A Biased View of the Nanoworld: Transport, Defects and Ferroelectrics

Sergei V. Kalinin

Condensed Matter Sciences Division, Oak Ridge National Laboratory

Progress in nanotechnology requires quantitative knowledge of structure, electronic and electromechanical properties, and transport behavior of materials and devices on the nano- and atomic levels. In this talk, I will illustrate the potential of Scanning Probe Microscopy (SPM) techniques for quantitative transport, electronic, and electromechanical imaging on the nanoscale. Nanoscale transport imaging is illustrated on an example of Scanning Impedance Microscopy of electroactive interfaces that combines the spatial resolution of traditional SPMs with the precision of C-V and I-V measurements. In Scanning Gate Microscopy, quantitative image interpretation using first principles density functional theory and quantum electrostatics allows transport behavior to be accessed on the level of individual atomic defects in carbon nanotubes.

The electronic structure behavior on the atomic scale is illustrated on an example of intriguing surface physics of layered strontium ruthenates, Sr_2RuO_4 and $Sr_3Ru_2O_7$, that exhibit an array of atomic defects after cleaving in vacuum observable using scanning tunneling microscopy [1]. At room temperature, surface defects are randomly distributed, but are surprisingly ordered at below 200 K and form extended stripe- and net ordering. These defects can be interpreted either as structural SrO defect pairs or electronic charge ordering and experimental results are compared with DFT calculations to verify these models.

In the last part of the talk, the quantitative electromechanical imaging of ferroelectric materials using Piezoresponse Force Microscopy (PFM) is illustrated. The solution of the coupled electroelastic problem for piezoelectric indentation is derived and used to obtain the tip-induced electric field and strain distribution in the ferroelectric material. This establishes a complete continuum mechanics description of the PFM imaging mechanism. Electroelastic field distributions are used for a quantitative analysis of the PFM polarization switching processes. Potential of PFM for nearly atomic density ferroelectric storage and lithography is illustrated.

[1] E. W. Plummer, Ismail. R. Matzdorf, A. V. Melechko. and Jiandi Zhang, *Prog. Surf. Sci.*, **67**, 17 (2001)

Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Dept. of Energy under contract DE-AC05-00OR22725.

Sergei Kalinin is currently a Wigner Fellow and research staff member at the Oak Ridge National Laboratory. He completed his Ph.D. in Materials Science at the University of Pennsylvania in the fall of 2002 working with Prof. Dawn Bonnell. His previous undergraduate and graduate work was completed in Materials Science at Moscow State University, Russia. During his academic career, Sergei has been the recipient of the Ross Coffin Purdy Award of the American Ceramic Society (2003), the American Vacuum Society Graduate Student Award (2002) and the Materials Research Society Graduate Student Award (Gold, 2001; Silver, 1999 and 2000), along with the Wigner fellowship at ORNL (2002). He is the author of more than 50 scientific publications and five book chapters. Currently he is working with Art Baddorf and Ward Plummer on the synthesis and SPM characterization of electronic, electromechanical and transport phenomena in transition metal oxides on the nanoscale.