ANECDOTES FROM AN ATOM-PROBE ORIGINAL

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The Atom-Probe Field Ion Microscope was introduced in 1967 at the 14th Field Emission Symposium in Gaithersburg, Maryland. The Atom-Probe was, and remains, the only instrument capable of determining "the nature of one single atom seen on a metal surface and selected from neighboring atoms at the discretion of the observer".[1] The development of the Atom-Probe is a story that highlights Erwin Müller's strong and sometimes volatile personality. It is a story of an instrument that one NSF proposal reviewer called "impossible" because "single atoms could not be detected". It is also the story of the Field Emission Laboratory at Penn State in the late 1960s and the contributions of two superb technicians, Gerald Fowler and Brooks McLane, and two graduate students, Douglas Barofsky and John Panitz. The anecdotes from this time are colorful and reflect Erwin's pedigree as Gustav Hertz's student in the Berlin of the 1930s.

In the summer of 1966 Erwin Müller returned from a trip to Europe with the concept of an *atom-probe*. Erwin had coined the term *atom-probe* in analogy with the electron microprobe developed previously by Castaing.[2] The latter instrument, a combination of an electron microscope with an x-ray analyzer, could investigate the constituents of a small sample volume, typically 1 μm in size, containing some 10^{11} atoms. The atom-probe would combine the ability of the field-ion microscope to visualize a surface in atomic resolution with single atom analysis provided by a sensitive mass spectrometer. Douglas Barofsky was completing his Ph.D. thesis, using a magnetic sector mass spectrometer to scan selected mass ranges where the ion species formed by field evaporation would occur. The timing was fortuitous. Doug had just completed a graduate course in electron and ion optics in which other mass spectrometers were discussed. He convinced Erwin that the atom-probe should be a time-of-flight (TOF) instrument because an entire mass spectrum could be display at one time. Although the signal-to-background ratio in a magnetic sector mass spectrometer would preclude single atom detection, a TOF mass spectrometer with a field-ion source could provide that capability. The combination was unique because ions formed by the field evaporation process in the field ion microscope originated at the apex of a field-emitter tip only a few hundred angstroms in diameter. Furthermore, the ions were formed at tip potential and acquired their full kinetic energy close to the tip apex, resulting in a well-defined ion kinetic energy. Doug realized that if the field-evaporation process was initiated by a high voltage pulse with a rapid risetime, an ion's travel time to a detector, t, could be measured with precision. If V is the potential difference between the tip and ground, and the ion's charge, q = ze, then an ion's kinetic energy is $1/2mv^2 = zeV$ where, e, is the electronic charge. If the tip was placed at the entrance to a grounded *drift region* of length, d, the ion's velocity, v = d/t. When Doug eliminated the velocity from the latter equations, an expression for the ion's mass-to-charge-ratio, m/z resulted. If the drift distance is expressed in meters, the tip voltage in kilovolts, and the travel time in microseconds:

$$\frac{m}{z} = \frac{0.193}{d^2} Vt^2$$

Microsecond travel times and the correlation between the pulse and the ion signal at the detector eliminated most spurious signals (UFOs) and single ion detection became feasible. The problem was finding a suitable detector. Erwin suggested an electron multiplier design using curved, beryllium copper dynodes. When I acquired the atom-probe as my Ph.D. project my first job was to build the detector from scratch! After several attempts to bend dynodes from beryllium copper sheet (and a few cut fingers) I found that commercial dynodes were available from the EMI company. Fifteen dynodes were acquired, I constructed an electron multiplier, single ions were detected and, as they say, *the rest is history*.

References

1. E. W. Müller, J. A. Panitz and S. B. McLane, Rev. Sci. Instrum 39 (1968) 83.
2. R. Castaing, in Adv. Electronics Electron Phys., New York Academic Press 13 (1960) 317.

