# The first image of the atoms and role of an Indian scientist

*Deepak Kumar*

It was not too long ago that atoms were considered too small to be seen by any microscope in existence then. Fifty years ago, in 1955, the image of a tungsten tip showing individual atoms was reported by Erwin W. Müller from the Pennsylvania State University in the *Journal of Applied Physics*[1]. This was made possible by the Field Ion Microscope (FIM), an instrument which had been invented by Müller four years earlier. This achievement was hailed worldwide as a major breakthrough, as imaging an atom was one of the most sought-after goals in physics. To be fair, by this time the atomic structure of matter and the nature of the atom had been established beyond doubt in any number of ways. Still it was a milestone in the long journey of validating the concept of the atom, a concept initiated by the Greek, Democritus two thousand years ago. The imaging of atoms opened new frontiers in our exploration of the microscopic structure of matter, and this development has had an enormous impact on solid state physics, materials science, surface science, nanoscience and many related disciplines in biology, chemistry and earth sciences. Today there are other instruments, like High Resolution Electron Microscope (HREM) and Scanning Tunnelling Microscope (STM) which have atomic-scale resolution, but it took another twenty-five years for HREM to achieve this resolution, and STM was developed only twenty-four years ago.

The fiftieth anniversary of this event of first imaging of atoms, was celebrated by holding a conference on Atomic Resolution Microscopy at the Penn State in June this year, under the joint auspicies of International Field Emission Society and the Penn State. The conference was appropriately dedicated to the memory of Müller. It covered developments in FIM, related electron microscopies and a range of applications spanning catalysis, atomic tomography to quantum dots. In addition to FIM, HREM and STM, the modern-day atomic microscopies include Atom-Probe Mass Spectroscopy, Holographic Electron Microscopy and Scanning Probe Microscopies. Their impact on common man has been described in an article covering the conference, in *Forbes* magazine as, 'Everything from cell phones, paints, medical prosthesis, drug delivery and development, airplanes and war on terrorism requires the ability to resolve atoms'.

The inaugural session of the meeting was devoted to reminiscences of Müller and of the days when this imaging was done in his laboratory. Here lies a story of great human interest to us in India. The first lecture in this session was given by Kanwar Bahadur, who was a graduate student in the laboratory at that time. This honour had been accorded to Bahadur, as he was indeed the first person to 'see' the atom. Bahadur had gone to Penn State in 1953 from National Physical Laboratory (NPL), New Delhi, where he had been working on electron microscopy and had earlier helped install an electron microscope. On reaching Müller's laboratory, he was put on the project of improving the resolution of the FIM to atomic scale. There was a worldwide race to achieve this target, and Müller was in evident hurry. After working for nearly two years, Bahadur noted that the quality of the image deteriorates with increase in temperature of the apparatus. Accordingly, he made a key suggestion to Müller that a part of the apparatus be cooled to liquid nitrogen temperature. Müller's initial reaction to the proposal was negative, as he and others had reported results from experiments in which the entire apparatus had been cooled in liquid air, with no improvement in image resolution.

To understand this point, it is worth recalling the principle on which the FIM works. A fine metal tip is placed at one end of a vacuum tube filled with an inert gas like helium at low pressure. At the opposite end of the tube, there is a screen coated with a phosphor, which gives off light when ionized atoms impinge on it. The tip is raised to a high voltage of the order of 10,000 V with respect to the surface of the tube. The large electric field, greatly enhanced due to the sharpness of the tip generates ions, and the ions accelerate out from the tip following the electrical lines of force. The ions impinging on the phosphor provide a visible and hugely magnified image of the charge distribution on the tip. The magnification is proportional to the ratio of the tip–screen distance to the tip diameter. However, the images obtained were rather blurred and

E. W. Müller

Kanwar Bahadur with the original apparatus.

lacking resolution. Bahadur's suggestion was to cool the tip with liquid nitrogen. Factors that affect the resolving power of the instrument were not clear at that time, as the mechanism of production of the ions was not clearly understood, particularly when the earlier cooling experiments had been tried. To reflect Müller's general feeling about cooling, I quote from a historical article by A. J. Melmed[2], who was then a fellow graduate student.

