thermionics laboratory, inc.

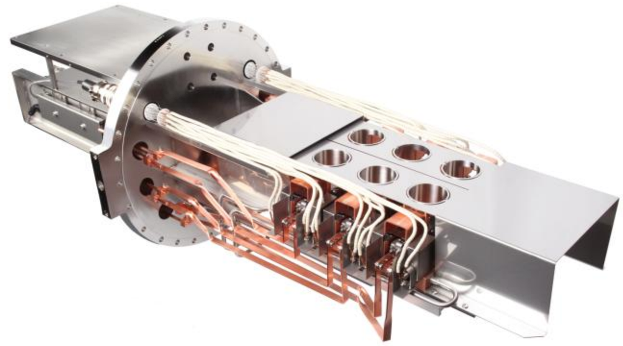

Figure 1. Complete Thermionics Hanks HM^{2}™ e-Gun™ assembly showing the compact vertical-magnet design and multi-crucible configuration.

A Modular Magnet Design for Enhanced Efficiency in Electron Beam Evaporation Sources

Abstract

Electron beam evaporation remains one of the most effective methods for thin-film deposition in ultra-high-vacuum environments, yet conventional transverse-field e-beam sources often suffer from magnetic inefficiency and limited beam control.[1] This paper presents the design and performance of the Thermionics Hanks HM2™ e-Gun™, which employs a modular vertical-magnet configuration and a high-frequency Hyper-Unimelt sweep system to address these limitations. The re-oriented magnetic circuit minimizes flux leakage and enables approximately 3.5× greater magnetic efficiency compared to conventional designs. Operating at sweep frequencies up to 200 Hz, the system promotes uniform melt heating and eliminates tunneling effects common in dielectric and sublimating materials. Experimental observations demonstrate improved beam collimation, reduced beam curl, and enhanced deposition uniformity, offering a compact, high-efficiency alternative for advanced thin-film research and multi-source co-deposition applications.

KEYWORDS: Electron beam evaporation, magnetic field design, thin-film deposition, beam sweep system, vacuum technology, Thermionics HM^{2}™ e-Gun™, Hydra™, Triad™, Hyper-Unimelt Sweep™

1. INTRODUCTION

Electron beam evaporation remains a core technique for thin-film deposition and material research, particularly in ultra-high-vacuum environments. Traditional e-beam sources often require large magnetic assemblies to achieve adequate beam focusing, leading to increased footprint and magnetic leakage.[1] The goal of the Hanks HM² design is to provide equivalent or improved performance in a smaller, more efficient magnetic circuit while enabling higher deposition uniformity through rapid beam sweep control. An overview of the HM² e-Gun assembly is shown in Figure 1.

2. MAGNET CONFIGURATION AND FIELD GEOMETRY

Conventional transverse-field e-beam sources utilize horizontally mounted permanent magnets and steel pole pieces to direct the magnetic flux toward the beam path. This configuration can result in significant magnetic leakage and reduced focusing efficiency.

The HM² design re-orients the magnetic field generator vertically, employing two modular arrays of small permanent or electromagnetic elements aligned along both sides of the crucible and beam path. The upper ends of the magnets extend slightly above the crucible, an optimal location for field delivery. Magnetic leakage is minimized through the use of a continuous steel base plate connecting the magnet arrays into a unified circuit. Adjustments to field gradient and beam shape are achieved by varying magnet geometry and positioning. This modular vertical-magnet configuration aligns with recent work modeling compact magnetic field structures for optimized e-beam focusing.[4]

3. HIGH-FREQUENCY HYPER-UNIMELT SWEEP SYSTEM

The Hyper-Unimelt system operates from 0–200 Hz—more than twice the sweep rate of conventional systems—enabling rapid redistribution of the electron beam across the melt surface. This minimizes tunneling and material eruptions that otherwise lead to non-uniform evaporation. Uniform surface heating is particularly critical when processing dielectric or sublimating materials, where uneven temperature profiles can degrade film quality. Uniform surface heating is particularly critical when processing dielectric or sublimating materials, where uneven temperature profiles can degrade film quality. Studies have shown that higher sweep frequencies directly improve evaporation uniformity and minimize tunneling behavior. [3]

4. MECHANICAL AND OPERATIONAL FEATURES

Key mechanical design considerations include:

- Filament alignment: The emitter assembly (see Figure 2) can be removed and aligned outside the vacuum chamber using a supplied alignment tool.
- Filament stability: The filament is clamped near the spiral to minimize thermal distortion (Figure 3).
- Electron containment: Shielding near the filament region suppresses low-energy electron tails.
- Cooling: Each crucible and emitter baseplate is independently water-cooled to maintain thermal stability (Figure 4).
- Modularity: Plug-in emitter and sweep-coil assemblies simplify maintenance and replacement (Figure 5).
- UHV compatible: Metal sealed, fully UHV compatible, measured base pressure: 2 x 10^{-11} Torr.

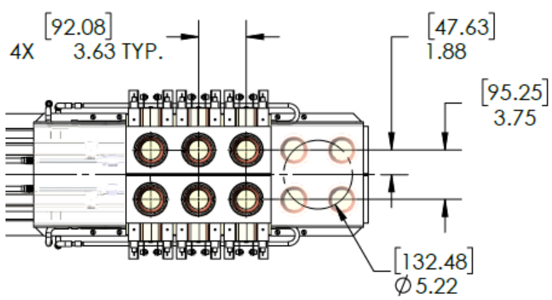

Figure 2. Engineering schematic of the HM^{2}™ e-Gun™ source head showing crucible spacing and modular geometry.

