now available operating at 100 kHz or more, and so a resurgence of activity in this area is to be expected. This field of activity is likely to expand rapidly as the size of individual semiconductor devices shrinks towards the nanometer range, and the need to locate individual dopant atoms becomes of critical importance.

A surprising omission in the applications of the 3-D atom probe has been in the area of surface studies. Some of the very earliest atom probe studies carried out by Muller and co-workers at

Pennsylvania State University were on adsorption and corrosion phenomena, using the original probe-hole aperture style of instrument. In principle, this kind of work is much easier to carry out using a wide-angle position-sensitive detector, yet very little research of this type has been reported. A new 3-D instrument developed at Oxford University, the Catalytic Atom Probe (CAP) is designed to open up this field of study [9]. By incorporating a reaction cell into the specimen preparation chamber, linked to a sophisticated gas handling system, atom probe specimens can be exposed to a range of active gases and gas mixtures at pressures of up to 1 bar and temperatures up to 600 °C. Initial studies have concentrated on the behaviour of platinum-based alloys during exposure to gases that occur in automotive exhausts. Fig. 1 shows an example of the type of data that can be obtained from an experiment involving the adsorption of nitric oxide on the platinum (012) surface. The location of individual adsorbed molecules can be seen, and the relationship between surface reactivity and surface site can be explored in atomic detail for the first time. By combining the 3DAP with pulsed desorption mass spectrometry, the kinetics of surface reaction process become amenable to direct, single-molecule-level study in unprecedented detail.

References

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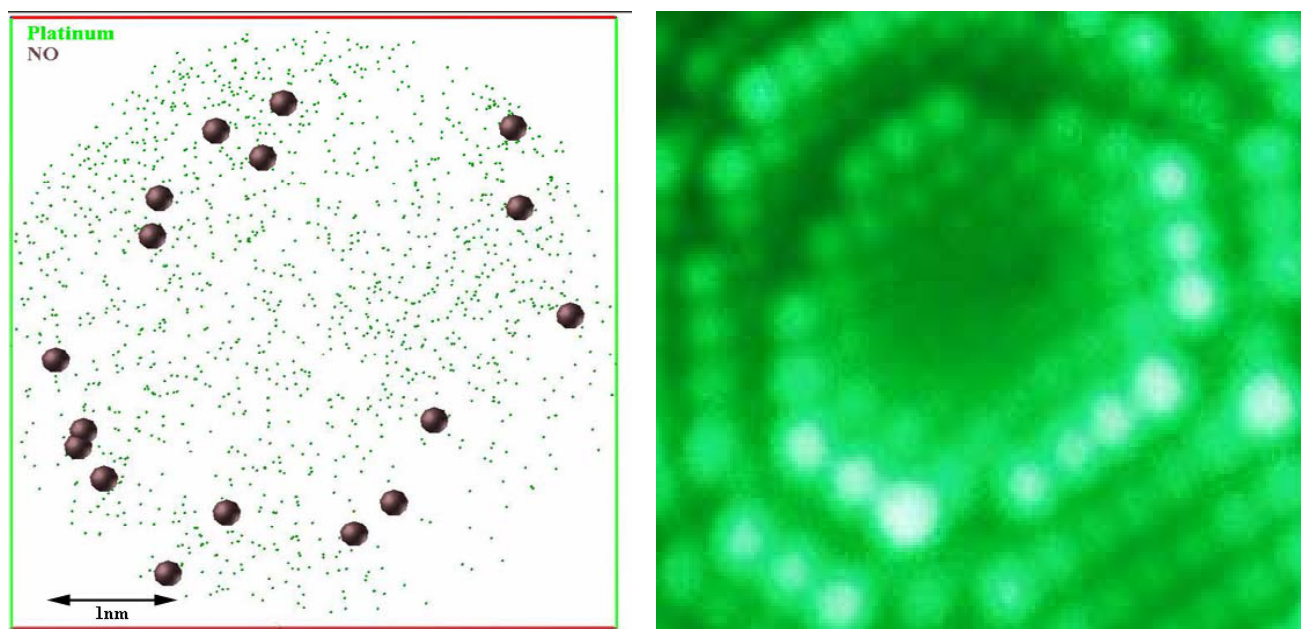


FIG. 1. (a) Atom map of Pt (012) surface after room temperature treatment with NO. (b) FIM image of a clean Pt (012) pole. Figure courtesy P.A.J. Bagot, Oxford University [9].