AU/PPY ACTUATORS FOR ACTIVE MICROMIXING AND MASS TRANSPORT ENHANCEMENT

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ABSTRACT

We developed a new micromixer based on Gold/Polypyrrole (Au/PPy) bilayer actuators. Several actuators (length x width from 10 x 1 mm to 380 x 38 μm) were tested at frequencies up to 3 Hz. Chronoamperometric experiments (in the mass transport-limited regime) with a Redox sensor implemented in front of the actuators were run. Differential mass transport effects with or without the activation of the actuators were recorded for several systems. In addition, numerical simulations of a DNA hybridization reaction under the effect of different configurations of these devices were carried out, and their effect on reaction rate increase was studied.

KEYWORDS: Micromixing, Au/PPy actuators, DNA hybridization.

INTRODUCTION

Passive diffusion-based micromixing can only be enhanced by reducing diffusion path-lengths [1] and inducing chaotic advection (flows with chaotic streamlines [2], even at very low **Re** numbers).

Here we present a micromixer that, to our knowledge, has the potential for integration in truly multiplexed and miniaturized assays no other demonstrated technology has. Passive micromixing due to chaotic advection or bubble formation in microchannels requires excessively long channel lengths per step (of several cm). Hence, multiplexability (parallel implementation of hundreds or thousands of assays) is dramatically reduced with these approaches because the integration of one single micromixing step per assay would require substrates incorporating channels of meters in length (idea totally incompatible with the goals of miniaturization technology).

Furthermore, this technology can attain micromixing in isolated volumes, it is reusable, easy to fabricate and actuate, biocompatible, and minimizes the amount of analyte and reagents needed for analytical tests.

THEORY

The micromixers here presented are based on the implementation of Au/PPy actuators, Figure 1 [3]. We propose, on the same terms introduced by Purcell in 1977 when discussing how microorganisms swim [4], that a system of Au/PPy microactuators can be used to move portions of fluid, Figure 2. This is so due to their flexible nature and also because several of them can be activated simultaneously. By doing so, microscopic flow structures can be promoted with enough complexity to develop chaotic advection and so enhance otherwise diffusion-limited mass transport processes (such as micromixing and the rate of bulk or surface reactions).

Twelfth International Conference on Miniaturized Systems for Chemistry and Life Sciences
October 12 - 16, 2008, San Diego, California, USA

978-0-9798064-1-4/µTAS2008/$20©2008CBMS

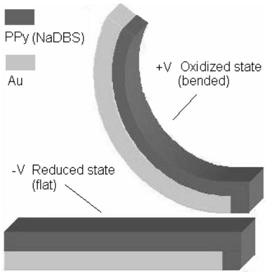

Figure 1. Au/PPy actuator. When PPy is deposited with NaDBS, the actuator bends upwards in its oxidized state (+ Voltage) and flattens in its reduced state (- Voltage).

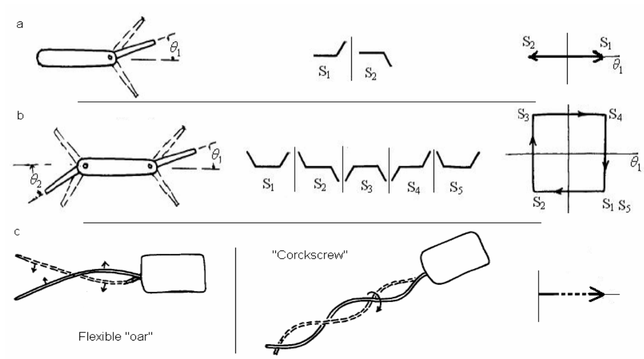

Figure 2. A microsystem with a single rigid micro-"oar", **a**, *moves back and forth to the same initial and final positions. Additional "oars",* **b**, *broaden the range of positions. Flexible oars,* **c**, *allow for real-like swimming (or, if the oars are anchored, for fluid propelling).*

EXPERIMENTAL

To test the previous hypothesis Chronoamperometric (CA) experiments [5] were run on a gold Redox sensor placed in front of an actuator. The system was submerged in Phosphate Buffered Saline (PBS) in the presence of $Fe(CN)_6^{-4}$. When comparing a CA experiment strictly under diffusive-limited conditions (stagnant, unstirred solution) with an identical experiment in the presence of a system of moving actuators, a direct measurement of mass transport enhancement due to convection was obtained by a comparative increase in the recorded current on the sensor.

