Monday Afternoon, October 2, 2000

Processing at the Nanoscale/NANO 6 Room 302 - Session NS+NANO6-MoA

Manipulation of Atoms and Molecules

Moderator: J.W. Lyding, University of Illinois, Urbana

2:00pm NS+NANO6-MoA1 Atomic/Molecular Manipulation with the Low Temperature STM, G. Meyer, Paul Drude Institut für Festkörperelektronik, Germany INVITED

The scanning tunneling microscope (STM) opened up new fascinating possibilities for the development of atomic scale technologies. The force between the STM-tip and a single adsorbate can be used to laterally position atoms/molecules with atomic precision (lateral manipulation), which allows the buildup of small nanostructures in an atom by atom way. By exploiting electric field and inelastic tunneling effects individual molecules can be desorbed, transferred to the STM-tip (vertical manipulation), dissociated or even synthesized. For future applications the basic physical mechanisms controlling these techniques have to be investigated first. As model systems we have studied the lateral/vertical manipulation of single metal adatoms (Cu), small molecules (CO, C@sub6@H@sub 4@I@sub 2@), and large molecules (CuTBPP) adsorbed on metal surfaces (Cu(111), Cu(100), Cu(211)) at low temperatures. Adsorbates can be moved laterally by applying attractive or repulsive forces. This results in a simple pulling or pushing behavior, which can be directly observed in the STM tip height or current signal. In the case of large molecules, which have additional internal degrees of freedom, a more complicated movement behavior is observed. Apart from single adsorbates, also complete chains of molecules can be laterally manipulated and information on the correlated motion of the molecules can be extracted. Finally several examples for the application of the manipulation techniques in the area of surface science will be given. These include: determination of adsorbate binding sites, buildup of small domains of ordered adsorbate phases, atomic scale structuring of the underlying substrate, measurement of weak substrate mediated long range adsorbate interactions, dissociation/synthesis of molecules, manipulation on thin insulating films.

2:40pm NS+NANO6-MoA3 Fundamental Approaches to Silicon-based Molecular Nanotechnology using the Scanning Tunneling Microscope, M.C. Hersam, N.P. Guisinger, L. Liu, J.W. Lyding, University of Illinois

The importance of molecular nanotechnology has recently been underscored by increased media, public, and government awareness of the subject. This paper outlines an approach for fabricating and characterizing single molecule units on the technologically significant Si(100) surface with the ultra-high vacuum scanning tunneling microscope (UHV-STM). Using feedback controlled lithography (FCL), individual H atoms can be removed from the Si(100)-2x1:H surface. The remaining dangling bond patterns serve as atomically precise templates upon which other materials can spontaneously self-assemble. By utilizing this selective chemistry in situ, several organic molecules (e.g., norbornadiene (NBE), copper phthalocyanine (CuPc), C@sub 60@, etc.) have been isolated. The mechanical, chemical, and electronic properties of these individual adsorbed species can then be immediately detected with the STM. For CuPc, the spatial extent of charge transfer from the substrate to the adsorbate is measured as a function of binding orientation. When the CuPc is reduced with ammonia, single molecule rotation is observed. STM spectroscopic measurements on C@sub 60@ reveal intra-molecular variations in the electronic density of states. A fundamental understanding of such phenomena will enable the design of nanoscale devices. For electronic applications, the application of lateral electrical fields to individual molecules is crucial. A fully compatible electrical contacting scheme based on p-n junctions will be presented. Efficient STM potentiometric location of these p-n junctions suggests their additional use as alignment markers. Finally, the robustness of this technique will be outlined. Even following exposure to ambient conditions, the in situ Hpassivated Si(100) surface remains atomically pristine. The ability to combine nanolithography with wet chemical processing opens up new opportunities for nanoscale chemical and biological applications.

3:00pm NS+NANO6-MoA4 STM Atom Manipulation, D.M. Eigler, IBM, Almaden INVITED

PLEASE SEND US AN ABSTRACT. Thank you.

