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Field Ion Microscopy: Historical and Recent Developments

Tien T. Tsong
Institute of Physics, Academia Sinica, Taipei, 11529 Taiwan

Two of the most important aspects of atomic resolution microscopy are imaging of sample atoms and chemical identification of specified atoms of the sample. Historically, field ion microscopy leads the way in both aspects.[1,2] The field ion microscope was invented by Erwin W. Müller in 1951. The field ion image was originally thought to be formed by continual adsorption and desorption of image gas atoms at the tip surface. Around 1955, it was realized theoretically that cooling of the sample should improve the image resolution. Early experimental attempts, however, failed to find much improvement. With the introduction of a cold finger by Müller, however, he and his graduate student K. Bahadur succeeded in achieving the atomic resolution of the FIM on October 11 of 1955.[3] This year marks the Golden Anniversary of their seeing atoms for the first time in human history. After that year, FIM continues to develop with many technical refinements and applications.

For the chemical identification of surface atoms, it was first attempted from the image contrast, particularly from the image contrast of ordered alloys PtCo and Pt_3Co, by Tsong and Müller. They found that in these ordered-alloys, Co atoms did not give rise to field ion images. In other words, Pt and Co atoms could be distinguished. A real breakthrough in microscopic chemical analysis came in 1967 when Müller realized the possibility of combining FIM with a single atom detection sensitivity mass spectrometer that can either be a time-of-flight mass spectrometer, now known as the ToF Atom-Probe FIM, or a magnetic sector mass spectrometer, now known as a magnetic atom-probe. The first ToF atom-probe was developed by Müller, Paniz and McLane in 1968 whereas Sakurai and Müller introduced a magnetic atom-probe although the latter could not achieve single atom detection sensitivity for specified atoms nor imaging capability at ion detection. The next great improvement in FIM is the introduction of an imaging atom-probe by Panitz which is further developed into fully automated powerful three dimensional commercial atom-probes for microanalysis of nano structured materials by University of Oxford, University of Ruon and Imago Scientific Instruments groups.

A very important area of application of FIM and atom-probe is the microanalysis of nano materials, especially alloys. It is now possible to obtain 3D chemically separated images of nano material structures with atomic resolution and to relate the structure to the mechanical property of these materials. Other important areas of applications are in surface and nano-science and surface analysis, and also in the development of various field emission sources, including field emission flat panel display and field ionization and liquid metal ion sources.

Of course, as most scientists are fully aware that in the meantime, transmission electron microscopy and scanning probe microscopy have also achieved atomic resolution. These microscopes have certain advantages over FIM. For examples, there is no need of an ultra-high electric field for imaging which limits the material applicability, sample shapes are less stringent, no cooling is needed and a wider variety of capabilities than FIM. Nevertheless, in instrumentation, Russell Young's invention of a Topographfinder contributed very directly to the successful development of the STM. In addition, I will show with several real examples, mostly from our own work, that FIM studies do directly or indirectly instigated the progress of other atomic resolution microscope studies, in particular in scanning tunneling microscopy. Of course, field ion microscopy continues to make unique and valuable contributions that are difficult to do with other atomic resolution microscopy.

[1] E. W. Müller and T. T. Tsong, *Field Ion Microscopy, Principles and Applications*, Elsevier (1969). T. T. Tsong, *Atom-Probe Field Ion Microscopy*, Cambridge University Press (1990).

[2] M. K. Miller, A. Cerezo, M. G. Hetherington, and G. D. W. Smith, *Atom-Probe Field Ion Microscopy*, Monographs on the Physics and Chemistry of Materials, Vol 52, Oxford University Press (1996).

[3] See A. J. Melmed, NAS Biographical Memoir 83 (2002) 3 for story of that historical event.

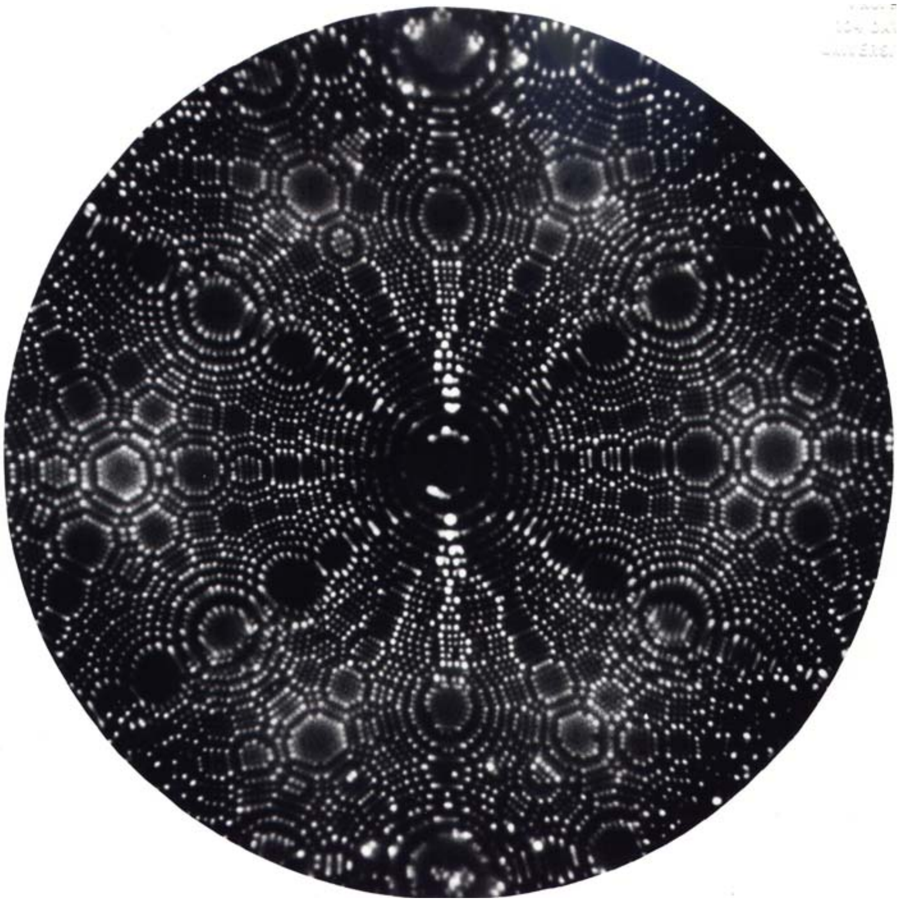

Fig. 1. Field Ion Image of a Tungsten Tip