Group of Optical Micromanipulation Techniques

Department of Optical Micromanipulation Techniques

Institute of Scientific Instruments ASCR

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THEMATIC RESEARCH FOCUS

Research area

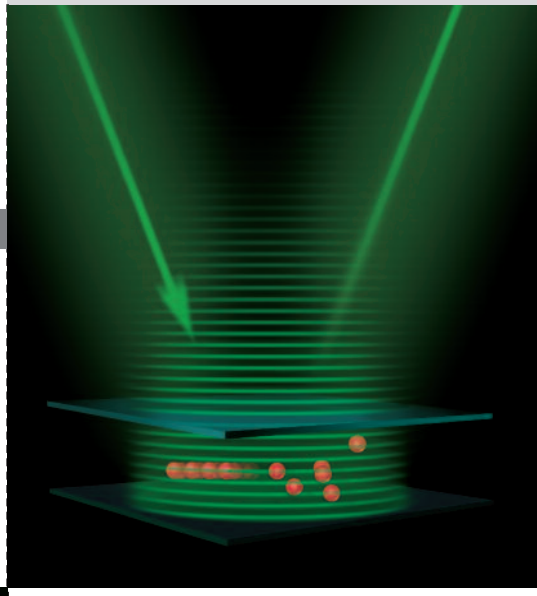
– Biophotonics and nanophotonics

Excellence

– Force interaction between light and objects (theoretical and experimental aspects)
– Applications of focused laser beams (laser microdissection, optical tweezers, optical cell sorters, long-range optical delivery of micro(nano)objects, polymerization of micro-structures)
– Laser beam shaping by spatial light modulators
– Design and manufacturing of custom-made laser beam systems

Mission

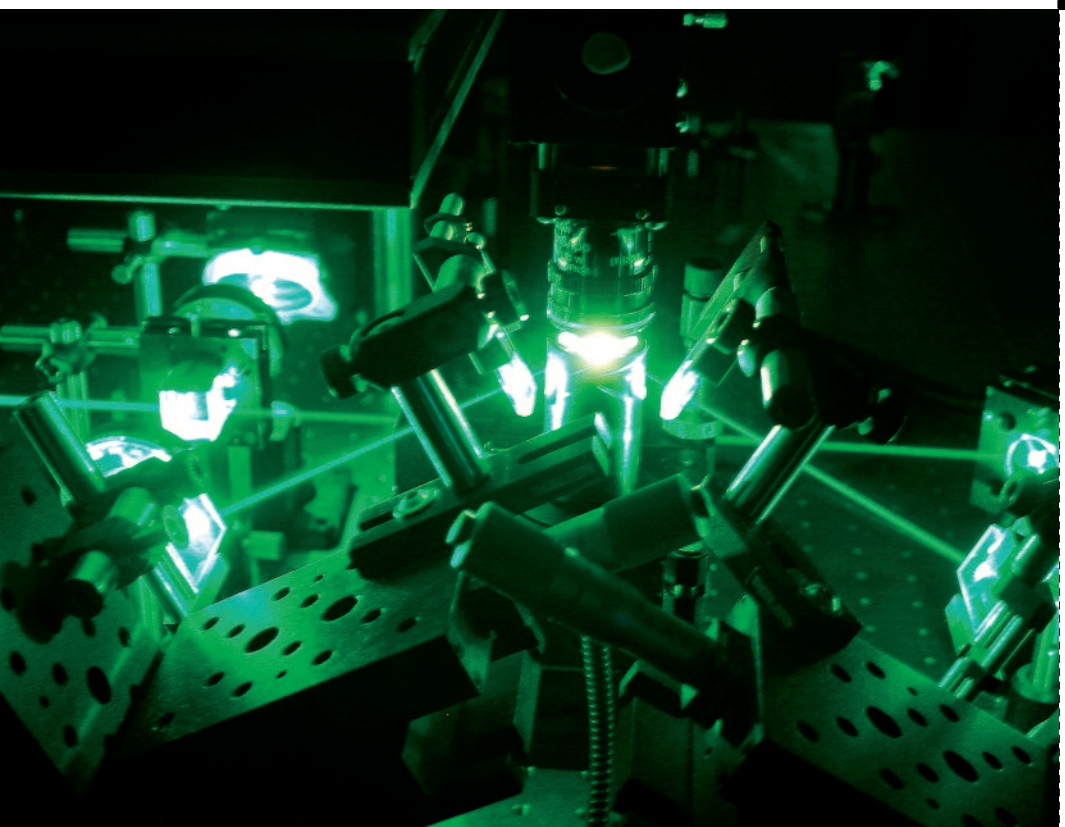
To be at the forefront in looking for new optical methods appropriate for contactless, nondestructive investigation of living or inanimate parts of the microworld.

