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2037-12

Introduction to Optofluidics

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Optical control in integrated optical microfluidic devices

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Introduction to optofluidics

Trieste, 2009

Optical control in integrated optical devices

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- Lóránd Kelemen
- Huba Kirei
- Vilmos Rakovics
- Sándor Valkai

Content

- Fabrication of microfluidics components
  - Optical waveguides
    - Integrated optical switch
    - Integrated optical traps
  - Channels
  - Optical sorter
    - Different sorting schemes
    - Capabilities

Structure building by photopolymerisation

- Lithography
- Direct laser beam writing (2D and 3D)

Preparation of optical waveguides

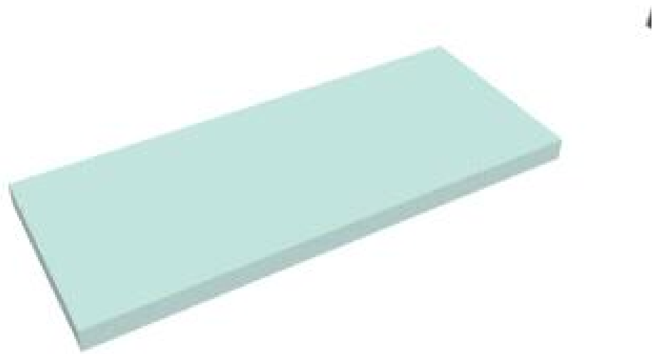
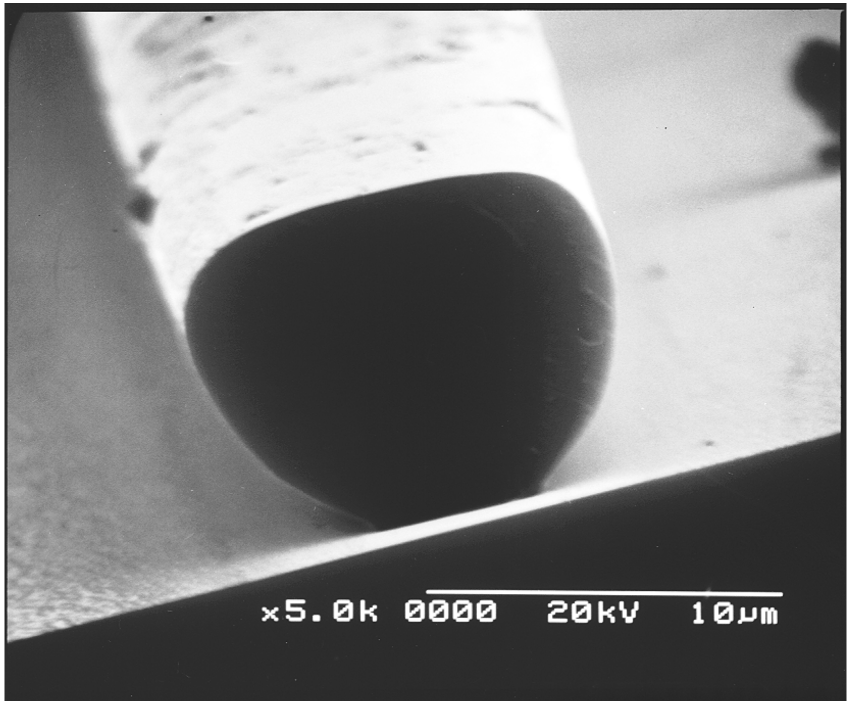
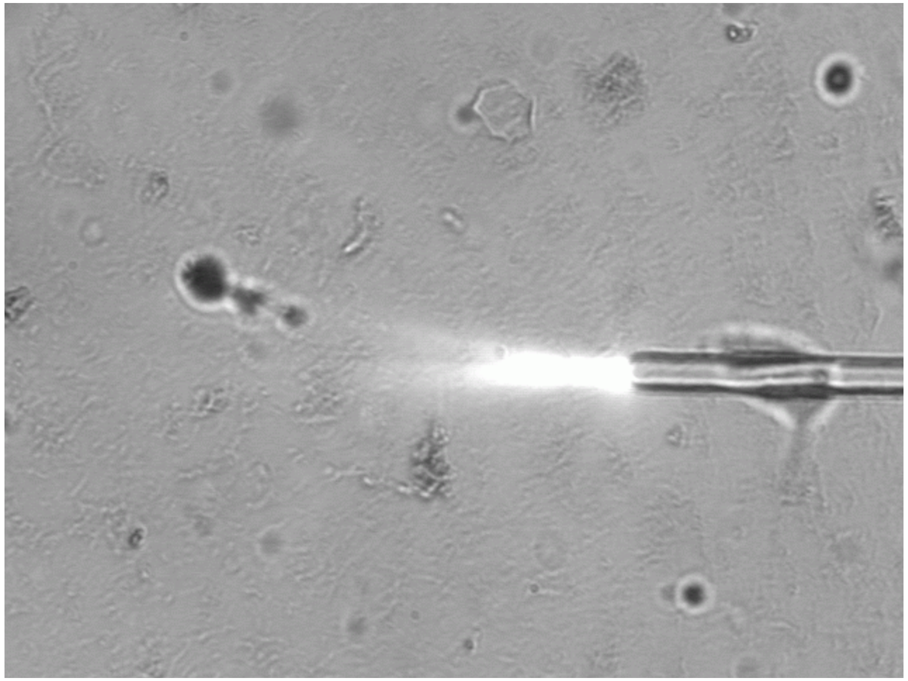


Image of a waveguide

Image of waveguide

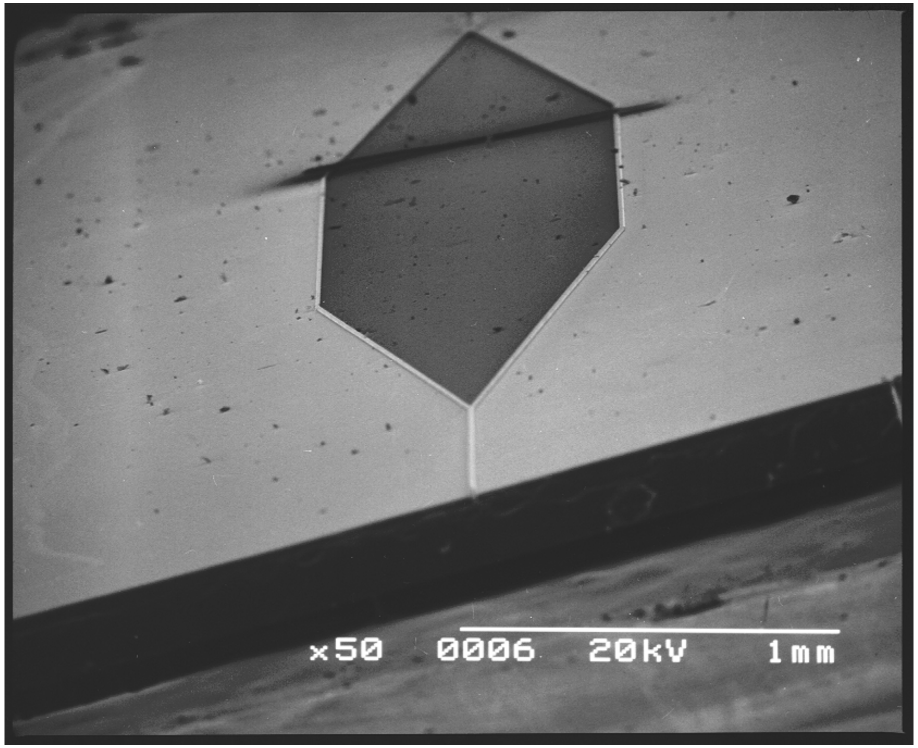


Properties of waveguides



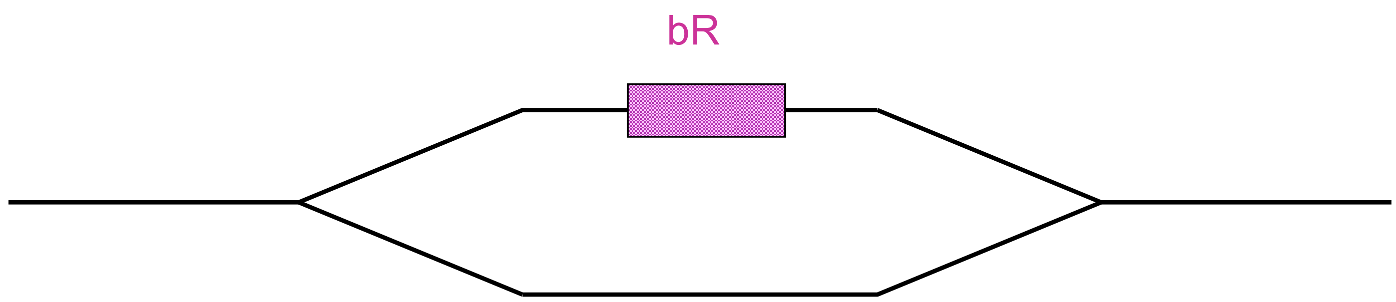
Integrated optoelectronic devices

Mach-Zehnder interferometer



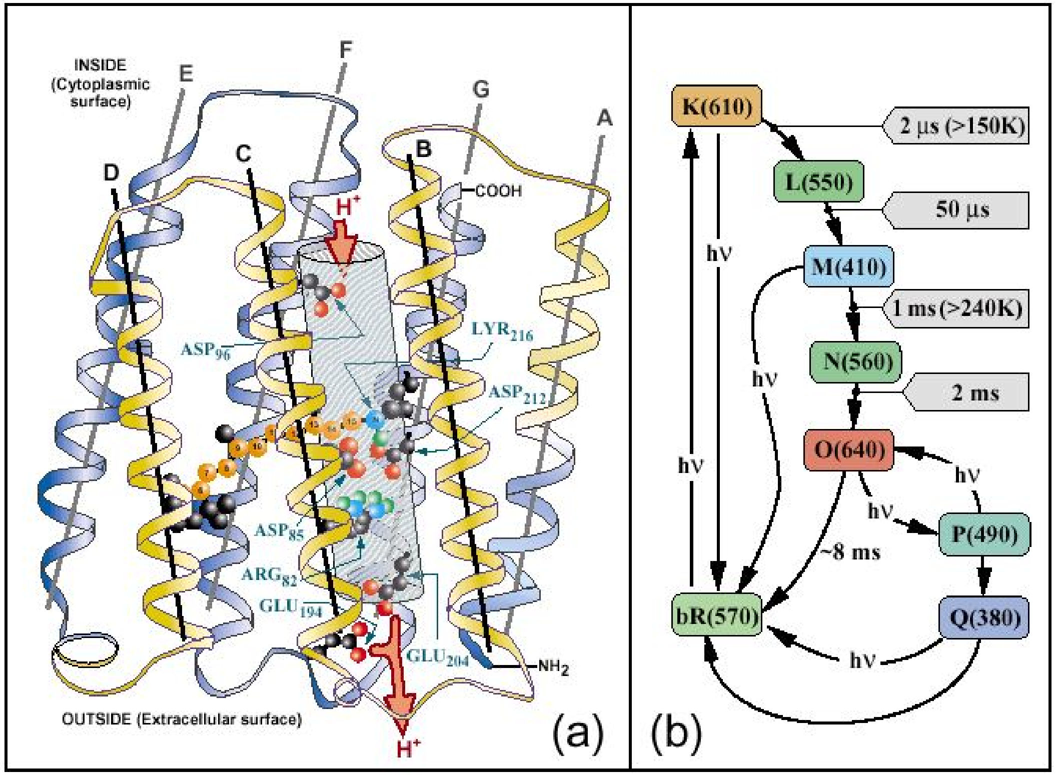
Mach-Zehnder interferometer

with NLO material (bacteriorhodopsin)



