High-Impulse, 3D-Printed CubeSat Electrospray Thruster Throttleable via Pressure and Voltage Control

Hyeonseok Kim

kimhs@mit.edu

H. Kim[1], L. F. Velásquez-García[2]

1. Mechanical Engineering, Massachusetts Institute of Technology
2. Microsystems Technology Laboratories, Massachusetts Institute of Technology

IDEAS TO IMPACT

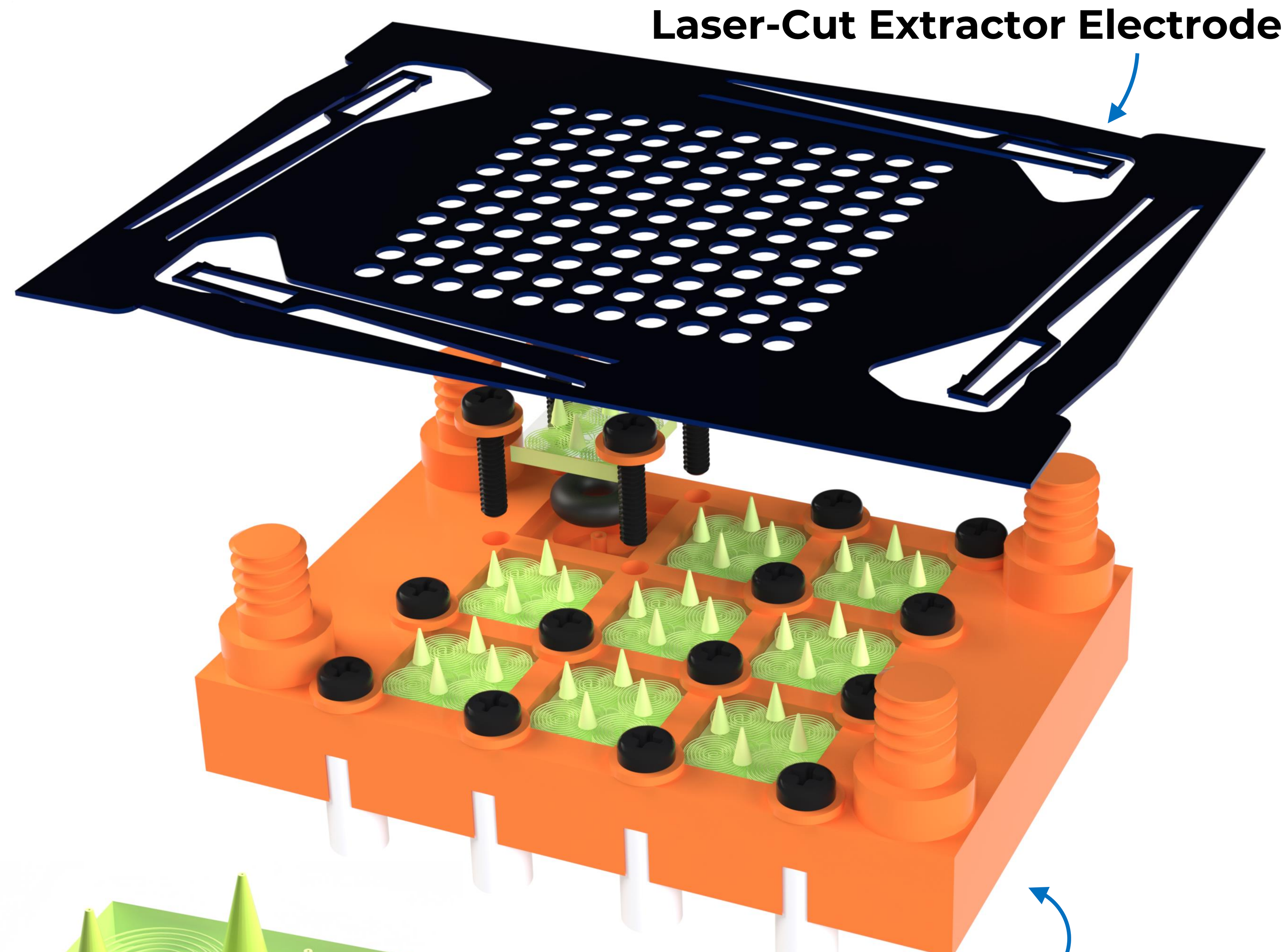
MIT Portugal
2024 Annual Conference

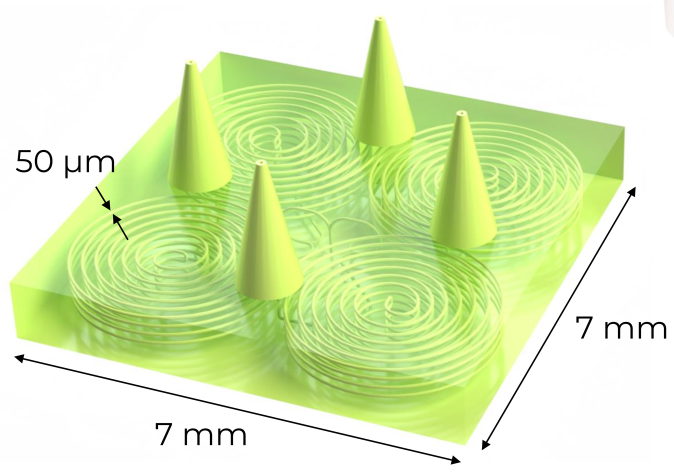
Introduction

Electrospray propulsion is achieved by electrohydrodynamically ejecting propellant. Electrospray is attractive for CubeSats due to its high specific impulse and potential for miniaturization. However, most electrospray thrusters are fabricated in semiconductor cleanrooms, which are expensive, time-consuming, and not