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ERWIN W. MÜELLER
1911–1977

A Biographical Memoir by

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ERWIN W. MÜLLER

June 13, 1911–May 17, 1977

BY ALLAN J. MELMED

THE FORTY-SEVENTH INTERNATIONAL Field Emission Symposium, which took place July 29 to August 6, 2001, was held in Berlin to commemorate the fiftieth anniversary of Erwin Müller's first publication on the invention of the field ion microscope there in the summer of 1951. The opening session of the meeting was devoted to historical accounts of the development of field electron microscopy (FEM), field ion microscopy (FIM), and atom probe mass spectroscopy (APMS, also known as APFIM for atom probe field ion microscopy)—all fields of scientific and technical endeavor originated by the late Erwin W. Müller. The achievements of these fields of study and their influence on other scientific fields stand as a tribute to the remarkable creativity and ingenuity of Professor Müller. Those of us who knew him remember with admiration his great ability as a scientist, an experimentalist, and a teacher. The history of the creation and development of FEM, FIM, and APMS is in large part the biography of Erwin Müller.

Erwin Wilhelm Müller was born in Berlin on June 13, 1911, the year the Kaiser-Wilhelm-Institute for Physical Chemistry and Electrochemistry (now the Fritz-Haber-Institute of the Max Planck Society) was founded. He died on May 17, 1977. A short time later his wife kindly reminisced with me about her husband, providing some insight into his early life. He was the only child of Wilhelm M. and Käthe Müller (nee Käthe M. Teipelke), a family of modest means. His father was a construction worker specializing in plastering ceilings in houses. Erwin Müller worked as a part-time research assistant at the Osram company in Berlin from 1932 to 1935; from 1935 to 1937 he was a research physicist at the Siemens company, also in Berlin, where he invented the FEM while continuing his education. He married Klara Thüssing in 1939, and their daughter Jutta, their only child, was born in 1940. He obtained his university education at the Technische Hochschule Berlin-Charlottenburg (now Technische Univerität Berlin), receiving an engineering diploma in 1935 and a doctor of engineering (physics emphasis) in 1936, working under the direction of the Nobel Prize-winning physicist Gustav Hertz. Those were stressful times for the young family because Erwin was not a National Socialist Party member and therefore had great difficulty trying to rise to a university post. Consequently, it was only after the war, in 1950, that he achieved his *Habilitation* from the Technical University Berlin (successor to the Technische Hochschule).

After Siemens he worked for the Stabilovolt company in Berlin, where he was director of research and development from 1937 to 1946, a critical time in German history. Of possible consequence to science, it is interesting that according to Klara Müller, he was protected from the party by his good research efforts. Michael Drechsler, a former coworker of Müller's has written[1] that the Stabilovolt laboratory in Berlin was destroyed by bombs in 1944 and that Müller attempted to rebuild it in Altenburg and in Dresden. He notes Müller's good fortune in managing to survive the firebombing of Dresden. Müller retained considerable resentment against the Allies for this late event in the Second

World War, which was made clear in a 1951 conversation with Ralph Klein in Berlin. Klara, and earlier Erwin Müller, told me that immediately after the war they survived by picking up scraps from recently harvested fields and by learning to prepare baking powder for making bread from scraps of marble in the cemetery, maintaining a diet of about 900 calories a day. At this time, from 1946 to 1947, Müller was lecturer of physical chemistry at the Technical Institute in Altenburg, several miles from his home, to and from which he walked every day.

While Müller was working in Altenburg, I. N. Stranski invited him to come to the Kaiser-Wilhelm Institute in Berlin, where Müller went next and where he worked from 1947 to 1951. He began as an assistant to Stranski and later became a group leader and then a department head. Here he invented the field ion microscope. (Considering the extensive war damage in Germany, one can imagine that conditions for research and development at the German institutes were as bad as the food situation, and it required unusual inventiveness and experimental skill for Müller to obtain his excellent results.) With his *Habilitation* in 1950 he also became a teacher at the Technical University Berlin, and in 1951 he became a professor at the Free University Berlin. Then he moved to the United States and started a new laboratory at Pennsylvania State University. At the same time he maintained close contacts with the Fritz-Haber-Institute by way of a lively correspondence with his former students and coworkers as well as with I. N. Stranski and M. von Laue, and mutual visits. The Max Planck Society officially recognized these good relations by making him an external scientific member of the Fritz-Haber Institute, Berlin, in 1957, which he accepted as much as an obligation as an honor. At Penn State he began as professor of physics. In 1955 he became a research professor of physics, and was appointed to the prestigious Evan Pugh Professor of Physics post in 1968. Finally, he was named professor emeritus in 1976.

