Engineering Ionic Liquid Ion Sources for Space Propulsion Applications

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Ionic liquid ion sources (ILIS) are devices capable of producing positive and negative molecular ion beams by field evaporation from ionic liquids, or room-temperature molten salts. In the basic configuration, the ionic liquid wets a micro-tip emitter, which is placed in front of an extractor aperture (Figure 1(a)). By applying a voltage difference between the emitter and extractor, the ionic liquid is deformed into a sharp meniscus. At the apex of this meniscus, the electric field could reach values sufficient to trigger direct ion evaporation from the liquid. If sufficiently high hydraulic impedance from the liquid-supporting emitter is provided to restrict the flow, a pure ionic regime (PIR) can be achieved, in contrast with traditional electrosprays that produce charged droplets, or mixtures of droplets and ions.

The PIR from ILIS could enable access to low power (~1 W), efficient and compact space propulsion ideal for small satellites (<10 kg). As the thrust attainable from a single emitter is in the order of 10 nN, it would be necessary to produce arrays of several hundred emitter tips to achieve useful amounts of thrust. At MIT, an ion Electrospray Propulsion System (iEPS) based on porous emitter substrates has been developed. The concept (Figure 1(b)) relies on passive transport of the ionic liquid from the fuel tank to the emitter tips, thanks to the wicking from the porous substrate. State-of-the-art emitter arrays based on porous glass contain 480 emitters in a 1 cm^2 chip. The porous glass iEPS operate in the mixed ion-drop regime, and as a result the efficiency and specific impulse of the device are lower than what could be obtained with the PIR[1]. There is a need for alternative substrates and tip geometries that provide a liquid supply compatible with the PIR.

We introduce porous carbon based on resorcinol-formaldehyde xerogels as an emitter substrate[2]. The carbon xerogel can be synthesized with pore morphologies that provide suitable hydraulic impedance, and also be shaped to the required micron-sized geometry through several manufacturing techniques. In particular, laser micro machining has been used to produce a single carbon xerogel emitter. Time-of-flight mass spectrometry is used to verify that charged particle beams produced from the carbon xerogel tip, infused with the ionic liquid 1-methyl-3-methylimidazolium tetrafluoroborate, contain solvated ions exclusively. This new material should enable the production of emitter arrays operating in the PIR for propulsion applications.

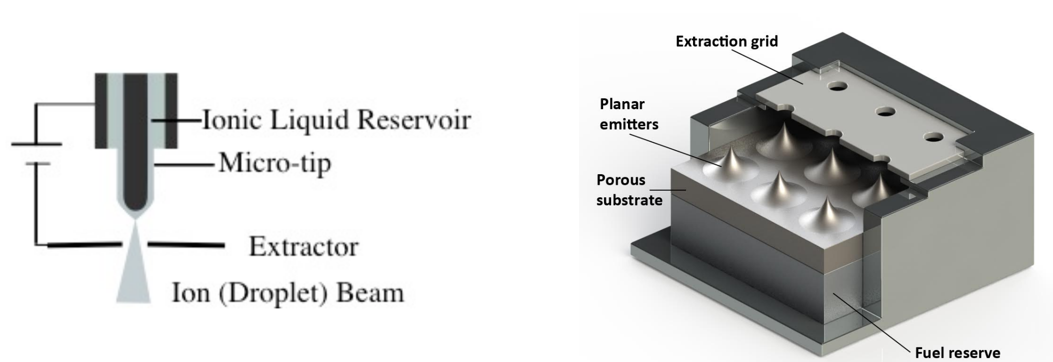

Figure 1. (a) Basic ILIS configuration (b) iEPS concept (diagram courtesy F. Mier Hicks, MIT)

[1] D. Krejci *et al.*, in Proceedings of the 34th International Electric Propulsion Conference, Kyogo-Kobe, Japan, 2015
[2] C. Perez-Martinez and P.C. Lozano, Applied Physics Letters, 107, 043501 (2015)