Bacteriorhodopsin – the movie

bR plays a model role among ion-transporting membrane proteins

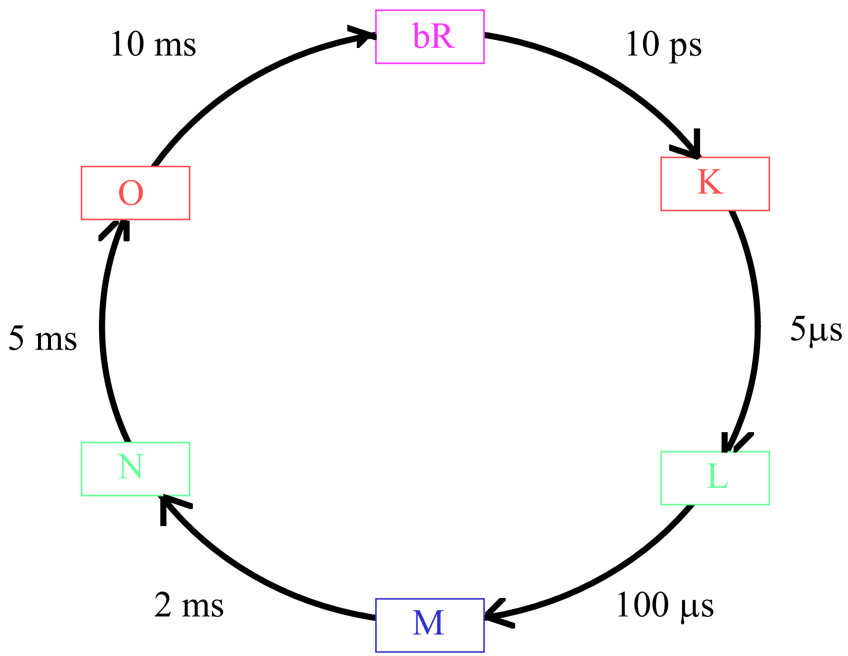


Genetic engineering, chemical and physical modifications -

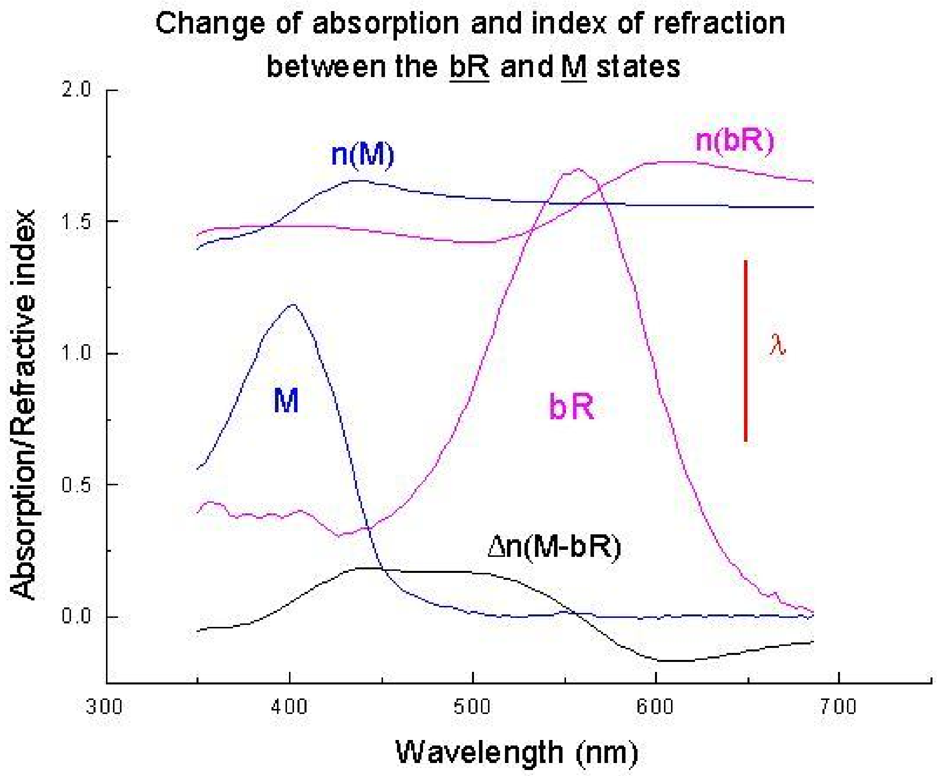
programmable protein

The photocycle

THE PHOTOCYCLE OF BACTERIORHODOPSIN

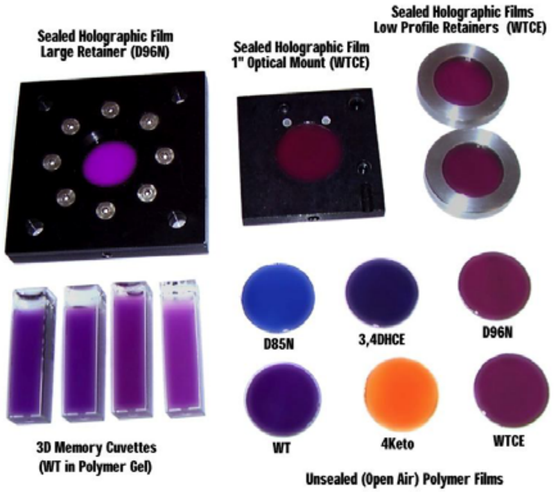


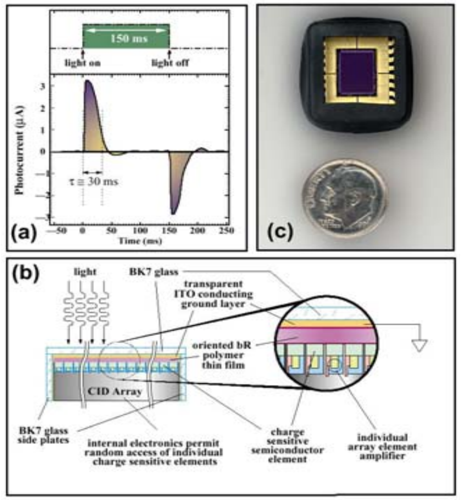
NLO properties of bR



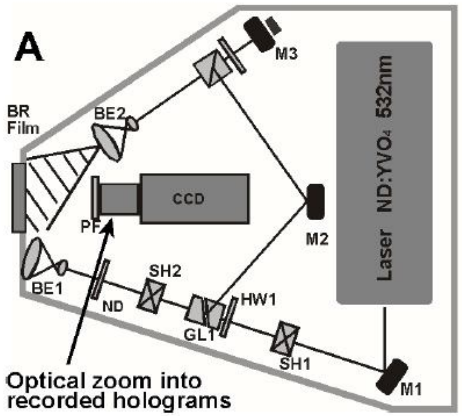
Bioelectronic applications

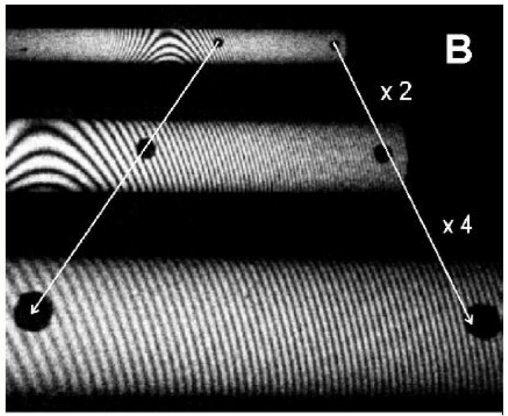
Keck Center for Molecular Electronics at Syracuse University





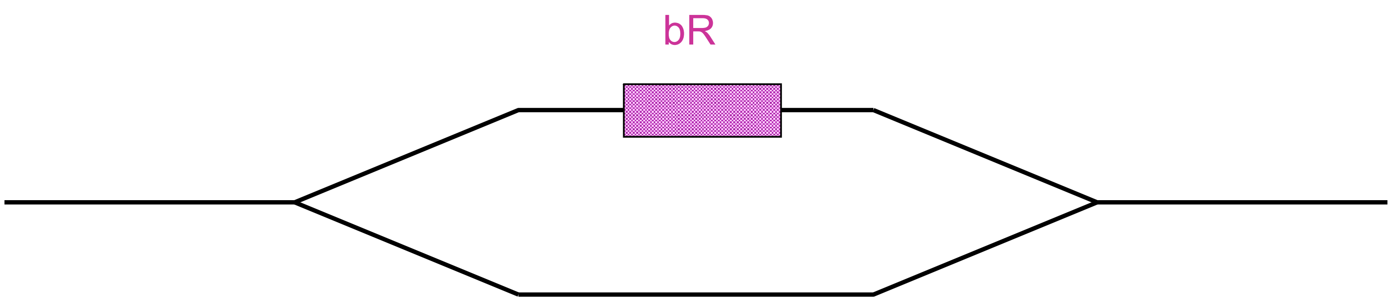
Institute of Physical Chemistry University of Marburg





Mach-Zehnder interferometer

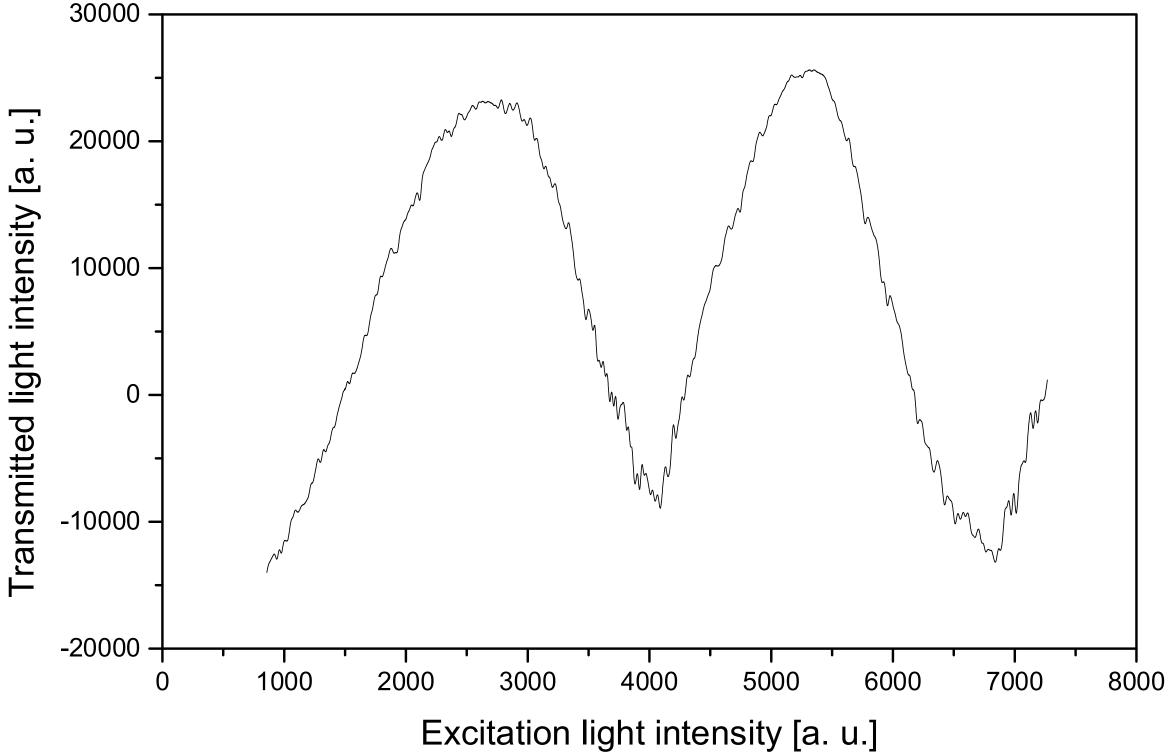
with NLO material (bacteriorhodopsin)



