Opto-fluidic micromanipulation system based on integrated polymer waveguides

P. JÁKL[a*], M. ŠERÝ[a], J. JEŽEK[a], P. ZEMÁNEK[a], P. ORMOS[b], S. VALKAI[b], L. KELEMEN[b]
[a]*Institute of Scientific Instruments, Academy of Sciences of the Czech Republic, Královopolská 147, 612 64 Brno, Czech Republic*
[b]*Institute of Biophysics, Biological Research Centre of the Hungarian Academy of Sciences, Temesvári krt. 62, P.O. Box 521, H-6701 Szeged, Hungary*

In this paper we present simple tool based on radiation pressure which is useful for manipulations with microobjects. It consists of three photopolymerized waveguides attached to planar surface. With precise setting of outgoing light power, we demonstrate controlled movement of micrometer-sized particles and their clusters. We also show separation of particular particle from a cluster into area outside the active region.

(Received November 15, 2006; accepted June 27, 2007)

Keywords: Radiation pressure, Colloidal particle, Optical trap, Light scattering, Opto-fluidic systems

1. Introduction

Integration of optical micromanipulation techniques and microfludic systems becomes very promising step forward to the future generation of lab-on-a-chip devices. Optical micromanipulation techniques became well-known especially due to the optical tweezers [1] – a device that uses single focused laser beam to trap and spatially transfer objects of sizes from tens of nanometers to tens of micrometers. Within the last two decades, a lot of new applications and methods have been developed in this field [2]. Some of them – optically controlled pumps, valves or switches [3–7], optical sorting [8,9], and fiber optical traps [10–13] – are very promising especially in microfludics because of their easy integration to these systems. They all together offer trapping, control of the micro-object motion, position sensing and optical spectroscopy. Unfortunately the frequently used commercial optical fibers have the cladding in hundreds of micrometers and the core diameter is in the range of 5–7 μm. These sizes complicate easy integration of the commercial optical fibers. Therefore we used polymer waveguide manufactured by photopolymerization [14] which provides complete control of the dimensions and topography of the waveguide.

2. Experimental set-up

The waveguides were prepared on a coverslip glass surface. First, a 15 μm thick layer of cureable optical adhesive (NOA 81, Norland Products, Inc., USA) was deposited on the glass surface by spin coating. In the next step the structure of the waveguides was drawn into the layer by the following procedure: The cover slip with the adhesive layer was positioned upon the motorized stage of an inverted microscope (Zeiss Axiovert 200). The light from a blue laser diode (405 nm, 35 mW) was focused into the adhesive layer by a 10X objective (Zeiss). The light polymerizes the adhesive in the focal region over a spot wide about 15 μm where the solid structure is formed and bound to the glass surface. The unexposed regions remain liquid. To draw the required pattern into the adhesive layer the sample was moved by the motorized stage along a preprogrammed trajectory. The movement of the microscope stage, together with a shutter in the laser light beam to switch the light on and off at appropriate positions was controlled by a home built computer program written in LabVIEW. After the writing process the unexposed and consequently fluid resin was dissolved and washed away by a 3:1 acetone-ethanol solution. In order to have flat input faces we cleaved the waveguides by breaking the glass at each designed point of incoupling. The cleaved waveguide structure with proper surfaces for incoupling was cemented to a glass substrate plate and finally the three optical fibers were also fixed one by one to the substrate at the input face of the waveguides. We chose three waveguides arranged so that free space of a length of 40 μm was obtained.

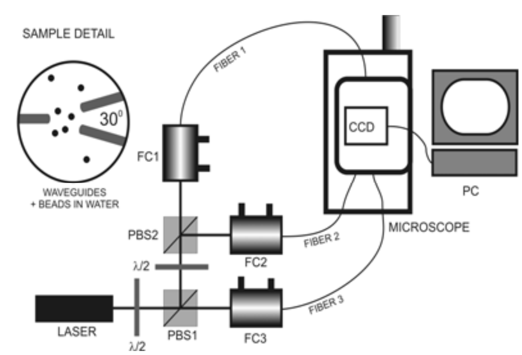

Fig. 1. Experimental setup. Laser beam passes through lambda half-plates λ/2 and polarizing beamsplitters PBS1 and PBS2, which control the power input into particular fibers. The beam is introduced to fibers through fiber couplers FC1, FC2 and FC3. The experiment is watched via the CCD camera and stored on personal computer.

