# Microfabrication Processes for the Realization of a Matrix of Solid-Propellant Microthrusters

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## INTRODUCTION

The pyrotechnical materials constitute a substantial and compact source of energy and gas that can be integrated into MEMS. Typical solid propellants feature an energy density of around $5 J/mm^3$. If we can simply convert the pyrotechnical energy into heat or work -even with a conversion yield of 10%- pyrotechnical systems remain competitive versus any micro actuator or micro batteries. The concept is based on the combustion of a solid pyrotechnical material stored in a micromachined chamber [1]. In this paper, we report on the development of fabrication processes for the realization of a matrix of solid propellant micro-thrusters.

## MICRO-THRUSTERS DESIGN

With the aim of fully explore solid propellant technology, two different designs of Micropyrosystems were investigated: a millimeter and a micrometer scale structure (Fig 1). In the millimeter scale design, one single 1.5 mm wide thruster consists of 4 parts of silicon:

- A silicon micromachined igniter (micro-hotplate);
- A propellant reservoir made in Foturan;
- A silicon nozzle part added over the igniter;
- A glass seal wafer.

A compact device has been developed to serve as a point of focus for investigating the basic concepts and limits of solid propellant technology. This device is achieved by using a more energetic propellant stored in a smaller chamber (250 to 500 µm- wide). Limitations when scaling down the device appeared due to the thermal cross talk and combustion considerations. The number of wafers was decreased to 2 by integrating the igniter directly under the nozzle and the chamber and the seal together (Figure 1).

The application and the chosen designs involve several technological challenges. Different parts have to be assembled together. These parts have to be compatible with the filling and bonding procedures and with the interconnections to the external driving circuitry. A thermal isolation between each thruster is necessary to obtain ignition on an individual basis. A given pressure has to be obtained for sufficient thrust generation.

## FABRICATION AND RESULTS

This communication aims to describe the technological development of both devices. The different potential designs and technologies for the realization of demo prototypes are reviewed. Silicon and glass micromachining was the technology chosen to realize three-dimensional microstructures. In the case of the mm-scale device, standard processes were used to fabricate the igniting micro-hotplates. Special processes were developed for the fabrication of the chamber and the nozzle parts and also for the realization of the suspended micro-igniters of the micro-scale device.

Chambers were fabricated through standard and thick silicon (0.5 to 1mm-thick) wafers using Deep Reactive Etching (DRIE). Thermal insulating grooves and a bottom seal made of an anodically bonded Pyrex wafer were integrated to the chambers. Specific mask designs and processes were used to achieve walls with a high verticality. The process to wet etch the chambers in photostructurable glass was also optimized. Different DRIE processes to etch cavities with inclined walls were investigated to structure the diverging throat of the nozzle part. A process to fabricate the nozzle part, combining dry and wet chemical etching of silicon, was demonstrated. The influence of the tolerances on the dimensions on the quantity of stored propellant was estimated. Bonding issues were also addressed. Arrays of 4×4 millimeter scale micro-thrusters were fabricated. Successful ignition of the thrusters was achieved [2].

For the µm-scale device, two types of Joule heating micro-igniters, made of polycrystalline and monocrystalline silicon, were fabricated using surface micromachining on silicon and on silicon-on-insulator (SOI) substrates. The parallel-suspended resistive beams reached temperatures higher than 500°C. The nozzle part was integrated in the fabrication process of these surface micromachined igniters. Chambers with smaller dimensions were fabricated using the processes developed for the mm-scale device.

The ignition of zirconium perchlorate potassium (ZPP) using suspended micro-igniters was demonstrated (Figure 2). A promising result to scale down Micropyrosystems was the combustion of the propellant in $275 \times 275\ \mu m^2$ sealed cavities.

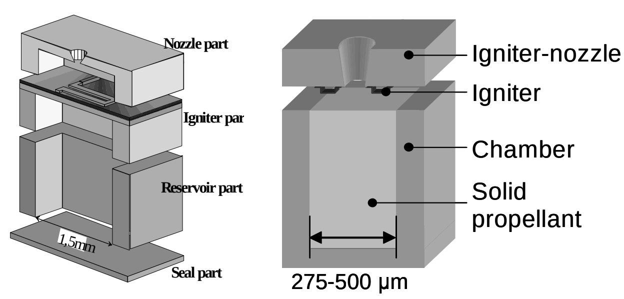


Figure 1. Schematic view of one single cell of the millimeter (left) and micro-scale structures (right).

Figure 2. Ignition of ZPP (time < 50 ms) using surface micromachined poly-Si micro-igniters (80 mW/beam).

## REFERENCES

[1] C. Rossi *et al.* Sensors & Actuators A, **99**, 125 (2002).
[2] C. Rossi *et al.* in Technical Digest of PowerMEMS 2003, Makuhari, Japan, p. 57 (2003).