ELECTRICAL AND MECHANICAL CONTACTS AT THE ATOMIC SCALE: A COMBINED UHV STM/AFM STUDY

Yan Sun, Henrik Mortensen, Sacha Schaer, Yoichi Miyahara, Anne-Sophie Lucier, Mehdi El Ouali and Peter Grutter*
Department of Physics, McGill University, 3600 University Street, Montreal, Quebec, Canada, H3A 2T8
Werner Hofer
Surface Science Research Centre and Department of Physics, University of Liverpool, Liverpool L69 3BX, United Kingdom
*E-mail: grutter@physics.mcgill.ca
http://www.physics.mcgill.ca/spmT

Scanning probe microscopes(SPM), such as STM and AFM are central tools for atom/molecule manipulation and characterization in nanotechnology. Understanding interactions between a probing tip and sample under well defined conditions is essential for a quantitative understanding of contrast in SPM. These interactions crucially depend on the tip-sample separation, the atomic arrangements, and the electronic structure of the tip and the sample.

Theoretical and experimental efforts have been made to investigate tip-sample interaction at the atomic scale, however, many important aspects are still not well understood. The transition from tunneling to electrical contact is not fully characterized. In this work, using a combined ultra-high vacuum scanning tunneling and atomic force microscope (UHV STM/AFM),(Fig.1) we have measured simultaneously at the atomic scale the interaction forces and the currents between a sharp tungsten tip and a Au(111) sample. With our customized digital controller, the following measurements are performed: Starting from a reference point defined by a tunneling gap (current 60pA, bias voltage 50mV), the feedback is switched off and the tip-sample separation is varied while simultaneously recording the cantilever deflection and current. Then the feedback is turned on again to recover the initial tunneling condition. After a few cycles of approach and retraction, the surface was scanned with the same tip to reveal any possible topography change.

Close correlation between conductance and interaction forces are observed in the regimes from weak coupling to strong interaction. The measured currents change from pA to µA and the interaction forces at close proximity are found to be a few nN. (Fig.2) In particular, the electrical and mechanical points of contact are defined based on the observed barrier collapse and adhesive bond formation, respectively. The points of contact as defined by force and current measurements coincide within measurement error. We find experimentally that at contact the very front atoms of the tip apex experience repulsive forces, while the total interaction force remains attractive as a consequence of competing interaction decay lengths. Ab-initio calculations of the current as a function of distance were performed for our experimental tip-sample system[1]. We find that in the weak coupling regime the calculated electrical current as a function of distance is in quantitative agreement with experimental results only if tip and sample relaxation effects are taken into account. The calculated relaxation of the tip apex atoms is 50-100 pm. We conclude that force effects of different decay lengths cannot be excluded if a detailed understanding of atomic scale contacts is to be achieved. Our on-going study on individual $C_{60.}$ molecules will further explore the force effects on mechanical and electrical properties of organic molecules.

References:

[1] W.Hofer, A. Fisher, R. Wolkow and P.Grutter, ***Phys.Rev.Lett.,*** **87**(2001)236104

Figures:

Fig.1 Schematic of the combined STM/AFM. A sheet of high quality mica (both sides coated with 100nm gold) is used as the substrate and force sensor. The interaction forces are measured directly with an interferometer. The electrical and mechanical properties of single molecules (such as C_{60}) will be studied.

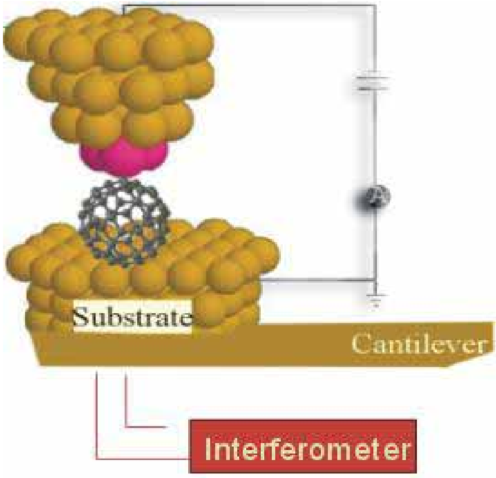

Fig. 2. Simultaneous force distance and current-distance curves obtained over a *hcp* region on Au(111).