Erwin Müller's first publication was in *Zeitschrift für Physik* in 1935: "A Method for Photometric Measurement of the Intensity of Spectral Lines." His dissertation research, "The Dependence of Field Electron Emission on Work Function," was published in *Zeitschrift für Physik* in 1936. Overall, four papers and most importantly the invention of the field electron microscope resulted from his work with Gustav Hertz at Siemens. He went on to publish some 211 scientific papers over an active research career of 41 years.

The political circumstances in Germany during the 1930s strongly influenced Erwin Müller's scientific career, and it is remarkable that he was able to develop FEM at that time. Drechsler has written about some of the prevailing circumstances.[1] The cast of great scientists then working and lecturing in Berlin was certainly impressive: Einstein, Planck, Schrödinger, Debye, Nernst, Hertz, Haber, von Laue, Grotrian, Volmer, and Schottky. This made for an inspirational setting for Erwin Müller to begin his scientific career. The political climate, however, was far from nurturing with respect to the scientific community. Many of the internationally well-known scientists reacted to the growing political persecution by leaving their university posts, either because they were directly persecuted or in protest of the treatment of their colleagues. Müller's research professor, Gustav Hertz, felt compelled to leave his university chair in protest, and he moved to the Siemens company, where he became director of a new laboratory set up especially for him. Fortunately for Müller, Hertz brought him along to Siemens, where he was able to continue his research into field electron emission.

Müller has described[2] the situation when he began his dissertation research. In 1936 A. Wehnelt and W. Schilling had used a magnetic electron microscope to image the electron field emission from the edge of a sharp knife to find that the emission was coming from discrete and non-stable small points along the knife edge. In addition, in 1936 R. P. Johnson and W. Shockley published their description of a cylindrical field emission microscope.[3] Their images viewed on a phosphor screen also showed that the electrons were being emitted by tiny protrusions on the wire cathode surface.

Müller decided to view the electron emission distribution, or pattern, from the point cathodes he was studying, so he made the point equivalent of the Johnson-Shockley microscope. Next, he constructed a vacuum tube in which an ingenious electrically heatable tungsten tip was positioned a few centimeters away from a thin phosphor screen on the front inside surface of the tube. This tube allowed him to visualize directly the electron emission from the tip, prior to and following tip heating. He observed the patchy emission from as-etched tips, similar to what had been seen in the emission from edges and wires. Very easily, however, he was able to thermally smooth the protrusions and remove contamination from the W tip and to view the electron emission pattern of the clean surface on the screen. This tube was the first point projection field emission microscope.[4] He was then able to measure the electron emission characteristics of the clean W surface and to verify the high field necessary for field emission predicted by the Fowler-Nordheim equation. Later, after Müller had left the Siemens laboratory, R. Haefer[5] quantitatively confirmed the F-N equation in 1940. FEM became a powerful microscopy, however, far beyond the attempt to visualize the surface condition of a point field electron emitter.

The simplicity of design of Erwin Müller's FEM instrument is evident when compared to other microscopes. Consider that a 10^5-10^6 enlarged image of a metal surface, with resolution of 2.5 nm (and 1 nm in special cases) can be gotten with a small laboratory-built FEM. However, in the years before the advent of commercially available metal vacuum components considerable experimental expertise was needed to actually make a working FEM. Müller devised a host of experimental "tricks," that is, special techniques, to enable most students to construct his microscope. Pankow related to me that later, from 1951 to 1961, he and P. Wolf and later Ralf Vanselow were assigned by Müller the task of making FEM microscopes for commercialization by the Leybold company. These were various sealed tubes including a barium evaporation source, sold primarily as demonstration equipment for schools.

As director of research and development at the Stabilovolt company Müller managed to continue some studies of field emission even though the Second World War had begun. Drechsler has noted[1] that Stabilovolt manufactured glow discharge tubes that used Ba-activated cathodes, and this provided the opportunity for Müller to investigate surface diffusion of Ba on W using his FEM. Müller's study of Ba adsorption and perhaps more importantly his discovery of field desorption of Ba from W was published in 1941.[6] His pioneering measurements of the velocity distribution of field emitted electrons[7] and his study of the resolution of the FEM[8] were published in 1943. Due to the war Müller published no further scientific research until 1949.

