Crawler for Microfluidic Systems Based on Switchable Polymers

by **B. C. Bunker, D. L. Huber (SNL), and Ulrich Wiesner (Cornell University)**

Motivation—One of the fundamental problems in microfluidics is the transformation of energy into directed motion and load transport on very small length scales. While it has been demonstrated that active motor proteins extracted from living cells can provide such motion, there are many potential advantages in using synthetic as opposed to biological materials for such systems. Synthetic devices could work in a much wider range of environmental conditions, and be easier to maintain and control. This collaboration between Sandia and Professor Uli Wiesner at Cornell University involves investigating one such transportation system based on the use of a switchable polymer gel called poly (n-isopropyl acrylamide) or PNIPAM.

Accomplishment—The switchable polymer we are investigating for active transport (PNIPAM) is one that Sandia has already utilized for creating programmable surfaces to grab and release species such as proteins. The polymer undergoes a phase transition at 35°C (Fig. 1, left). Above the transition temperature, the polymer is in a collapsed, dense state. Below the transition temperature, the polymer swells in water, increasing its net volume by an order of magnitude. Experiments conducted by the Weissner group at Cornell have shown that this volume change can be exploited to create polymeric plugs that can be programmed to "crawl" through microchannels (Fig. 1, right). This mechanism for motion is inspired from the locomotion of earthworms, which move by making their body "fat" or "thin" at different point in time and space. "Fat" segments provide anchor points and allow for further extension of the "thin" parts. The Weissner group has created nanocomposites of PNIPAM and 30 nm wide hectorite clay particles as stabilizers and demonstrated that composite plugs can transport glass beads at a rate of 15 microns/second in a 1 mm capillary tube. The Wiesner group has also developed a theoretical expression indicating that gel velocities should be inversely proportional to the square of the gel diameter. Uli Weisner is interested in collaborating with Sandia to test this model. Sandia's major contribution to the project involves the developing the means to thermally program the PNIPAM gel on small length scales. Sandia has developed a microdevice (Fig. 2) that is capable of providing highly localized heating (and cooling) on a length scale of around 10 microns. Sandia is also exploring the use of focused IR lasers to provide localized heating to PNIPAM gels in microchannels. Integrated fluidic systems are currently being developed for the PNIPAM experiments, and should be ready to be deployed within a few months.

Significance—Volume phase transitions in polymer gels are diffusion controlled, which means that transition times are dependent on sample dimensions. By reducing the size of our polymer plugs down to microns, we should be able to create a transportation system in which the phase transition could drive objects in microchannels at velocities that could exceed 100 microns/second. Our Cornell-Sandia collaboration will enable us to test theoretical predictions of the transitional velocity of polymer gels, elucidate the length scale at which macroscopic behavior of the gel will break down (e.g. due to gel heterogeneities), and help CINT explore new concepts for microfluidic systems based on engineered nanomaterials.

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Contact: Bruce C. Bunker, Chemical Synthesis and Nanomaterials, Dept. 1816
Phone: (505) 284-6892, Fax: (505) 844-9781, E-mail: bcbunke@sandia.gov

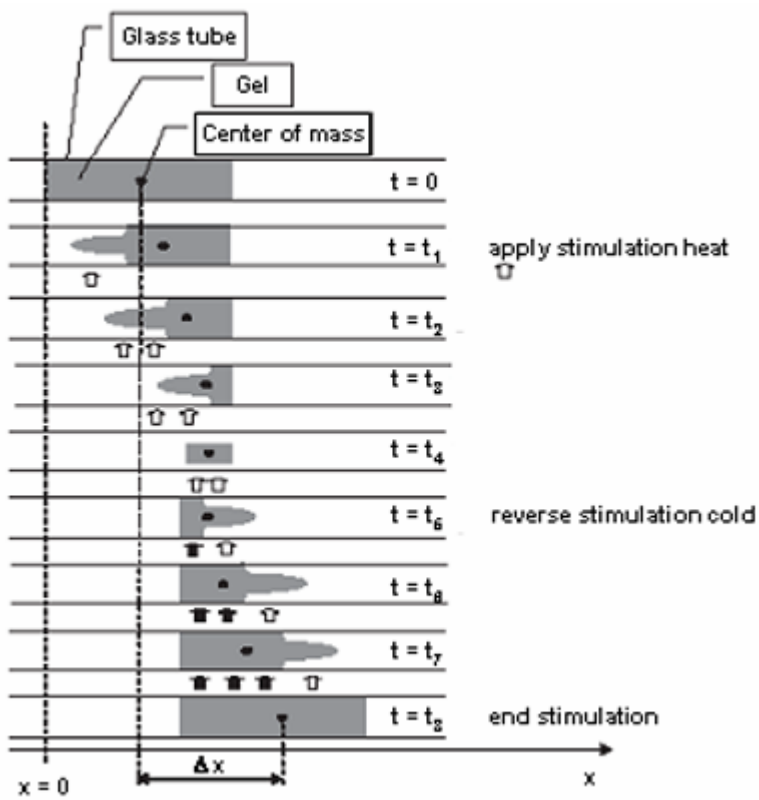

Figure 1. Schematic representation of the translation of a PNIPAM gel plug in a microchannel.

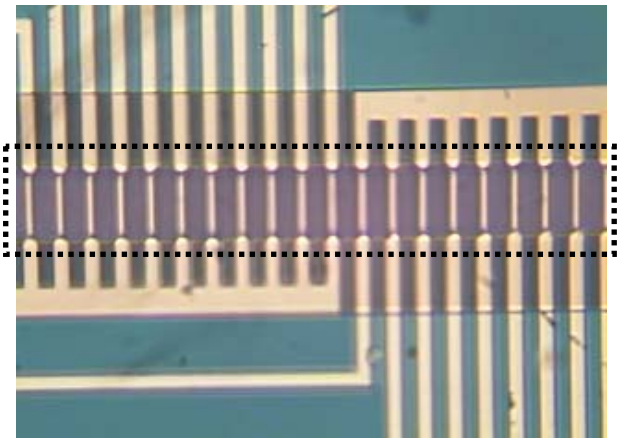

Figure 2. Sandia's micro-hotplate that will be used to program the phase transition in PNIPAM contained in a microchannel above the heater. Each hotline in the center has a diameter of 10 microns and can be independently programmed to induce the translation of the PNIPAM gel.