

Chen, C.-Y. et al: Artificial Cilia Micromixer

Electronic Supplementary Information (ESI) for Lab Chip

**“Magnetically actuated artificial cilia for optimum
mixing performance in microfluidics”**

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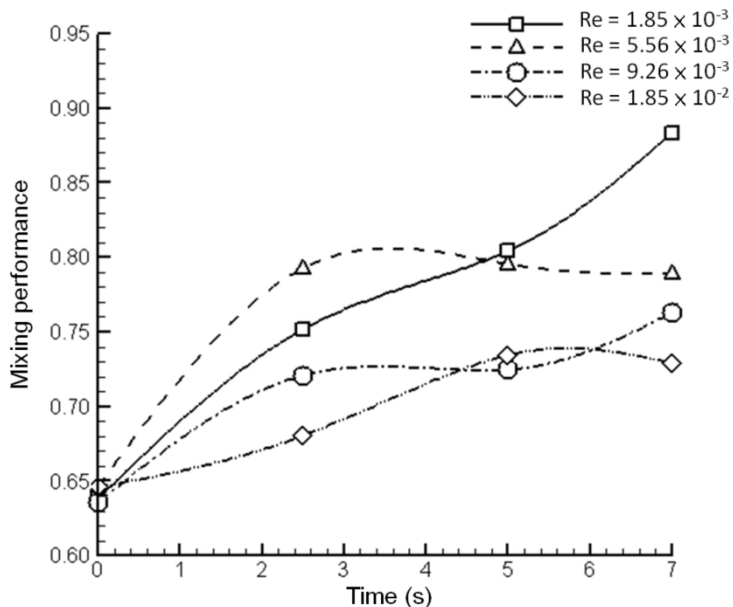
Chen, C.-Y. et al: Artificial Cilia Micromixer

This electronic supplementary information includes : (1) Time-lapse ciliated structure motions recoded in WMV format; (2) Time-dependent mixing performance of the presented micromixer at different Re numbers in mode III ; (3) Time-dependent mixing performance of the presented micromixer at different actuation frequencies in mode III; (4) Vorticity and Probability Density Function (PDF) results for flow fields induced by artificial cilia under three different modes of actuation using μ PIV analysis; (5) 3D numerical analysis of induced flow fields in mode I, II, and III using FSI module.

(1) Time-lapse ciliated structure motions recoded in wmv format (Video S1, S2, and S3) :

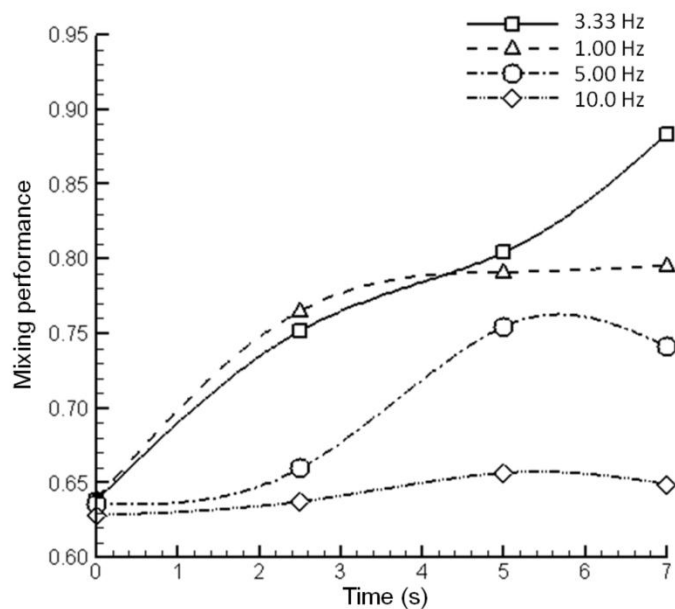
Recordings were done using a high speed camera with a recording rate of 100 Frames per Second (fps). The actual video play speed is 7 fps. The actuation frequency for these three modes is 3.3 Hz.

(2) Time-dependent mixing performance of the presented micromixer at different Re numbers in mode III (Figure S1) : Through the adjustment of the Re from 1.85×10^{-3} to 1.85×10^{-2} , it is found that the mixing performance of the artificial cilia micromixer decreased as Re increased. Therefore, this micromixer can be applied for low- Re applications.