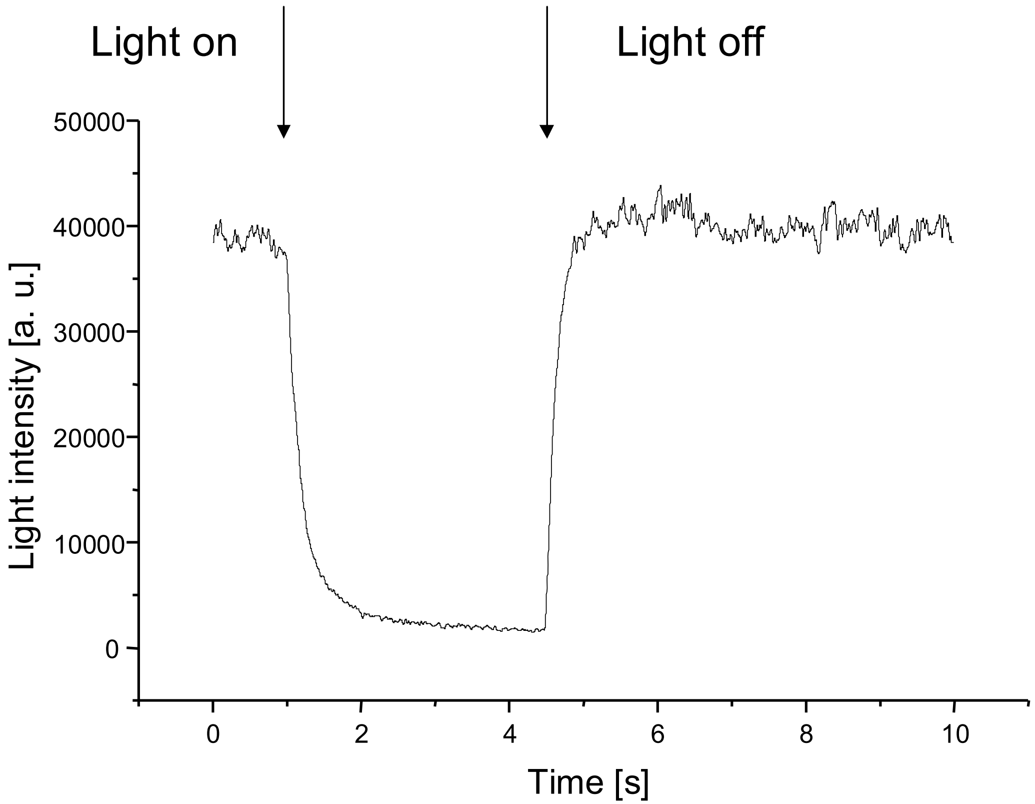
Mach-Zehnder interferometer

Output intensity as a function of light intensity on bR

Illustration of the sensitivity: the total refraction index change $\Delta n = 2*10^{-3}$



Optically controlled optical switch



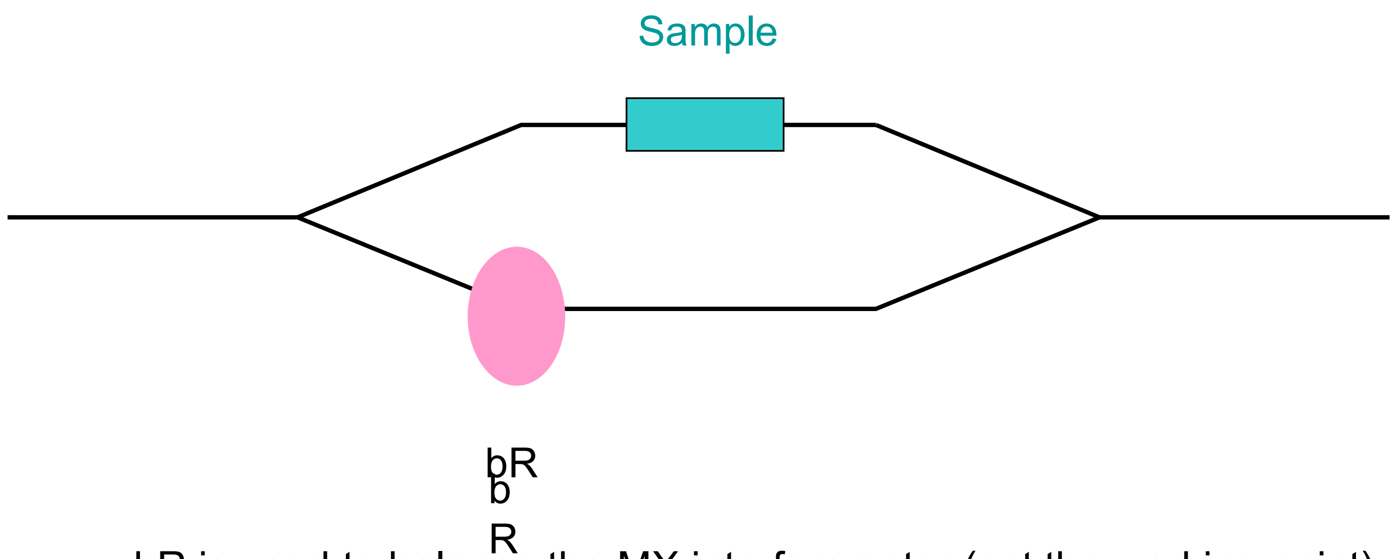
Outlook

- Increase of switching rate (other reactions of the photocycle, modified bR)

- Composite integrated optical structures

- Application in sensorics (combination with microfluidics and microelectronics)

Mach-Zehnder interferometer
as a sensor

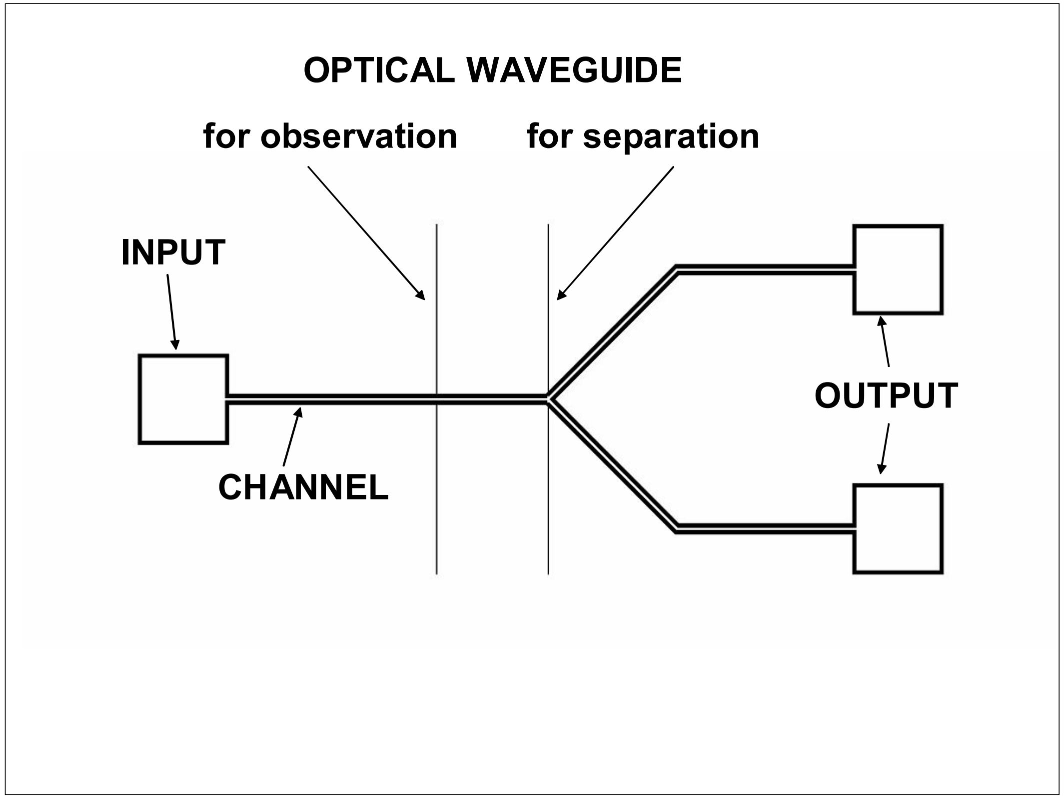


bR is used to balance the MX interferometer (set the working point)

Optical cell sorter

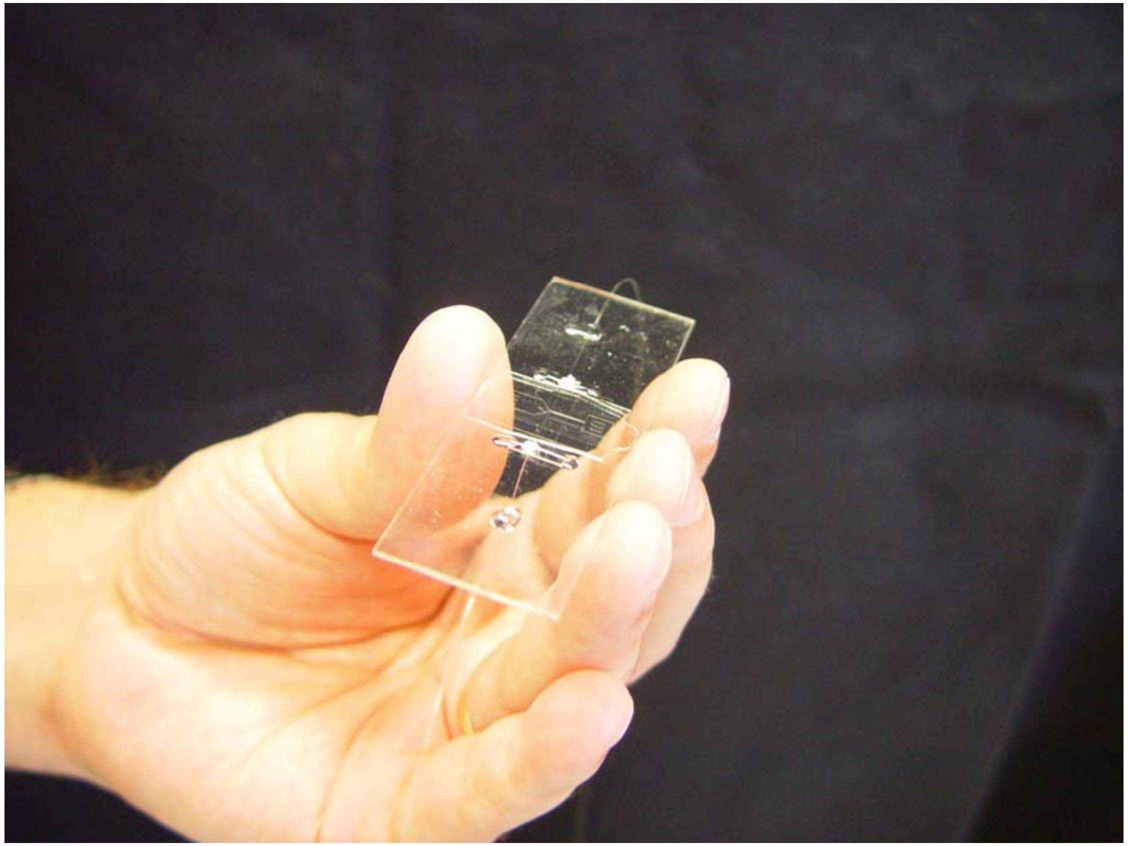
- Fully optical
- Fully integrated
- Made in a single photolythographic step (channel and optical waveguides at the same time from the same material)