3:40pm NS+NANO6-MoA6 Scanning Tunneling Spectroscopy via Adsorbate Resonances: Kondo vs. Non-magnetic Systems, *M. Plihal, J.W. Gadzuk,* National Institute of Standards and Technology

Resonance tunneling STM studies of transition metal atoms adsorbed on noble metal surfaces, some combinations forming Kondo systems defined by the presence of a localised magnetic moment on the adsorbate and a spatially extended spin compensation cloud within the substrate, have recently been reported. The intriguing additional influence of artificiallysynthesized boundaries such as other atoms, guantum wires, and guantum corrals on the surface has also received much attention. Typically the spectroscopic results are given as spatially-dependent differential conductance versus voltage spectra, usually observed to be close in form to an asymmetric Fano lineshape. This form is characteristic of the interfering "decay" of an initially excited localized state (here an electron or hole state within the STM tip) into a continuum which has been perturbed by a discrete localized state (here the substrate conduction band states coupled to the adsorbate valence electron states). We sketch a detailed theory of the spectral properties of the tunneling for such systems valid for arbitrary intra-adsorbate electron-electron interactions, taking into account nonequilibrium effects when tunneling into the resonance is strong in comparison with direct tip-to-surface tunneling. We present the temperature and tip-position dependence for tunneling through both a Kondo resonance and that of a non-interacting, hence non-magnetic adsorbate. Most of the predicted tunneling characteristics are common to both types of resonances. Issues associated with the spatial dependences, including impurity scattering and mirages within corrals are treated in a natural way using our model.

4:00pm NS+NANO6-MoA7 Manipulation and Inelastic Tunneling Spectroscopy Measurement of CO on Pd(110) using Low-temperature STM, T. Komeda, Y.S. Kim, M. Kawai, Riken, Japan

The ability of the scanning tunneling microcopy (STM) to manipulate a single molecule adsorbed on metal surfaces and induce local chemical reaction makes it an idealistic tool to investigate fundamentals of chemical reactions and the catalytic phenomena. In addition, the recent success of inelastic tunneling spectroscopy (IETS) to obtain chemical information by measuring its vibration state makes it more attractive. In this paper, we show the results of the manipulation and the IETS measurement by STM on carbon monoxide (CO) adsorbed on Pd(110) surface at the temperature of 4.8 K. Intriguing 1D chains of CO molecules along Pd(110) row ([-110] direction) was observed at very low-coverage region which grew to islands with local ordered structure of c(2x2). No movement of the molecule was observed during the STM measurement (tunneling current of 1nA with bias of 100 mV) for the temperature range upto 40 K. The manipulation on isolated CO molecules were done with the following method. The tip was positioned to give 0.1 nA tunneling current with 10mA substrate bias, then feedback loop was turned off. The bias between the tip and the sample was varied between -350 mV and +350 mV with the frequency of 3Hz which gives the maximum current less than 5 nA which is guite moderate for metal observation. However, this method caused the CO molecule hopped single site along [-110] direction. The driving force for the CO movement can be understood by the interaction between the electric field formed by the tip-and-sample and the dipole-moment of CO, which is considered to be very controllable method without touching between the tip and the sample. Also inelastic tunneling spectroscopy (IETS) has been carried out on an isolated CO molecule and on the CO chains. The I-V curve showed characteristic features around 250 mV.

4:20pm NS+NANO6-MoA8 Benzene and Its Derivatives on Transition Metal (111) Surfaces, Y.-J. Song, J.-Y. Park, U.D. Ham, H.J. Kim, Y. Kuk, Seoul National University, Korea

Benzene and its derivatives such as bromobenzene, iodobenzene, and xylene, adsorbed on transition metal surfaces (Cu and Pd) have been investigated with an ultrahigh vacuum low temperature scanning tunneling microscope (STM). At room temperature, these molecules are highly mobile so that it is difficult to study low coverage behaviors. On the other hand, they form close-packed ordered structure with three different domains at saturation coverage, as observed with STM. At low temperature, the mobility of molecules is reduced that single molecules can be studied. With high-resolution imaging capability of our STM, internal structures of molecules are revealed. Therefore, different isomers can be distinguished. Furthermore, manipulation of these molecules is performed with the STM tip. Possible mechanisms of different manipulation modes will also be discussed. The possibility of STM-induced molecular reaction will also be presented.