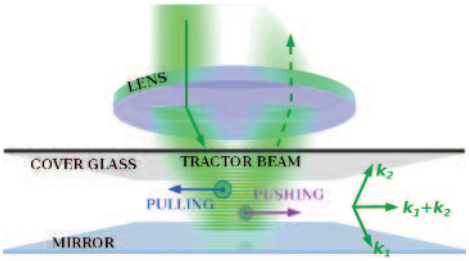


DEVELOPED TECHNOLOGIES

Content of research

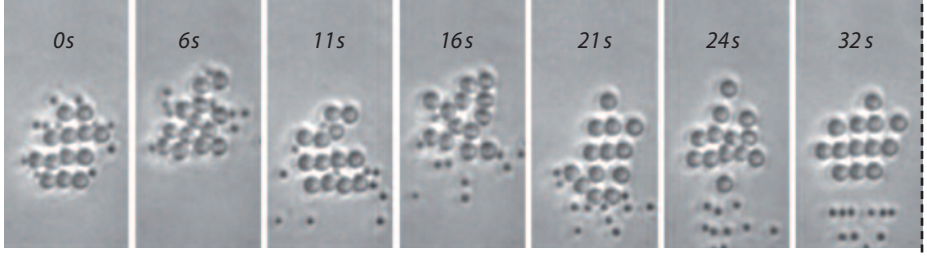
– Theoretical and experimental activities related to optical micromanipulations with microobjects and nanoobjects (light scattering, optical tweezers, optical sorters, optical scalpel, optical delivery, optical binding, localized plasmons, photonic force microscope, force spectroscopy, microfluidics)
– Raman microspectroscopy, Raman tweezers
– Photopolymerization, soft-lithography, lab-on-a-chip





Geometrical configuration of the optical tractor beam setup and visualization of the pulling and pushing optical force acting upon particles of different sizes

Example of experimental set-up.



Example of optical sorting of suspension of polystyrene particles of sizes 800 nm and 1600 nm in travelling interference fringes

Main capabilities

Basic research

- Theoretical simulations of light scattering and optical forces acting on microparticles and nanoparticles illuminated by spatially structured laser beams
- Experimental activities related to micromanipulation with microparticles or nanoparticles using laser beams (sample preparation, laser beam shaping and positioning, microobjects position measurement in nm resolution, pN force measurement, optical sorters)
- Spatially resolved Raman spectroscopy combined with optical micromanipulation techniques

Applied research

- Manufacturing of custom-made opto-mechanical laser beam systems
- Design and manufacturing of microfludic chips by soft-lithography
- Photopolymerization of microstructures
- Optical sorters of microobjects or living microorganisms

Fields of research results application

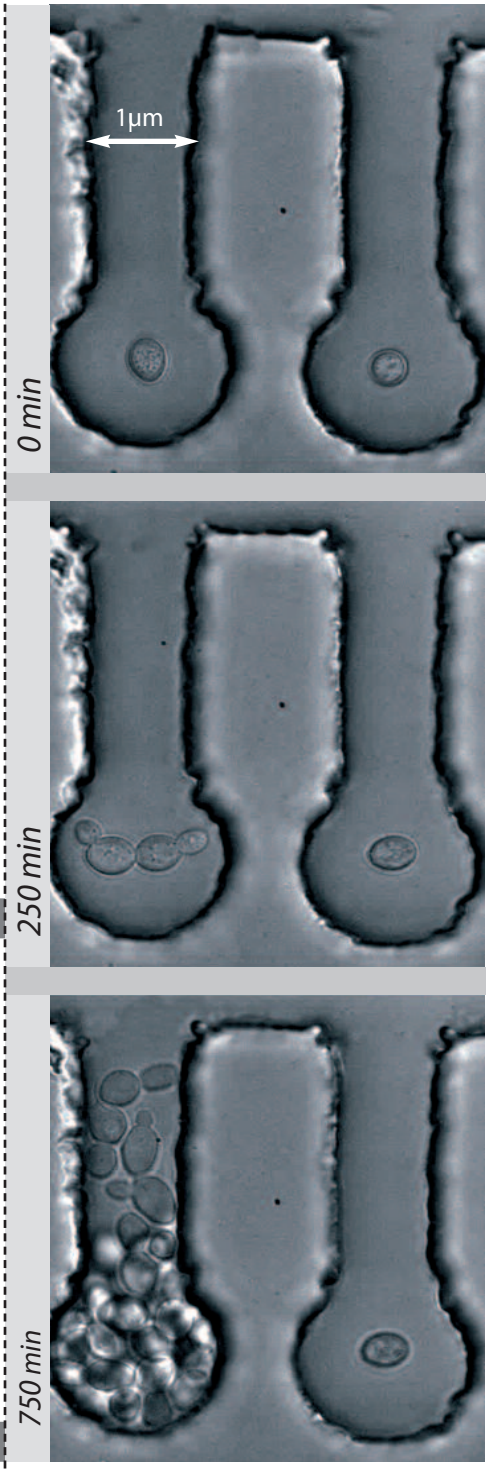
- Optical microscopy
- Microtechnology, nanotechnology
- Cell biology
- Colloidal chemistry
- Laser spectroscopy
- Microfluidics
- Lab-on-a-chip systems
- Microbiology (algae, bacteria)