Layout

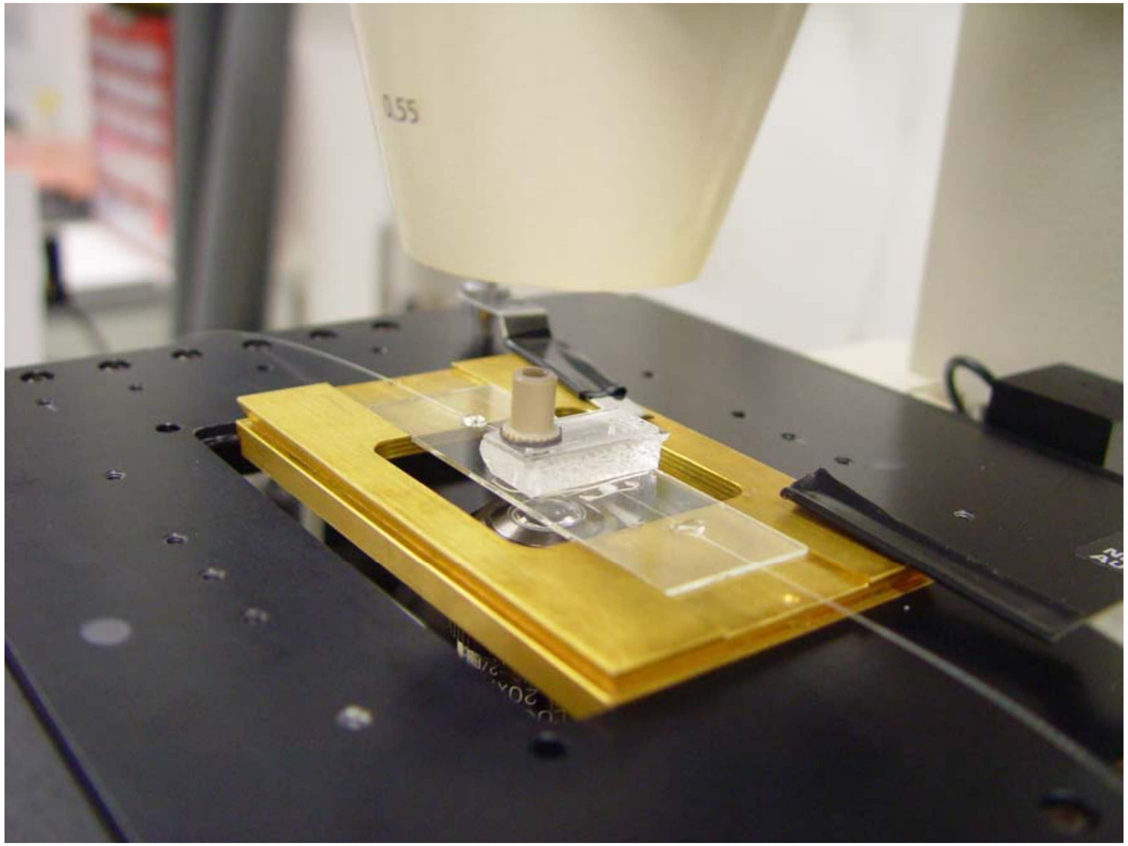


OPTICAL WAVEGUIDE
for observation
for separation
INPUT
OUTPUT
CHANNEL

The device

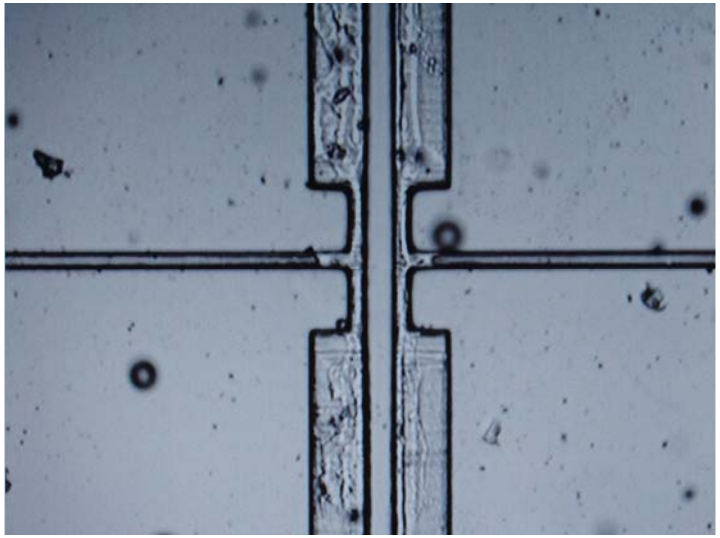


The device

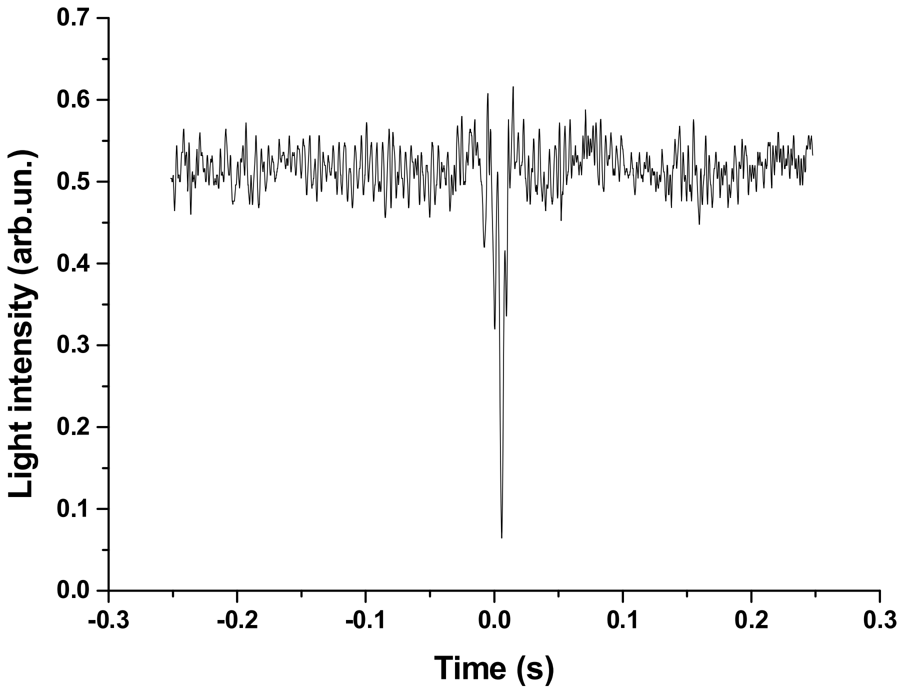


Details

The analysing waveguides
(integrated trap)

