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MEMS Water Micro-Resistojets for CubeSats and PocketQubes

A. Cervone[1], V. Pallichadath[1], M.A.C. Silva[1], D.C. Guerrieri[1], S. Silvestrini[1] S. Mestry[1], D. Maxence[1], B. Zandbergen[1], H. Van Zeijl[2]

[1]Space Systems Engineering section, Faculty of Aerospace Engineering
[2]Else Kooi Laboratory, Faculty of Electrical Engineering, Mathematics and Computer Science

Delft University of Technology, The Netherlands

Micro-propulsion is universally recognized as one of the key enabling technologies to help nano- and pico-satellites making the next step to become credible candidates for a wide range of scientific and commercial applications. To address this need TU Delft is developing different types of miniaturized electro-thermal propulsion systems operating with green liquid propellants, for application on various small satellite formats including CubeSats (10×10×10 cm units) and PocketQubes (5×5×5 cm units).

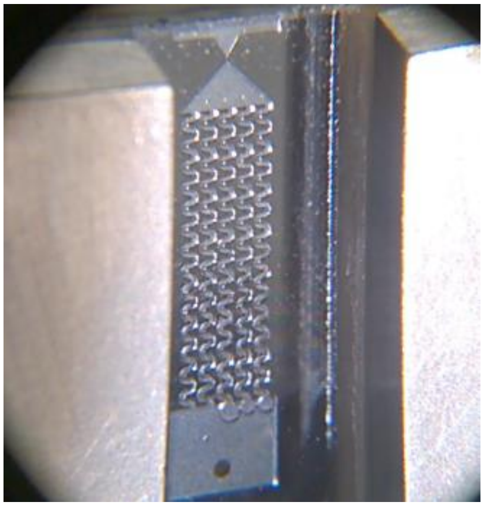

Figure 1. Water vaporization in a MEMS resistojet prototype tested at TU Delft (nozzle throat size is 25 μm).

The choice of an electro-thermal system, more specifically a micro-resistojet, has been driven by the unique capability of this type of propulsion to cover a thrust range from 1 to 10 mN, providing at the same time a specific impulse potentially higher than 100 s and still requiring an average power lower than 10 W (typically expected limit in a 3U CubeSat). Water has been chosen as the candidate propellant not only due to its safety and non-toxicity but also because, even with a propulsive performance partially affected by its relatively high heat capacity and latent heat of vaporization, it is still the propellant of highest specific impulse for fixed input power among all non-toxic fluids storable as liquids at ambient conditions, as we have shown in a recently published study [1].

A demonstrator of the complete micro-propulsion system is currently being designed at TU Delft, including the thruster, propellant tank, valve and driving electronics. This demonstrator is expected to fly as a payload on the Delfi-PQ satellite, the next generation PocketQube bus under development at TU Delft with a first planned launch in 2018. The requirements set by this application demand for a thrust level in the range from 0.1 to

3 mN and a specific impulse from 50 to 100 s, while meeting the critical constraints for low mass (75 g for the complete system including propellant) and low power consumption (less than 5 W) within a small volume of 42×42×40 mm^3.

We are currently considering two micro-resistojet concepts: a Vaporizing Liquid Micro-resistojet (VLM) [2] and a Low Pressure Micro-resistojet (LPM) [3]. The VLM is based on liquid water and MEMS-manufactured heating channels, with a modular approach to combine different design solutions for the three most important thruster sections (inlet, propellant heating and nozzle for propellant acceleration). Silicon carbide or molybdenum are used for the resistive heater elements, with silicon dioxide electrical insulation. Figure 1 shows water vaporization in a thruster prototype with serpentine channels, covered with a glass layer to visualize the internal flow. The LPM is based on water ice stored at very low pressure under sublimating conditions. The ice vapor molecules move from the tank through the feed system into a plenum, and are then accelerated by flowing through heating sections with high temperature walls, thus playing the role of heating elements and expansion slots at the same time. They absorb heat from the walls, and some of them finally exit into outer space and generate thrust. The system has been preliminary tested with gaseous nitrogen to avoid the additional challenges introduced by the sublimating propellant, showing a very promising performance.

The presentation will discuss a number of test results on the electrical, mechanical and functional characterization of the MEMS thrusters, fabricated in the Else Kooi Laboratory at TU Delft. These tests have proven that the thrusters are compliant to all target parameters, therefore validating the design and manufacturing process flow. In particular, tests conducted on thruster models covered with a transparent glass layer (such as the one shown in **Figure 1**) allowed for identifying the characteristics of the two-phase flow in the boiling propellant. Finally, the feasibility of using commercially available valves for actively controlling the flow has been assessed through the results of simulations in time and frequency domains, validated by successive hardware-in-the-loop test activities.

[1] D.C. Guerrieri, M.A.C. Silva, A. Cervone, E. Gill, Selection and Characterization of Green Propellants for Micro-Resistojets, *ASME Journal of Heat Transfer* **139**, Is. 10 (2017).

[2] A. Cervone, B. Zandbergen, D.C. Guerrieri, M.A.C. Silva, I. Krusharev, H. van Zeijl, Green Micro-Resistojet Research at Delft University of Technology: New Options for Cubesat Propulsion, *CEAS Space Journal* **9,** 111-125 (2017).

[3] A. Cervone, A. Mancas, B. Zandbergen, Conceptual Design of a Low-Pressure Micro-Resistojet Based on a Sublimating Solid Propellant, *Acta Astronautica* **108**, 30-39 (2015).