KEY RESEARCH EQUIPMENT

- Various CW high power lasers working at 1064 nm, 980 nm, 785 nm, 532 nm, 680–1000 nm (Coherent, Spectra Physics, IPG, Sacher)
- Femtosecond laser systems Mira 800 HP, Mai Tai HP Deep See
- Renishaw inVia Raman microscope
- Raman tweezers made by the research team
- Photonic force microscope made by the research team
- Optical cell sorters made by the research team
- Several different flexible systems for advanced optical micromanipulation experiments (holographic tweezers, dual-beam holographic traps)
- Fast CCD cameras (thousands fps)
- Ion etching system (Plasmalab System 100)

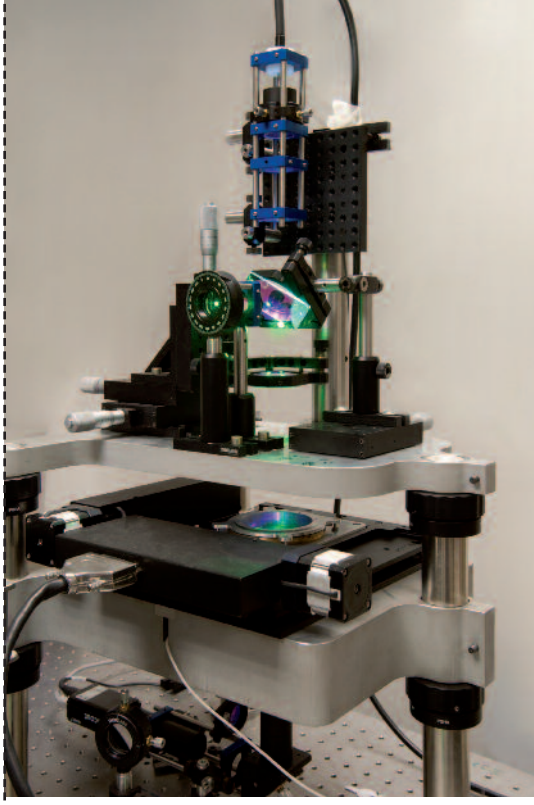
ACHIEVEMENTS

We deepened the understanding of the force interaction between light and micro/nanoparticles and developed original methods how to manipulate with individual particles or even thousands of particles, how to sort and self-arrange them. We published about 50 papers in impacted journals with very good citation response and about 70 longer contributions in conference proceedings or local journals.

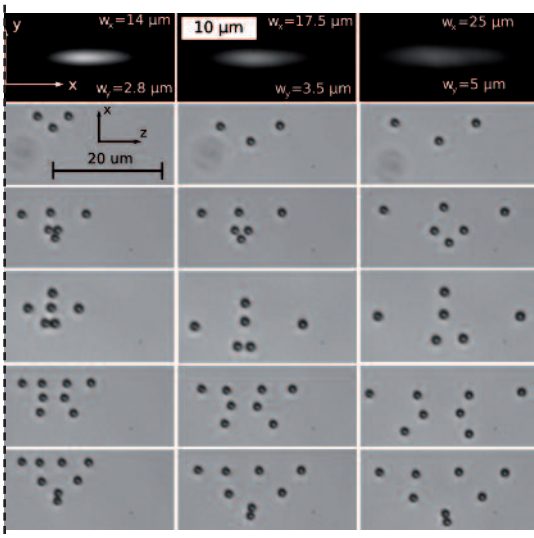


Example of a small part of a microfluidic chip enabling cultivation of individual cells in separated micro-compartments under different conditions (right illuminated by a laser beam)

