

Two-photon Printing of Electro spray Emitters

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Primary CNF Tools Used: Nanoscribe GT2, DISCO Dicing Saw, AJA Sputters, Odd/Even Evaporators

Abstract:

This report summarizes the study "Two-photon printing of monolithic glass electro spray emitters with TPMS micro-architectures" [1]. We present a high-resolution additive manufacturing approach to fabricate monolithic fused-silica electro spray emitters using two-photon polymerization (TPP) printing followed by thermal conversion. Triply-periodic-minimal-surface (TPMS) micro-porous architectures were deterministically integrated into the emitter body to provide passive capillary propellant transport to the tip.

Research Summary:

Motivation: Electro spray propulsion offers high efficiency and precise thrust control for small spacecraft like CubeSats. However, traditional subtractive manufacturing methods (e.g., wet/dry etching, laser ablation, CNC milling) lack independent control over internal and external geometries. This restricts the design space and prohibits integration of engineered microporous networks for passive capillary propellant transport. Additive manufacturing (AM) has emerged as a promising alternative for electro spray emitter fabrication, offering key advantages over traditional subtractive techniques. In this work, we leveraged two-photon polymerization (TPP) printing to fabricate high-resolution electro spray emitters, with embedded triply-periodic-minimal-surface (TPMS) engineered micro-structures for passive fluid transport.

Fabrication Process: An overview of the emitter fabrication process is presented in Figure 1. The emitter baseline geometry is modeled using standard computer-aided-design (CAD) software, in which the size and characteristic dimensions (tip radius, height, cone angle) were prescribed. Next, the template CAD model was processed using a geometric algorithm to embed TPMS lattice structure into the body of the emitter geometry,

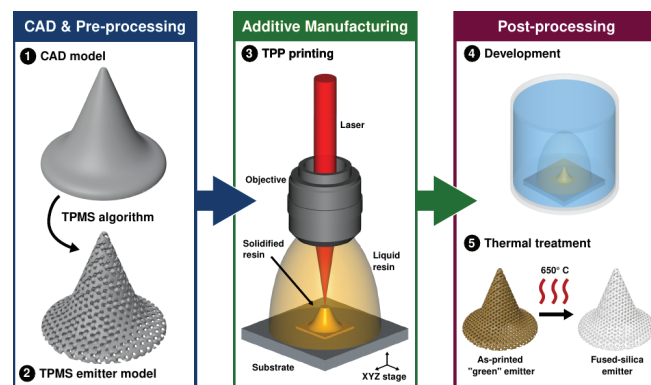


Figure 1: Overview of the emitter fabrication process.

producing a micro-porous internal structure as illustrated in step (2) of Figure 1. The TPMS emitter geometry was TPP-printed using the Nanoscribe Photonic Professional GT2, available in the CNF cleanroom. TPP printing operates by selectively exposing a photosensitive resin using a focused laser, creating solidified "voxels" which are formed into lines and layers to build the desired structure. The 10X objective was used to maximize the printing field and minimize print time. Slicing distance was reduced to 1 μm (5 μm default) to best resolve the intricate TPMS structure. The first 3 layers were printed at half scan speed to improve adhesion to the substrate, and the rest of the structure was printed at full scan speed to minimize print time. Total print time per emitter was approx. 8 minutes. After TPP printing, the emitters were developed in isopropyl alcohol (IPA) for 20 minutes and set aside to dry naturally. The emitters were TPP-printed using a nanoparticle-free silica resin (synthesized in-house) which chemically transforms into fused silica after mild thermal treatment at 650°C for 1 hour.

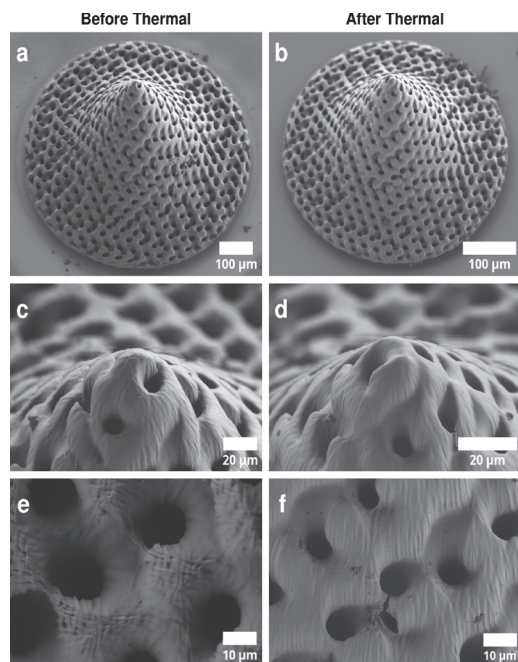


Figure 2: SEM images of a TPP-printed emitter before (left column) and after (right column) thermal processing. The emitter tip is shown in the middle row (c, d), and close-up images of the pores are presented in the bottom row (e, f).