'Shortly later Bahadur began to feel strongly that, somehow, cooling the tip would make a difference, and he discussed the matter again with Müller. Müller was not at all encouraging, but gave his permission for Bahadur to do the experiment, if he really wanted to, and the design of an appropriate experimental tube was discussed. (On similar occasions, most of the time students felt it wasn't worth the time to do such an experiment in view of such pessimism). Fortunately, Kanwar Bahadur's conviction was strong enough that it drove him to try the low temperature imaging once more.'

Bahadur built the new glassware with the required arrangement for the flow of liquid nitrogen to cool the tip. He got the experiment running in October 1955. Here is an account of the day on which the experiment finally worked from Melmed[2].

'The day of October 11, 1955 was a day to remember by those of us who were in the laboratory. Bahadur had built the FIM to retest the hypothesis that cooling the tip was worthwhile, and had gotten the experiment going. Now, he called Prof. Müller into his laboratory room to show him the result. Russel Young and the author (Melmed) shared the room between Bahadur's room and Prof. Müller's office, and we watched Müller enter Bahadur's lab and close the door. We waited outside quite anxiously, imagining Müller waiting for his eyes to become dark adapted, in order to see the image and wondering what Müller's reaction would be to this long-awaited event. Inside, Bahadur has related to the author, when Müller saw the low temperature helium image, he said something like "This is it". When Müller emerged from the room, he walked quickly across our lab to his office muttering simply "Aoms, ja atoms". For us it was a time for unprecedented awe and joy; we thought that a Nobel Prize for Müller was shortly forthcoming. After all, Müller's microscope now made it possible to see atoms.'

The world learnt about this achievement from an oral presentation by Müller, at a conference on Electron Microscopy at Penn State in November, 1955. After this event, Müller himself got involved with experimentation and introduced further refinements with Bahadur's assistance to improve the resolution and quality of images. Now, the nature of effect of cooling on resolution was also surmised. The resolution size depends critically on the fluctuation in the transverse velocity of the ions, which in turn depends on the temperature at the point where they are produced. Thus the tip temperature is the key factor in improving the resolution. Another factor for achieving the atomic scale resolution was the fineness of the tip (diameter of less than 0.00001 cm), towards which also Bahadur devised a special procedure[2]. The results of these investigations were published in two single-author papers by Müller[1], acknowledging Bahadur's assistance.

Bahadur defended his thesis in January 1956, obtaining his Ph D in a record time of two and a half years. He returned to NPL, New Delhi soon after. In spite of the recognition that the achievement of atomic resolution received, Müller did not get the Nobel Prize. The role Bahadur played has remained largely unknown outside a close circle of friends from the laboratory at Penn State. While Müller acknowledged Bahadur's help in the experiment in his papers, he did not mention his specific contribution to the key idea. This is sad and is attributed to the politics and sociology of the Nobel Prize. In his address at the June meeting this year, Bahadur recalled his association with Müller with great humility, reverence and fondness, treating him as the guru from whom he learnt everything. He expressed no regrets at being denied the authorship of a landmark paper, which many of his colleagues feel that he deserved. I had the privilege of talking recently to Bahadur, who is now 80 years old, and to listen to parts of this story in person. I am filled with admiration for such humility and grace and feel that our scientific community is ennobled by such people.

1. Müller, E. W., *J. Appl. Phys.*, 1956, **27**, 474–476.
2. Melmed, A. J., *Appl. Surf. Sci.*, 1996, **94/95**, 17–25.

ACKNOWLEDGEMENT. I am grateful to Bahadur for explaining to me some subtle features of the FIM.

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Edited and published by P. Balaram, Current Science Association, Bangalore 560 080.
Typeset by WINTECS Typesetters (Ph: 2332 7311), Bangalore 560 021 and Printed at Lotus Printers, Bangalore (Ph: 2320 9909)