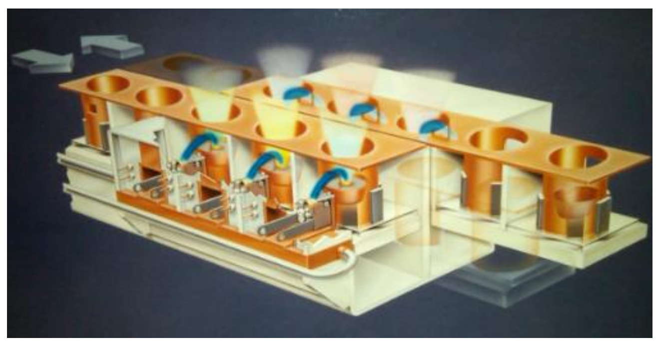

Figure 3. Internal cutaway rendering illustrating magnetic field orientation and electron beam paths within the vertical-magnet array.

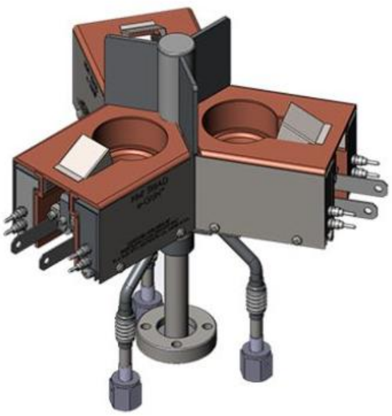

Figure 4. Three-source Thermionics e-Gun™ configuration demonstrating independent emitter modules for multi-material co-deposition

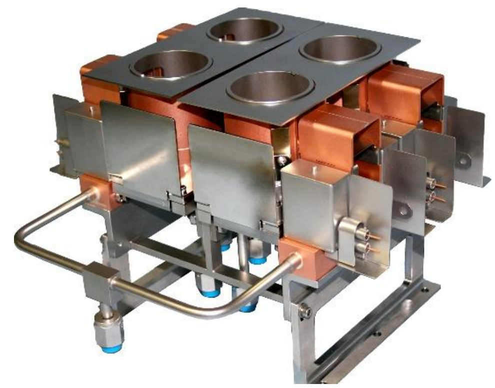

Figure 5. Four-source Thermionics e-Gun™ configuration with integrated cooling and shielding assemblies for reduced cross-talk and thermal coupling.

5. PERFORMANCE AND EFFICIENCY

The compact magnetic configuration provides approximately 3.5× greater magnetic efficiency relative to traditional horizontal-magnet designs. The HM^2 achieves equivalent crucible volume (40 cc) and evaporation rates to larger legacy sources while occupying roughly two-thirds the footprint. These gains allow for closer crucible spacing—less than 3.8 in. center-to-center—supporting multi-source configurations such as the Thermionics Hydra system. The resulting geometry enables up to six or more simultaneous evaporation sources with minimized magnetic cross-talk. The compact magnetic configuration provides approximately 3.5× greater magnetic efficiency relative to traditional horizontal-magnet designs, consistent with prior observations that improved circuit geometry enhances overall source efficiency. [2]

6. APPLICATIONS AND INTEGRATION

The HM^2 and Hydra systems are designed for advanced thin-film research and multi-material co-deposition. Independent sweep coils and magnet arrays for each source maintain beam integrity even in tightly packed arrangements. This makes the configuration suitable for optical coatings, complex multilayers, and materials research requiring precise control over deposition rate and composition. This makes the configuration suitable for optical coatings, complex multilayers, and materials research requiring precise control over deposition rate and composition, aligning with established multi-source co-evaporation practices. [5]

7. CONCLUSION

The modular vertical-magnet e-beam design demonstrates that compact geometry and reduced leakage flux can significantly enhance efficiency and beam control without sacrificing power capability. The integration of high-frequency beam sweep further improves melt uniformity and deposition quality. These design principles may serve as a basis for future refinements in high-performance vacuum evaporation sources.

Author Declarations

Conflict of Interest

The author has no conflicts to disclose.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

1. J. R. Arthur, "Design and operation of electron beam sources for thin film deposition," *J. Vac. Sci. Technol.*, 3, 243–248 (1966). DOI: 10.1116/1.1492501.

2. A. Anders, "Compact and efficient electron beam sources for thin film deposition," *Vacuum*, 67, 673–680 (2002). DOI: 10.1016/S0042-207X (2)00223-2.

3. R. K. Singh and J. Narayan, "Effect of beam sweep frequency on evaporation uniformity in electron beam sources," *Thin Solid Films*, 213, 78–85 (1992). DOI: 10.1016/0040-6090(92)90374-9.

4. K. Zhang et al., "Magnetic field analysis and optimization for electron beam evaporation guns using finite element modeling," *Surf. Coat. Technol.*, 377, 124911 (2019). DOI: 10.1016/j.surfcoat.2019.124911.

5. G. H. Chapman, "Co-evaporation and multi-source electron beam systems for optical coating production," *Appl. Opt.*, 32, 5654–5661 (1993). DOI: 10.1364/AO.32.005654.

6. D. M. Mattox, *The Foundations of Vacuum Coating Technology* (Elsevier, 2018).

7. U.S. Patents 4,835,789; 4,891,821; 4,947,404.