Reversible shape changes of the end facet on Schottky electron emitters

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Schottky electron emitters are predominant in today's focused electron beam equipment, both electron microscopes and electron beam lithography machines. The emitter is a single crystal W wire, etched to a tip with a diameter of typically 1 μm and processed to have a ZrO_x reservoir, and at the tip end a {100} facet. For most applications the beam current is in the pA up to sub μA range. This beam is cut from the much larger beam emitted by the end facet of the source, which contains of the order of tens of μA. Two parameters that are essential to the relation between probe current and probe size are the brightness and energy spread in the beam. These are determined by the electric field on the facet (and by temperature and work function). The field distribution across the end facet is a function of the geometry of the emitter and the gun it is in, and the potentials applied to the emitter. Clearly, for stable performance the emitter geometry should be controlled.

The geometry of the emitter is however not a constant. Its shape changes because it is not in thermodynamic equilibrium, and the operating temperature is hot enough to allow for surface diffusion. It is of interest to know how large the variations can be, how fast changes can take place and how this depends on the operating conditions. We have investigated this by monitoring the changes of the end facet geometry of a commercial Schottky emitter by recording the evolution of the emission pattern. The emission pattern can be seen as a blurred and distorted shadow image of the end facet, although its interpretation in terms of facet geometry is not always straightforward. We will show, however, that with simulations we can get close to the experimental patterns for different operating conditions, and feel confident enough to translate between geometry and pattern. For further support SEM images have been used (Fig. 1).

It was found that the shape and size of the facet are a strong function of the operating conditions (Fig. 2). The facet gradually becomes smaller at a reduced operating voltage, and upon restoring the operating voltage it quickly grows again before it stabilizes (Fig. 3). This behavior was found to be reproducible (to certain extent), and can be explained, at least qualitatively, with equilibrium crystal shape theory.

The 'reaction' time of the changes and its effect on the field strength at the emitting surface are something to take into account when changing the operating conditions for a source in a practical system.

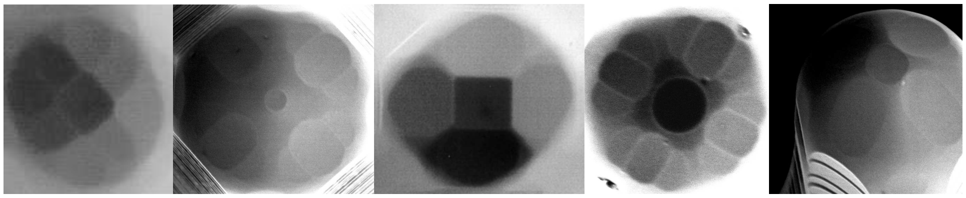

Fig. 1. SEM images of the end facet of different Schottky emitters, operated in different conditions. The typical facet diameter is a few hundred nanometers.

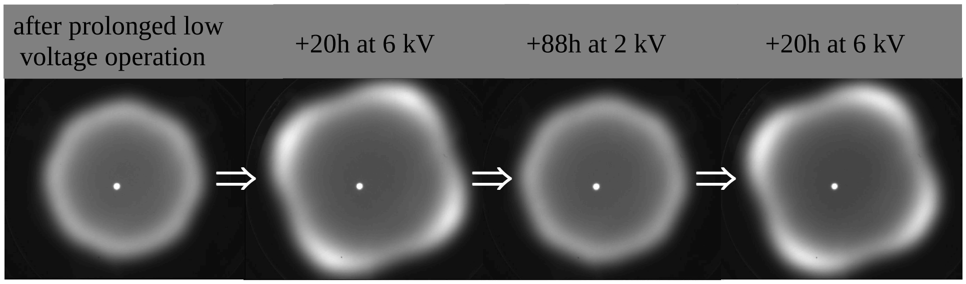

Fig. 2. The shape and size of the end facet of a Schottky emitter change with the applied operating conditions. Patterns are taken for the same emitter at the same conditions: 6 kV extraction voltage, 2.29 A heating current (~1765 K). N.B. The central bright dot is light emitted by the hot source, penetrating the semi-transparent YAG-screen.

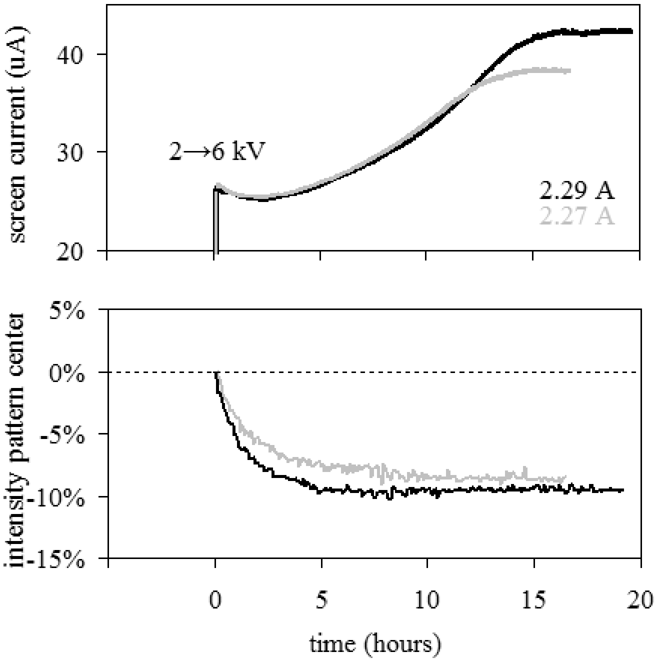

Fig. 3. On t = 0 the operating voltage is increased from 2 kV to 6 kV. After an initial decrease, the total facet current increases, but the current density in the facet center decreases. To check the reproducibility the process was repeated (25 K lower) after an additional 88h at 2 kV. This result is given in gray.