The light from the laser Verdi V6 (Coherent, λ=532 nm) was coupled to the optical fibers so that the power in each fiber could be controlled (see Fig. 1). The final spatial distribution of the light between the waveguides was visualized by fluorescently labelled polymer nanoparticles 63 nm in diameter (R60, Duke Scientific – see Fig. 2).

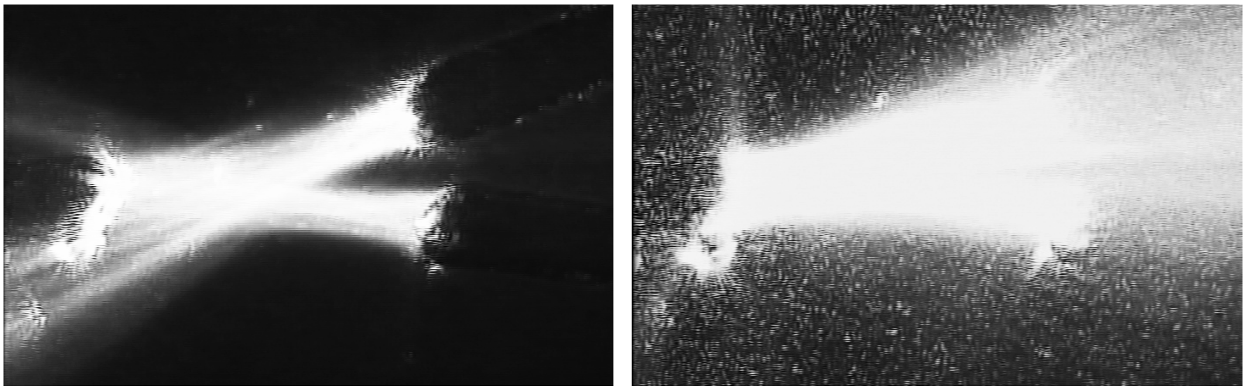

Fig. 2. Light coming out of the two right waveguides (left) and out of all three waveguides (right). The light is visualized by fluorescent nanobeads of 63 nm diameter.

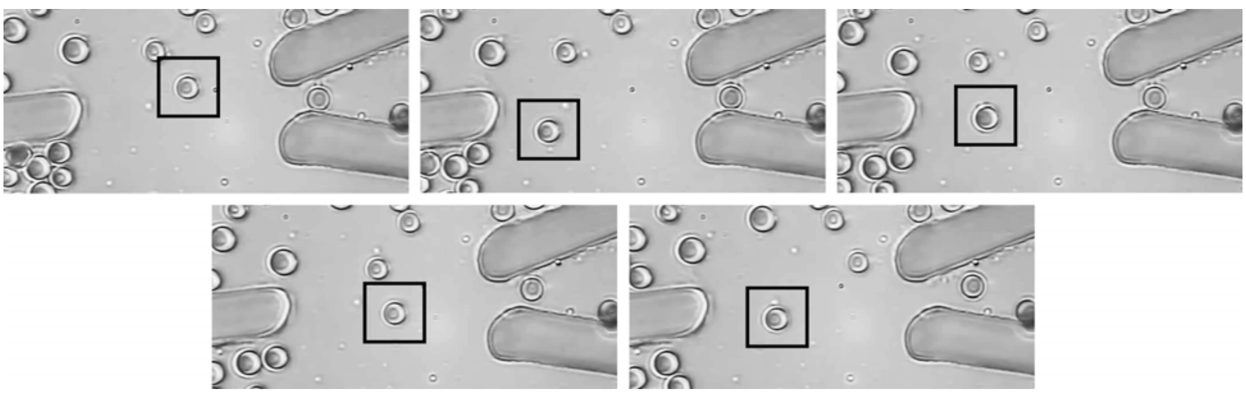

Fig. 3. Single polystyrene bead of diameter 5 μm is confined in between the waveguides. Its motion in the lateral plane was controlled by the power coming out of each waveguide.

3. Micro-objects manipulations

We injected polystyrene objects into the free space between the waveguides filled with water. The control of the power in each waveguide provides a tool to manipulate a single micro-object (see Figs. 3 and 4). It is seen that even if the spatial distribution of the light was far from perfect, the power control in this arrangement is flexible enough to ensure reproducible lateral manipulation of such small object as a 1 μm polystyrene bead. Any types of microobjects that have refractive index higher than the surrounding medium can be used. This set-up is not limited only to manipulation of single object but also a cluster of objects can be trapped, aligned and transported (see Fig. 5).