compatible with in-space manufacturing. This research focuses on an alternative approach that uses multiple 3D printing methods to fabricate an array of internally fed electrospray emitters that emit droplets. Our modular thruster design incorporates multidimensional features necessary for scaling up thrust with low power consumption. It also includes an optimized channel design to ensure that multiplexed emitters operate uniformly, resulting in a high propulsive efficiency and throttleability.

Device Design

Laser-Cut Extractor Electrode



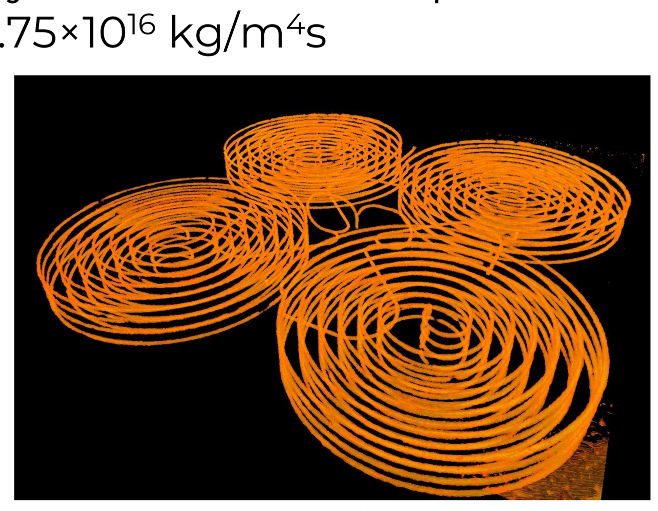


3D-Printed Manifold Block

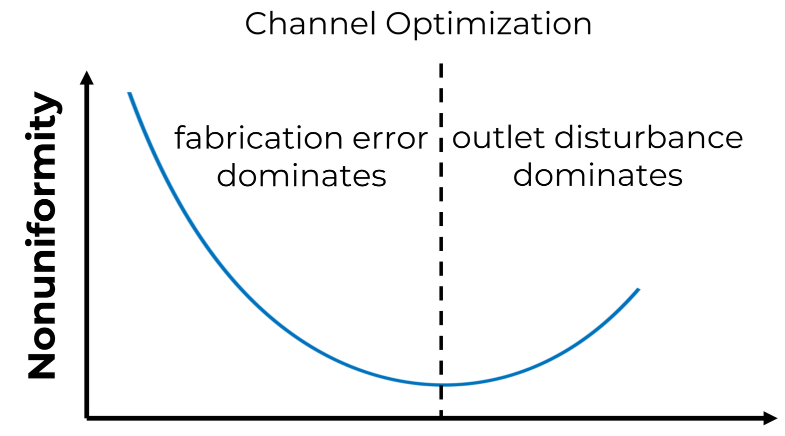
- Printed by a DLP printer
- 42 mm x 29 mm x 6 mm
- Single inlet to 9 emitter blocks
- Emitter-Extractor separation: 0.4 mm

