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Development of a Fully Integrated Lab-on-a-Chip Electrophoresis System for ExoMars and Future Astrobiology Missions

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This paper will describe current and future development efforts in lab-on-a-chip instrumentation for astrobiological investigations underway at JPL. We will begin with a discussion of the current technology status of our autonomous microfluidic capillary electrophoresis (µCE) system integrated with on-chip perfluoropolyether (PFPE) membrane valves and pumps [1], as part of the Urey Instrument. This work builds on the µCE system developed by Skelley et al. [2], but extends the system capability through the use of bio- and spaceflight-compatible PFPE-membrane valves rather than utilizing a PDMS-based approach. The ultimate goal of this µCE system is to perform ultrasensitive compositional and chiral analysis of amino acids in order to determine if Mars harbors signatures of past or present life. An autonomously functioning flight version of this instrument will examine extracts from the Martian regolith as part of the Pasteur Payload of the 2016 ExoMars astrobiology mission.

The four-layer wafer stack design utilizes independent CE channels patterned in glass, along with a PFPE membrane, a pneumatic manifold layer, and a fluidic bus layer. Three pneumatically driven on-chip diaphragm valves placed in series are used to peristaltically pump reagents, buffers, and samples to and from capillary electrophoresis electrode well positions. Electrophoretic separation occurs in the all-glass channels near the base of the structure. The valve geometries and layouts in our integrated two-channel PFPE system have been optimized for valve sealing characteristics and uniform device spacing across the wafer surface. This paper will discuss current experimental development work in our research group involving further integration of functionality into an autonomous multi-channel system with no human intervention, enabling CE analysis upon a dried sample after receipt of a single pre-programmed instruction set from the user. The key structure under current development is an expanded sample handling bus, which performs on-chip derivitization of samples with fluorescent tags, serial sample dilutions, and mixing with standard samples for the purpose of data calibration.

For laboratory general-purpose use, the wafer stack is mounted on a fluorescent microscope stage in a custom fixture, which interfaces the pneumatic and high voltage lines and has the capability for controlled atmosphere testing. Additionally, simulation work is also underway on a more complex six-channel system with additional functionality. A 3D SolidWorks model of this more highly integrated six-channel autonomous system capable of all expected instrument functionality is modeled using COMSOL FEMLAB multiphysics software to ensure that the integrated system will perform as desired aboard a roving Martian platform. FEMLAB simulations of µCE separations of relevant mixtures of amino acids have been performed using custom code written at JPL, which enables direct comparison of experimental and simulated data, as well as providing crucial engineering data, in particular, the electric field strengths present throughout the instrument during operation. Finally, a discussion of advanced instrument concepts under development at JPL for "next-generation" Urey-like astrobiology instrumentation will also be presented.

References:

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