By this time, as described above, Müller was at the Kaiser-Wilhelm-Institute. He continued to do FEM research, publishing papers on W surface self-diffusion,[9] the imaging of phthalocyanine molecules,[10] the visibility of atoms and molecules,[11] and (with M. Drechsler) the polarizability of atoms and molecules,[12] and other seminal experiments. His interpretation of the images of adsorbed barium and phthalocyanine molecules as atoms and molecules, respectively, met with considerable skepticism. However, these pioneering FEM experiments, especially the surface self-diffusion work, led to considerably more work by many researchers.

As important as his FEM results were, Müller's greatest contribution to microscopy and in fact to the scientific world was his invention of FIM. Let us consider the context in which this achievement took place. The electron microscope (TEM) had achieved Ruska's original aim of exceeding the resolution of traditional optical microscopy and had reached a resolution of about 2 nm. Müller's FEM had a resolution of about 2.3 nm in general and 1 nm in special cases. Ruska and Müller, both at the Kaiser-Wilhelm-Institute, were in friendly competition with each other, according to Gustav Klipping (private communication), to get the best results. Erwin Müller, however, aimed to make a great leap forward to achieve his dream of atomic resolution. After all, scientists had no direct proof that matter consisted of discrete atoms—only indirect evidence from X-ray diffraction and chemical experiments. No one had seen atoms to prove their existence.

Erwin Müller reached 40 years of age in the summer of 1951. Ten years earlier he had reported that atoms adsorbed on a W surface could be torn off, or desorbed, by the application of a large positive electric field,[7] and since then he had pondered a way to use the desorption phenomenon to image the tip surface. It was clear to him that simply desorbing a monolayer of Ba, for example, and accelerating the resulting positive ions to the screen would not provide sufficient image intensity. He recognized the need for a continuous supply of ions but did not immediately realize how to accomplish this. Finally in 1951 the solution occurred to him.

His assistant at that time, Gerrit Pankow, recently related to me (private communication) the circumstances surrounding the first FIM experiments. One morning in the summer of 1951 when Pankow came into the laboratory, Müller was preparing to do an experiment. Pankow noticed that something was wrong, so he told Professor Müller that the tip voltage polarity was set to be positive instead of negative! Müller looked at him and simply said, "From now on, we work with positive tip voltage." The first FIM microscope was an FEM operated with positive tip voltage plus the addition of a palladium tube that when heated with a hydrogen flame, allowed the introduction of hydrogen into the microscope. (A small anode ring was added to minimize any field emission from the inside wall of the microscope but was later found to be unnecessary.) This microscope, primitive by our present scientific criteria, operating at room temperature enabled Erwin Müller to see that the surface did not have a continuous structure; rather he could clearly see rows of atoms.

The invention of FIM by Erwin Müller was a remarkable achievement, especially considering the utter simplicity of such a lens-less microscope, which achieves magnification of 10^6 or more and atomic resolution by radial projection of ions from the specimen point. In contrast to the somewhat stepwise development of FEM, with contributions by several people, it is not obvious that anyone else could have or would have invented FIM. Even after Müller had the concept of imaging by field desorption of a continuously renewed source of ions, it required his great experimental ingenuity to make the microscope an actuality. His earlier experience with gaseous discharges and his lifelong interest in optics and activities as an amateur astronomer were important, especially considering that the room temperature FIM image was extremely dim, and image intensifiers did not yet exist.

Müller proceeded with great efficiency to publish his historic first FIM paper,[13] describing the significant improvement in contrast and resolution brought about by imaging with positive (hydrogen) ions compared to imaging by FEM and presenting the first evidence that atomic resolution was achieved. Müller's original manuscript was submitted on August 27, 1951. Interestingly, in terms of the friendly competition between Müller and Ruska, in a 1954 conference in Milan Ernst Ruska presented a published lecture in which he stated that the theoretical limit of TEM is such as to permit proving the existence of atoms. This is remarkable because Ruska knew first-hand about Müller's FIM results. One has to wonder how Müller reacted, especially because TEM had not come close to that objective, which he had reached in 1951.

