Looking for the Origin of Power Laws in Electric Field Assisted Tunneling

H. Cabrera[1], D.A. Zanin[1], L.G. De Pietro[1], A. Vindigni[1], U. Ramsperger[1], D. Pescia[2]

[1]Laboratory for Solid State Physics, ETH Zurich, Zurich, Switzerland
[2]Laboratory for Solid State Physics, ETH Zurich, 8093 Zurich, Switzerland

Abstract

Introduction
Recent experiments[1] measuring the current I vs voltage V characteristics of a diodelike junction in the electric field assisted regime find that all I-V curves, taken at different distances d between the sharp electron emitter and the planar collector, collapse onto one single graph when d is varied over six orders of magnitudes. We have measured the voltage vs distance V-d characteristics at constant current I of a tunnel junction consisting of an electron emitting sharp tip placed at a variable distance d from a planar anode (schematic view of the experiment in Figure 1).

The tip is biased with a negative voltage, such that field emitted electrons flow from the tip into the anode. The collecting plane is a W(110) or a Si(111) single-crystal surface, prepared with standard surface techniques at basis pressure of (10)^11 mbar[2]. By mounting the tip onto a piezocrystal, which can move the tip perpendicularly to the surface, i.e. the distance d can be varied. The value of d was also double checked by an optical sensor device.

Use of COMSOL Multiphysics®
A realistic simulation of the full process involving electric field assisted quantum tunnelling is a difficult task. It appears, however, on the basis of our COMSOL-numerical simulation, that knowledge of the electrostatics alone is already providing a satisfactory explanation of the observed scaling results. For the simulation, the tip was modelled as a hyperboloid of revolution and the sample was a plane placed at the largest distance measured in experiment (Figure 2).

Results
Plotted in the Figure 3 are the values of the electric potential Φ as a function of the spatial coordinate z along the the tip axis. It turns out that the two curves (simulation Φ(z) and experiment V(d)) can be rescaled onto each other with great accuracy and almost within the entire range. To find an explanation -- at least on a qualitative level -- we turn to the actual process that governs the emission of electron from a sharp tip in the regime of large d. The electric field assisted regime can be described by the quantum-mechanical Gamov exponent given in its simplest version

(8π/ħ)^(1/2)∫(φ-|e Φ(z)|)^(1/2) dz

Φ being the work function of the tip and the spatial integration being performed between the classical turning points. The similarity presented in Figure 3 and the almost power-law behaviour recorded can be explained by the Ansatz:

Φ(z)~(V(z/d))^λ.

Figure 3 shows typical experimental V-d characteristic curves. The current is set to some value, the distance d is then varied and the voltage required to keep the current at the prefixed value is measured. In the range d≥10 nm a power-law behaviour ∝d^λ is observed to fit properly the experimental data, with λ converging to λ = 0.21 for large values of d. In the range of small d the dependence becomes almost linear, indicating that a different regime of tunneling -- the direct tunneling regime -- sets in at short distances.

Reference

[1] H. Cabrera et al., Phys. Rev. B 87, 115436 (2013).

[2] D.A. Zanin et al., Advances in Imaging and Electron Physics bf 170, 227 (2012).

Figures used in the abstract

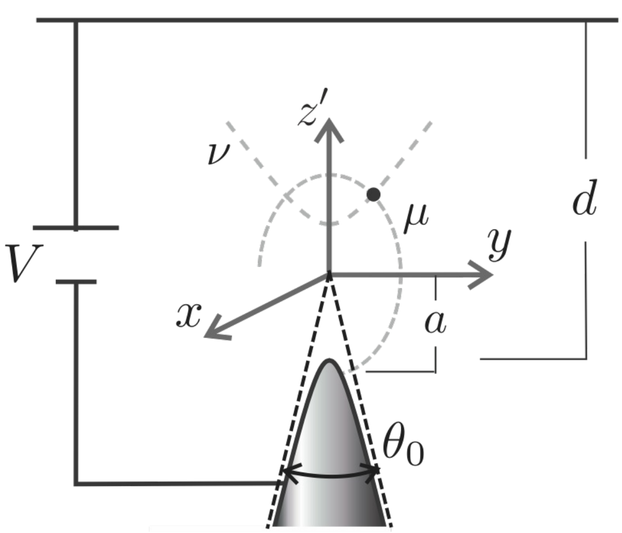

Figure 1: Schematic view of the experimental setup.

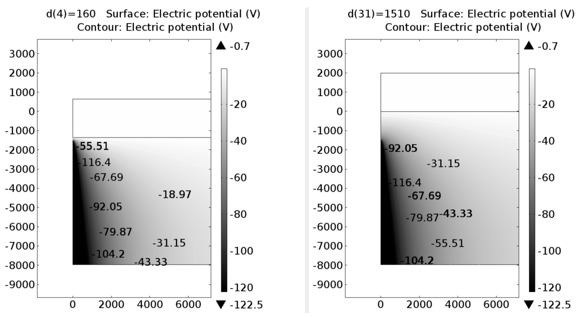

Figure 2: COMSOL simulation of the diodelike junction for different distances between electron emitter and collector.

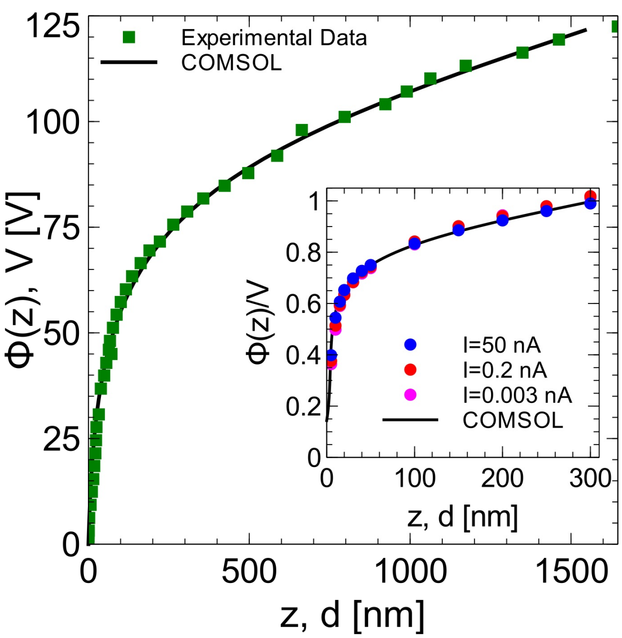

Figure 3: Examples of V-d curves for a field assisted emission current and two different tips.