Recent advances in scanning tunneling microscopy and spectroscopy

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The exponential dependence of tunneling current through a vacuum gap enables sensitivity to changes in the size of the gap at well below atomic dimensions. Therefore, when Binnig and Rohrer realized more than 30 years ago that it would be possible to measure spatially resolved tunneling between an atomically sharp conducting tip and surface, it soon became clear that the result was a revolutionary new imaging technique: scanning tunneling microscopy (STM) [1]. In the most common imaging mode, constant current imaging, STM maps out contours of tip height that correspond to constant values of tunneling current. For surfaces with uniform electronic structure (e.g. many metals), this can provide an accurate measure of topography. In most cases, however, variations in local density of states (LDOS) occur across the surface, giving rise to apparent topographic contrast. This makes interpretation of STM images more difficult but also gives rise to one of its most powerful capabilities: spatially resolved spectroscopy.

Elastic tunneling spectroscopy traces its origins back to measurements of the superconducting gap in planar tunnel junctions [2]. Combined with the spatial resolution of STM, elastic tunneling allows for the mapping of the LDOS of metallic, semiconducting, and superconducting surfaces at the atomic scale. This has revealed a variety of phenomena, ranging from standing waves of electronic surface states [3] in metals to novel ordering in high-Tc superconductors [4]. In addition to being a powerful technique in its own right, STM-based spectroscopy also offers complementary information to other techniques that are able to measure surface DOS, such as angle resolved photoemission spectroscopy (ARPES).

A major breakthrough in extending the capabilities of STM came with the development of the ability to filter tunneling electrons based on the orientation of their spins. The resulting technique of spin polarized STM (SP-STM) enabled the atomic scale spatial mapping of the spin orientation of magnetic layers, nanostructures, and even individual atoms [5]. More recently this has been extended to fabricate and explore more complex spin structures, including those that can be used to perform fundamental logic [6] and data storage [7] operations.

Although accessing the spatially resolved LDOS of a surface can reveal substantial information about its electronic and magnetic properties, additional insight can also be obtained by probing the low energy excitations in the system. This was also accomplished many years ago in planar tunnel junctions using inelastic electron tunneling spectroscopy (IETS), which first revealed the vibrational modes of molecules trapped in the tunnel junction [8]. With the development of STM-based IETS, it became possible to measure the vibrational modes of individual molecules on surfaces [9], and then more recently rotational [10, 11] and spin excitations [12].

These advances in STM imaging and spectroscopy have dramatically expanded its applicability to a much wider range of systems. Of particular note are new classes of materials with atomic-scale thickness. Some of these, such as sodium chloride and aluminum oxide, are insulators and can therefore be placed on top of metallic systems to act as an isolating buffer that enables adsorbates placed on top to be substantially less disturbed by interactions with the underlying metal. This has been particularly useful in enabling the observation of well-defined molecular states that resemble the states of free molecules as well as very strong spin excitations through IETS measurements [14–17].

On the other hand, there is also great interest in layered materials that exhibit new classes of conducting properties. The first and most famous of these is graphene [18, 19], a 2D honeycomb lattice of carbon that was first isolated almost a decade ago. However, rather than being unique, graphene has instead spurred interest in a range of other 2D materials...
whose properties change dramatically when their thickness is reduced to a few atomic layers; recent examples that are attracting interest include silicene [20, 21] and transition metal dichalcogenides [22, 23]. There is also much interest in the recently realized properties of materials that are bulk insulators but have topologically protected surface states: topological insulators [24, 25].

In this special issue, we present a collection of articles that cover some of the most exciting areas of recent advances in scanning tunneling microscopy. Two reviews highlight the fields of STM studies of topological insulators and magnetic systems with complex orderings, including spin spirals and skyrmions. We also feature new work in the areas of atomic and molecular scale magnetism and other 2D layered materials including graphene and copper nitride.

We hope that readers will enjoy the articles in this issue. Our special thanks go to the authors who contributed their exciting work, the referees who judiciously reviewed them, and the JCPM staff who efficiently managed the entire process.

References

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