3D-Printed Emitter Block

- Printed by a 2PP printer
- 7 mm x 7 mm x 1 mm
- Single inlet to 4 emitters
- Channel diameter: 50 µm
- Single channel length: 0.183 m
- Hydraulic resistance per channel: 3.75×10^{16} kg/m^{4}s



X-ray CT scan image of an emitter block.

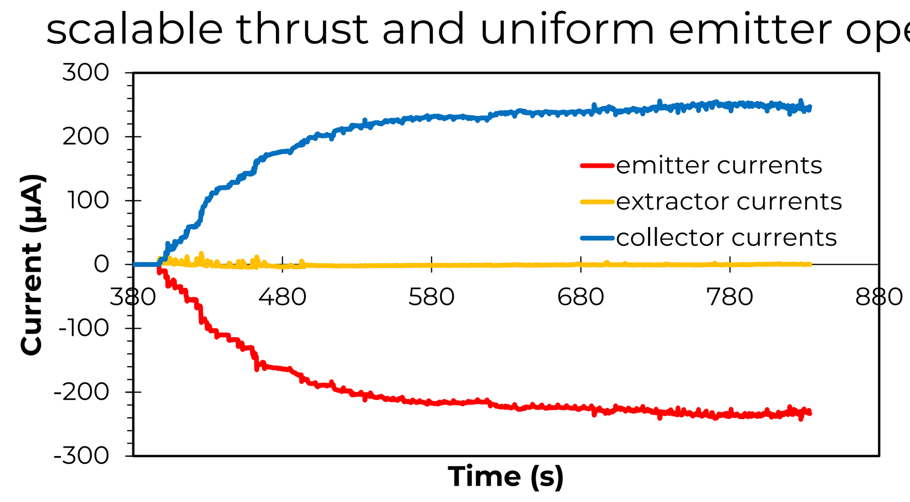


A long channel promotes uniform flow; however, there is an optimal channel diameter. If flow nonuniformity across the emitter array is too high, some, or even entire emitter array may not function, as electrospray only works within a specific flow rate range.

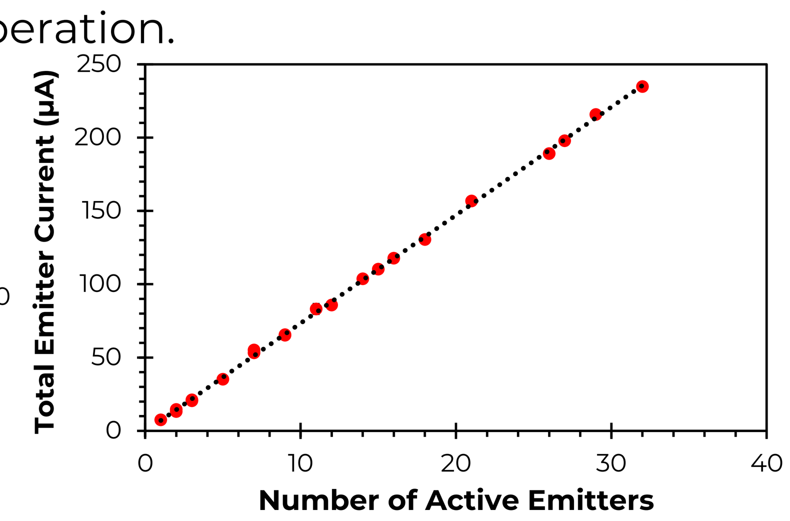
Device Characterization

Scalability and Uniform Operation

The number of active emitters can be estimated by measuring the current and relating it with modeling predictions. The data show a linear increase in emitter current with the number of activated emitters, demonstrating scalable thrust and uniform emitter operation.