Micro-structure Characterization: Figure 2 presents scanning electron microscopy (SEM) images of a TPP-printed microporous electro spray emitter before (left column) and after (right column) thermal processing. The top-most row (a, b) shows full-view images of the overall emitter geometry, and the zoomed-in views (c, e) and (d, f) focus on the detailed TPMS microstructure and surface texture. At the full-emitter scale (a, b) there are no observed changes/effects from thermal treatment on the emitter shape or TPMS microstructure. The overall emitter shape and TPMS structure look almost identical when comparing the pre-thermal and post-thermal images. However, the higher magnification images (c, d, e, f) reveal some changes in surface roughness and TPMS pore morphology resulting from thermal treatment. Before thermal treatment (d, f) the pores exhibit irregular, jagged boundaries, with visible printing (hatch) lines and artifacts, and a rough surface texture. After thermal treatment (d, f) the surface appears significantly smoother and densified, which suggests localized material reflow and relaxation that occurs during the thermal treatment.

Performance Testing: The emission characteristics of the TPP-printed electro spray emitters were evaluated using direct current-voltage (I-V) measurements. This diagnostic provides insight into key electro spray operating parameters, including onset voltage (to initiate emission) and emission linearity. Sequential I-V curves of a TPP-printed emitter are presented in Figure 3. The I-V curves show highly linear emission behavior

in both positive and negative firing modes across all four runs, with emission currents reaching approx. 800 nA at +3 kV and -500 nA at -3 kV. The measured onset voltage and current response remained consistent across sequential sweeps, indicating repeatable emission behavior over the duration of testing. Overall, the TPP-printed emitters show competitive performance metrics compared to conventionally-fabricated electro spray emitters.

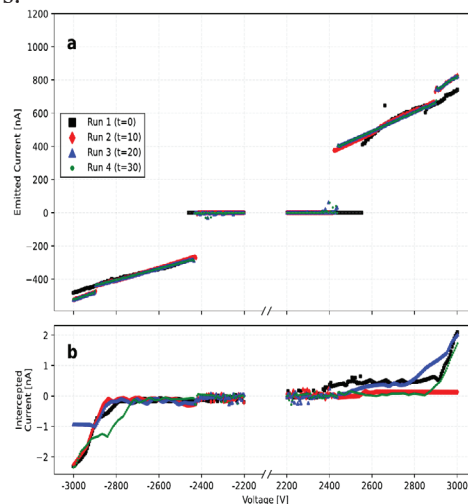


Figure 3: Emission characteristics of a TPMS porous glass electro spray emitter operating with EMI-BF₄ propellant. (a) I-V curves recorded over four consecutive runs at intervals of 10 minutes in both positive and negative polarities. (b) Corresponding intercepted current traces for each run.

Conclusions and Future Steps:

In this work demonstrated the first TPP-printed, monolithic fused-silica electro spray emitters featuring embedded TPMS internal micro-architectures. Combining microscale print resolution, deterministic micro-fluidic porous structure, and inorganic glass conversion enables a previously inaccessible design space for electro spray thrusters. These devices achieve performance metrics comparable to traditional state-of-the-art ionic liquid electro spray systems while providing superior geometric flexibility.

Future research will focus on scaling the TPP process to produce dense multi-emitter arrays capable of providing mission-relevant thrust levels. Achieving this will require optimizing print parameters, such as increasing layer slicing distance, to reduce overall array print times. Additionally, we plan to refine TPMS geometries, pore sizes, and surface morphology to optimize capillary transport, propellant distribution, and emission stability.

References:

- [1] B. Kingsley et al., "Two-photon printing of monolithic glass electro spray emitters with TPMS micro-architectures," *Journal of Micromechanics and Microengineering*, 2026.