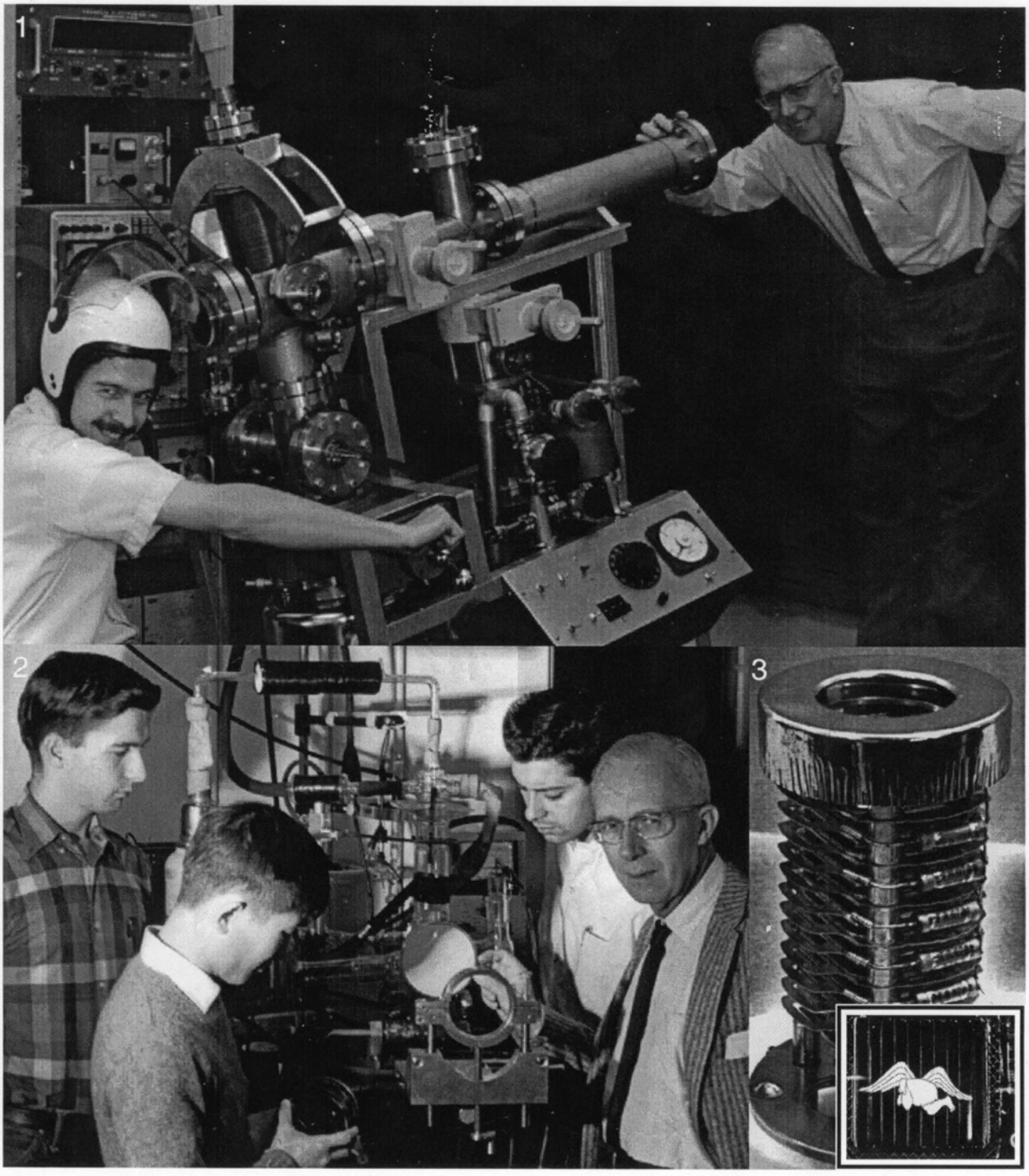

FIG. 1. The second Atom-Probe FIM. The resemblance to a *gun* prompted two photographs. In this photograph, Erwin Müller is peering into the *gun barrel* while John Panitz operates the controls. In the other photograph (preferred by Erwin Müller) the position of professor and student was reversed!

FIG. 2. Several members of the Field-Emission Laboratory (in Erwin Müller's laboratory) at Penn State in the late '60s. Clockwise: John Panitz, Douglas Barofsky, Erwin Müller and Tsien Tsong.

FIG. 3. The electron multiplier that verified single ion detection in the Atom-Probe. Insert: A UFO?