It is fascinating and somewhat ironic that knowledge gained through research using Müller's FEM was important in developing the present-day atomic resolution capability of the electron microscope. In a technical discussion tape-recorded at the first field emission symposium, in McMinnville, Oregon, in 1952 it was suggested that the use of a W point field electron emitter as the electron source in an electron microscope might lead to improved resolution. Then in 1959 the results of field-electron-emission energy distributions, mentioned above, revealed an unexpectedly narrow energy distribution, which is the basis of achieving atomic resolution with the electron microscope.

The decision for Müller to leave Germany must have been difficult. He had lived and worked most of his life in Berlin and had begun to raise a family. In fact, his daughter was now 11 years old. However, after the Second World War the U.S. Joint Chiefs of Staff invited him to spend six months visiting universities in the United States, with the hope of enticing him and other good scientists to move to the United States. In September 1951, only a few weeks after submitting for publication his now celebrated first paper on FIM, he accepted the invitation and went to New York City, staying at the Alamac Hotel, visiting various universities, and probably not yet decided definitely to leave Germany. However, according to Müller, when he visited the Pennsylvania State University in central Pennsylvania he and Klara were immediately reminded of rural Germany. This and no doubt the miserable conditions of postwar Berlin convinced him to accept the suggestion of Dean Hall to move there, and he arrived in about February 1952. He became an U.S. citizen in 1962. At first he did only a minimum amount of classroom teaching, but he did an appreciable amount of informal teaching in the laboratory. This was perfectly suited to Müller's preferred working mode, which was devoting as much time and effort as possible toward his dream of achieving what he considered the ultimate accomplishment of microscopy: the full resolution of the surface atomic lattice of a metal. Thus far his FIM operating at room temperature with hydrogen as the imaging gas could only resolve atoms along multiple step-height ledges formed, for example, by heating the W tip after carbon adsorption—a very special case.

By late spring or early summer of 1952 Müller had begun to attract students and to set up his new Penn State field emission laboratory, in the sub-basement of Osmond Hall, which housed the Physics Department. Two years later he moved his laboratory to more spacious and more pleasant quarters on the second floor of the building. Here he worked for the remainder of his scientific career. In the early years at Penn State the majority of students in his laboratory did research on issues related to field electron emission and FEM, and only one student worked, with Müller, on FIM matters. Müller's first few publications in this period were either papers written in collaboration with M. Drechsler, his former assistant at the Fritz-Haber-Institute laboratory or review articles, most notably Müller's 1953 review of FEM.[2] However, events significant to the development of FIM were taking place. I have written about the relevant historical details,[14] from the personal perspective of my years, 1954-58, as a student of Professor Müller. I will summarize here the key points and suggestions related to his thinking that may be of biographical interest.

Müller's first paper, in 1951, introducing FIM was remarkable. Of course, it provided the world's first view of the atomic nature of solid matter and began an entirely new field of study. It also presented Müller's ideas for several further developments of FIM, such as cooling the microscope, the use of helium for imaging, and the phenomenon of field-induced surface dissolution, later termed field evaporation. This phenomenon ultimately made the FIM and the APFIM (atom probe field ion microscope) uniquely powerful analytic instruments. He clearly believed that his success in achieving improved image contrast and resolution, compared to FEM, validated his hypothesis that operating the FIM with a low-pressure hydrogen-ambient-enabled image formation by positive ions desorbed from a layer of continuously replenished adsorbed gas atoms. He also believed that the factor limiting resolution of the FIM was diffraction. Although he later showed that these mechanisms were not strictly correct, his belief in them somewhat retarded the complete fruition of the FIM.

Another remarkable aspect of Müller's first FIM publication was the relatively short time between the conception of the experiment and the actual publication. This undoubtedly resulted from his genius for conceiving eloquently simple experiments, one of the defining characteristics of his scientific career. During the period 1954-58, while studying under Müller, I observed what I came to recognize as his awesome experimental talent, evident to all of his students and coworkers. The time span between an idea and setup of a new experiment was typically only a few days. This was true also for his later introduction of various low-temperature FIM microscope designs, and T. T. Tsong has related (private communication) that it was the case also for his invention of the atom probe.

