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RESEARCH PAPER

High field asymmetric waveform for ultra-enhanced electroosmotic pumping of porous anodic alumina membranes

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Abstract An electroosmotic EO process is presented for nanoporous membranes capable of generating EO flow rates over thirty times higher than previously possible with the same membrane and solution. In generating high EO flows, a limiting factor is faradaic reactions which appear at high electric fields. A process is presented capable of limiting and even canceling these reactions allowing electric field between one and two orders of magnitude higher. This is achieved by applying an asymmetric bipolar rectangular voltage waveform. The results show the enhanced EO pumping capabilities of membranes under a high electric field asymmetric waveform which prevents gas generation at high voltages. A baseline is established by measuring the EO pump performance when a constant voltage is applied to SiO_2-coated nanoporous anodic aluminum oxide membranes. The analysis compares the effect of the applied voltage type on the maximum flow rate, power consumption, and maximum pressure. Results show that large gas generation prevents membrane operation when direct current DC voltages above 50 V are applied. On the other hand, it operates normally under an asymmetric voltage +1,800/−900 V applied, with negligible gas generation. This results in a thirty-time flow rate increase. Larger flow rates/voltages are possible but were not considered due to hardware limitations.

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1 Introduction

An EO pump generates a flow rate or pressure change due to the ion migration in the electric double layer toward the electrode which causes viscous drag creating a net flow. These pumps can be fabricated using a variety of methods from capillary columns packed with particles (Zeng et al. 2001; Wang et al. 2006; Chen 2005) to porous membranes (Yao et al. 2003; Chen et al. 2005; Yao et al. 2006; Cao et al. 2012; Kwon et al. 2012; Kim et al. 2013; Garg et al. 2012). EO pumps have several advantages compared to typical mechanical pumps. These include having no moving or mechanical parts, being compatible with lab-on-a-chip components and being used for accurate and adjustable flow rate control. EO pumps are used in a variety of applications including power electronic cooling (Berrouche et al. 2009), fuel cells (Buie et al. 2006), actuation (Prakash et al. 2006), drug delivery (Pikal 1992), chromatography (Chen et al. 2004), and lab-on-a-chip systems (Kim et al. 2013; Li and Harrison 1997).

High flow rates are of interest in many applications, but they require high electric fields. A well-known issue at those conditions has been faradaic reactions. These limit the maximum electric field that can be applied and the flow rate that can be obtained. Faradaic reactions can result in pH changes, electrode degradation, and electrolysis. Gas evolution due to electrolysis occurs at the electrodes and can decrease the efficiency, the flow rate performance and increase the possibility of channel blockage. To reduce pH changes, large reservoirs can be used, but are not practical for on chip devices. To prevent electrode erosion, many EO pumps utilize platinum electrodes due to their high inert properties. Nevertheless, they still produce bubbles from the reaction of hydrogen and oxygen at the cathode and anode, respectively. One method of reducing this reaction is to stay below the voltage limit of 2 V