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4:40pm NS+NANO6-MoA9 Artificial Surface Structure on H/Si(100)4x3-In Surface Using STM Tip, O. Kubo, T. Harada, T. Kobayashi, N. Yamaoka, M. Katayama, K. Oura, Osaka University, Japan

Scanning tunneling microscopy (STM) recently has considerable attention as an apparatus not only for observation of surface structures but also for manipulation of surface atoms. Since Lyding et al.@footnote 1@ reported about hydrogen (H) extraction from Si(100)2x1-H (monohydride) surface using STM tip, H extraction has been investigated both experimentally and theoretically. When superstructures on Si surface induced by metal (Ag. In. etc.) adsorption are exposed to atomic H, peculiar H terminated surface phases are induced. For instance, Si(100)4x3-In surface phase is produced by the deposition of 0.5ML In onto Si(100)2x1 surface at 400°C. When this surface is exposed to atomic H at 300°C, In atoms form clusters, and the reconstructed Si layer which have been formed under In layer is frozen by H termination of Si dangling bonds.@footnote 2@ This H terminated Si layer has monohydride dimer rows whose interval is 4a (a = 3.84 Å), and among the dimer rows, it has dihydride Si atoms (what we call Si(100)4x1-H). In this study, we have performed H extraction from the Si(100)4x1-H surface using STM tip. The H extraction could be performed by applying about 5 V of sample voltage and about 0.2 nA of tunneling current, which were almost the same condition for the H extraction from Si(100)2x1-H. After H extraction, the 4a periodicity of dimer rows was preserved and the H extracted area was observed higher than a surrounding H terminated surface as well as the extracted area on Si(100)2x1-H surface. This result means that peculiar Si surface structure can be formed artificially. The dimer rows consisted of buckled dimers in spite of room temperature observation contrary to the case on Si(100)2x1-H surface. It is most likely that these dimers were induced by surface stress as same as seen on step edges. @FootnoteText@ @footnote 1@ J.W. Lyding et al., J. Vac. Sci. Technol. B 12 (1994) 3735 @footnote 2@ J.T. Ryu et al., J. Vac. Sci. Technol. B 17 (1999) 983.

5:00pm NS+NANO6-MoA10 Adsorption and Manipulation of Endohedral Fullerenes on Silicon Surfaces, M.J. Butcher, P.H. Beton, University of Nottingham, UK; P. Kuran, L. Dunsch, IFW Dresden, Germany

The adsorption and manipulation of an endohedral fullerene, LaC82 has been investigated using a scanning tunnelling microscope (STM) operating at room temperature in ultra-high vacuum. These molecules are adsorbed on top of both rows and troughs on the Si(100)-2x1 surface, and like C60 may be manipulated in a repulsive mode using the STM tip. However for LaC82 a much stronger interaction between adsorbate and tip is required to promote manipulation resulting in a lower voltage threshold for this process. Adsorption of this species on a less reactive substrate (for example, Ag/Si(111)) results in the formation of close packed hexagonal islands oriented, primarily, parallel to the principal axes of the Si surface. This result confirms an expected commensurability of the intermolecular spacing, d, and the surface lattice constant, namely d~3a, indicating that it should be possible to form close packed rows of LaC82 along the troughs of Si(100)-2x1. The formation of pairs and other simple close packed assemblies of molecules has been demonstrated. A comparison of the response to manipulation of a range of fullerenes and heterofullerenes will also be presented and discussed in terms of the effects of size and chemistry of the adsorbed molecules.

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