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Review

Scanning tunneling microscopy of functional nanostructures on solid surfaces: Manipulation, self-assembly, and applications

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ABSTRACT

The manipulation, self-assembly, and application of functional nanostructures on solid surfaces are fundamental issues for the development of electronics and optoelectronics. For a future molecular electronics the fabrication of high-quality organic thin films on metal surfaces is crucial, which can be achieved by thermal evaporation for various organic/metal systems. The switching property of single molecules can be manipulated and measured, revealing a possibility to realize single molecular devices. Manipulation of a local conductance transition in organic thin films, used for ultra-high density data storage, has also been achieved based on several different mechanisms. The stability, reversibility, and repeatability of the local conductance transition have been improved by molecular design. In this article, we will summarize our recent scanning tunneling microscopy studies on these issues and discuss their perspectives.

Contents

Abbreviations: AFM, atomic force microscopy; DFT, density functional theory; EDP, electron diffraction pattern; HOMO, highest occupied molecular orbital; HOPG, highly oriented pyrolytic graphite; ITO, indium tin oxide; LB, Langmuir–Blodgett; LEED, low energy electron diffraction; LUMO, lowest unoccupied molecular orbital; MBE, molecular beam epitaxy; STM/STS, scanning tunneling microscopy/spectroscopy; TED, transmission electron diffraction; TEM, transmission electron microscopy; UHV, ultra-high vacuum.

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1. Introduction

Functional nanostructures on solid surfaces are an important concern not only for the academic but also for the industrial community in view of their importance in the development of electronics and optoelectronics. Exploring new materials and developing new techniques for materials preparation [1,2] are of the heart in most of the developments in science and technology. The surface science community is well placed to explore functional materials due to versatile surface analysis techniques, including the scanning tunneling microscopy (STM). STM allows us to "see" the surface with atomic-resolution by quantum mechanical effect of tunneling. STM can resolve the local electronic structure on the atomic scale on all kinds of conducting surfaces, under various environments with little damage to the sample. Since its invention [3–7], STM has become more and more powerful due to the rapid development of STM-related techniques, and has been helping to expand considerably the scope of atomic scale research [8–18]. The primary advantage of STM is its capability of high-resolution imaging. For example, both the rest atoms and the adatoms of Si(1 1 1)-(7 $\times$ 7) surface simultaneously were observed by STM [19]. STM has been widely used to study the adsorption behavior of atoms or molecules on surfaces [20–25]. Another important application of STM is manipulation at nanometer scale, where single atoms or molecules can be assembled into various desired nanostructures on surfaces. The atomic-scale apex of STM tip can also be used to perform local modifications on surfaces, which is promising for ultra-high density data storage from the perspective of technological applications.

Organic semiconductors have great potential applications in electronics and optoelectronics [26]. For example, organic thin-film transistors (OTFTs), which offer the possibility of applications for flexible displays, all-plastic smart cards, as well as organic light-emitting devices (OLEDs), have received widespread attention in recent years [27–34]. In organic devices, carrier transport and luminescent behavior are governed by the orientation and packing of molecules [35–37]. Therefore, enormous efforts have been made to understand and precisely control the formation of organic thin films with various structures [38–47]. Practical applications of organic devices require the use of inexpensive high-quality organic films deposited on various substrates, such as metal, oxidized silicon [48] and silicon surfaces. In this article, we focus on our recent studies on organic/metal systems. Organic semiconductors on single-crystalline metal surfaces are typical systems for injection contacts in OTFTs and OLEDs. While organic multilayers are already applied in current organic devices, the interfaces