Secondary Electron Trajectories in Scanning Tunneling Microscopy

H. Cabrera[1], D. A. Zanin[1], L. G. De Pietro[1], A. Vindigni[1], U. Ramsperger[1], D. Pescia[1]

[1]Laboratory for Solid State Physics, Microstructure Research, ETH Zurich, Zurich, Switzerland

Abstract

The recently developed technique Scanning Tunneling Microscopy in the Field Emission regime (STM FE) is based on the Russell Young's topografiner technology [1]. The set-up is a no contacting device consisting of a sharp tip approached vertically to a conducting surface at variable distances and biased with a small voltage with respect to the surface (Figure 1). The system builds a junction across which electrons can be transferred from the tip apex to the surface by direct quantum mechanical tunneling if the distance is in the sub nanometer region. In this case the surface topography can be imaged with atomic spatial resolution using the STM technique. In the STM FE mode, the distance between tip and collector is increased and the current is dominated by electrons emitted from the tip into the vacuum region via electric field assisted tunneling. In the experiment, secondary electrons carrying chemical and magnetic information are produced via diverse mechanisms on the surface of the sample and form a cloud in the vicinity around the interaction region in a macroscopic environment. Some of them are attracted by an electric potential to the entrance of a lens system designed for focusing the electrons into a counter and a Mott detector. The imaging of the sample with a resolution in the nanoscale depends on the amount of secondary electrons that effectively reach the detectors. We use COMSOL Multiphysics® to optimize the electrostatic and geometric parameters by calculating the trajectories of the secondary electrons from the sample to the final position on the detectors. The set of results achieved on the physical characterization of the instrument refers to a situation where a nanoscale quantum process, comprising field emission, secondary electron production and electron transport in the presence of strongest electric fields is shown to couple efficiently to a macroscopic environment. An accurate modeling of this multiscale process requires the solution of the Laplace and movement equations in two separate subsystems with different space scales. In the first component, the system consists of a tungsten tip in front of a silicon surface in a subspace of some hundreds of nanometers [2]. In the second component, the geometry is generated by importing a simplified version of the CAD-construction files of the instrument (in a scale of centimeters) (Figure 2). In both cases the electrostatic problem is solved using the AC/DC Module and the trajectories of the electrons are calculated with the Particle Tracing Module. For coupling the two simulations, in analogy to the model "Syngas Combustion in a Round-Jet Burner" (Model Library), the final positions and velocities on the walls of the first Component are used as initial values in the second Component (Figure 3). Most of the calculations are performed on a cluster. First results shown that only a few electrons can escape from the interaction region if their energies

are about 70 eV. From the escaped electrons, a 10% can reach the Mott detector (Figure 4).

Reference

[1] R. Young et al., The topografiner: An instrument for measuring surface microtopography, Review of Scientific Instruments, Vol. 43, pp. 999-1011 (1972).
[2] T. Michaels et al., Scaling theory of electric-field-assisted tunnelling, Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, Vol. 470 (2014)

Figures used in the abstract

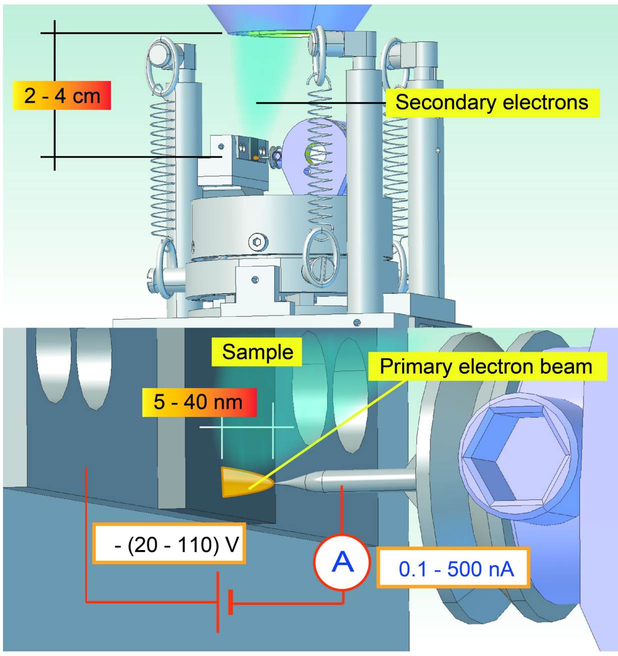

Figure 1: Schematic diagram of the experiment showing the electrostatic junction, the primary electron beam and the secondary electrons.

