Optimizing Electron Emitter Module Geometry for Improved Lifetime through Test-Particle Monte Carlo (TPMC) Simulation

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Thermal field emitters (TFEs) are the most common electron sources used in scanning electron microscopes (SEMs) due to their stable emission and long lifetime (>10,000 hrs). To maintain long lifetime, TFE's must operate at pressures less than $\leq 5\text{x}10^{-9}$ Torr, in ultra-high vacuum (UHV). The TFE's consist of a cylindrical suppressor cap which is mounted a few hundred microns above the SEM lens stack. This narrow gap between the emitter and the top of lens is a region where there is potential for an increased local pressure due to low vacuum conductance. In this work, we used advanced vacuum modeling to simulate the local pressure increase around TFE tips and use this knowledge to optimize the geometry of TFE emitter (suppressor cap) module to increase conductance and improve lifetime.

The model consists of a base vacuum chamber, emitter mount, emitter module and lens. For the emitter module (suppressor cap), four different geometries have been modelled and compared. A total pumping speed of 20L/s and tabulated material outgassing values for the components were employed, and MolFlow+ was used to perform vacuum simulations. The background pressure in the chamber was simulated across all four geometries, as shown in Fig. 1, and was verified to be consistent, at $1.5\text{x}10^{-9}$ torr. The cylindrical emitter module (baseline) showed a peak local pressure of $1.5\text{x}10^{-8}$ torr. The two beveled cylinders, with minor diameters 4.7mm and 3mm, showed notable improvements with local peak pressures of $7.5\text{x}10^{-9}$ torr and $6\text{x}10^{-9}$ torr respectively. The rounded design demonstrated the greatest reduction in peak pressure, with a local high of $4\text{x}10^{-9}$ torr which falls well within the acceptable operational limits, thereby preserving lifetime.

Machine downtime is a critical factor for SEM tools used for wafer inspection and metrology making it essential to preserve and extend the lifetime of TFE's to maintain optimal service intervals. The results from study were used to determine an optimized suppressor cap geometry for TFE modules, allowing for high conductance, and ultimately improved TFE stability and lifetime.

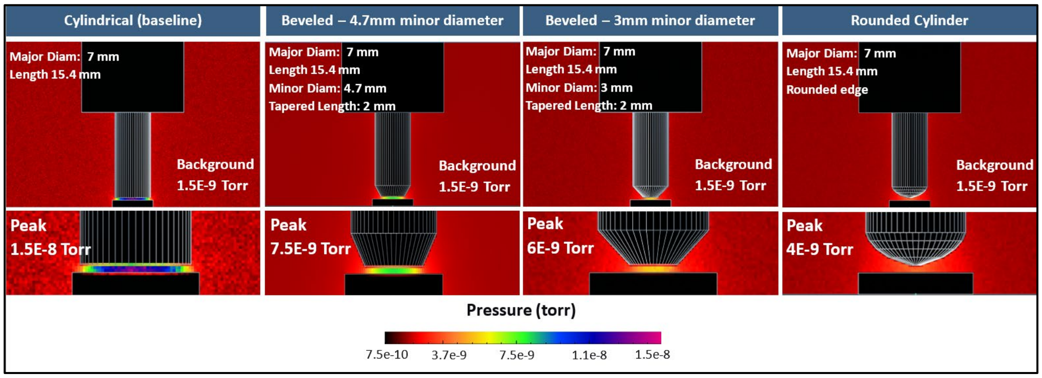

Fig. 1. Peak local pressure comparison between different emitter module geometries

Supplementary Pages

Method used: Pressure simulations were conducted using Molflow+, which is a test-particle Monte Carlo (TPMC) simulation software proven to be accurate for vacuum simulations in the molecular flow regime [1]. Simplified vacuum chamber and suppressor cap geometries were implemented, consisting of a base vacuum chamber, emitter mount, emitter module (suppressor cap) and extractor lens (Fig. 2). For the emitter module, four different cylindrical geometries have been modelled: a standard cylinder, two beveled cylinders with minor diameters of 4.7mm and 3mm, and a rounded edge cylinder. All other variables are maintained consistent across models in this study. The distance between the emitter module and the extractor lens is set at 0.46mm – which replicates typical distances in SEMs. For chamber pumping, a total pumping speed of 20L/s is set, divided equally between left and right surfaces of the vacuum chamber. For outgassing rates, tabulated values from literature have been employed: the base vacuum chamber and emitter mount are set at a rate of $3.75\text{x}10^{-12}$ torr L s^{-1} cm^{-2}, corresponding to electropolished, 316 stainless steel with 150 °C vacuum bake [2]. The emitter module and the extractor lens are set at $7.5\text{x}10^{-9}$ torr L s^{-1} cm^{-2}, corresponding to electropolished, vacuum cleaned titanium [3].

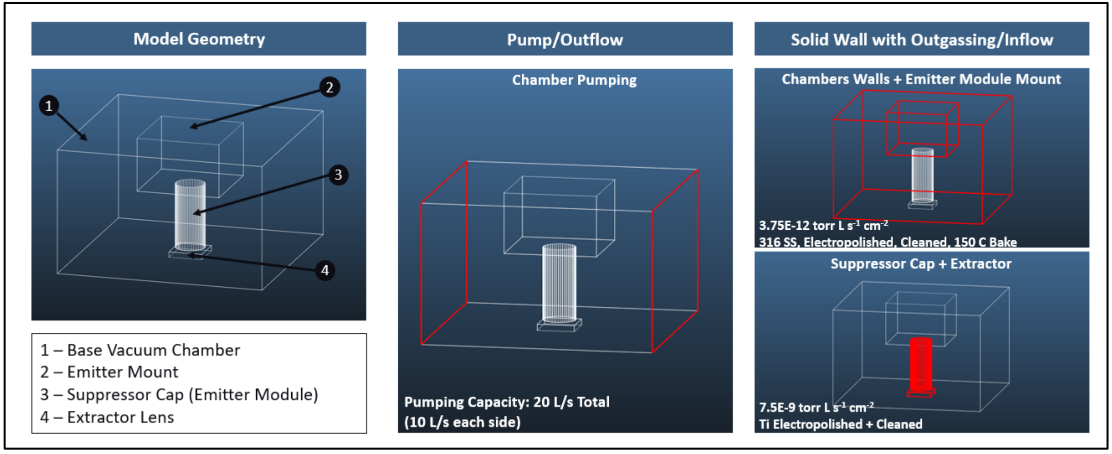

Fig. 2. Proposed model geometry and boundary conditions in Molflow+

Surface temperature study: During actual operation, the TFE suppressor cap and extractor are anticipated to have elevated temperature, as a result of Joule heating. To understand if surface temperature impacts local pressure calculations, the optimized rounded cylinder geometry was modeled at various surface temperatures. Fig 3. plots peak pressure as a function of local surface temperature. The graph shows peak pressure has low sensitivity to local surface temperatures. These results demonstrate that surface temperature does not need to be considered in this simulation study.

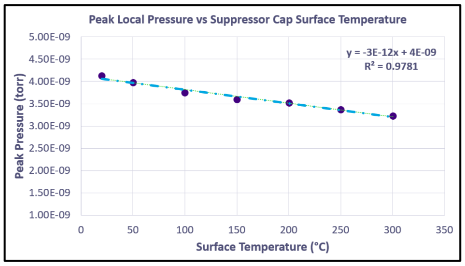

Fig. 3. Peak local pressure vs surface temperature

References

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