The year 2021 is the 40-year anniversary of the invention of scanning tunneling microscopy (STM), by Gerd Binnig and Heinrich Rohrer in the IBM Zurich research laboratory. The invention of STM provides us with unprecedented power to observe the arrangement of individual atoms on surfaces in real space. By drawing a vivid view of atoms in the real world, and even allowing us to manipulate individual atoms, STM changes our imagination of atoms and our way of thinking. The physical and chemical properties of various materials’ surfaces can thus be studied in atomic detail.

The principle of STM is to utilize a sharp metal tip to scan a conducting surface at a very close distance of a few nanometers, while instantaneously recording the tunneling current signal between the tip-sample where a bias voltage is applied. The tunneling current can be described by the quantum mechanical principle for electron tunneling through an energy barrier, which is extremely sensitive to the tip-sample distance, making it possible to follow the tiny atomic corrugations on the surface. Instead of the tunneling current, by probing other signal sources based on the interaction between the tip and surface, different variations of STM, for example atomic force microscopy (AFM), magnetic force microscopy and scanning near-field optical microscopy, have been developed, and they form the scanning probe microscopy (SPM) family. The SPM technique is thus the most powerful and volatile among various techniques in studying nanoscience and surface science.

Even though STM has a history of over 40 years, the development of state-of-art techniques based on STM has still experienced surprisingly rapid progress in the last decade. First, the combination of STM and light gives rise to a series of interesting techniques. When a laser beam is focused on a STM tunneling gap, an optoelectronic current emitted out of the surface can be detected by the tip. When ultrafast pump-probe laser beams are applied instead of a continuous-wave laser beam, the relaxation dynamics of the excited states can be resolved in an ultrafast time scale (time-resolved STM). When both the STM tip and the surface are made of plasmonic metals such as Au and Ag, a strong, localized plasmon resonance will be formed in the tunneling gap, which can give a drastic enhancement of the local Raman spectrum underneath the tip, reaching a Raman special resolution of <0.5 nm. Moreover, the ultra-sensitive optical spectrum is capable of detecting the light emission from the tunneling gap (current induced photoluminescence), with atomic resolution. Apart from the combination with light, the combination of STM with extreme conditions such as low temperature (down to 10 mK) and magnetic field (up to 15 T) is now commercially available, which significantly accelerates the fundamental study of quantum materials. The emergence of the q-Plus sensor with high quality factor and high sensitivity to short-range forces further pushes the resolution of AFM to...
the single chemical bond limit, even better than STM. By coupling with the microwaves and solid-state quantum bit technologies, SPM has been able to probe and manipulate various quantum coherent phenomena, which may open up the new possibility of nanoscale quantum sensing.

Another hot emerging research field in condensed matter physics and materials science is low-dimensional quantum materials. Topological material is a superstar. Three-dimensional topological materials have insulating bulk and conducting surface states with spin-momentum locking. The combination of topological order in materials with superconductivity results in intriguing Majorana fermions with potential application in quantum computing. STM has played key roles in the history of topological materials, including the detection of topological surface states and Majorana fermions. Another forefront in materials science is two-dimensional (2D) materials. The emergence of 2D materials is the result of continuously improving the capability of our techniques to precisely control the fabrication of materials, ultimately to individual atomic layer precision. Represented by graphene, transition metal dichalcogenide, black phosphorus and borophene, 2D materials exhibit amazing properties such as valley optoelectronics, quantum Hall effect, interlayer excitons, flat bands, strongly correlated effects, 2D ferroelectricity and superconductivity. It is particularly attractive that by stacking different 2D materials into van de Waals heterojunctions or superlattices, one can extend the artificial materials with unlimited possible structures and properties, which makes it possible to design high performance materials and devices. STM is the most advantageous technique to study of atomic structures and properties in 2D limit. The atomic structure arrangement, the electronic properties such as quantum well states and flat bands have been resolved in various 2D materials with the help of STM.

In this special issue we have included a research article [1], where the heterostructure of 2D materials CrTe$_2$/Bi$_2$Te$_3$ prepared by molecular beam epitaxy has been studied by STM/scanning tunneling spectroscopy. In addition, selected topical reviews [2–4] on the application of STM and AFM to carbon-based materials, 2D materials as well as topological materials have been included. We expect that this special issue will provide some basic concepts of materials physics, which can be revealed by advanced scanning probe techniques.

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