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AC nanopump design and manufacture

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ABSTRACT

In this paper, we design and manufacture for the first time a novel AC nano-pump to generate flow velocity. AC voltage is needed at nanoscale pump designs and manufacture because DC voltage nano-pumps design and manufacture generate bubbles/cavitation/instability and are not scalable designs and are not scalable to manufacture. AC voltage driven nano-pump designed in and manufactured demonstrated in this paper overcomes bubble generation/cavitation/instability and our AC nano-pump is a scalable design and manufacture.

Keywords— Nanopump, Nanotechnology

1. INTRODUCTION

The advent of technology for fabricating devices of the order of a few nano-meters have paved way for single molecule sensing [1-15], DNA sequencing [11], water desalination[11], protein translocation [11] and nano-power generators [1]. In this paper, we demonstrate for the first time a novel AC nanopump. We design and manufacture for the first time a novel AC nanopump to generate flow velocity. AC voltage is needed at nanoscale pump designs and manufacture because DC voltage nano-pumps design and manufacture generate bubbles/cavitation/instability and are not scalable designs and not scalable to manufacture[12]. AC voltage driven nanopump designed in and manufactured demonstrated in this paper overcomes bubble generation/cavitation/instability and our AC nanopump is a scalable design and manufacture.

2. EXPERIMENTAL SECTION

2.1 Materials

Unless otherwise noted all chemicals were purchased from Sigma-Aldrich (Milwaukee, WI). The running buffer was 1 mM phosphate buffer, pH 7. The fluorescent dye, 200 μ M Riboflavin, dissolved in running buffer. Sylgard 184, a poly(dimethylsiloxane) prepolymer (PDMS) and curing agent was from Dow Corning (Midland, MI). Tri-decafluoro-1,1,2,2-tetrahydroctyl-1-trichlorosilane was from United Chemical Technologies (Bristol, PA). SU-8 2050 photoresist and SU-8 developer were purchased from MicroChem Corp. (Newton, MA) Distilled deionized water with a nominal resistivity of 18 M Ω cm when dispensed from a Millipore Milli-Q Direct water purification system equipped with BioPak polisher (Billerica, MA). The track-etched Anodic Alumin Oxide (AAO) ceramic membrane nanocapillary membrane (NCM) with 13 nm ID pores and 50 μ m in length and pore density of $6 \times 10^{10}/\text{cm}^2$ were purchased from Synkera Technologies Inc. (Longmont, CO).

2.2 Device Fabrication

The microfluidic and nanofluidic interfaces were made by coupling PDMS microfluidic channel with the AAO ceramic membrane that contains nanocapillaries. The experimental set-up is shown in Fig. 1(a). The device has vertical microfluidic channels that connect the microchannels with the inlet and outlet. The horizontal microchannels are 200 μ m in width and 40 μ m in depth, and the vertical microfluidic channels are 150 μ m ID with 40 μ m depth connecting the horizontal microfluidic channel to the nanocapillaries. The horizontal channels are composed of two microfluidic channels intersecting at an injecting tee: the main

microfluidic channel across which the AC voltage is applied and the side channel that connects sample and waste reservoirs to inject a plug of EOF marker (see Fig. 1(b)).

Standard photolithography and molding processes were used to make the PDMS layers. Briefly, three dimensional masters were fabricated by patterning SU-8 photoresist on a silicon wafer using photolithography. The masters were made with two layers of SU-8 developed separately. The second layer of SU-8 was fabricated by repeating the photolithography process following the completion of first SU-8 layer. The first SU-8 layer formed the horizontal microfluidic channel, and the second layer formed posts that extended 40 μm above the first layer to create the vertical microfluidic channels in the PDMS. The master surface was treated with Tri-decafluoro-1,1,2,2-tetrahydroxy-1-trichlorosilane under the vacuum for 40 minutes and was heated at 120 $^{\circ}\text{C}$ for 20 min. A 10:1 mixture of PDMS prepolymer and the curing agent was degassed under the vacuum to remove all the bubbles formed during the mixing process and was spin coated at 1100 rpm for 30 seconds to make a thin PDMS film with a thickness of 65 μm and cured on a hot plate at 120 $^{\circ}\text{C}$ for 1 minute. The PDMS film patterned with the horizontal and vertical microfluidic channels was released from the master in isopropanol solvent and transferred onto a Corning glass slide (Corning, NY) pre-coated with the same thickness of PDMS, 65 μm . The bottom part of the device composed of a glass slide coated with PDMS and channel patterned thin film PDMS, was plasma treated with the top part PDMS slab bearing 3 mm ID access holes using a PDG-32 G surface plasma cleaner from Harrick Scientific (Ossining, NY) for 30 second. The track-etched Anodic Aluminum Oxide (AAO) NCM was placed on top of the vertical microfluidic channel on the outlet side and, finally, the top and bottom parts of the device were irreversibly bonded together with the AAO ceramic membrane NCM sandwiched in the middle.