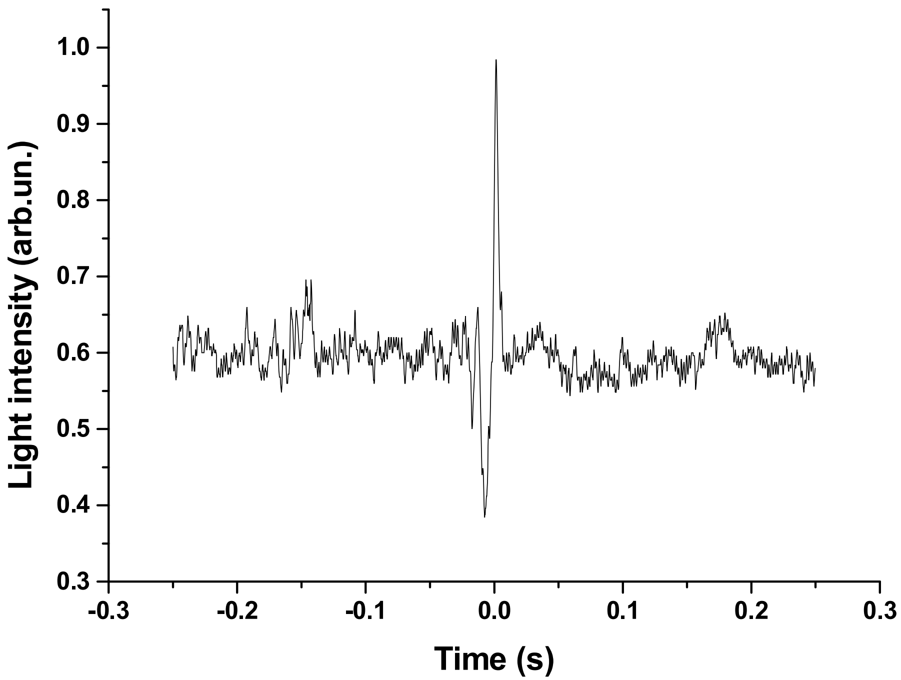
Illuminate →  → Measure

Analysis signals



Non fluorescent bead passing the waveguides

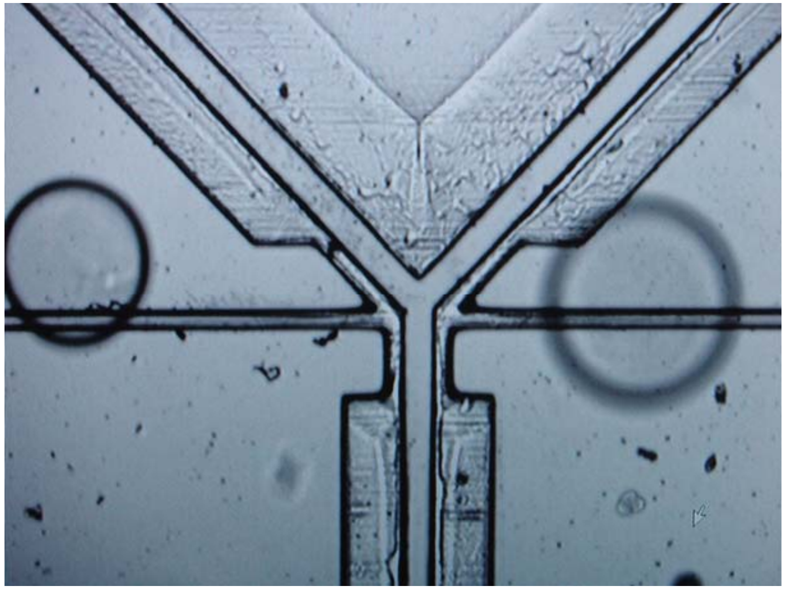
Analysis signals



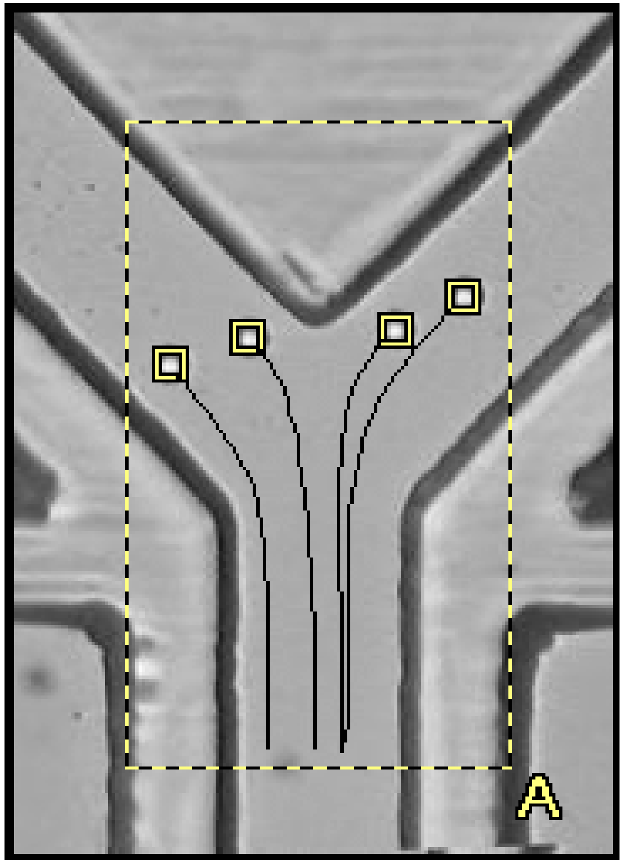
Fluorescent bead passing the waveguides

Details

The separating waveguides



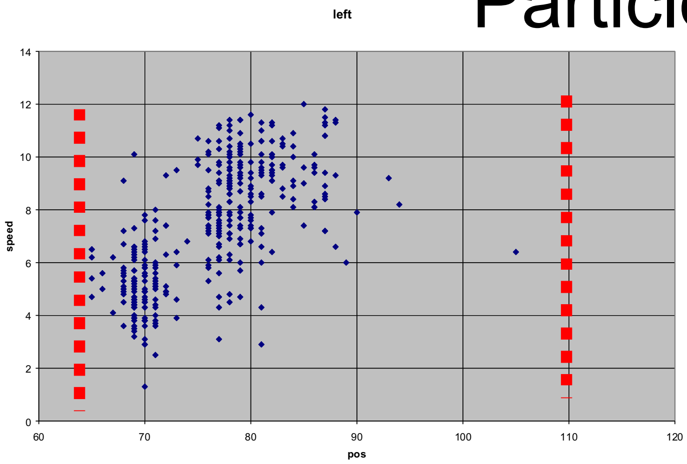
Separation

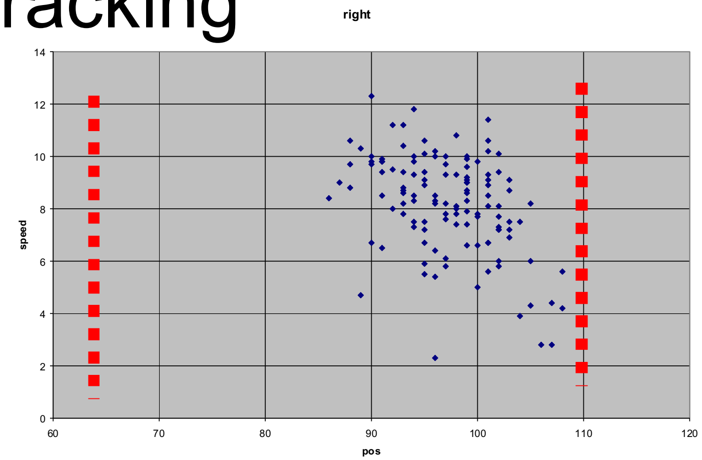


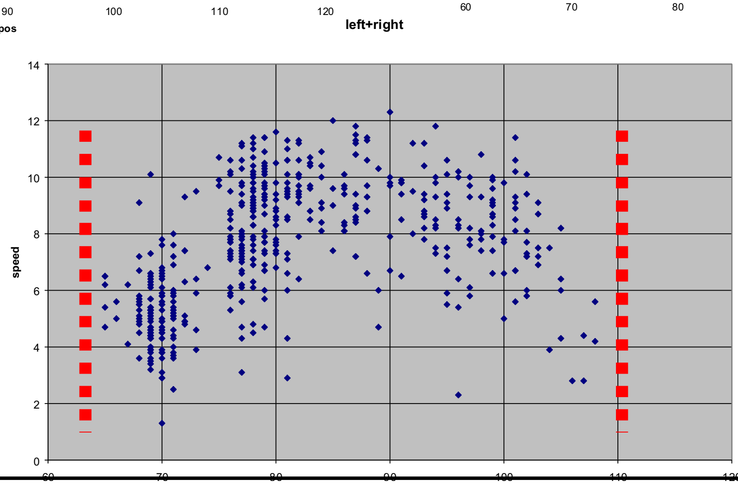
Control

Motion analysis

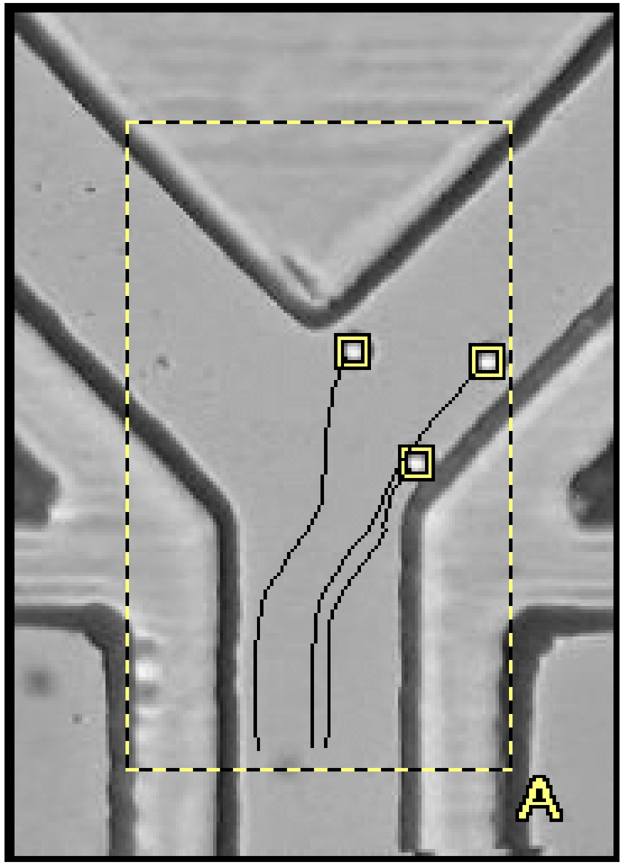
Particle tracking







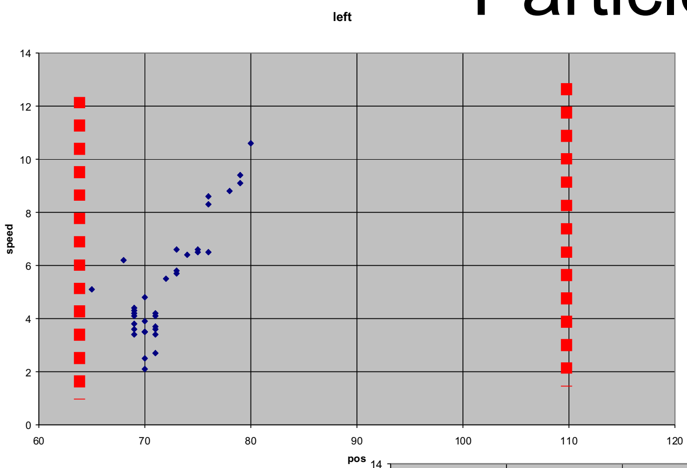
Separation

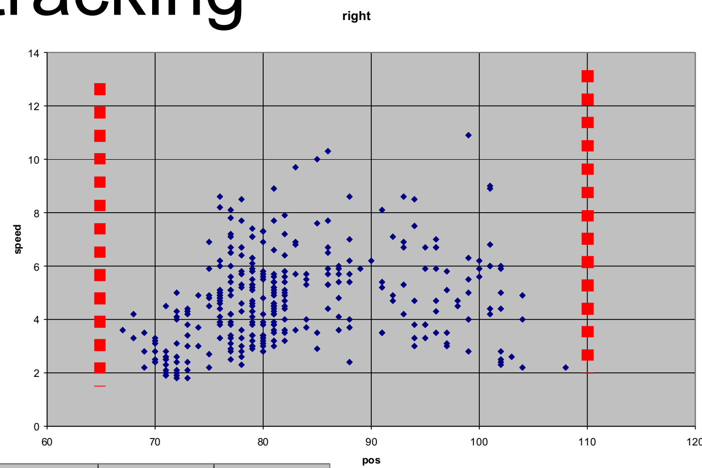


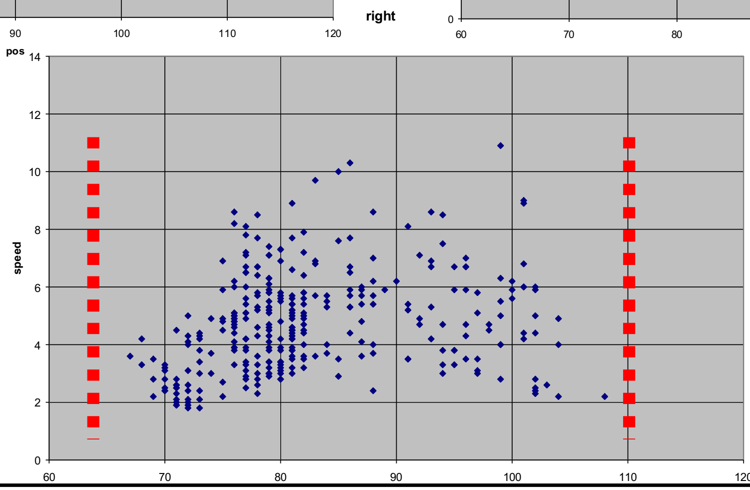
Separation

Motion analysis

Particle tracking

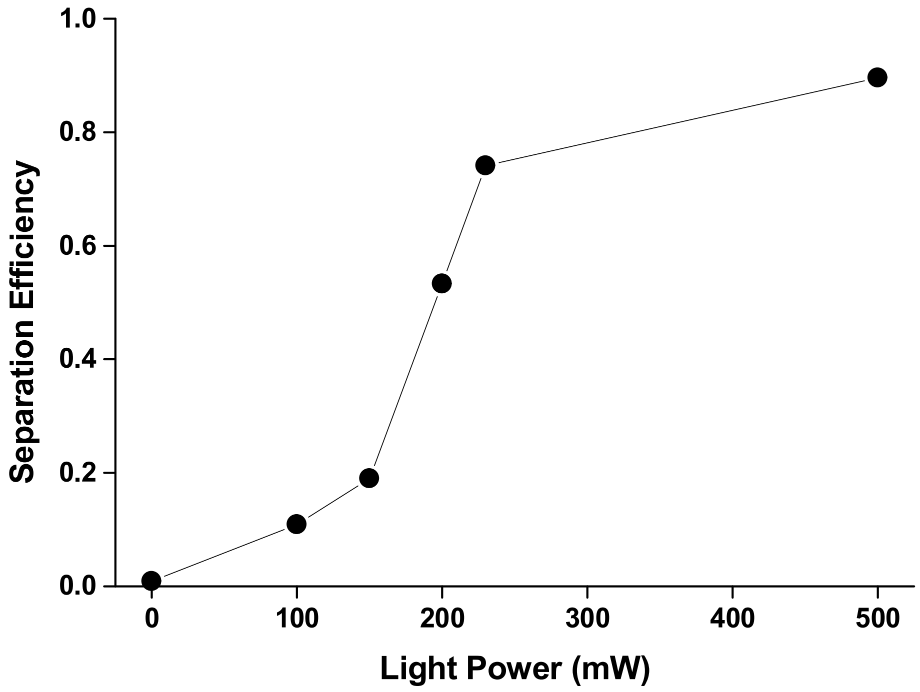






Separation efficiency

$$\eta = 2 * (\frac{a}{t} - 0.5)$$



New version

- Hydrodynamic focusing in the input
- Same waveguides used for measurement and separation

