# Simulation Of Low Energy Electrons In Scanning Field Emission Microscopy (SFEM)

C.G.H. Walker[1], H.C. Cabrera[1], D. Pescia[1]

[1]Institut für Festkörperforschung, ETH Zürich, Switzerland

## Abstract

The study of low energy electrons (0-300 eV) and especially secondary electrons (typically < 50 eV) are of technical importance in many areas such as Scanning Electron Microscopes [1], spacecraft charging [2], the electron cloud effect in particle accelerators [3] and in radiological/medical studies [4]. Typically, the interaction of particles with matter are studied using Monte Carlo methods such as CASINO [5] or at higher energies Geant4 [6]. However, most such studies do not also include an electric or magnetic field particularly when that field is non-uniform.
We have explored the use of COMSOL Multiphysics® (using AC/DC Module and Particle Tracing Module) in combination with some code that uses the Geant4 library to study the interaction of low energy electrons with matter in a Scanning Field Emission Microscope (SFEM) [7]. Electrons are field emitted from a sharp Tungsten tip and strike the sample surface with an energy of a few 10´s of eV. The electrons may then excite secondary electrons in the surface or may simply "bounce" off the surface due to Quantum Mechanical effects [8]. The electrons that emerge into the vacuum will again feel the electric field from the tip and be forced back down on to the surface (see Fig 1).

The electrons that interact with the material use a Monte Carlo code to simulate the elastic and inelastic scattering that the electrons undergo. In the case of SFEM, it is important to understand where the electrons of certain energy ranges originate, so that the spatial resolution of SFEM can be understood.
Although Geant4 can simulate particles in electric and magnetic fields, it cannot generate those fields and they need to be imported from other software. COMSOL Multiphysics® can be used for this, but ensuring that the field is correctly simulated is a challenge in Geant4 when the field varies significantly over small spatial distances (in our case nm), but the simulation needs to be carried out over a relatively large distance (in our case up to mm). The Monte Carlo simulation could be carried out purely in MATLAB® and connected to COMSOL Multiphysics® via the LiveLink™ for MATLAB®, but this would require a lot of new code to be written and the Geant4 Monte Carlo code already exists and is written in C++ (so it´s fast).
We explore the different options of combining COMSOL Multiphysics® with Geant4 and the pros and cons of each and show some initial results.
References
1. J. Tian, J. Wu Y.-L. Chiu, Ultramicroscopy, 187, 2018, pp 13-19.
2. Shu T. Lai, "Fundamentals of Spacecraft Charging: Spacecraft Interactions with Space Plasmas", 2012, Princeton University Press, ISBN 978-0-691-12947-1
3. M. A. Furman, M. T. F. Pivi, SLAC-PUB-9912 LBNL-49771, CBP Note-415
4. M.A.Bernal et al., Physica Medica 31, 2015, pp 861-874.
5. P. Hovington, D. Drouin, R. Gauvin, Scanning 19, 1997, pp1-14.
6. S.Agostinelli et al., Nucl. Inst. Meth. Phys. Res. A, 506, 2003, pp 250-303.
7. H. Cabrera, D. Pescia, https://www.comsol.de/paper/download/442361/cabrera_presentation.pdf
8. J. Cazaux, Journal of Applied Physics, 111, 2012, p064903.

## Figures used in the abstract

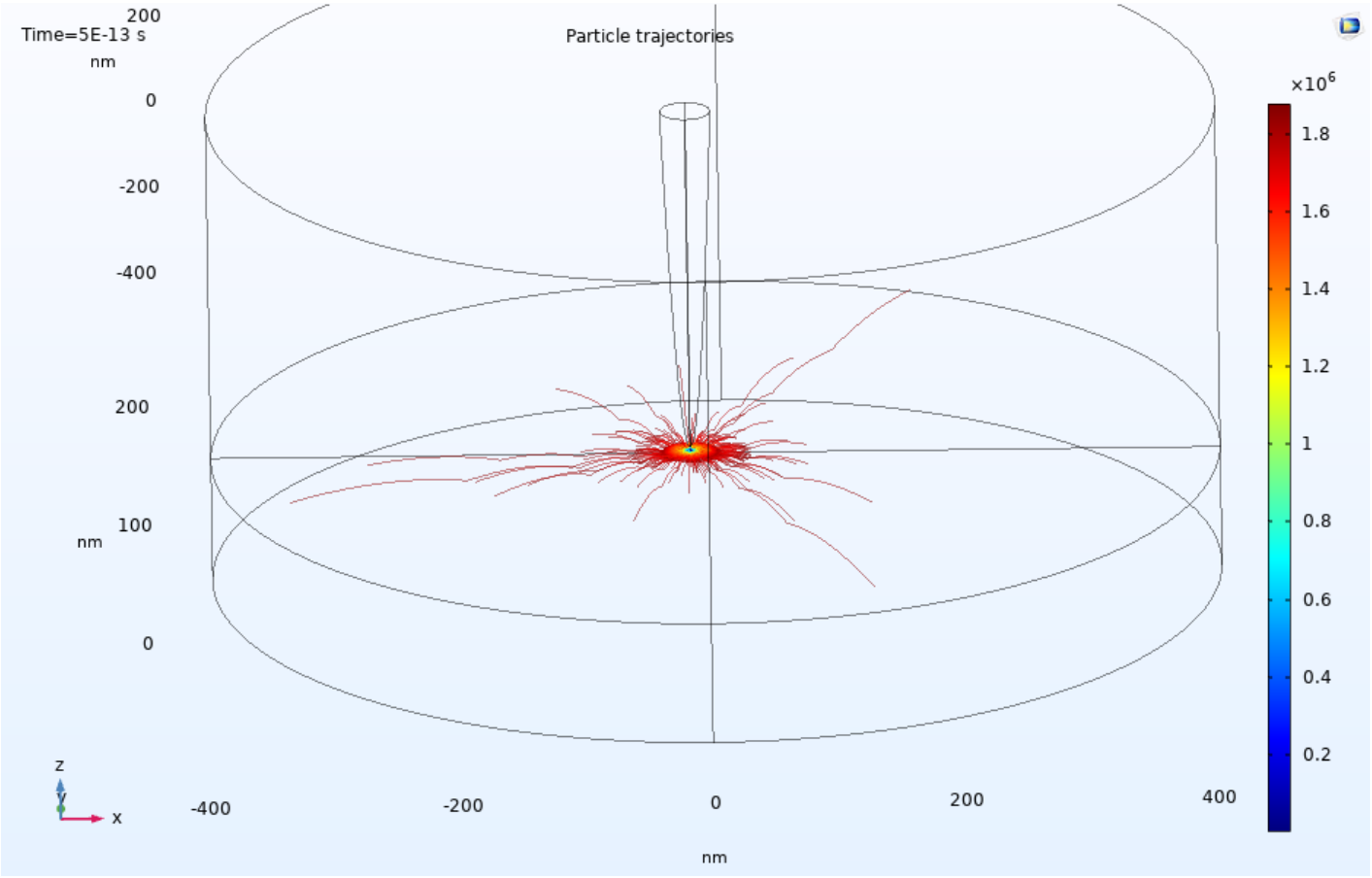


**Figure 1** : Figure 1. Electrons of energy 10 eV bouncing in the field between field emission tip and sample surface.