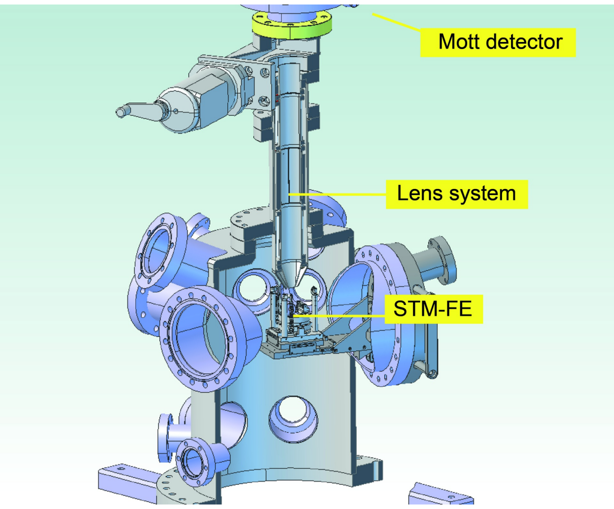

Figure 2: Partial view of the STM-FE set-up with the microscope inside the experimental chamber and the lens system.

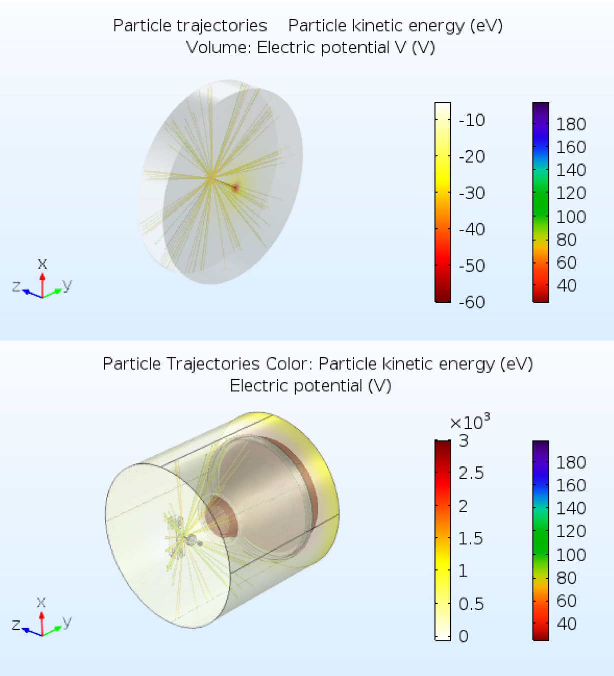

Figure 3: 70 eV-secondary electron trajectories in the coupled simulation.

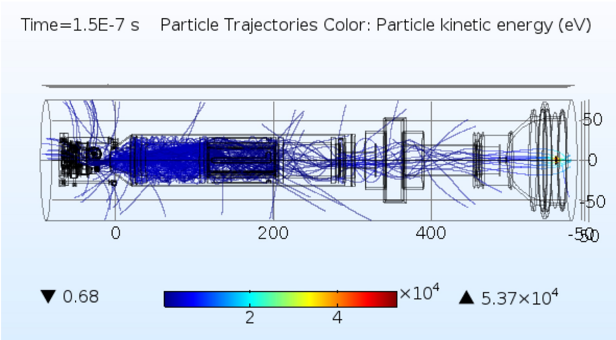

Figure 4: Example of the simulations. Trajectories of secondary electrons with an initial kinetic energy of 10 KeV.