- Maximum rate ~ 1000 s^{-1}
  (limited by the light's pushing force)

Advantages: It works on small amounts of sample with very little dead volumes

Counterpropagating trap

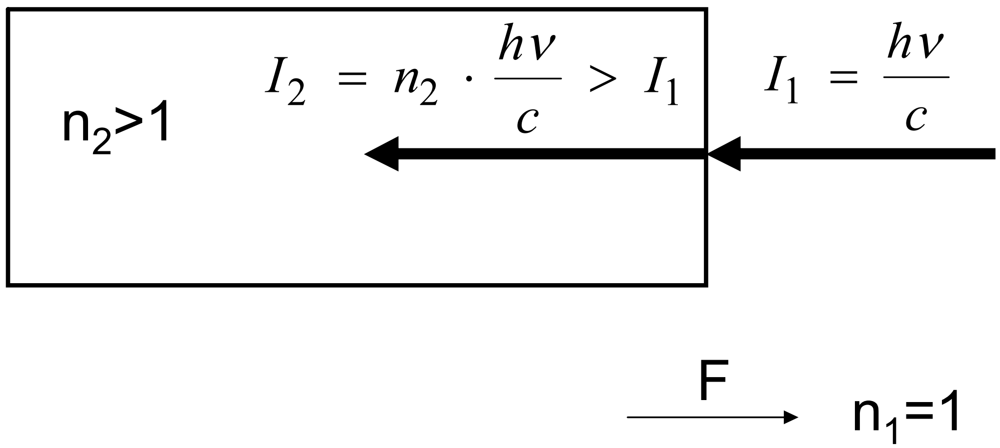
The optical stretcher

Joseph Käs (Leipzig)

Jochen Guck (Cambridge)

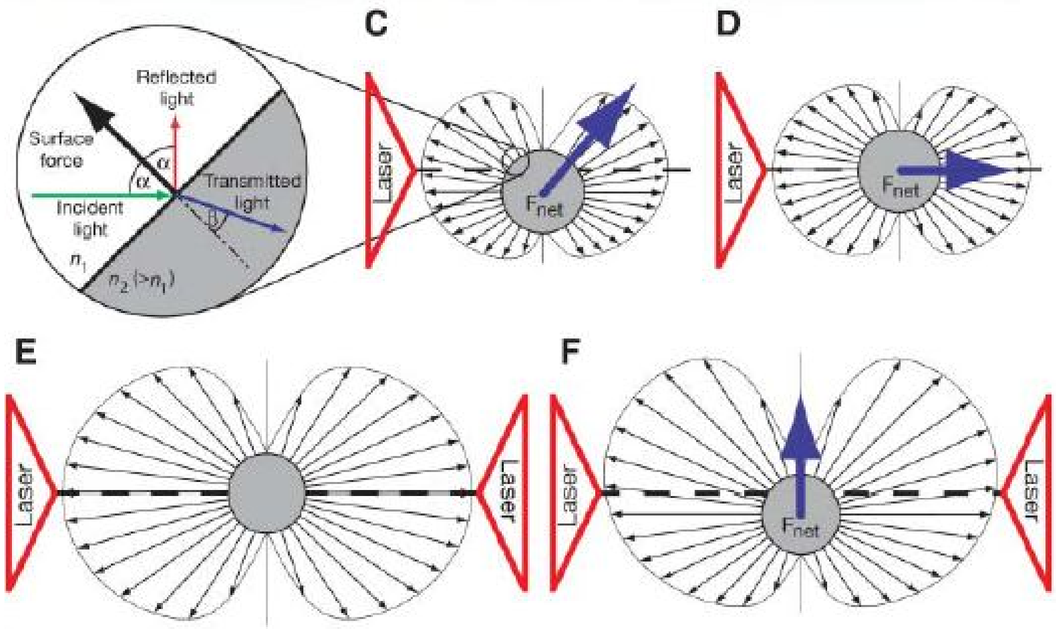
Optical stretcher

Basis: **Light going into more dense medium pulls**



Optical stretcher

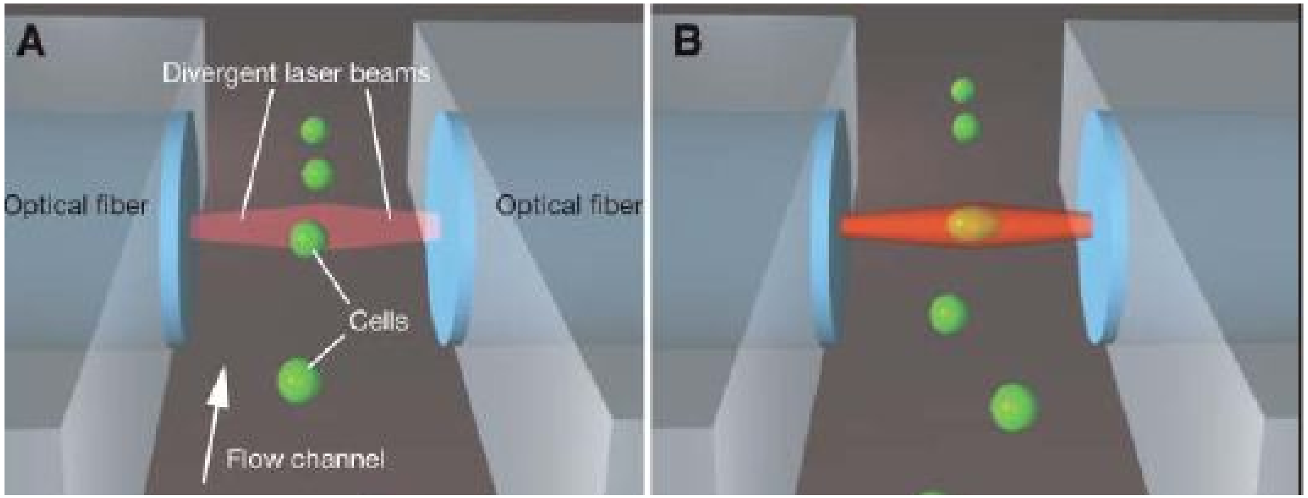
The forces worked out in detail



Objects are stretched in counterpropagating tweezers

Guck et al. Biophysical Journal 88(5) 3689–3698

Optical stretcher

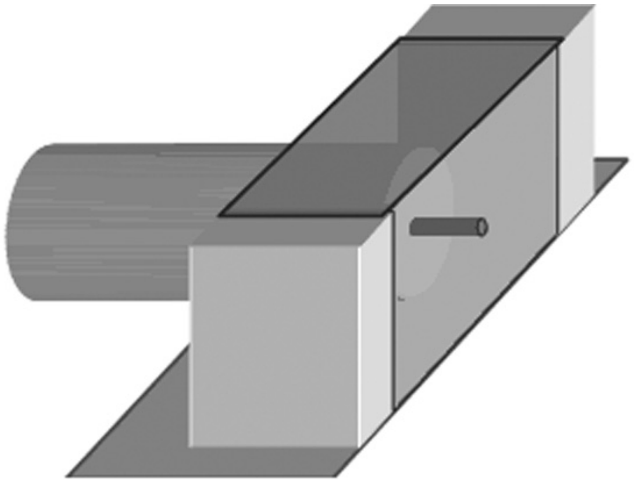


Cancer cells are softer than healty ones, they can be separated

A device able to differentiate between healthy and cancer cells

Tip grown at the end of optical fiber by photopolymerisation

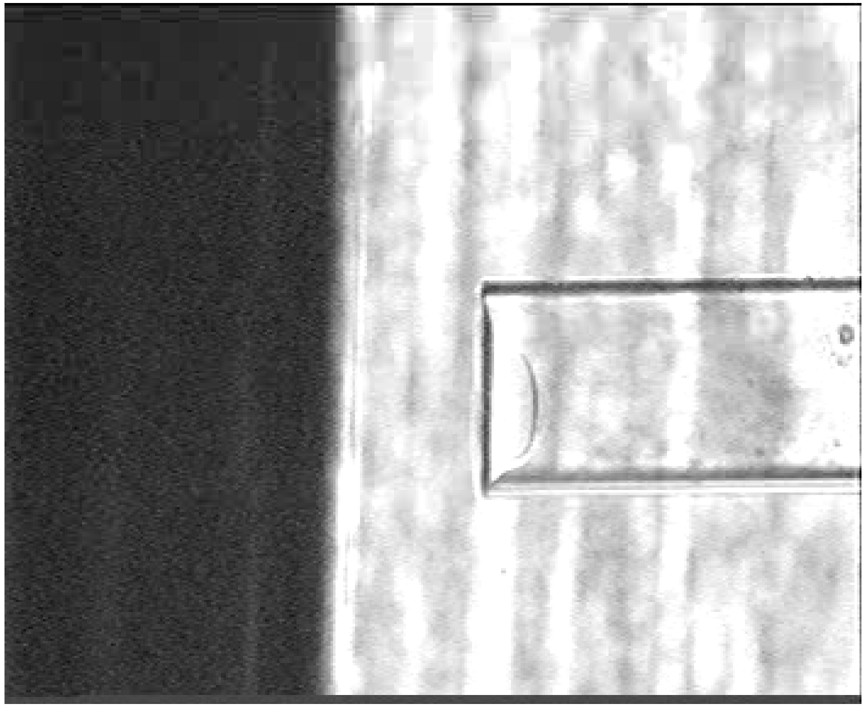
Tip growing chamber



The chamber to grow the tip by photopolymerisation. The left and right sides of the brick shaped chamber are open, and the resin is held in place by surface tension.

