Title of Investigation:

A Colloidal MEMS Thruster

Principal Investigator:

Eric Cardiff 597

Other Investigators/Collaborators:

Other Investigators/Collaborators: Brian Jamieson 553

External Collaborators:

Peter Norgaard (Summer Intern, University of Washington); Ariane Chepko (Intern, Purdue University); and Loral O'Hara (NASA Academy Student, University of Kansas)

Initiation Year:

FY 2003

Aggregate Amount of Funding Authorized in FY 2003 and Earlier Years:

$25K

FY 2004 Authorized Funding:

$36,000

Actual or Expected Expenditure of FY 2004 Funding:

$6,000 for wafer fabrication; $2,500 for data acquisition computer; $18,000 for experiment supplies, $2,500 for a vacuum pump

Status of Investigation at End of FY 2004:

Completed in FY 2004

Purpose of Investigation:

The goal of this project is to design a thruster with a thrust range from 1 micro-Newton (μN) to 100 milli-Newton (mN) using Micro-Electro-Mechanical Systems (MEMS) methods. (MEMS is used to create mechanical devices whose functional features are measured in microns or one-millionth of a meter.) Precision propulsion is needed for future formation-flying satellite missions, such as the Laser Interferometer Space Antenna (LISA), with instruments that will often need to be positioned remotely to nanometer accuracy. Our device works via electrostatic propulsion. Developing the thruster as a MEMS device on a silicon wafer allows many arrays to be manufactured cheaply and rapidly, and will allow more devices to be used, thereby extending the range of thrust that can be produced. This means that one single, small propulsion system can cover a wide range of thrust needs that traditionally would require several propulsion units, potentially reducing the mass of propulsion systems by a factor of 10. Our systems also would require less propellant. The primary challenge in designing a MEMS electric thruster is the development of insulation between t he accelerating electrodes and the emitter.

FY 2004 Accomplishments:

The manufacturing process for producing MEMS colloidal emitters was revised to allow improved fabrication of the insulation lattice and the emitter hole. An example of the prototype device is shown in Figure 1. The primary challenge of the insulation technique was solved in FY 2003 by using a novel MEMS fabrication technique to increase the thickness of the silicon dioxide. A high aspect ratio lattice structure (concentric circular columns of silicon dioxide 80 microns tall and 4 microns thick) was etched into the silicon thruster substrate using a deep reactive ion etcher (DRIE). This structure was then thermally oxidized to produce an insulating spacer an order-of-magnitude thicker than that which can be achieved with the thermal oxidation of silicon alone. Using this technique, the electrical breakdown voltage was increased by more than a factor of 10 to more than 3 kV, allowing the electrode to be placed in contact with the emitter body. Results on the electrical breakdown were presented at the American Institute of Aeronautics and Astronautics (AIAA) Joint propulsion Conference in July 2004.

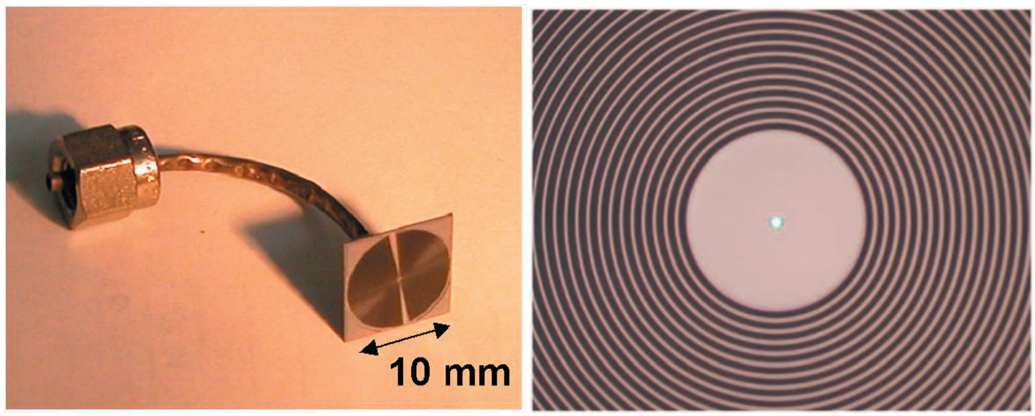


Figure 1. Image of a MEMS colloidal thruster emitter (left) with a close-up of the insulation (right)

In addition to the design effort, a modeling effort was performed to examine the formation of the Taylor cone. The Taylor cone is formed by the interaction of the electrostatic field and the surface tension. Thrust is produced at the tip of the Taylor cone where the fluid becomes unstable and breaks down into droplets, which are accelerated away from the emitter by the electrostatic field. A schematic of the Taylor cone and colloidal thruster is shown in Figure 2. The model has been successfully used to examine the early stages of the Taylor cone growth. The model also was used to determine the critical dimensions of the emitter electrode, as shown in Figure 3. Based on these predictions, the inner diameter of the emitter electrode was reduced.

Figure 2. Schematic of the Taylor cone and the MEMS colloidal thruster, showing the applied electric field, E, and the surface tension, σ.