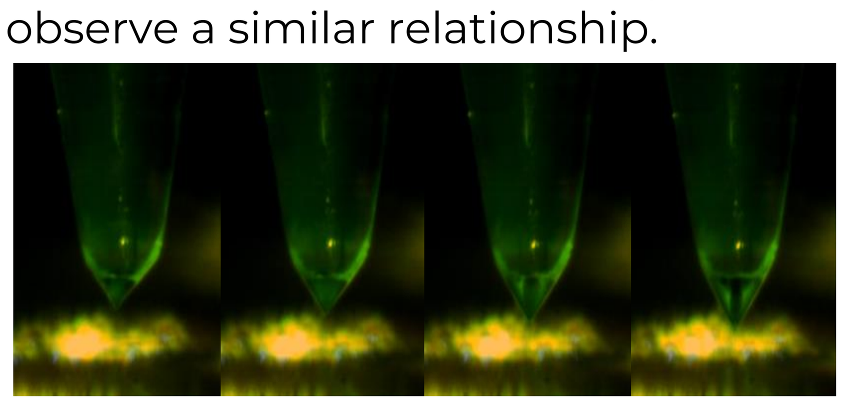
Electrospray Currents Over Time During Startup



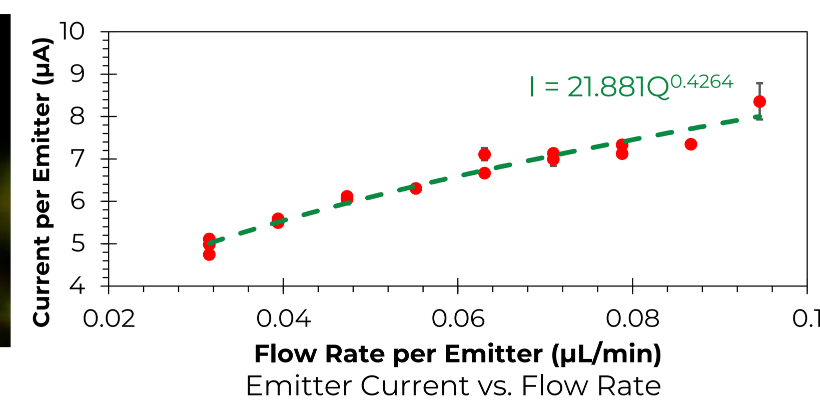
Emitter Current vs. Number of Active Emitters

Thrust Control via Flow Rate

Traditionally, an electrospray thruster that emits droplets modulates its current (therefore, its thrust) via flow rate control. In the droplet regime, the current scales with the square root of the flow rate; we experimentally observe a similar relationship.



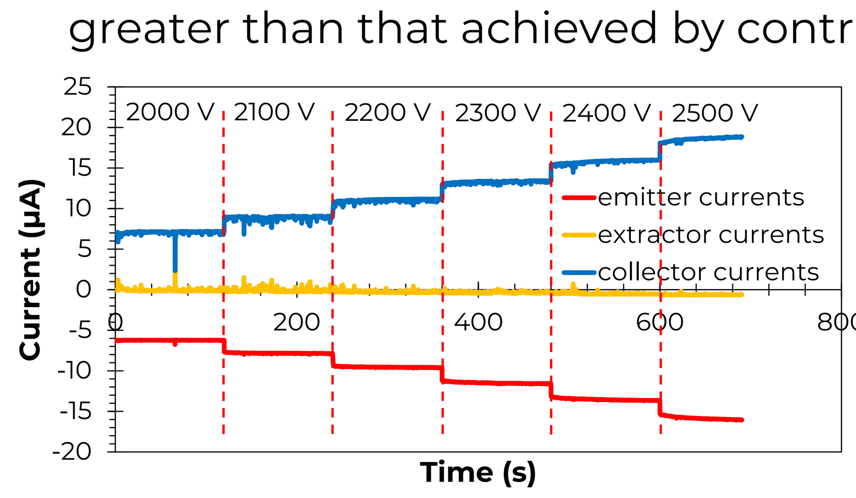
Increasing size of a Taylor cone as flow rate is increased.