Fiber trap with tips grown at the end of optical fibers

- Long, good optical quality tips can be grown at the end of optical fibers by photopolymerisation



Valkai et al., J. Appl.Opt., 2008)

Image of the tip

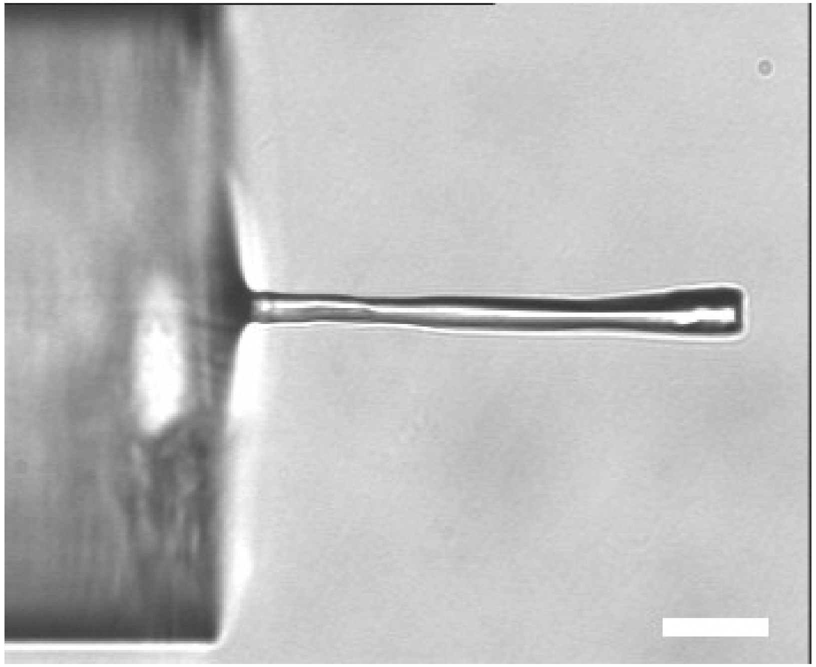
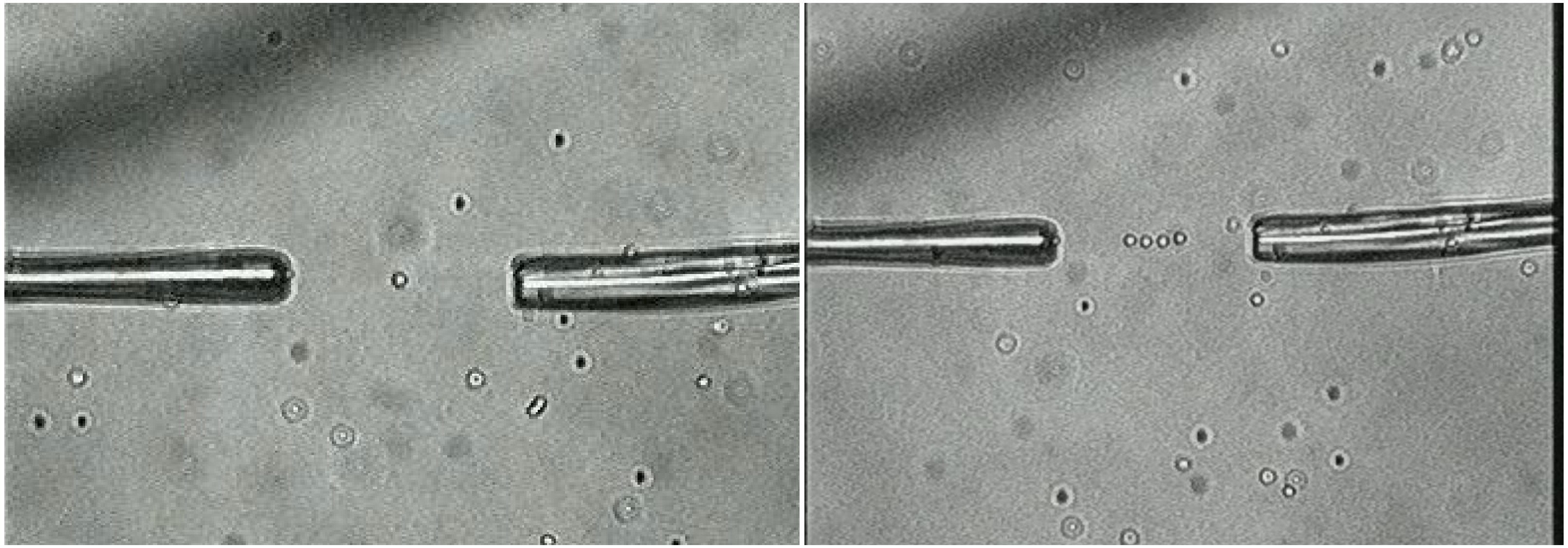


Image of a typical tip grown at the end of the optical fiber. Notice the flat end of the tip. The white bar represents 20 micrometers.

Counterpropagating trap formed

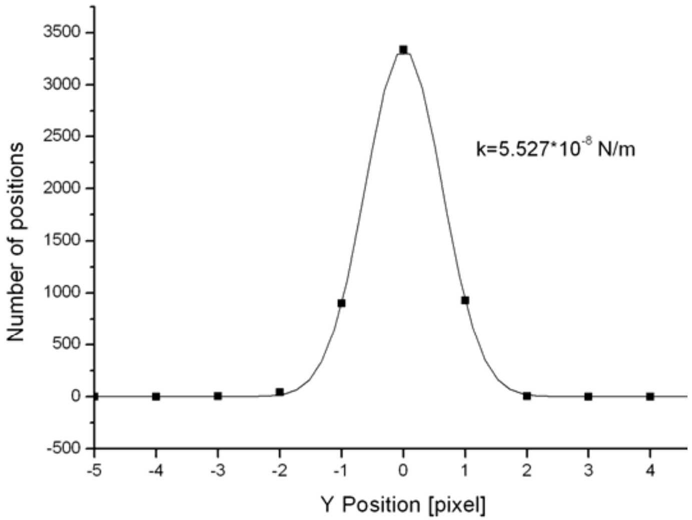


Regular trapping

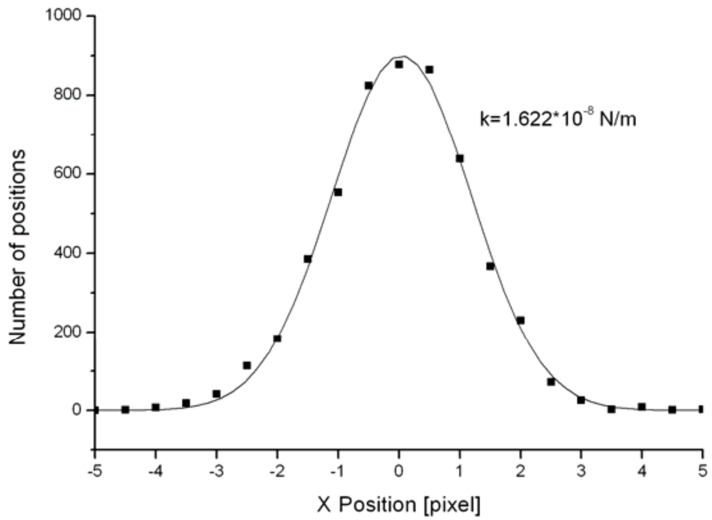
Optical binding

O
p
t
i
c
a

Force calibration



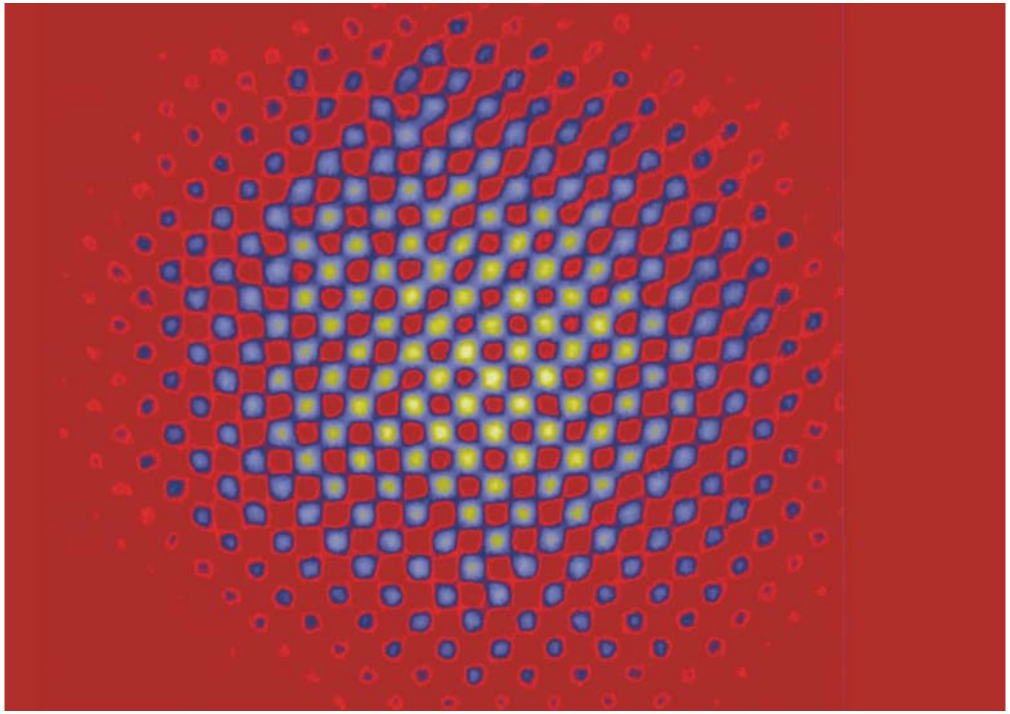
Transversal direction



Longitudinal direction

Different optical sorting schemes 1. Optical lattice

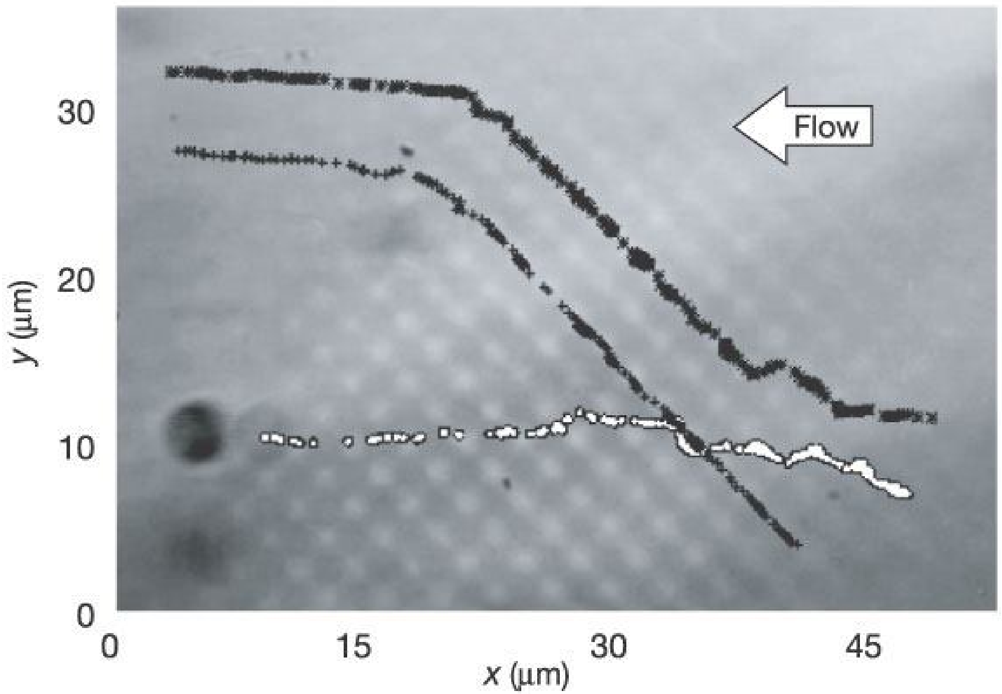
Kishan Dholakia group (St Andrews)



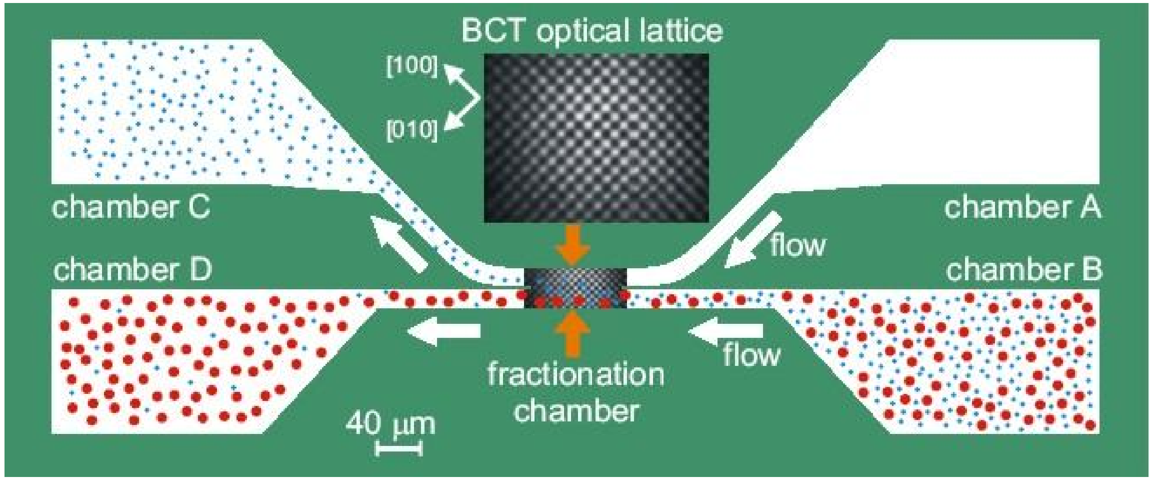
Optical lattice generated interferometrically

MacDonald, M.P., Spalding, G.C. & Dholakia, K. Microfluidic sorting in an optical lattice. *Nature* **426**, 421–424 (2003).