2.3 Device operation and fluorescence imaging

A sequentially programmable power supply (LabSmith Inc., Livermore, CA) was used for injection of a Riboflavin band and applying the AC voltages. Injection of the sample band was achieved with the electrokinetic pinched injection process. Three reservoirs and microchannels and nanocapillaries were filled with 1 mM sodium phosphate running buffer at pH 7 and the sample reservoir with Riboflavin in 1mM sodium phosphate running buffer at pH 7.

The fluorescence of sample bands were imaged using an Olympus IX81 inverted fluorescence microscope (Center Valley, PA) with 5 times (0.15 NA) objective and captured with a Hamamatsu CCD camera (Medel C9100-13, Bridgewater, NJ). Images were collected at sampling rate of 1.0 Hz and processed with MetaMorph (version 7.7.4.0). AC Electroosmotic flow rates were calculated by dividing the known distance and the time traveled by the sample band. The electroosmotic flow velocity was measured in the microfluidic channel downstream of the inlet reservoir from the injection tee as shown in Fig. 2.

2.4 Mathematical modelling

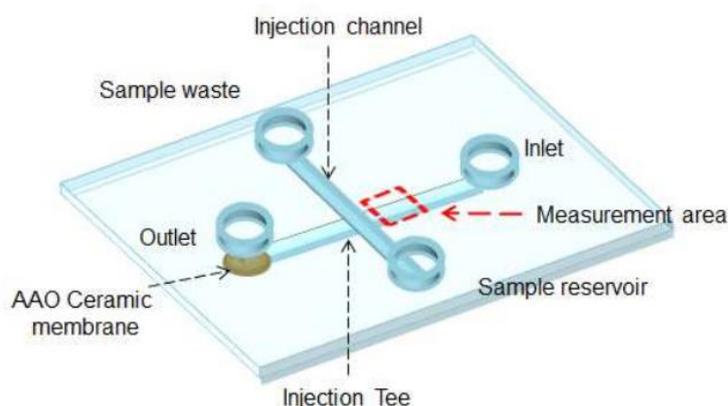
Here, we used OpenFOAM open source, freely accessible software, and an open source package platform, developed in earlier works [1-10], a multiscale multi-physics Two Reservoir + nanoporous membrane unit open source package platform, in which Poisson-Nernst-Planck (PNP) and Navier-Stokes (NS), together hereafter referred as PNP+NS software package are numerically solved using CFD numerical methods, to use for multiscale multi-physics use [1-10]. The PNP+NS software platform package is available in the GitHub, under free access and download at https://github.com/nandiga/PNP_Navier_Stokes_Foam.

2.5 Simulation Details

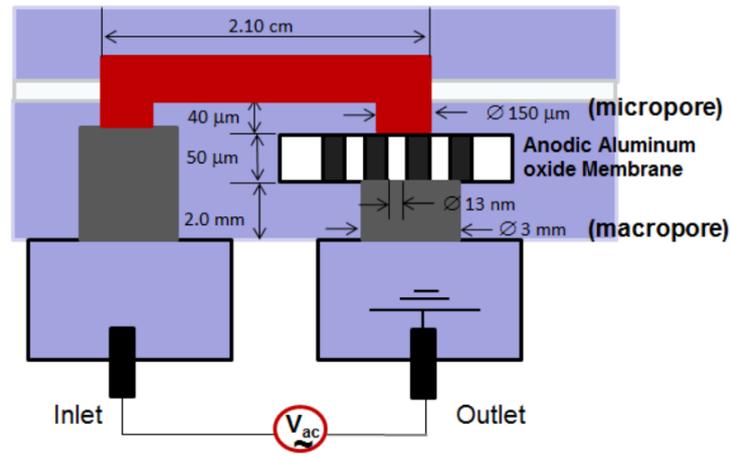
The simulated domain consists of a nanopore of length $L_n = 0.5 \mu\text{m}$ and diameter $d_n = 13 \text{ nm}$. An AC voltage is applied across the reservoirs and the frequency of the AC field was 5 Hz. Phosphate buffer of concentration 1 mM is used. The charge on the walls of the nanopore is $\sigma = -0.05 \text{ mC/m}^2$.

3. RESULTS AND DISCUSSION

Fig. 3 (a) shows the flow velocity with AC frequency. Fig. 3 (b) shows the flow velocity with AC amplitude. There is no DC voltage to generate the flow velocity. From our numerical simulations, we observe that the space charge density has contributions from higher harmonic modes upto $n = 4$ and the higher harmonic modes are asymmetric owing to concentration polarization [16] (see Fig. 4).