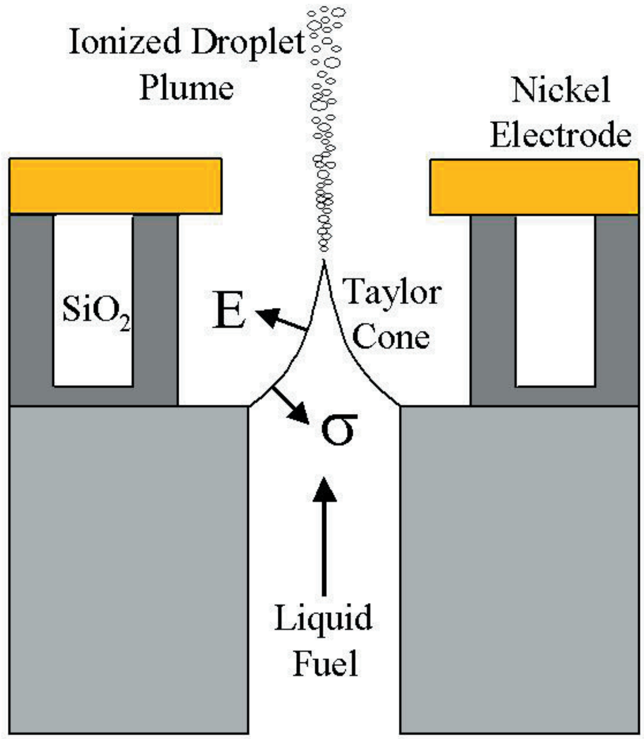
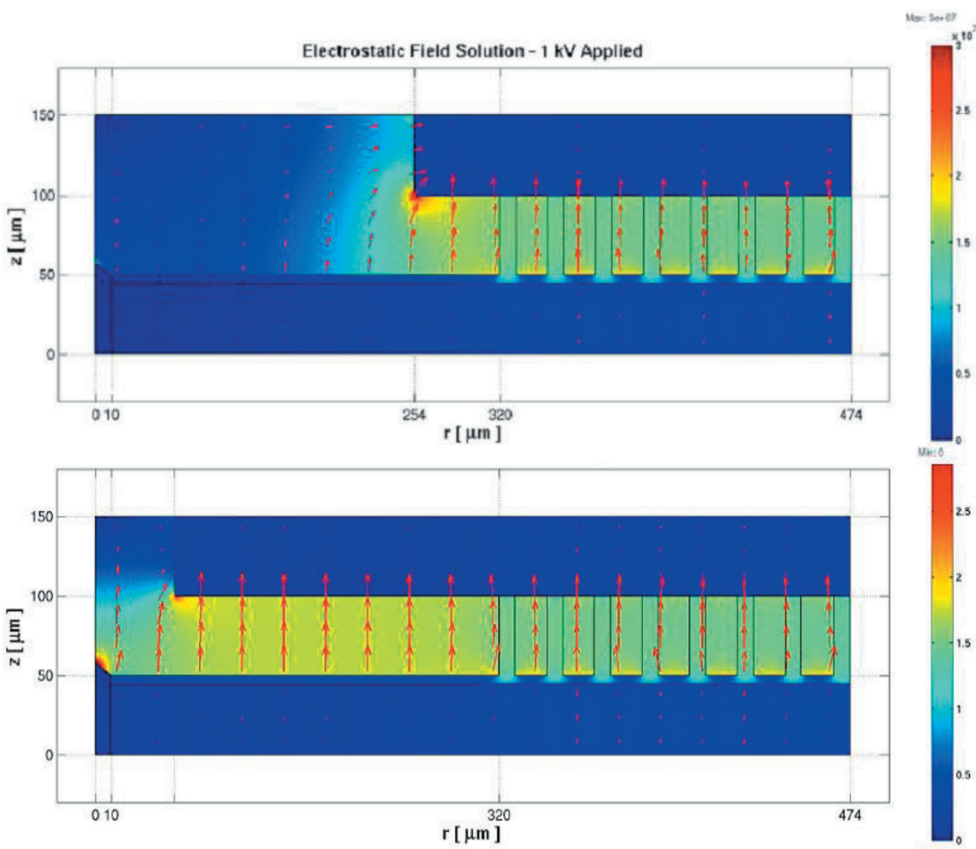


Figure 3. Results from a computer simulation of the electric field strength between the emitter and the electrode. The field is constant within the silicon dioxide columns, but is intensified at the tip of the electrode. For the electrode with ID=50 μm, the field is sufficiently strong at the tip of the Taylor cone to produce an instability.



The operational characteristics (thrust and specific impulse) of the colloidal emitters were also determined. This was accomplished using a Time-Of-Flight (TOF) technique to measure the velocity of the droplets as they leave the emitter. Circuits were successfully developed to rapidly cut off an applied voltage of up to 4 kV and to measure the collected current.

TOF results were obtained with a 100-μm ID emitter. The maximum TOF was 50.1 μs with the collector at a distance of 5 cm. The nominal current was ~20 μA. This is equivalent to a thrust of ~80 μN and a specific impulse of ~200 seconds.

Planned Future Work:

The results of this research will be presented at the AIAA Joint Propulsion Conference in July 2005.

Summary:

From this investigation, we developed a novel MEMS fabrication technique for electrode insulation. The insulation was the main technical risk. Earlier attempts by other researchers to develop this type of thruster all failed because the insulation broke down electrically. Since the beginning of this work, other researchers have successfully developed MEMS colloidal emitters. The advantage of the thruster we developed at the NASA Goddard Space Flight Center is the insulation, which allows the electrode to come into contact with the emitter body and to be integrated as a complete unit.