Atom-Probe Field Ion Microscopy

Tien T. Tsong
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The field ion microscope (FIM), invented by Erwin W. Müller in 1951, allowed for the first time the observation of solid surfaces with atomic resolution. However, the problem related to the chemical nature of imaged atoms remained. With the introduction of atom-probe techniques (AP-FIM) in 1967 by the designer of both the field emission and field ionization microscopes, the atoms that one can image by field ion microscopy could be identified individually and unambiguously. The invention of this new quantitative microanalysis tool with high spatial resolution opened new application areas in materials science as well as in solid-state physics. Both FIM and atom-probe can now be used to image and analyze a large variety of materials, including metallic alloys, semiconductors, or even high-temperature superconductors.

This book, written by one of the pioneers in field ion microscopy, is intended for scientists interested in field emission physics and materials science. As compared to the recent books of M.K. Miller and G.D.W. Smith,[1] T. Sakurai, S. Sakai, and H.W. Pickering,[2] or that of R. Wagner,[3] the applications detailed here are essentially focused toward surface science. Special attention is given also to the basic physical mechanisms involved in FIM atom-probe techniques.

The choice of subjects reflects the author's own research and personal interest. For instance, almost 100 pages of the book are devoted to the various theories of field ionization, field evaporation, field adsorption and desorption, and field dissociation. In the same way, a large part of the applications are related to the atomic structure of surfaces and to the behavior of migrating atoms on solid surfaces, while few illustrations or results are given in physical metallurgy.

The monograph is organized around five main chapters. The first section describes the fundamentals of field ion emission phenomena as well as the basic principles of techniques. As compared to the previous book written by Müller and Tsong[4] in 1969, the basic theories of field evaporation (image-hump and charge-exchange models) have been complemented with new models or emerging theories including post-ionization concepts. Photon-stimulated field desorption and atomic tunnelling processes in field dissociation are also discussed. The end of this first chapter relates to the classical but crucial problems of field ion image formation such as resolution and magnification.

Since the invention of the atom-probe, many innovative improvements to the initial instrument have been made. New types of apparatus (i.e., pulsed laser atom-probe, imaging atom-probe, and energy-compensated time-of-flight mass spectrometer) then followed. More recently, a new generation of three-dimensional atom-probes was designed.[5] Chapter 2 provides experimental details related to these new aspects and to the basic problems of specimen preparation or image interpretation.

Very little attention is given to the statistical methods of interpreting atom-probe data currently used to investigate phase transformations (i.e., decomposition, precipitation, and clustering). Little information is given regarding factors affecting instrument performance (i.e., preferential evaporation and local magnification effects), despite their crucial importance for obtaining quantitative atom-probe data.

Chapter 4 is devoted to surface science applications and gives a nice picture of the subtle effects and fine-scale phenomena that FIM atom-probe techniques enable us to investigate. For instance, the chapter discusses experiments related to atomic reconstruction of metal surfaces, FIM studies of silicon surfaces, and research aimed at determining the atomic structure of thin films. Impressive results related to the diffusion and interactive migration of atoms on solid surfaces are described in great detail. After a discussion of the electronic properties of adsorbed atoms, the author outlines the ability of FIM techniques to investigate surface segregation phenomena. The chapter concludes with discussion of gas-surface interactions and related field-induced effects.

After a review of the information FIM provides in the domain of lattice defects, Chapter 5 offers a brief discussion of applications in phase transformations. The role of this technique for the three-dimensional reconstruction of vacancy clusters (voids) in irradiated metals is then discussed. The last sections of this chapter are devoted to the formation of compound layers, liquid ion sources, and field desorption tomography of imaging biomolecules. The chapter ends by comparing atom-probe techniques to other atomic resolution microscopies such as HRTEM and STM.

In conclusion, this work provides a good source of basic information and references for scientists new to the field or for physicists working in this domain who would like a convenient monograph. Although this book may be inadequate for graduate students entering this field and wanting to use atom-probe techniques in physical metallurgy, it constitutes a precious and interesting reference for scientists studying field-emission-related phenomena and applications in surface science.

[1]M.K. Miller and G.D.W. Smith, *Atom Probe Microanalysis: Principles and Applications to Materials Problems* (Mater. Res. Soc., Pittsburgh, PA, 1989).

[2]T. Sakurai, S. Sakai, and H.W. Pickering, *Atom-Probe Field Ion Microscopy and Its Applications* (Academic Press, New York, 1989).

[3]R. Wagner, *Field Ion Microscopy* (Springer, Berlin, 1985).

[4]E.W. Müller and T.T. Tsong, *Field Ion Microscopy, Principles and Applications* (Elsevier, New York, 1969).

[5]A. Cerezo, T.J. Godfrey, and G.D.W. Smith, *Rev. Sci. Instrum.* **59** (1988) p. 862.

Reviewer: D. Blavette is a professor at the Laboratoire Microscopie Ionique Faculte des Sciences, URA, France. □