During 1952-55 attempts were being made toward improving the resolution of the FIM both in Germany by Müller's former students and coworkers at the Fritz-Haber-Institute and in the United States at Penn State. Müller was striving to achieve what he considered the ultimate objective of microscopy, that is, the ability to see the atomic surface structure of a metal. However, before 1954 both theory and experiment seemed to agree that the FIM was not likely to succeed in improving beyond the 1951 room temperature image quality. In 1952 R. Gomer published a paper in which he theorized that no improvement in resolution of the hydrogen FIM would be expected by cooling the emitter, and at about that time Pankow reported to Müller that he had found no improvement in image quality by immersing the FIM in liquid air. Then in 1954 M. G. Inghram and R. Gomer found that most of the ions contributing to the FIM image intensity originated slightly away from the surface, which was contrary to Müller's original concept of image formation. In 1954 Müller and Bahadur tried imaging at liquid nitrogen temperature and again found that cooling the FIM specimen, even using helium as imaging gas, did not improve the resolution. This added to Müller's pessimism about achieving his goal. A fascinating breakthrough occurred in October 1955, and I have described and analyzed this event and its background in detail.[14] Müller, assisted by his student Kanwar Bahadur, once again cooled the FIM specimen with liquid nitrogen. This time, due to a fortuitously well-prepared specimen, they unintentionally discovered the phenomenon of surface smoothing by low-temperature field evaporation while imaging with helium. This immediately gave them the world's first view of the atomic surface structure of a metal—Erwin Müller's long sought goal.

The FIM had evolved somewhat from Müller's original design, now using helium for imaging, cooling the specimen by liquid nitrogen or liquid hydrogen and smoothing the tip by field evaporation, but it still was by all criteria a marvelously simple instrument, something that Müller never tired of reminding audiences. He had wonderful showmanship and frequently exaggerated this instrumental simplicity, to the delight of audiences.

During the period 1956-66 Müller increasingly emphasized further development of FIM techniques and conducted exploratory research into many areas of FIM applications, although he continued to make significant contributions to the applications of FEM. In 1960 he published a major review paper[15] that gave practical information so that others could more easily get started doing FIM, and this helped to spread the technique around the world. In addition, in this period his work with R. D. Young, a student of his, refining the method of measuring electron energy distribution[16] led to a new theoretical analysis[17] and experimental verification of field emission energy distributions, and revealed an unexpectedly narrow energy distribution. Müller published a paper in 1957[18] that motivated the later extensive FIM research by others, notably G. Ehrlich, T. T. Tsong, and D. W. Bassett, on the diffusion of single atoms on surfaces. Müller's final research papers in FEM were published in 1962, with Young on the electron work function of (011)-oriented W, and with W. T. Pimbley on their unsuccessful search for polarized field electrons. Müller reviewed the progress in his microscopies in his 1969 book with T. T. Tsong.[19]

Müller's final major contribution to science was his invention of the instrument he called the atom probe, in 1967.[20] It later also became known as the atom probe field ion microscope, recognizing that it incorporates an FIM capability to give an atomic map of the specimen surface, by means of which the user selects atoms for chemical identification by time-of-flight mass spectrometry. This uniquely powerful analytical instrument has made and continues to make important contributions to materials science. The introduction of the atom probe by Müller burst like a supernova, at least on the international field emission community. After all, he was already 56 years old, had created two microscopies, and had given the world its first view of atoms. It would still be some 13 years until any other microscopy could claim the capability of seeing atoms in a solid.

In retrospect it is fascinating that at least in principle other scientists came very close to inventing the atom probe. Inghram and Gomer, H. D. Beckey, W. A. Schmidt, and J. H. Block all designed, built, and worked with mass spectroscopic instruments using field ion sources that could have been adapted to analyze the composition of the tip itself, perhaps leading them to invent the atom probe FIM. They were dedicated, however, to using the instrumentation to analyze only the composition of field ionization or adsorbed species, while Erwin Müller was focused on trying to determine the composition of individual surface atoms.

