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# Demonstration of Longevity of Microdevices for *in situ* Analysis of Organic Molecules on Outer Planet Icy Moons

**Z. A. Duca** (1), G. K. Tan (1), T. P. Cantrell (1), M. A. Van Enige (1), R. A. Mathies (2), and A. M. Stockton* (1)
(1) Georgia Institute of Technology, GA, USA, (2) University of California, Berkeley, CA, USA (astockto@gatech.edu)

## Abstract

Quantitative compositional *in situ* analysis of small organic molecules in extraterrestrial environments provides essential information on planetary formation and evolution, as well as the capability to find potential signatures of past or present life. Microchip capillary electrophoresis (µCE) with laser-induced fluorescence (LIF) detection has proven to be capable of highly sensitive (sub parts-per-trillion, or pptr) automated quantitative compositional analysis of multiple organic compound classes. Here, we demonstrate the retained functionality of automated µCE-LIF microdevices fabricated in 2005. After 5 hours of vacuum cycling, a pneumatically-controlled valve re-opened and regained normal use. The ability of these microdevices to retain functionality after over 10 years of storage combined with system sensitivity, reliable autonomous control, and chiral resolution further supports the value of µCE-LIF as an *in situ* technique for outer planetary missions.

## 1. Background: µCE-LIF for Planetary Exploration Missions

The ability to obtain quantitative compositional analysis of small organic extraterrestrial molecules *in situ* can enable the acquisition of essential information on planetary formation and evolution, as well as the capability to find potential signatures of past or present life. However, due to lengthy mission transit times, the requirement for automated control, and the costs and risks associated with space flight, the development of new organic analytical technologies for outer planetary missions have been limited. MicroCE-LIF is an emerging technology under development that enables highly sensitive (sub pptr), automated, and quantitative compositional analysis of multiple organic compound classes, [1] including amines,[2] amino acids,[3] aldehydes,[4] ketones, carboxylic acids,[5] thiols,[6] and polycyclic aromatic hydrocarbons.[7]

While µCE-LIF systems have been proposed for missions to Mars (Mars Organic Analyzer, or MOA), Enceladus (Enceladus Organic Analyzer), and Europa (Ice Shell Impact Penetrator), little has been done to raise the technology readiness level (TRL) of the microdevice itself.

Resources for outer planetary space flight are limited. The high costs of sample return and extreme risks associated with a lengthy mission flight times force the use of autonomously-controlled, *in situ* techniques. With the additional requirement for highly sensitive quantitative compositional analysis to truly gain insight from organic composition, few techniques are capable of meeting these needs. As demonstrated extensively in the laboratory[8] and the field,[9] µCE-LIF meets these needs in a unique and powerful way. However, in order to fully demonstrate the capability of the µCE system to complete an entire mission successfully and raise the TRL to the point where the instrument could be readily put on a mission payload, the microvalves must be demonstrated to function efficiently after a 9-10 year space flight, in addition to being able to withstand extreme temperature, pressure, and vibrational conditions.

## 2. µCE-LIF Microdevice Longevity

Automation of µCE-LIF systems is achieved using pneumatically-actuated microfabricated monolithic membrane microvalves (Figure 1). Microvalves consist of a discontinuous fluidic channel etched in a glass substrate with a displacement chamber etched in a pneumatic layer opposite the fluidic layer across

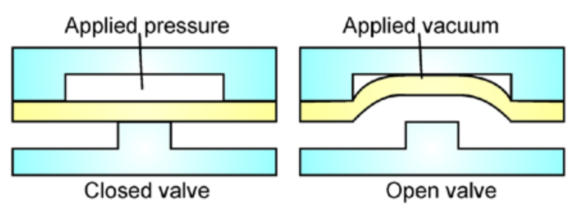


Figure 1: Cross-section of a pneumatically-actuated monolithic membrane microvalve.

Figure 2: Rigid mount holding a 10+ year old automated µCE-LIF microdevice.

an elastomeric membrane. When a vacuum is applied to the displacement chamber, the membrane deflects, drawing fluid into the resulting chamber and enabling fluidic flow across the discontinuity. Upon the application of a mild pressure to the displacement chamber, the membrane deflects again, forcing fluid out of the valve through the nearest open fluidic connection. Multiple valves in series operated sequentially form a peristaltic pump, and digital arrays of these microvalves enable complex microfluidic processing with operations including metering, mixing, dilution, reaction, etc…

To investigate the effect of an outer planetary mission flight time on automated µCE-LIF microdevices, microdevices fabricated in the UC Berkeley Microfabrication Laboratory were stored unused for 10+ years. After this time, the microdevices were housed in a custom-built rigid mount for testing (Figure 2). The mount enabled air-tight connection between the microdevice and the off-chip pneumatic control system and steadied the microdevice to enable constant video capture during valve cycling. Valves were opened by cycling the following process: apply a -0.750 bar pulse for 500 miliseconds (ms), let return to standard pressure for 500 ms. Actuation was controlled via a custom program installed on an Arduino, which in-turn regulated a custom-built electronic circuit, which then controlled a custom-built pneumatic circuit that used a Lee Company solenoid valve to switch between vacuum and ambient pressure.

Figure 3 shows the opening of a valve over 5 hours of repeated cycles. When open, the shadow of the valve appears more bubble-like, giving off a stronger reflection. When tested on a colored fluidic sample, no bleed of fluid into the pneumatic control line was observed, even after continuous and prolonged operation, indicating that the elastomeric membrane

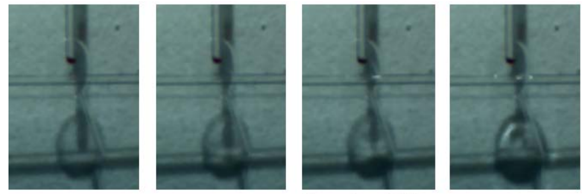


Figure 3: Photographs of valve opening.

remained intact during both prolonged storage and throughout the opening protocol. The opening of these valves after repeated cycling shows retained functionality even after over 10 years of storage time, which is a significant result towards increasing the TRL of µCE-LIF microdevices.

# 3. Summary and Conclusions

The µCE-LIF system for detecting and analyzing organic compounds could prove to be an essential tool in the search for life elsewhere in the solar system. Previous work has shown that automated µCE-LIF gives sub-pptr sensitivity and chiral analysis of organic compounds. The work reported here showing that microdevice functionality is retained after 10+ years of storage is a significant step towards acceptance of this technology for space flight. Further work will demonstrate microdevice functionality after extreme swings in temperature, pressure, and vibrational conditions.

# Acknowledgements

Alison Skelley, Will Grover and Robin Ivester could not have anticipated when they designed and fabricated the devices that they would be used in this work over a decade later.

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