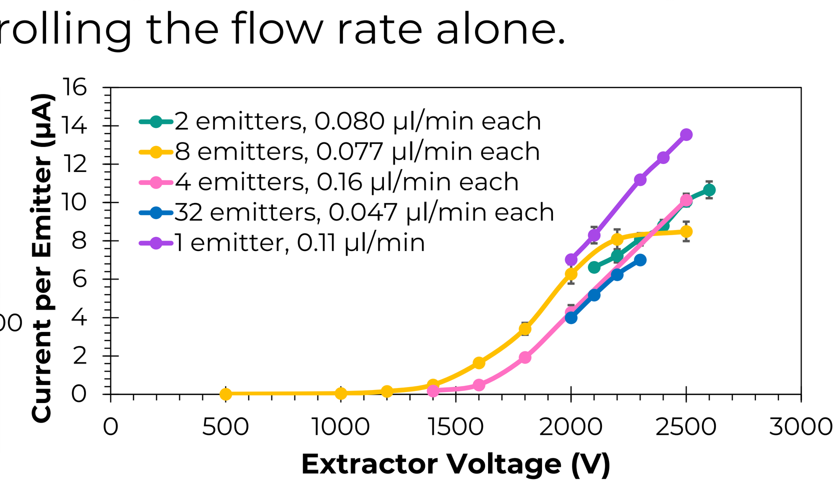
Emitter Current vs. Flow Rate

Thrust Control via Extractor Voltage

We demonstrate that controlling thrust by modulating the extractor voltage is also feasible, though it is not as well known as flow rate control in the droplet regime. Despite having a limited voltage range that supports stable electrospray, the resulting current and thrust range is greater than that achieved by controlling the flow rate alone.



Electrospray Currents Controlled By Voltage



Emitter Current vs. Extractor Voltage

Thrust and Specific Impulse Comparison

Study	Number of Emitters	Thrust per Emitter (µN)	Specific Impulse (s)
L. Velásquez-García et al., 2006	240	0.21-2.7	150-350
V. Hruby et al., 2008	9	0.56-3.98	240-400
G. Lenguito et al., 2014	91	0.253-0.716	690-1140
E. Grustan-Gutierrez et al., 2017	64	0.13-0.844	96-236
A. Cisquella-Serra et al., 2022	256	0.132-0.64	Not reported
This Study	**32**	**2.4-5.4***	**260-370***

*Thrust and specific impulse were estimated by $T=\sqrt{2\dot{m}VI\eta_i\eta_{tr}^2\eta_\theta\eta_E\eta_p}$ and $I_{sp}=T/(\dot{m}g)$ with $\eta_i=1, \eta_{tr}=1, \eta_\theta=0.87, \eta_E=1, \eta_p=0.5$ for a conservative estimation.

Conclusion

We have demonstrated for the first time a multiplexed, 3D-printed electrospray thruster that operates stably in the droplet regime. Its thrust can be controlled by either changing the pressure applied to the propellant tank or the bias voltage on the extractor electrode. This lesser-known voltage control poses a significant advantage, as it allows for a wider range of controlled current without the need for a control valve.

Co-funded by: The Operational program for Competitiveness and Internationalisation (COMPETE2020), Portugal 2020, the European Regional Development Fund (ERDF), and the Portuguese Foundation for Science and Technology (FTC) under the MIT Portugal program. H. Kim has a MathWorks Fellowship.

COMPETE 2020 | PORTUGAL 2020 | UNIÃO EUROPEIA Fundos Europeus Estruturais e de Investimento | fct Fundação para a Ciência e a Tecnologia | MIT Portugal

under the Flagship Project: NewSat | Earth Systems: Oceans to Near Space