SINGLE ELECTRONS, CONTACTS AND FORCES – WHAT AFM CAN DO FOR NANOELECTRONICS

Peter Grutter
Physics Department, McGill University, Montreal (Quebec) Canada
grutter@physics.mcgill.ca

In this talk I will give an overview of our attempts to understand electrons in nanoscale structures using various scanning probe techniques. I will first concentrate on our recent attempts to measure single-electron charging in an individual InAs quantum dot with a 4.5 K atomic force microscope (AFM) [1]. The resonant frequency shift and the dissipated energy of an oscillating AFM cantilever were measured as a function of the tip-back electrode voltage, and the resulting spectra show distinct jumps when the tip was positioned above the dot. The observed jumps in the frequency shift, with corresponding peaks in dissipation, are attributed to a single-electron tunneling between the dot and the back electrode governed by the Coulomb blockade effect, and are consistent with a model based on the free energy of the system (fig. 1). The observed phenomenon may be regarded as the ‘‘force version’’ of the Coulomb blockade effect. The peaks in dissipation are essentially due to a single electron back action effect on a micromechanical transducer.

In the second part I will concentrate on molecular electronics. I will describe recent measurements of the forces and currents between atomically defined contacts [2]. We used a combined ultra-high vacuum scanning tunneling, atomic force and field ion microscope to study W tip- Au(111) sample interactions in the regimes from weak coupling to strong interaction and simultaneously measure current changes from pA to µA. Close correlation between conductance and interaction forces in a STM configuration was observed. In particular, the electrical and mechanical points of contact are determined based on the observed barrier collapse and adhesive bond formation, respectively. These points of contacts as defined by force and current measurements coincide within measurement error. Ab initio calculations of the current as a function of distance in the tunneling regime is in quantitative agreement with experimental results. The obtained results are discussed in the context of dissipation in non-contact AFM as well as electrical contact formation in molecular electronics.

Finally, I will briefly describe first steps to build an atomically defined here terminal device. We used UHV AFM to study the nucleation and growth of a variety of molecules on various insulators [3]. First efforts of fabricating atomically defined metal contact electrodes in-situ will be discussed.

References:

Complete references can be found at
www.physics.mcgill.ca/~peter or www.physics.mcgill.ca/SPM

[1] Stomp et al., Phys. Rev. Lett. **94**, 056802 (2005)
[2] Sun et al., accepted Phys. Rev. B (2005)
[3] Burke et al, Phys. Rev. Lett **94,** 096102 (2005)

Figures:

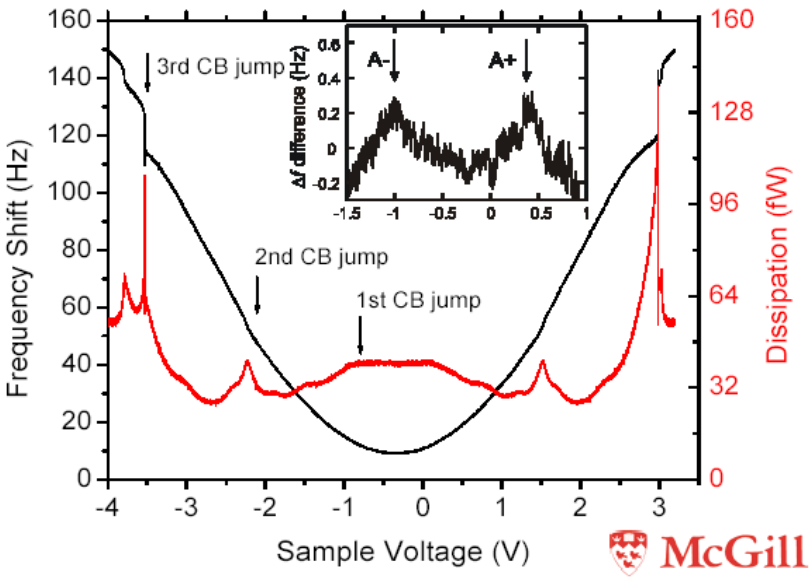

Fig. 1: Resonant frequency shift, *f*, and dissipated energy of the AFM cantilever as a function of the tip sample bias voltage. The arrows point to the sudden increases in the *f* caused by a single-electron charging in a QD and they appear as a peak in the dissipation at the corresponding bias voltage. The inset shows the magnified spectrum around the structures A+ and A-. Here, a fitted parabola to the spectrum around the minimum is subtracted. [1].

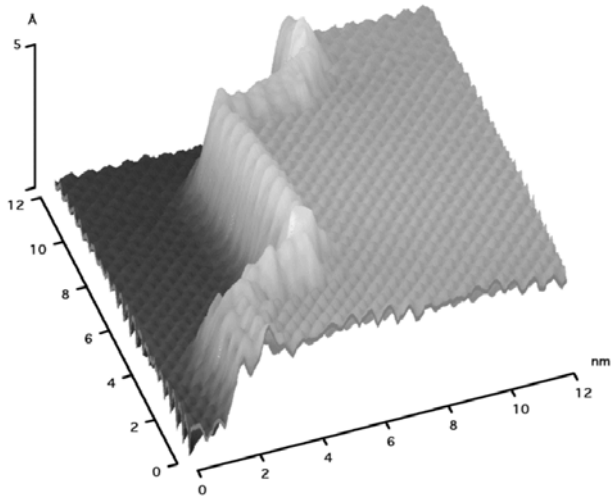

Fig. 2: Left: Atomic resolution by NC-AFM across KBr step at RT.
Below: Atomic resolution of KBr showing kink sites in <100> steps. The blurred, or noisy areas, are most likely C60 molecules loosely bound at the kink sites. In (b) the molecule marked by the arrow has been removed in the imaging process, revealing the underlying KBr structure. (a) _f=-7.1Hz, A=7nm, image size: 18 nm × 18 nm, (b) _f=-7.4Hz, A=7nm, image size: 18 nm × 18 nm. From [2]