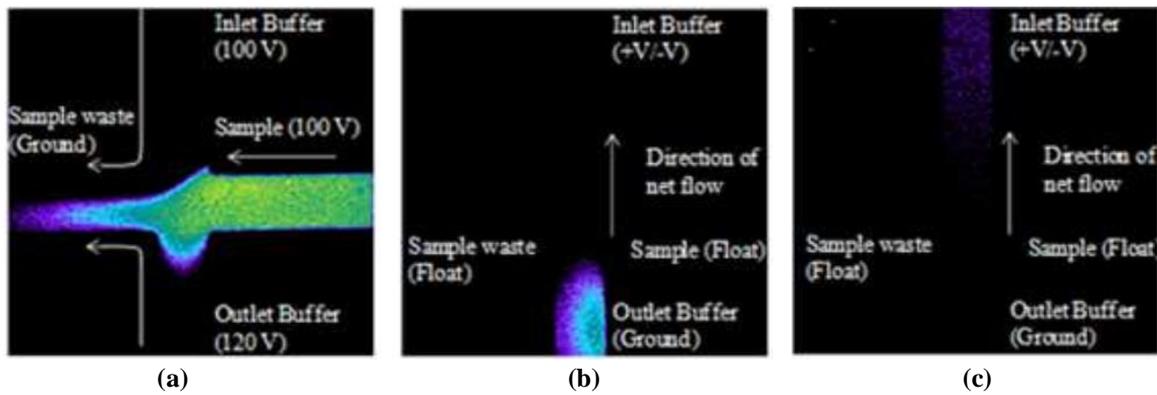


(a)



(b)

Figure 1. AC nano-pump experiment design. (b) 2D schematics of AC nano-pump experiment design.

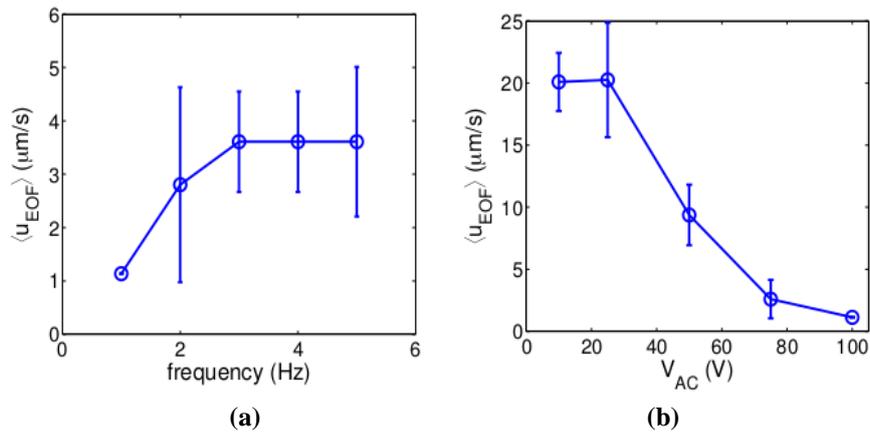


(a)

(b)

(c)

Figure 2. (a)-(c) Experimental fluorescent images of a plug injection of a neutral marker to measure the fluid velocity generated by the AC nano-pump.



(a)

(b)

Figure 3. Experimental measurements of flow velocity with (a) AC frequency (b) AC amplitude.

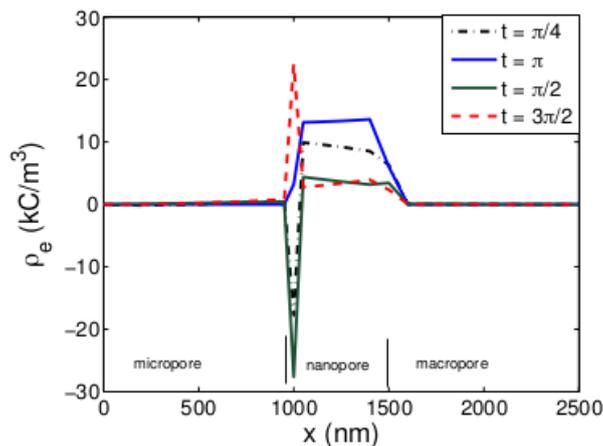


Figure 4. Numerical simulation of space charge density with higher harmonic modes inside the AC nano-pump design and manufacture.

4. CONCLUSIONS

Here, a novel AC nanopump is designed and manufactured for the first time. Our AC nanopump does not generate bubbles and is scalable overcoming challenges to design and manufacture a nanopump.

5. ACKNOWLEDGEMENTS

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