

# Two-Photon Printing of Polymer and Glass Electrospray Emitters

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*Primary CNF Tools Used: Nanoscribe GT2, Photolithography hoods, YES O2 Asher, DISCO Wafer Dicer*

## Abstract:

Advances in nano-scale additive manufacturing technologies have opened new possibilities for fabrication of precision components/parts with highly complex geometries. Within the field of space propulsion, these technologies are particularly relevant in the development and fabrication of electrospray thrusters – propulsion systems which utilize charged droplet/ion emission for thrust generation. A fundamental component of these thruster systems is the electrospray emitter, wherein performance depends heavily on the resolution and geometrical characteristics of the emitter structure. Conventional fabrication processes (MEMS techniques, micromachining, etc.) often lack the resolution, geometric flexibility, or material compatibility needed for optimal emitter design and fabrication. This work investigates an alternative technique of electrospray emitter fabrication using Two-Photon Polymerization printing, exploring its potential to produce intricate emitter architectures and integrated microfluidic structures that can enhance the performance of electrospray thrusters.

## Summary of Research:

Two-Photon Polymerization (TPP) printing is an emerging nano-scale additive manufacturing process which utilizes a high-power laser to print 3D structures from photosensitive resin. Figure 1 shows a generalized schematic of a TPP printing system. A NIR (near infrared) laser is projected through a microscope objective and focused within a pool (dip) of photosensitive resin. Two-photon absorption near the focal region of the beam elevates the energy above the activation energy of the resin, resulting in cross-linking and solidification of the resin into a solid feature. Using precise positioning systems, the beam is drawn in XYZ space to fabricate 3D parts/components. In this work, we utilize the Nanoscribe Photonic Professional GT2 printer available in the CNF facilities. Using the GT2 system, we fabricate electrospray emitters from polymer

(IP-Q) and glass (GP-Silica and POSS) resins.

The user-friendly nature of the GT2 printing system greatly simplifies the emitter fabrication process, as follows: (1) the emitter geometry is modeled using standard CAD software and exported to a mesh, (2) the emitter mesh is sliced using Nanoscribe's slicing software (Describe) and transferred to the GT2 system for printing, (3) a clean substrate (silicon) is loaded into the printer with the selected photosensitive resin (polymer/glass), (4) emitter geometry is printed (typically <10 minutes), (5) substrate and emitter removed from GT2 and developed to remove residual resin, and (6) thermal post-processing (glass resins only). This simplified fabrication process promotes rapid prototyping and development of novel emitter designs which would be difficult with conventional methods, such as chemical etching which would require multiple stages of etching and new masks developed for each new prototype [1]. Additionally, TPP printing enables emitter architectures that would be extremely challenging or impossible to achieve with traditional fabrication techniques. We leverage this capability by integrating microfluidic channels and structures within the body of the printed emitters to promote propellant transport to the emitter tip and improve performance. One such microfluidic structure we implement is the Triply-Periodic Minimal Surface (TPMS), which is a lattice structure that is generated from 3D mathematical equations. Figure 2 contains an SEM image of a polymer (IP-Q) emitter printed with the gyroid TPMS lattice structure. This structure contains a network of interconnected micropores (~8  $\mu\text{m}$ ) for propellant to transport from the base (where it is loaded) to the tip (the site of emission). We note that this work uses the 10X microscope objective for printing, which has a minimum TPMS pore size of approx. 6  $\mu\text{m}$ . A higher objective (e.g., 25X) would be required for smaller pores, at the expense of longer print times.

As mentioned previously, glass emitters are fabricated using TPP printing with specialized photosensitive resins. Here, we use two formulations of glass resins:

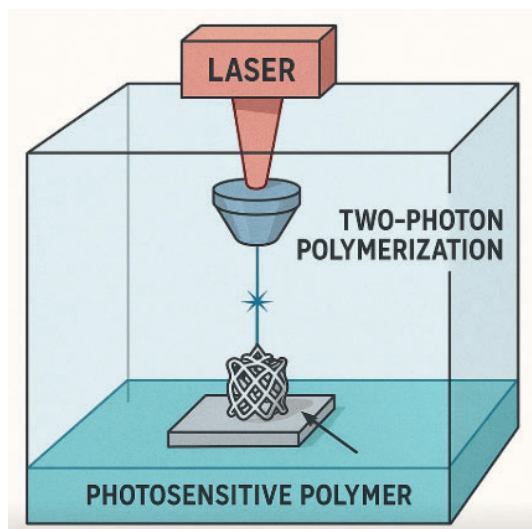


Figure 1: Schematic of two-photon polymerization (TPP) printing.

