# Integrated VCSEL Trap Arrays for Microfluidic Particle Separation and Sorting

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*We introduce a novel concept of particle manipulation in microfluidics based on integrated linear arrays of optical traps. The integration into the microfluidic system is enabled by using vertical-cavity surface-emitting lasers as trap sources. Device layout and fabrication as well as simulations of the sorting process are presented.*

## 1. Introduction

Microfluidic systems have evolved into an important tool in cell analysis, especially on the single-cell level, where conventional flow cytometry techniques are no longer convenient. Here, high throughput operation is not essential but small sample volumes and a possible integration of serial analysis steps. A basic analysis process is the sorting and separation of particles, where the use of optical forces has gained increasing interest owing to their independence on electrical charges and the compatibility to biological material [1]–[4]. To avoid the bulky and expensive optics commonly used to create optical traps, different approaches have been published which enable an integration into the microfluidic system [5, 6]. Here, the use of vertical-cavity surface-emitting lasers (VCSELs) offers not only small dimensions, high beam quality and low costs, but also a direct transfer of the sorting scheme presented in [1] and [2] into the microfluidic system. The concept is based on tilted arrays of optical traps, where the drag caused by the fluid medium is of the same size as the trapping force of each trap. Therefore, the traps will not fix a particle completely, but only deflect it from its initial flow direction as it passes by. So, while passing the traps, the particle follows the tilt of the array as it moves from the domain of one trap to the next. In this article we present a new approach based on one-dimensional VCSEL arrays directly integrated beneath microchannels to realize this sorting scheme in compact devices [7].

## 2. Device Layout and Simulation Results

Figure 1 shows the schematic of the integrated optical trap array which is based on top-emitting VCSELs with 850 nm emission wavelength. Photoresist microlenses are integrated on the output facets to focus the beam into the microfluidic channel which is placed on a 30 μm thin glass substrate [6]. The lenses are fabricated by a thermal reflow process and have radii of curvature of about 20 μm. Furthermore, a shallow surface relief is etched into the top mirrors to enhance transverse single-mode emission. In a similar

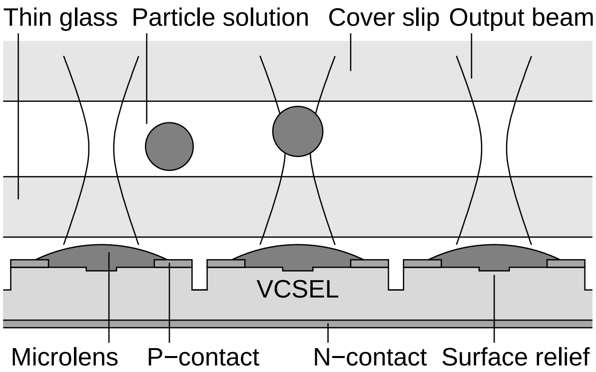


**Fig. 1:** Schematic of the integrated trap array.

setup with a single lensed relief VCSEL, we already demonstrated deflection, elevation and trapping of 10 µm diameter polystyrene particles with optical powers as low as 5 mW [6].

To determine the appropriate dimensions of the trap array like trap distance or tilt angle, we performed simulations of the separation process. The trapping potential created by a parallel beam with a transverse, Gaussian-shaped intensity profile was calculated based on a ray optics model [8]. The potential was then extended to a linear array, forming a two-dimensional potential profile. By solving the equation of motion including fluidic drag forces, the movement of a particle through the array can be determined. Figure 2 shows the result for a 15 µm diameter polystyrene particle passing a trap array tilted by 10°, where the water velocity is 90 µm/s. Each trapping beam has 5 mW of optical power, a diameter of 8 µm (based on experimental results on lensed relief VCSELs), and

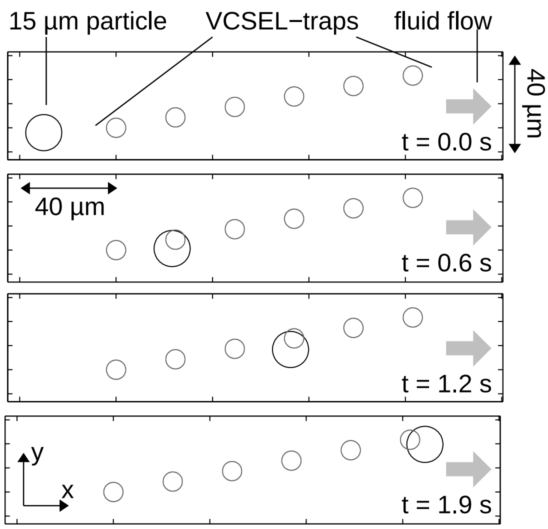


**Fig. 2:** Calculation of particle movement through a 10° tilted array of VCSEL traps for different points in time (top view on the microfluidic channel).

