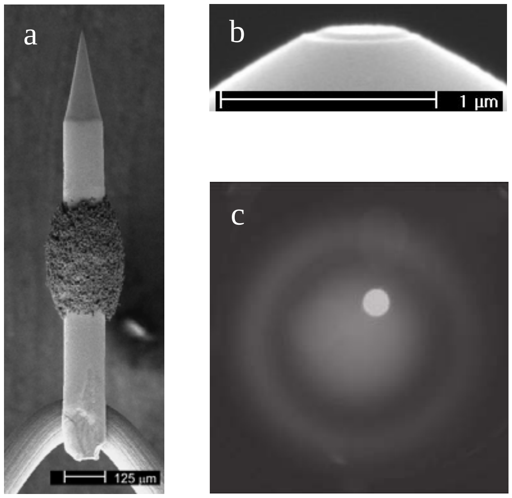
Effect of the electric field on the decay of a Schottky electron emitter tip end: a step flow model

M. S. Bronsgeest, P. Kruit
Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, Netherlands

The Schottky source is predominant in today's focused electron beam equipment and its quality determines the ultimate system performance for most applications. Preferably the source quality remains high over a long time period (months to years) and for some applications also the short-term stability (hours) is relevant. A key factor in both long & short term stability is the stability of the physical shape of the source.
The Schottky electron emitter[1] is a single-crystalline tungsten wire (1 mm long, 125 μm ∅) with (100) planes perpendicular to the wire axis. One end is etched down to a radius of 0.5-2.0 μm and halfway it is coated with a reservoir of ZrO_x (Fig. 1a). In operation the source is at 1800 K and the electric field at the tip is 0.5-1.0 V/nm. The high operating temperature enables surface diffusion. Because the shape of the operating emitter is generally not in thermodynamic equilibrium it will evolve and as a consequence the source performance is not a constant in time.
A known instability is the instability of the facet at the tip (~0.3 μm ∅): the so-called collapsing rings[1] (Figs. 1b-c), which develop only when operating the source at relatively low extraction voltage.
In this work we use a step flow model based on the work of Israeli & Kandel[2] to describe the experimentally observed collapsing step bunches and we expand the model by taking into account the electric field gradient at the tip surface using the work of Giesen *et al*.[3].
In the step model the pointed shape of the Schottky electron emitter is thought of as a stack of concentric (100) terraces. Such a shape will decay due to differences in point defect (adatom/vacancy) concentration near the terrace steps of different radius. Applying the potential difference between emitter and extractor will affect the defect concentrations because adatoms and vacancies have dipole moments: to create a defect dipole now the power supply has to do work in order to keep the potential constant.
The pointed shape of the Schottky emitter tip end yields an electric field along the surface that is decreasing with increasing distance from the facet edge (Fig. 2). This yields an additional position dependent term in the defect concentration and will affect the decay of the tip end.
The shape evolution is calculated by solving the diffusion equation under the appropriate boundary conditions (Figs. 3-4). The model confirms that collapsing rings can be prevented by applying high enough extraction voltage. The important parameters for developing a collapsing step bunch besides extraction voltage are the initial facet size and the curvature in the vicinity of the facet, and the temperature.

---

[1] L. W. Swanson and G. A. Schwind, in 'Handbook of charged particle optics' chapter 2, ed. J. Orloff, CRC Press New York (1997), 77.
[2] N. Israeli & D. Kandel, Phys. Rev. B 60, 5946 (1999).
[3] M. Giesen, G. Beltramo, S. Dieluweit, J. Müller, H. Ibach, W. Schmickler, Surf. Sci. 595, 127 (2005).



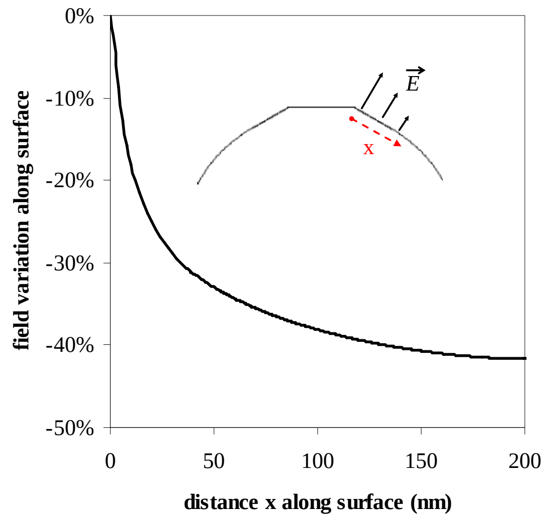
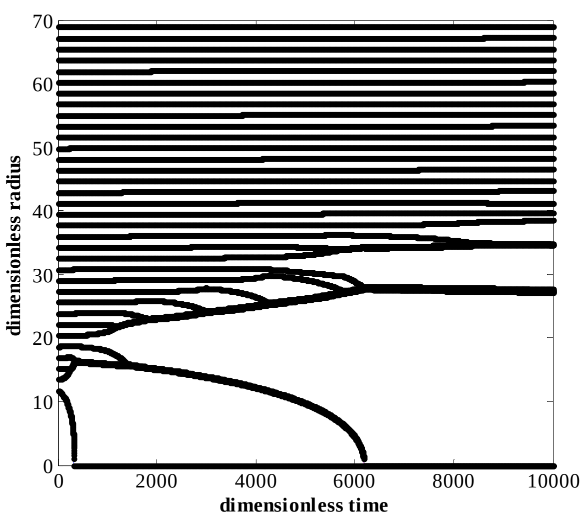


Fig. 1. a) SEM image of a Schottky electron emitter, b) SEM image of a frozen collapsing ring on a tip end, c) typical emission pattern associated with the geometry in b (the bright spot is light emitted by the hot source and penetrating the semitransparent scintillating screen).

Fig. 2. Variation of the electric field strength $\vec{E}$ along the surface of a Schottky electron emitter with given tip end geometry in a standard gun module, calculated with the charge density method.



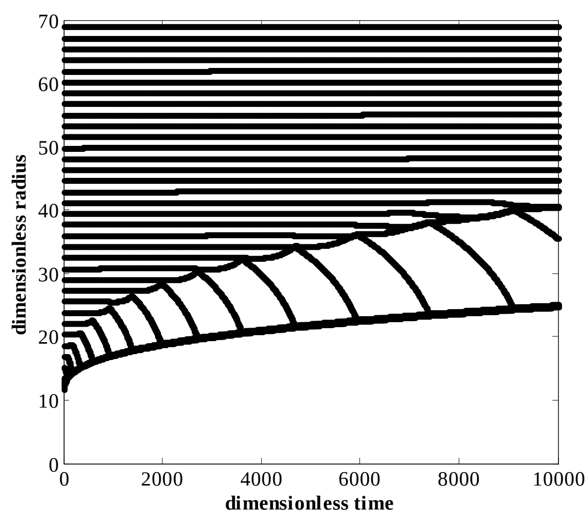


Fig. 3. Simulated time evolution of step radii at a tip end without field showing collapsing rings. Preliminary results.

Fig. 4. Simulated time evolution of step radii at a tip end in a field. Preliminary results.