Furthermore, numerical simulations of a DNA hybridization reaction (constrained at the bottom surface of a microchamber) under the effect of several configurations of microactuators of this sort were conducted [6].

RESULTS AND DISCUSSION

A result on how the flow promoted with these actuators affects the response of the Redox sensor during a CA experiment is presented in Figure 3. The maximum effect, which enhances mass transport by a 100%, takes place under the following actuation conditions: high amplitude of movement and recovery of initial flat position.

Figure 4 shows the results of the simulated DNA hybridization reaction with two moving microactuators as in the presented manner. As it is shown in the figure, after only 11.2s of elapsed reaction, the presence of the actuators enhances the concentration of hybridized DNA by a 28.3%.

CONCLUSIONS

Au/PPy microactuators can enhance processes such as micromixing and microreactions in a multiplexable way without compromising the size of final devices, unlike most other micromixing strategies that require cm-long channels per mixing step.

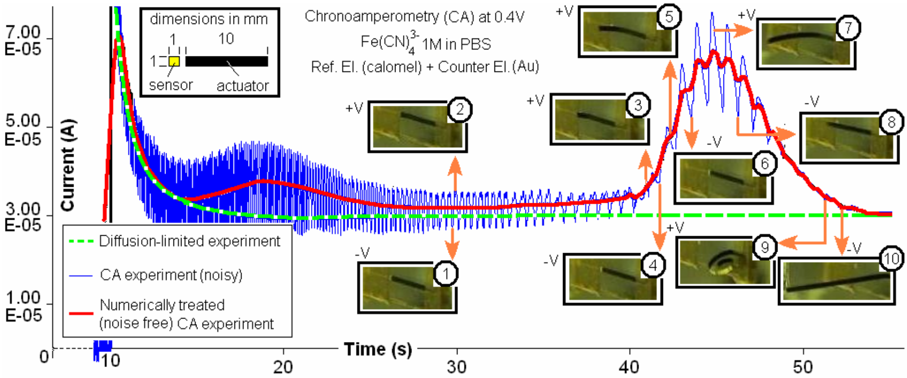

Figure 3. CA results for diffusive-limited experiment (green dashed line) and experiment in the presence of a moving actuator with direct, "noisy" signal (blue thin line) and numerically treated, "noise-free" signal (red thick line). High movement amplitudes and recovery of initial flat position induce a peak in current (pictures 3-4 and 5-6), indicating convection-enhanced mass transport of $Fe(CN)_6^{-4}$ towards the surface of the sensor. Small motion amplitudes (pictures 1-2) and actuation away from initial flat position (pictures 7-8 and 9-10) induce no relevant effects.

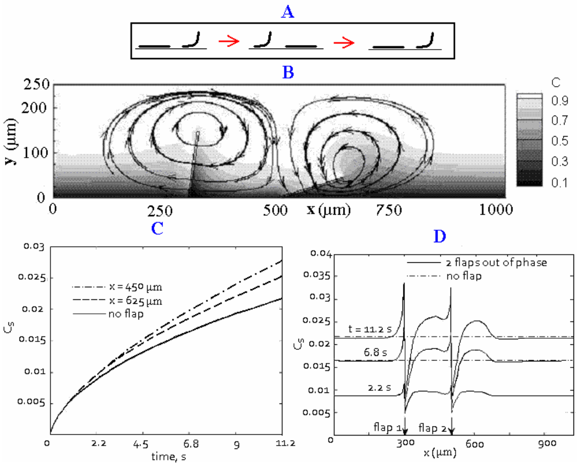

Figure 4. ssDNA targets in a sample hybridize with complementary ssDNA probes immobilized at the bottom of a microchannel. **A** *Two 150 µm long actuators move in parallel out of phase.* **B** *Concentration profiles of ssDNA target after 11.2 s (7 actuation cycles).* **C, D** *Concentrations of hybridized DNA at several lengths as a function of time and presence or not of actuators.*

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