Microfluidic applications in optical trapping

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Abstract: *Current research techniques that seamlessly combines optical trapping and microfluidics have blended into a symbiotic relationship to achieve ever more complex application, allowing for a full control of an organism (cell, bacterial, molecule, etc.). Here we review the latest applications of microfluidics, especially the ones fabricated with PDMS, together with optical trapping. Introducing some optical trapping configurations and typical fluidic systems that are employed mainly in biological systems such as single cell sorting/analysis, and single molecule applications (DNA/RNA). We conclude with our implementation of both systems towards characterizing sperm cell motility.*

Key-Words*: Optical trapping; optical manipulations, lab-on-a-chip, microfluidic chip, Optical tweezers.*

Introduction: Current research techniques that seamlessly combines optical trapping and microfluidics have blended into a symbiotic relationship to achieve ever more complex application, allowing for a full control of an organism (cell, bacterial, molecule, etc.) and its environment. Optical trapping is based on the transfer of momentum from photons to a transparent object immersed in a medium of different refractive index. The high photon flux sources, in lasers, provides sufficient momentum transfer to manipulate microparticles, as originally demonstrated by Ashkin in 1970.**[1]** The most common optical trapping configuration is a one-beam gradient trap, known as optical tweezers.**[2]** This trap is created when a continuous-wave laser beam is introduced into an optical microscope, in such a way that the generated radiation force at the focal point (in the image plane) can selectively trap a micro/nanoparticle suspended in a liquid medium by using a high numerical aperture objective.**[3]** Most commercial systems for optical trapping uses near-IR lasers in the range of 800–1100 nm in order to minimize the risk of damage by heating of the handled object. **[4]** Manipulating forces are on the order of 10 fN to 100 pN**,[5]** well within the range of most molecular interactions, this is the reason that optical tweezers have been an invaluable tool in biological cell research.**[6]** Meanwhile, microfluidic techniques started to play an increasingly important role towards discoveries in cell biology, neurobiology, pharmacology, and tissue engineering.**[7]** The combination of optical micromanipulation techniques with microfluidics renders a non-contact and contamination-free environment that has been successfully employed for in positioning and classifying cells,**[8,9]** by moving specific cells it into different parts of the microfluidic chamber system, independent of the flow direction of the surrounding media.

Experimental: Different materials such as poly(dimethylsiloxane) (PDMS), and borosilicate glass have been used to build a microfluidic chip, with the accompanying optical trapping. PDMS is by far the most dominant material for fabricating cell culture chip. Standard fabrication techniques could be employed using advanced clean room facility and electron beam lithography, or a 1200 dpi resolution laser printer in a standard laboratory. This low-cost approach is used to produce the fluidic channels layout pattern, with 20–30 μm wide channels and 15 μm deep.**[10]**

Results and discussion: Optical trapping allows detection of individual biological nanoparticles, such a single HIV-1 virus, in fluid close to physiological conditions.**[11]** With microfluidic and optical trapping single cell can be stressed by changing the osmolarity around a typical yeast cell thereby observing a volume change. This can be done repeatedly and rapidly (less than 0.2 s) enabling analysis of cytological responses (pH, osmolarity, ion concentrations, and access to nutrition or potential drugs).**[12]** A counter-propagating laser, delivered from optical fibers can be embedded directly into the PDMS fluidic device, this is known as an optical stretcher, and has been applied to stretch erythrocyte and eukaryotic cells. Measuring the cell deformation from the video microscopy, the measurements of cytoskeletal elasticity can be determined.**[13]** This can be compared to an alternate approach for measuring the elastic properties of red blood cells using a modified optical fiber tip.**[14]** Previous applications of micromanipulation in microfluidics on cells are presented as a review for the years 2002-2005, which in the last ten years has greatly changed especially for optical manipulation.**[7]** While different microfluidic applications starting from the optical micromanipulation community was initially focused on spectroscopic characterization of cells and the establishment of micro gears for fluid flow.**[15]** In the low Reynolds number regime, fluid flow is laminar, and this could be used to easily oriented cells to line up in a row, which could later be separated and sorted out with an optical trapping into microchannel **[16,17]** or dual-

microchannel**.[18,19]** However, the laminar flow might not be ideal and there is a need for turbulent flow as in a vortex. For this case, optical micro/nano-rotors was developed within a microfluidic device, they are extremely useful for particle transport or induce curl flows within a laminar flow device at the micro and nanoscales, while being optically powered they require no mechanical contact and no electrical wire.**[20]** For these systems micro-pumps have been designed with flow speeds up to 4 μm/s in a 6μm wide channel,**[21]** these are useful for nanomachines in biomedical applications, drug delivery, nanoscale surgery, and basic study of the cell.**[22]**

Conclusion: Microfluidic devices are becoming widespread tools in cell biology and medicine because of their ability to analyze single cells or molecules with a high throughput. However, the lack of precise positioning control makes this tool incomplete, thereby merging successfully with the use of optical trapping as a complementary tool ensures precise position control inside a micro fluidic chamber. A review of trapping configurations and sample analysis has been presented for the last few years. New applications of both techniques are sure to be presented. Our ongoing research is going to explore bovine sperm cell motility that requires special environmental conditions that should be provided by a microfluidic device, enabling several studies also with the optical tweezers technique. In addition, we hope to validate mathematical models of mobility on single sperm cell motion and study the thrust provided by the flagellum under different conditions.

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