CELL TRAPPING VIA COUNTER-ROTATING MICRO-VORTECTES

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ABSTRACT

Trapping of suspended cells is fundamentally important for cellular studies. This work presents a suspended oscillating micro-plate, actuated by Lorentz force law, and generated a pair of counter-rotating micro-vortices to trap bioparticles. In contrast to other approaches, this microfluidic device allows bio-particles to flow freely through unobstructed region, trapped, and controlled release. The trapping force is in pico-Newton range, and varies linearly with the flow. This hydrodynamic approach should be useful for controllable trap/release of bioparticles.

Keywords: Micro-vortices, Microfluidics, Lorentz force, Trapping of cells

1. INTRODUCTION

Recent interests in cellular studies, microfluidic devices play an important role for providing the platform for biological applications because microfluidic devices are easy to fabricate, convenient to control, and fast to process of detection. Cell trapping devices are based on mechanical and electrical principles. However, little is done on cell trapping in a local region using gentle environment without perturbing the properties of cells. Although the optical tweezers (OT), dielectrophoresis (DEP), acoustical tweezers (AT) methods can trap cells in suspension, they might harm the cells. Recently, some have utilized hydrodynamic approaches, particularly vortical flow. Shelby et al. [1] utilized microvortices to manipulate a bioparticle and measured its rotation rate within a confined region, and applied the technique to nano-particles [2]. Lutz et al. [3] trapped cells using microeddies behind circular cylinder. The purpose of this study is to present an entirely new device leveraging on a pair of counter-rotating micro-vortices to trap bioparticles. In contrast to other approaches, this device allows bioparticles to flow freely through unobstructed region, trapped, and controlled released.

2. EXPERIMENTAL

The device is in resonance and actuated based on Lorentz law. Alternating current (140kHz) flows along a suspended microelectrode thin-plate structure with direction normal to an external magnetic field (~1 Tesla), forcing the structure to oscillate in the third direction (Fig. 1). The oscillatory structure induces flow non-linearity at the two plate edges (parallel to its centerline) causing an adverse time-mean pressure gradient in the direction outward from its centerline. The net result is inducing a pair of counter-rotating micro-vortices.
Fabrication methods utilized conventional lithography. Silicon wafer coded with silicon nitride (~1µm) was sputtered with metallic layer (0.15µm thickness of Cr/Au). Photoresist (Shipley 1813) was patterned to define the microelectrode structure. Unnecessary metal was removed by etchant. By repeating the procedure of coating photoresist and developing, the cavity underneath the oscillatory structure was formed. Reactive ionic etch (RIE) removed the silicon nitride unprotected by photoresist. Potassium hydroxide (KOH) performed bulk micromachining to remove unwanted silicon to suspend the structure, as shown in Fig. 1B.

3. RESULTS AND DISCUSSION

Results in Fig. 2A shows the counter-rotating micro-vortices above the two edges of the oscillatory structure. The fluid was drawn by low pressure in the center of the plate (from simulation) and flows outward, loops upward (adverse pressure gradient at the edges), and returns to the plate. Moreover, this swirling velocity is easily controllable by adjusting the input voltage to the microelectrode structure (via changing the oscillatory displacement). Figure 2B shows the relation between the angular velocity of the flow and input voltage is distinct and parabolic.

Trapping study used polystyrene particles (10µm) injected into the PDMS channel by a syringe pump. Figure 3A shows a particle approached the structure (left trajectory) and eventually trapped by the micro-vortices. By increasing the background flow velocity, controlled release of the trapped particle is demonstrated. Quantitatively, for example, the
micro-vortices can trap the particles under 140µm/s background flow at 7V (peak to peak) input voltage (Fig. 3B). Using Stokes drag on a sphere \( F = 6\pi \eta U a \) where \( \eta \) is the viscosity, \( U \) the velocity, and \( a \) the particle radius, the maximum trapping force is calculated against a fixed vortex velocity (expressed as \( \text{Re}\Gamma = \Gamma / \eta \), where \( \Gamma = \int \nu \cdot dl \) or the circulation of a vortex) as the background flow is increased.

Figure 3. Trapping of 10µm particles by micro-vortices. (A) Trajectory of a particle being trapped (left dotted line) and upon release (right dotted line). When the background flow velocity is greater than the trapping force, the particle is released. (B) Map of trapping force verse Reynolds number of micro-vortices (as defined in the text). The gray region illustrates the boundary between trapped and untrapped regions. The Reynolds number scale (\( \text{Re}_f = U h / \eta \)) on the far right ordinate characterizes the flow in the microchannel.

4. CONCLUSIONS

This research describes a non-contact approach of rotating, controlling, and quantifying suspended microparticles via micro-vortices generated by an oscillating thin plate. This device combined with the simple theory, controllable trapping strength, and small trapping region identify the oscillating plate as a potential candidate may be integrated easily for other applications, such as cell cultural platform, drug detection, and various bioassays.

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REFERENCES