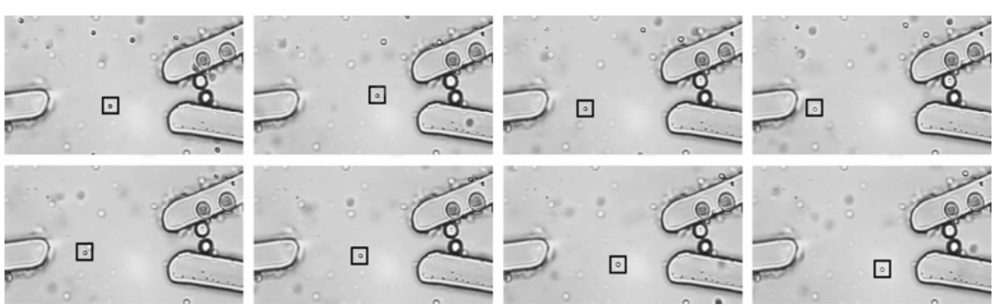

Fig. 4. Lateral position control of polystyrene bead of diameter l μm in the region between the waveguides.

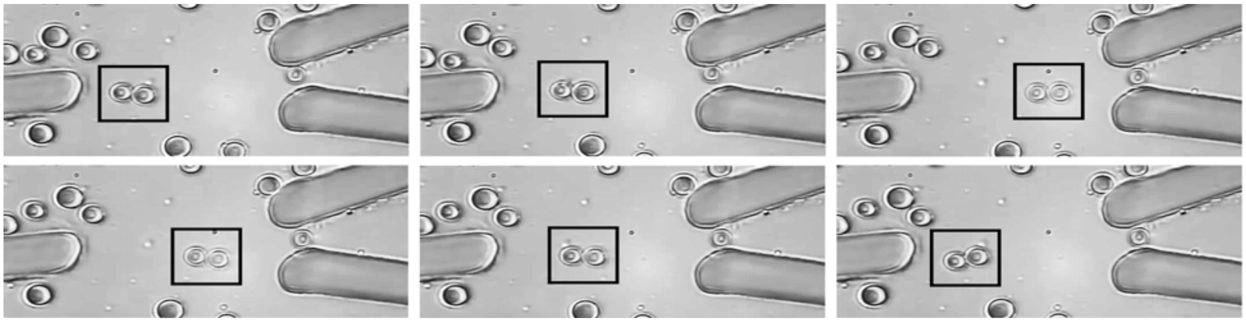

Fig. 5. Manipulation of two polystyrene beads of diameter 5 μm. The power coming out of the two right waveguides was changed to push the objects against the single fiber on the left.

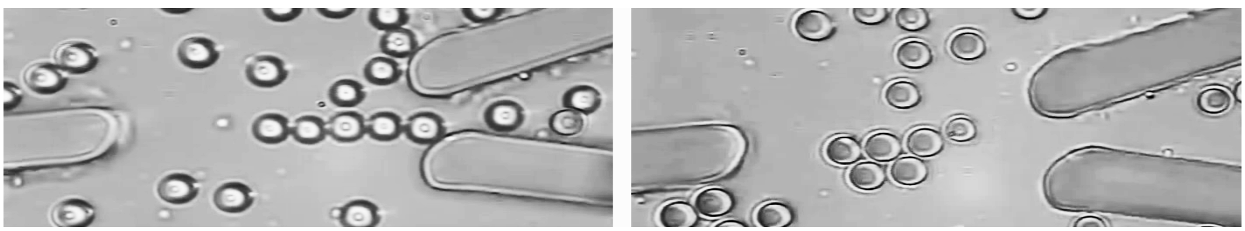

Fig. 6. Five polystyrene beads of diameter 5 μm arranged into a linear array (left). Cluster formation of 5 μm polystyrene beads between the waveguides if the outcoming power is increased (right).

Linear array of microobjects can also be obtained. Objects with higher refractive index than the surrounding medium are aligned in the beam with the highest light intensity. With increasing power in each waveguide even more microobjects are confined in the intersection of all three beams. In this case they are not aligned into linear array but form clusters as it is seen in Fig. 6.

The used geometry of the waveguides enables also the disposal of unwanted microobjects. If the object is pushed by the light coming out of the left waveguide between the two waveguides on the right, it is removed from the central region and is no more influenced by the radiation pressure (see Fig. 7).