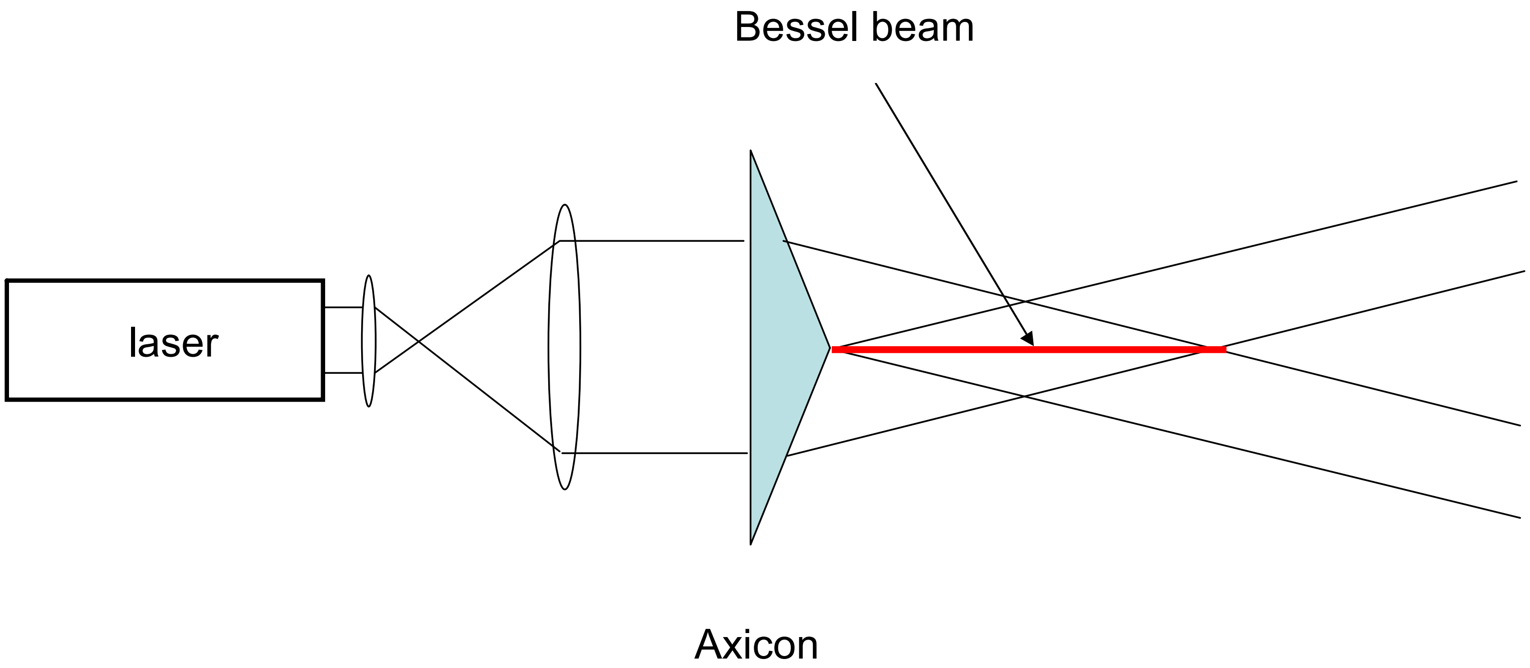
Different optical sorting schemes 1.



Different optical sorting schemes 1.

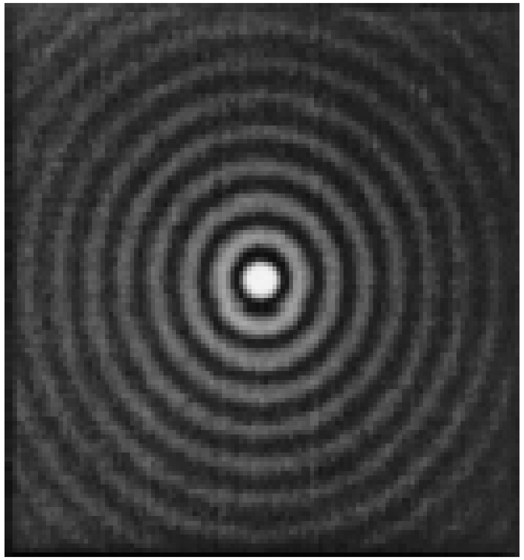


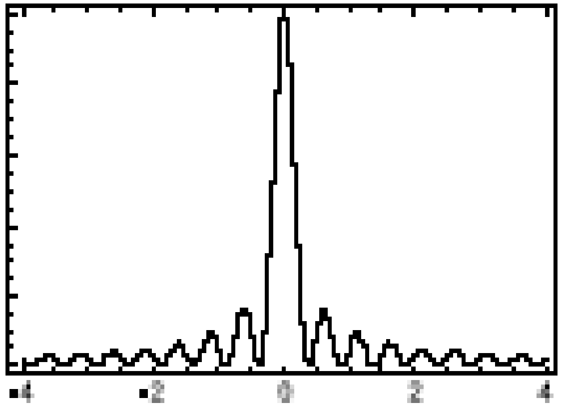
Different optical sorting schemes 2. Bessel beams
Kishan Dholakia Group,



Light induced cell separation in a tailored optical landscape. Applied Physics Letters 87: 123901 2005. L. Paterson, E. Papagiakoumou, G. Milne, V. Garcés-Chávez, S.A. Tatarkova, W. Sibbett, F.J. Gunn-Moore, P.E. Bryant, A.C. Riches & K. Dholakia.

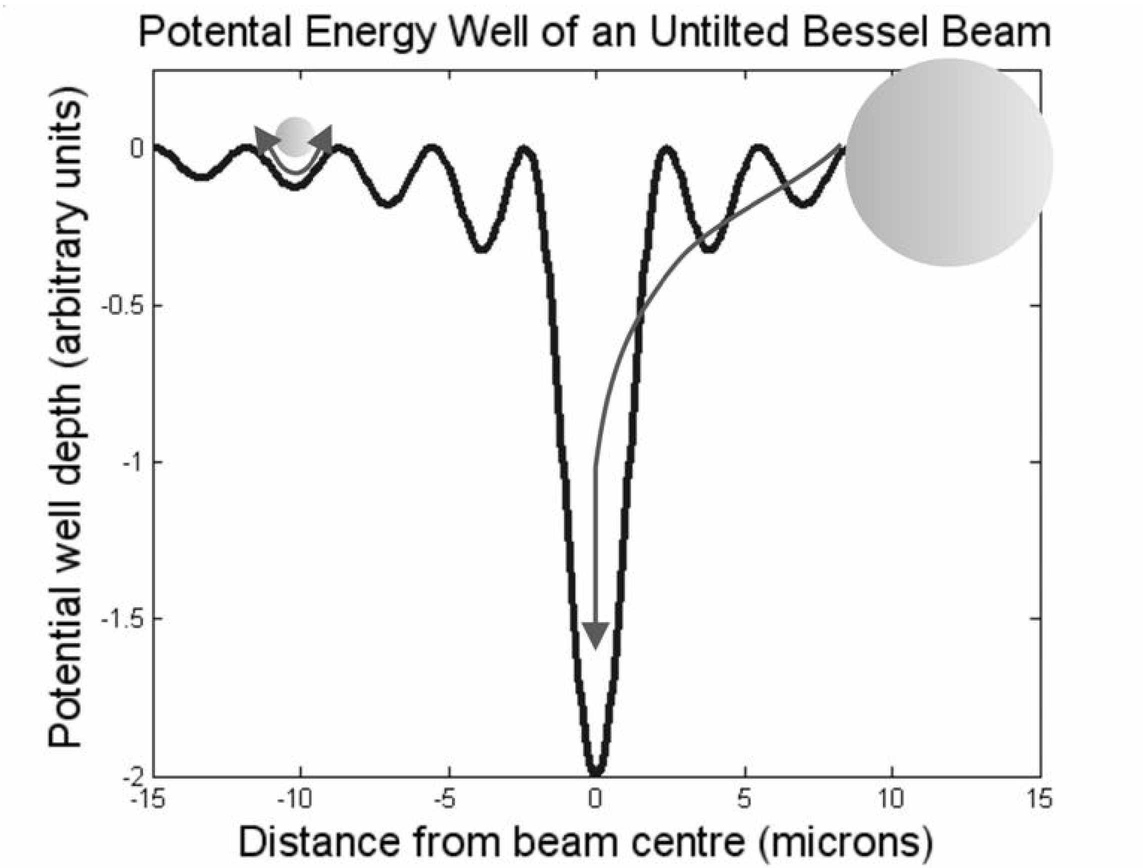
Different optical sorting schemes 2. Bessel beams



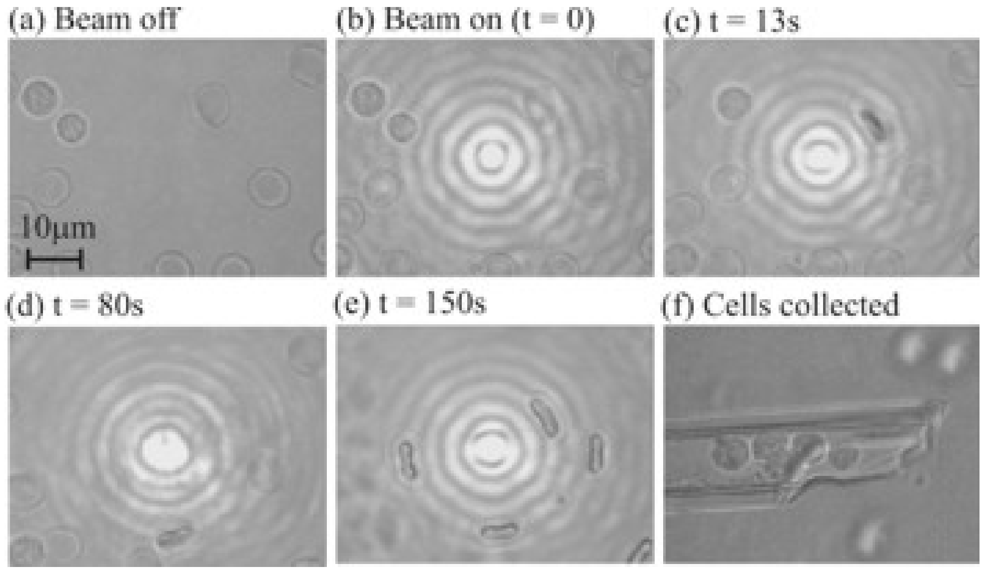


Beam characteristics

Different optical sorting schemes 2. Bessel beams



Different optical sorting schemes 2. Bessel beam



White and red blood cells are separated