Chen, C.-Y. et al: Artificial Cilia Micromixer

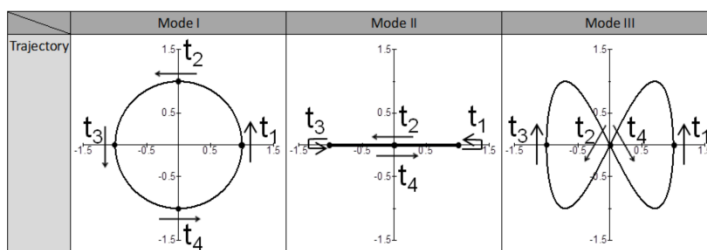
(3) Time-dependent mixing performance of the presented micromixer at different actuation frequencies in mode III (Figure S2) : Through the adjustment of the actuation frequency from 1 Hz to 10 Hz, it is found that as actuation frequency increases, the mixing performance of the artificial cilia micromixer increases initially, and then decreases after reaching the maximum mixing performance at 3.3 Hz.



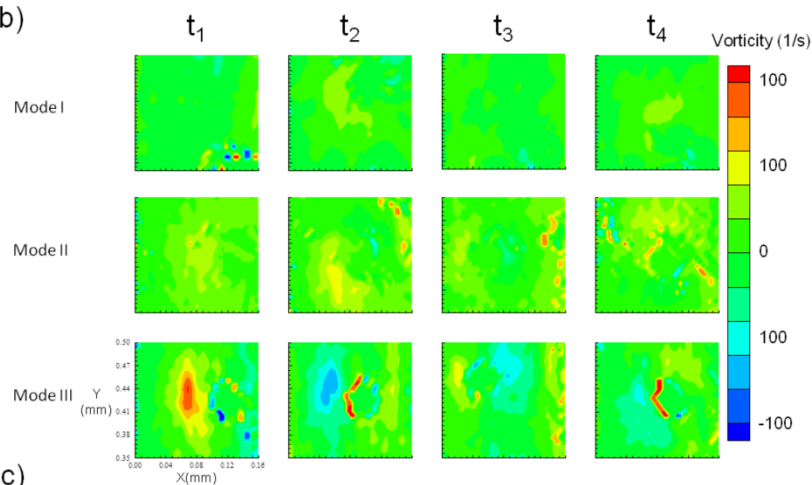
Chen, C.-Y. et al: Artificial Cilia Micromixer

(4) Vorticity and Probability Density Function (PDF) results for flow fields induced by artificial cilia under three different modes of actuation using μ PIV analysis (Figure S3) : Three actuation modes were analyzed by μ PIV (a), and obtained vorticity distribution on x-y plane (b) as well as calculated probability density function results (c) obtained at four distinct time points. Among these three modes of actuation, mode III has the largest probability to generate the substantial vortices with high magnitude.

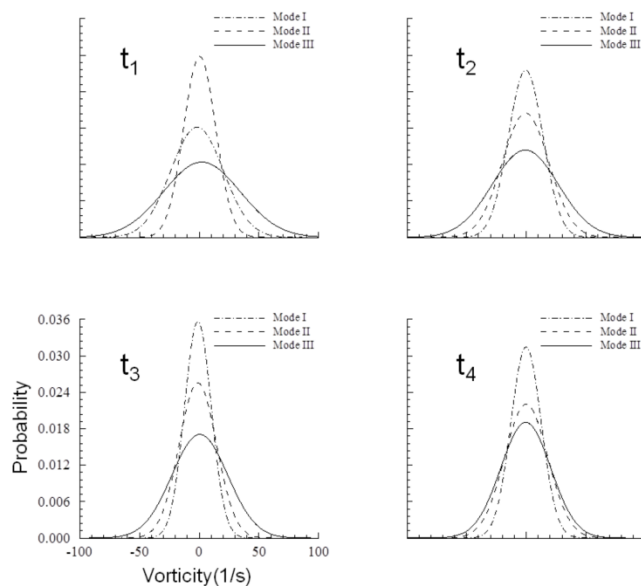
(a)



(b)



(c)



Chen, C.-Y. et al: Artificial Cilia Micromixer

(5) 3D numerical analysis of induced flow fields in mode I, II, and III using FSI module. (Figure S4) : Left, middle, and right columns: flow fields acquired during the actuation mode I, mode II, and mode III, respectively. V_z velocity distribution along transverse plane (a) and sagittal plane (b). (c): Spatial locations of the induced flow vortex cores (marked in red). The in-plane fluid path is denoted by black line. Among these three modes of actuation, the highest induced out-of-plane velocity (V_z) and largest vortex radius were both found in mode III.