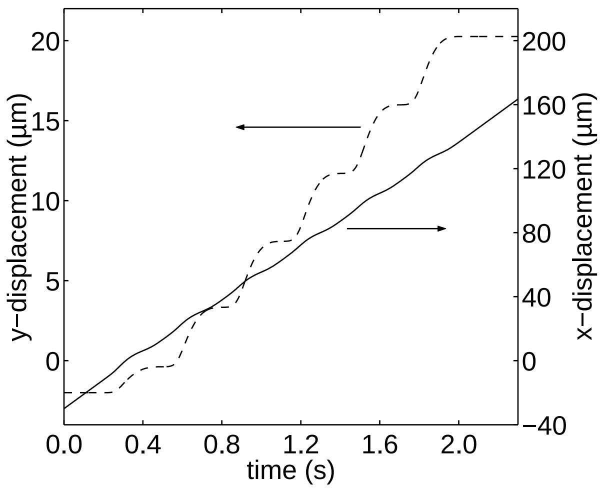


**Fig. 3:** Calculated $x$- and $y$-displacement in dependence on time for the particle movement shown in Fig. 2.

the trap distance is 25 µm. Caused by the six-trap array, the particle is deflected by more than 20 µm in $y$-direction, while the movement in $x$-direction is only slightly disturbed, what can be seen in Fig. 3, showing the the $x$- and $y$-displacement in dependence on time. Thus, a separation of specific particles can be performed by switching the array on or off. Since the interaction between trap and particle is dependent on particle properties like size or refractive index, also sorting can be achieved, e.g. 10 µm particles are not deflected for the above given conditions.

## 3. Conclusion

Integrated VCSEL trap arrays promise separation and sorting on the single-cell level in compact devices which are still compatible to other analysis steps like Raman spectroscopy, fluorescence analysis or electrophoresis. First experiments on particle manipulation confirmed the concept of the integrated trap and simulations were performed to analyze the separation process in trap arrays. The achieved results were used for specialty array design. VCSEL array fabrication is currently in progress.

## References

[1] M.P. MacDonald, G.C. Spalding, and K. Dholakia, "Microfluidic sorting in an optical lattice", *Nature*, vol. 426, pp. 421–424, 2003.

[2] K. Ladavac, K. Kasza, and D.G. Grier, "Sorting mesoscopic objects with periodic potential landscapes: optical fractionation", *Phys. Rev. E*, vol. 70, no. 1, pp. 010901-1–4, 2004.

[3] R.W. Applegate Jr., J. Squier, T. Vestad, J. Oakey, D.W.M. Marr, P. Bado, M.A. Dugan, and A.A. Said, "Microfluidic sorting system based on optical waveguide integration and diode laser bar trapping", *Lab Chip*, vol. 6, no. 3, pp. 422–426, 2006.

[4] M.M. Wang, E. Tu, D.E. Raymond, J.M. Yang, H. Zhang, N. Hagen, B. Dees, E.M. Mercer, A.H. Forster, I. Kariv, P.J. Marchand, and W.F. Butler, "Microfluidic sorting of mammalian cells by optical force switching", *Nat. Biotech.*, vol. 23, no. 1, pp. 83–87, 2005.

[5] S. McGreehin, K. Dholakia, and F. Krauss, "Monolithic integration of microfluidic channels and semiconductor lasers", *Optics Express*, vol. 14, no. 17, pp. 7723–7729, 2006.

[6] A. Kroner, J.F. May, I. Kardosh, F. Rinaldi, H. Roscher, and R. Michalzik, "Novel concepts of vertical-cavity laser-based optical traps for biomedical applications", in *Biophotonics and New Therapy Frontiers*, R. Grzymala, O. Haeberlé (Eds.), Proc. SPIE 6191, pp. 619112-1–12, 2006.

[7] A. Kroner, A. Gadallah, I. Kardosh, F. Rinaldi, and R. Michalzik, "Integrated VCSEL trap arrays for microfluidic particle separation and sorting", in Proc. *EOS Topical Meeting on Biophotonics and Biomedical Optics*, pp. 140–141. Paris, France, Oct. 2006.

[8] A. Ashkin, "Forces of a single-beam gradient laser trap on a dielectric sphere in the ray optics regime", *Biophys. J.*, vol. 61, no. 2, pp. 569–582, 1992.