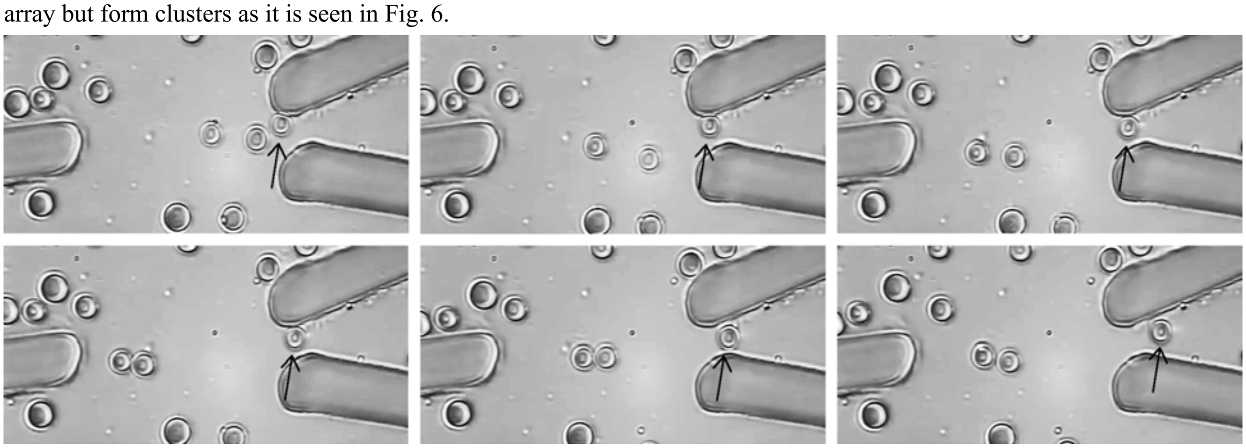

Fig. 7. The bead marked by the arrow is pushed out of the central region by the radiation pressure coming from the left waveguide. It is pushed in between the two waveguides on the right and so it is irreversibly separated form the others objects in the central region between the waveguides.

3. Conclusions

In this paper we present how the potential of photopolymerization can be employed to manufacturing polymer waveguides integrated in microfludic system. Light coupled to these waveguides control the motion of microobjects dispersed in the fluid between the waveguide via the radiation pressure.

Independent control of the light power coming out of each fiber provides simple but efficient tool to laterally manipulate microobjects, align them into arrays and even to sort them. Even though this method has been tested on well defined polystyrene objects of diameter 1 and 5 μm, it can be applied to any other type of microobjects including living cells. Therefore together with optical diagnostic methods it could find many applications in the future generation of light controlled lab-on-a-chip systems.

Acknowledgements

This work was supported by the GA AS CR (grant No. KJB2065404), by the AS CR (IRP No. AV0 Z20650511), by Országos Tudományos Kutatási Alap T046747 and by EC FP6 ATOM 3D Contract No 508952.

References

[1] A. Ashkin, J. M. Dziedzic, J. E. Bjorkholm, S. Chu, Opt. Lett. **11**, 288 (1986).
[2] M. J. Lang, S. M. Block, Am. J. Phys. **71**, 201 (2003).
[3] P. Galajda, P. Ormos, Appl. Phys. Lett. **78**, 249 (2001).
[4] A. V. Terray, J. Oakey, D. W. M. Marr, Science **296**, 1841 (2002).
[5] P. Galajda, P. Ormos, Appl. Phys. Lett. **80**, 4653 (2002).
[6] S. L. Neale, M. P. MacDonald, K. Dholakia, T. F. Krauss, Nature Materials **4**, 530 (2005).
[7] L. Kelemen, S. Valkai, P. Ormos, Appl. Opt. **45**, 2777 (2006).
[8] M. P. MacDonald, G. C. Spalding, K. Dholakia, Nature **426**, 421 (2003).
[9] T. Čižmár, M. Šiler, M. Šerý, P. Zemánek, V. Garcés-Chávez, K. Dholakia, Phys. Rev. B **74**, 035105 (2006).
[10] A. Constable, J. Kim, Opt. Lett. **18**, 1867 (1993).
[11] E. R. Lyons, G. J. Sonek, Appl. Phys. Lett. **66**, 1584 (1995).
[12] K. Taguchi, H. Ueno, M. Ikeda, Electron. Lett. **33**, 1249 (1997).
[13] C. Jensen-McMullin, H. P. Lee, E. R. Lyons, Opt. Express **13**, 2634 (2005).
[14] H. Misawa, K. Sasaki, M. Koshioka, N. Kitamura, H. Masuhara, Appl. Phys. Lett. **60**, 310 (1992).

* Corresponding author: jakl@isibrno.cz