**Proceedings of the ASME 2013 Summer Bioengineering Conference**
**SBC2013**
**June 26-29, 2013, Sunriver, Oregon, USA**

# SBC2013-14441

## IONIC ELECTROACTIVE POLYMER ACTUATORS FOR ON-CHIP SAMPLE PROCESSING INTEGRATED WITH MICROFLOW CYTOMETER

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## Abstract

As interest in and potential uses for microfluidic and optofluidic analytical techniques grows, the need for on-chip, automated sample processing becomes increasingly important because this aspect is critical to allowing the devices to be commercially feasible and practical. One such design that implements on-chip processing is using ionic electroactive polymer (IEAP) actuators to perform mixing of particles in the microchannel and using a single magnet positioned beneath the channel to trap the magnetic beads. IEAP actuators consist of a central ionic membrane with conductive network composite (CNC) layers on either side. Gold electrodes placed on the outside of CNC layers are connected to a metal anode and cathode. When subjected to an electric field, the ions in the actuator move, electromechanically causing the entire length of the actuator to flex [1]. Although most actuators to date have been developed for use in air rather than in solutions, we have adapted previously developed actuators by optimizing their electromechanical functions to suit our needs and coating them in a protective film. The actuators are embedded in a microchannel in different configurations, which are then tested to determine which configuration most effectively trapped, mixed, and released the magnetic beads. The most effective configuration will subsequently be used to perform automated sample processing for an assay.

## Introduction

Recently developed MagTrap, or spinning magnet trap, consists of a wheel embedded with parallel polarity strip magnets positioned beneath a microfluidic channel. When magnetic microbeads or microspheres flow through the channel, the wheel is rotated against the current to capture and mix the magnetic beads; the beads can be released and allowed to flow downstream to a microflow cytometer, for example, simply by reversing the rotation of the magnetic trap. This device has demonstrated an ability to effectively both trap and release the beads while sufficiently mixing them to prevent aggregation. The MagTrap was used to conduct sample processing for assays, in which magnetic beads coated in *E. coli* were inserted into the microchannel and then rinsed with various reagents before being analyzed in a microflow cytometer. The MagTrap proved to allow faster and more sensitive testing when compared to traditional static assays [2]. However, the MagTrap is quite large and development of smaller system that performs the same functions would ultimately allow greater portability for any medical diagnostic device utilizing on-chip sample processing. Here, we use embedded actuators in combination with a single magnet for on-chip sample processing. This configuration has a significantly smaller footprint than MagTrap.in a similar way to the MagTrap.
The actuator/magnet design is a viable alternative to the MagTrap, as it outperforms standard assays and performs just as well as MagTrap.

## Experimental Details

The actuators were constructed using Nafion as the internal ionic membrane. The CNC membranes consisted of poly(allylamine hydrochloride) (PAH) and gold nanoparticles (AuNP) and were fabricated using the layer-by-layer (LbL) technique. The material was immersed in EMI-Tf ionic liquid and then gold electrodes were pressed on both sides. Multiple films were tested for coating the actuators; those were applied different ways depending on the film. The microchannels are made of poly(methylmethacrylate) (PMMA) and are hot-embossed into the surface using a mold. The actuators are embedded by inserting them into notches cut into the side of the channel and then sealed in place with silicone. The magnets used are neodymium iron boron (NeFeB) with a minimum pull rating of 2000 gauss. The previously constructed microflow cytometer to be used for experimental analysis has been detailed in previous works [3]. The three configurations of actuators are shown below in Figure 1.

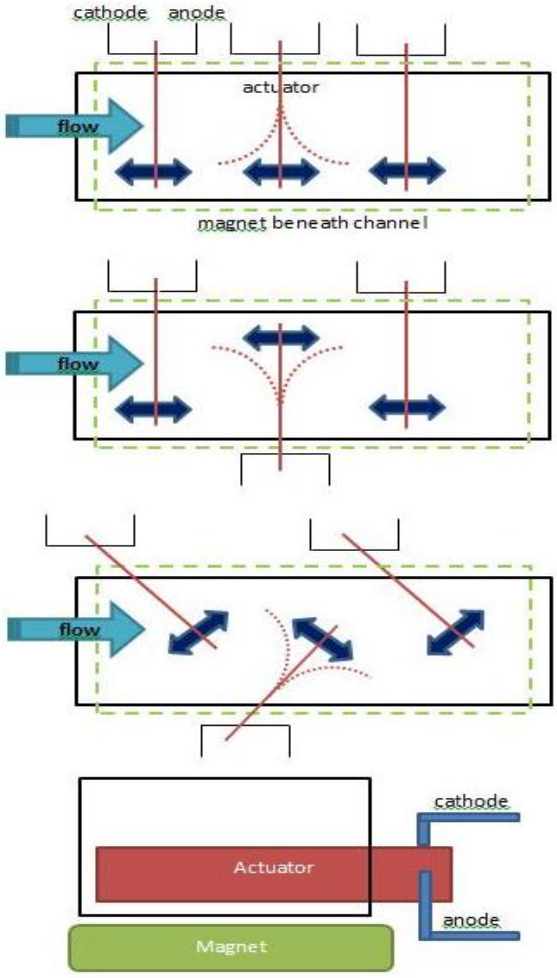


**FIG. 1.** Schematics of microchannel segment containing actuator/magnet assembly, top view of the 3 different designs being tested. The inset dotted line demonstrates how the actuator flexes. Cross-section of assembly shown immediately above. Diagrams not to scale.

## Results and Discussion

To determine the most effective configuration, bead solutions of a known concentration are introduced to the microflow cytometer and then the solutions are collected during both the trapping and releasing phases and the microflow cytometer is used to count the beads. Capture efficiency is determined as the amount of beads trapped versus the number of beads that would have passed through the channel without the magnet/actuator system present; the fraction of beads released compared the number of beads trapped is defined as the release efficiency [2]. Once the optimum design is determined to be capable of performing on-chip sample processing, it will be integrated with our microflow cytometer unit. For comparison purposes, the same type of assay is performed using the actuator/magnet design as was the MagTrap device described earlier. *E. coli* is used as the detection target, with chicken IgY as the positive control and bovine serum albumin as the negative control. Microbeads incubated with *E. Coli* are introduced to the channel at 10 μl/min and trapped, then followed by tracer reagents and rinsing solutions, all at the same flow rate. The microbeads are then released to flow downstream to the cytometer for analysis. Multiple assays are conducted with varying concentrations of microbeads to study the sensitivity of the new design. Our experiments as well as previous research show it is possible to reduce processing time while improving sensitivity, as the assays utilizing a dynamic mixing device were better able to detect concentrations of *E. coli* near to the previously established limit of detection. Dynamically mixing the beads throughout the assay process allows reagents to reach more of the surface area of the beads and preventing reagents from being depleted in areas around the beads [2].

The next step for this particular project would be to construct a device such that both the microflow cytometer and the microchannel containing the actuator/magnet structure can be integrated into a single, one-piece device consisting of a continuous central microchannel. Further miniaturization or simplification of the current design for the automated sample processing portion of the microfluidic system would increase to the ability of the design to eventually make it out of the lab and into commercial production and use.


## Acknowledgements

This work is supported by the Iowa State University and William March Scholar Fund. The author thanks Pouya Asrar for his assistance with this project.


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