Students of Müller who were present during the time of the invention of the atom probe have described some of the relevant events to me, and J. A. Panitz has recently published[21] his description of the historical development. Müller had been trying for a few years to find a way to chemically identify atoms for which the FIM image contrast was not understood. The immediate motivation for this effort was the uncertainty in interpretation of FIM contrast in some binary alloys, where one element imaged with bright contrast and the other with dark contrast (his student, T. T. Tsong was studying Co-Pt, for example). Müller was well aware of the techniques of field ion mass spectroscopy and had students working with them. In addition, his students, M. P. R. Thomsen and D. F. Barofsky, had shown that field-evaporated metallic species could be mass analyzed. However, Müller realized that there were two existing shortcomings for his purposes. The detectors did not possess single-ion sensitivity and there was no way to pre-select and localize the region of analysis to do single-atom identification. He conceived the idea of using a probe hole to limit the field of view, or field of analysis, to a pre-selected atom or atoms, and believed that improved detectors could be built to detect single ions. He asked Barofsky to assess the feasibility of doing single-ion mass spectroscopy using a magnetic sector instrument with a continuous dynode detector. A short while later Barofsky learned about the time-of-flight technique from a course he was taking and suggested its use to Müller, who directed him to determine the instrument parameters suitable for an atom probe using the contemporary timing electronics. His technicians, Gerry Fowler and Brooks McLane, were assigned to put together the hardware to make such an instrument and then his student J. A. Panitz was given the project for his Ph.D. research. The atom probe came to fruition in mid-1967, a matter of only several months from its conception by Müller.

Müller's steadfast, focused effort to improve the microscopy he had invented was the defining characteristic of his scientific career. He strove to be first in all aspects of FEM and FIM, so much so that the phrase "for the first time" became his mantra. In point of fact, until about 1960 Müller had personally discovered most of the aspects of the microscopies, and it was not uncommon for him to remind the author following a presentation, or as a manuscript reviewer, that he had done it first, usually years ago. This zeal sometimes caused resentment and certainly masked his warm personality. In private Erwin Müller was friendly, kind, and charming. But his public persona was something else—more like a lion defending his lair.

Müller retired from active research in 1976 and was named professor emeritus. He was suffering from the after-effects of treatment for cancer of the throat, which caused him difficulty in lecturing, but his condition seemed to be improving. Then, on May 17, 1977, at the age of 65 he died from a stroke while attending the annual meeting of the National Academy of Sciences in Washington, D.C.

Erwin Müller received a number of awards and honors during his lifetime. These were as follows:

1936	Bronze Medal for outstanding work, the Technische Hochschule Berlin-Charlottenburg
1952	C. F. Gauss Medal (laudatio by Max von Laue)
1957	External scientific member, Fritz-Haber-Institute of the Max Planck Society, Berlin
1960	Achievement Award, Instrument Society of America
1961	Fellow, American Physical Society
1964	H. N. Potts Gold Medal, Franklin Institute, Philadelphia
1968	Elected member, Deutsche Akad. d. Naturforscher, Leopoldina, Halle
	Dr. rer. nat. honoris causa, Free University, Berlin
1969	Honorary fellow, Royal Microscopical Society, Oxford
	Centenary Lectureship Silver Medal, Chemical Society, London
1970	M. W. Welch Gold Medal, American Vacuum Society
	John Scott Medal, City of Philadelphia (oldest Am________ Sci_______ Award)
1972	Davisson-Germer Prize, American Physical Society

1975 Dr. honoris causa, Claude-Bernard University of Lyon
Honorary member, Indian Vacuum Society
Elected member, National Academy of Engineering
Elected member, National Academy of Sciences

In addition, he was to have received the very prestigious National Medal of Science in 1976, but the award ceremony was postponed. It was awarded instead posthumously to Müller's daughter by President Jimmy Carter on November 22, 1977, at the White House.

Erwin Müller's career had an immeasurably large impact on science and technology. His invention and development of FEM clarified the physics of field electron emission from metals and led to important contributions to the progress of surface science. In recent years knowledge gained from FEM research has become important in product development for flat-panel image displays and vacuum electronics applications. His development of ultra-high vacuum techniques, from the pioneering use of barium and other metal vacuum getters to his early achievement of vacuum levels down to below $10\&^{12}$ torr quietly advanced both surface science and vacuum technology. His invention of the FIM dispelled the intellectual myth that atoms were too small to be seen and began the age of atomic resolution metallurgy and materials research. With it Müller brought to surface science the ability to study surface phenomena, such as single-atom and cluster surface mobility on the atomic scale. Müller's atom probe (APFIM) transformed the FIM to a major analytical instrument. A few years after his death, as instrumental innovations extended APFIM capabilities even beyond Müller's concepts, the instrument began to have and continues to have wide impact on materials research.

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