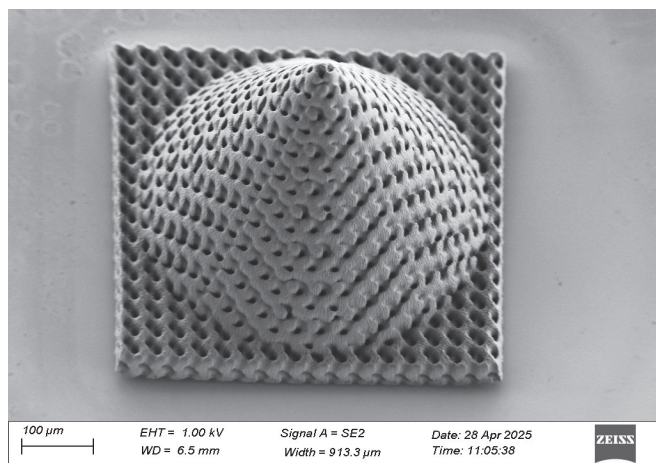


Figure 2: SEM of a polymer electro spray emitter TPP-printed with a TPMS lattice structure.

(1) the GP-Silica resin from Nanoscribe which contains silica nanoparticles that fuse together during thermal treatment, and (2) a POSS (polyhedral oligomeric silsesquioxane) formulation which chemically transforms into fused silica during thermal treatment [2]. For the application of electro spray emitters, glass/fused silica is advantageous over polymer materials due to its higher degree of wettability and stability (chemical, thermal, etc.). Figure 3 contains 3D optical profilometry scans of a TPP-printed glass emitter before (a) and after (b) thermal post-processing. As can be seen in the profilometry scans, thermal processing introduces significant shrinkage (~35-40%) of the emitter structure which must be accounted for during the design stage to achieve accurate geometry/dimensions.

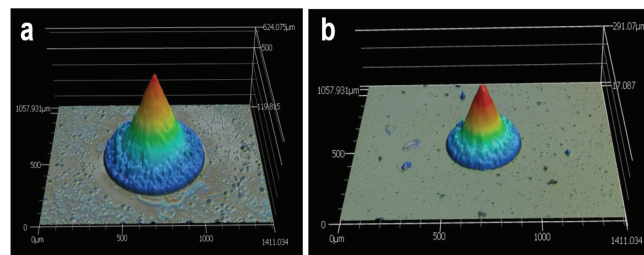


Figure 3: 3D optical profilometry scan of a TPP-printed glass emitter (a) before and (b) after thermal treatment.

## Conclusions and Future Steps:

This work investigates a new/alternative technique of fabricating electro spray emitters using two-photon polymerization (TPP) printing. The unique capabilities and advantages of TPP printing enable highly complex emitter architectures that would be very challenging or impossible to fabricate with traditional emitter fabrication processes. Microfluidic channels and structures (TPMS) can be integrated directly into the body of the printed emitters to tailor fluid/propellant transport to the tip for optimized emission. TPP printing supports different materials systems, enabling emitters to be fabricated out of polymer or glass materials.

This work is ongoing and testing is currently underway to evaluate the emission performance of these printed emitters compared to standard electro spray emitters. Additionally, we have plans to scale-up to fabricating emitter arrays (i.e., gridded emitters) for implementation in electro spray thruster systems.

## References:

- [1] L. F. Velasquez-Garcia, A. I. Akinwande and M. Martinez-Sanchez, "A Planar Array of Micro-Fabricated Electro spray Emitters for Thruster Applications," *Journal of Microelectromechanical Systems* 15, 1272-1280 (2006), DOI: 10.1109/JMEMS.2006.879710
- [2] J. Bauer, C. Crook and T. Baldacchini, "A sinterless, low-temperature route to 3D print nanoscale optical-grade glass," *Science* 380, 960-966 (2023), DOI: 10.1126/science.abq3037.