# Frozen Refractory-Metal Taylor Cones as Potential Regenerable Electron and Ion Point-Sources for Nanofabrication and Lithography

G. Hirsch
*Hirsch Scientific, 446 Old County Road, Pacifica, CA 94044*
*graviton99@gmail.com*

A novel method for the rapid in situ creation of field emitters possessing desirable physical characteristics has recently been developed. [1] In this process, the end of a refractory metal wire is melted in vacuum using a focused laser beam. Simultaneously, a high positive potential applied between the wire and a nearby extractor electrode is used to electrostatically form a Taylor cone from the molten meniscus. This configuration can be regarded as an unusual high-temperature Liquid Metal Ion Source (LMIS). Upon cessation of laser power, the Taylor cone freezes almost instantaneously due to extremely high radiative and conductive cooling. Rapid solidification of the cone results in a solid structure having a shape and surface smoothness almost identical to that of the original liquid cone. The resultant frozen Taylor cones can subsequently be employed as field emitters by reversing the polarity of applied voltage. These tips can also be used as gas field-ion sources (GFIS) after solidification by maintaining positive polarity, and introducing a low pressure gas. As shown in Figure 1, very uniform and sharp metal cones have been generated from a variety of refractory metals having melting points as high as tungsten. The ability to form single-crystal field emitters having reproducible tip orientation has also been demonstrated. The current state of development of this technology, and future goals will be described.

These field emission structures have thus far been developed with an emphasis on their use for ultrafast electron microscopy and diffraction experiments. A prototype electron gun using laser-assisted field emission to produce electron pulses in the picosecond range has been constructed. The basic features of this apparatus, which is shown in Figure 2, will be outlined. Beyond this more specialized use, the potential use of these conical structures as replacement sources in more conventional scientific instrumentation employing continuously operating field-emission and field ionization sources is of significant interest. Their ability to be readily restored to pristine physical condition is a compelling advantage over standard point-sources, which are well known for having high susceptible to operational degradation. This is especially pertinent for high brightness cold-field-emission (CFE) cathodes. Possible applications, as well as some of the particular design challenges for introducing these sources into existing instruments will be discussed.

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[1] G. Hirsch, J. Vac. Sci. Technol. B, **35**, 02C106 (2017)

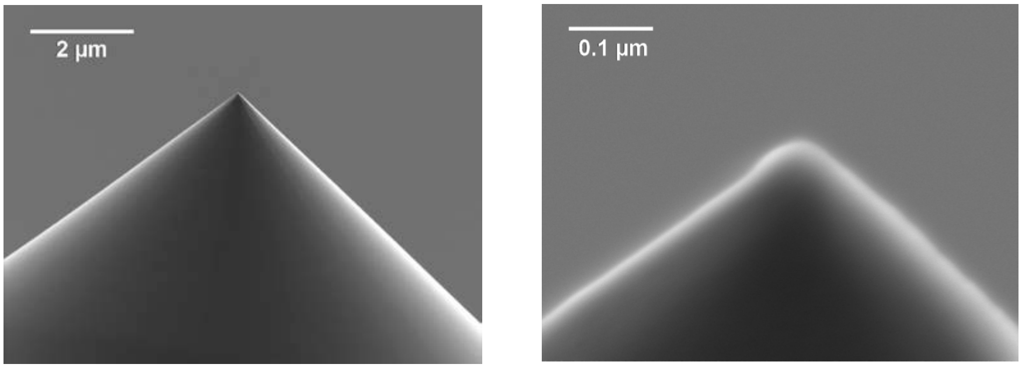


Figure 1. SEM images of a frozen tungsten Taylor-cone situated on the end of a laser melted wire at different magnifications are shown. Radius of curvature at apex is approximately 40 nm.

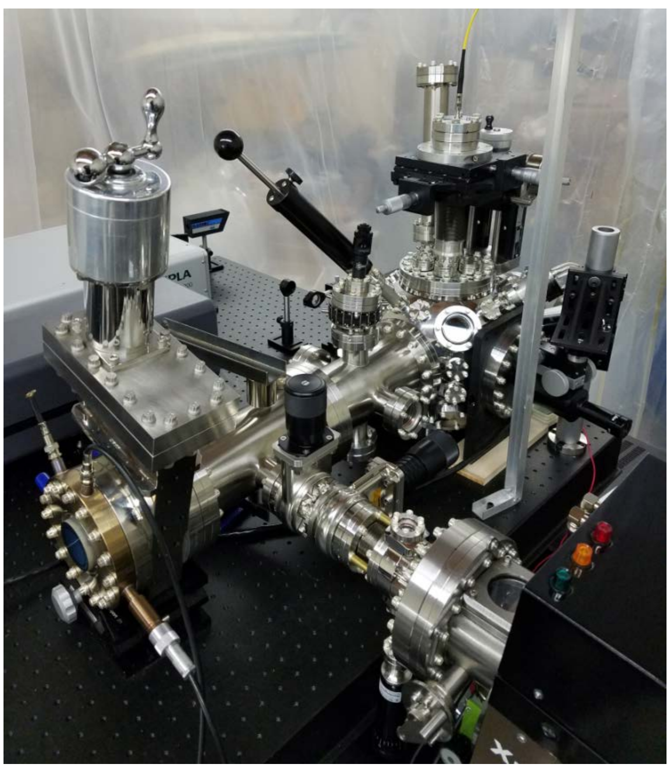

Figure 2. Photograph of the pulsed electron gun apparatus is shown. Frozen refractory-metal Taylor cones are produced in the vacuum chamber on the right side. Laser power for melting the wire is introduced from the top via a fiber-optic cable. An in-vacuum laser focusing system is mounted on a 3-axis vacuum manipulator. The high temperature tips can be viewed through a filtered viewport by the microscope visible on the right side. Two different pulsed lasers partially visible on the left side are used to generate electron pulses from the tip in either the nanosecond or picosecond timescale. The electron beam produced by the gun is imaged on the MCP detector on the left. An x-ray streak camera partially visible on the right is used for temporal measurements of both the laser pulse, as well as the electron beam when it is magnetically deflected by $90^0$.

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