- **Experimental demonstration of optical "tractor" beam and its utilization in optical sorting and self-arrangement of microobjects.** This result attracted strong interest of media all over the world.
  - Brzobohatý, O.; Karásek, V.; Šiler, M.; Chvátal, L.; Čižmár, T. & Zemánek, P.; *Experimental demonstration of optical transport, sorting and self-arrangement using a 'tractor beam'.* Nature Photonics 7, (2013), p. 123–127
- **Microparticles illuminated by wide laser beams tend to self-organize into structures bound together by light (optically bound matter).** We developed methods to study such behaviour and performed pioneering experiments to understand it.
  - Karásek, V.; Čižmár, T.; Brzobohatý, O.; Zemánek, P.; Garcés-Chávez, V.; Dholakia, K.; *Long-range one dimensional longitudinal optical binding.* Physical Review Letters 101, (2008), 143601:1–4
  - Dholakia, K. and Zemánek, P.; *Colloquium: Gripped by light: Optical binding.* Reviews of Modern Physics 82, (2010), p. 1767–1791
  - Brzobohatý, O.; Čižmár, T.; Karásek, V.; Šiler, M.; Dholakia, K. and Zemánek, P.; *Experimental and theoretical determination of optical binding forces.* Optics Express 18, (2010), p. 25389–25402
  - Brzobohatý, O.; Karásek, V.; Čižmár, T. and Zemánek, P.; *Dynamic size tuning of multidimensional optically bound matter.* Applied Physics Letters 99, (2011), 101105
  - Čižmár, T.; Brzobohatý, O.; Dholakia, K. and Zemánek, P.; *The holographic optical micro-manipulation system based on counter-propagating beams.* Laser Physics Letters 8, (2011), p. 50–56
  - Šiler, M.; Čižmár, T. and Zemánek, P.; *Speed enhancement of multi-particle chain in a traveling standing wave.* Applied Physics Letters 100, (2012), 051103
- **Simultaneous optical trapping and delivery of thousands of sub-micrometer particles in non-diffracting laser beams or evanescent waves – so called Optical conveyor belt.** This tool attracted attention all over the world in 2005.
  - Čižmár, T.; Garcés-Chávez, V.; Dholakia, K.; Zemánek, P.; *Optical conveyor belt for delivery of submicron objects.* Appl Phys Lett 86, (2005), 174101-1
  - Čižmár, T.; Kollárová, V.; Bouchal, Z.; Zemánek, P.; *Sub-micron particle organization by self-imaging of non-diffracting beams.* New Journal of Physics 8, (2006), 43:1–23
  - Čižmár, T.; Šiler, M.; Zemánek, P.; *An optical nanotrap array movable over a milimetre range.* Applied Physics, (2006), B 84, p. 197–203
  - Šiler, M.; Čižmár, T.; Šerý, M.; Zemánek, P.; *Optical forces generated by evanescent standing waves and their usage for sub-micron particle delivery.* Applied Physics, (2006), B 84, p. 157–165
  - Šiler, M.; Čižmár, T.; Jonáš, A.; Zemánek, P.; *Surface delivery of a single nanoparticle under moving evanescent standing-wave illumination.* New Journal of Physics 10, (2008), 1130101:1–16
- **Discovery of several original methods of spontaneous optical sorting of polydisperse sample of sub-micron size objects according to their sizes in interfering laser beams (optical sorter).** Up to now the smallest difference in the sizes of sorted objects was 60 nm for polystyrene beads of diameters 350 a 410 nm.
  - Čižmár, T.; Šiler, M.; Šerý, M.; Zemánek, P.; Garcés-Chávez, V.; Dholakia, K.; *Optical sorting and detection of submicrometer objects in a motional standing wave.* Physical Review B 74, (2006), 035105:1–6
  - Jákl, P.; Čižmár, T.; Šerý, M.; Zemánek, P.; *Static optical sorting in a laser interference field.* Applied Physics Letters 92, (2008), 161110:1–3
  - Dholakia, K.; MacDonald, M. P.; Zemánek, P.; Čižmár, T.; *Cellular and colloidal separation using optical forces.* Methods in Cell Biology 82, (2007), p. 467–495
  - Jonáš, A.; Zemánek, P.; *Light at work: The use of optical forces for particle manipulation, sorting, and analysis.* Electrophoresis 29, (2008), p. 4813–4851
- **Optical cell-sorter based on fluorescences or Raman spectra of microorganisms (in cooperation with Photon Systems Instruments).**



Experimental setup of the optical tractor beam



Optical self-arrangement of microparticles into 2D optically bound structures tunable by the width of the laser beam

- **Combination of Raman microspectroscopy and optical tweezers** offers a unique tool that provides contactless and nondestructive manipulation and information about the chemical bonds inside mobile living microobjects including living microorganisms.
  - Samek, O.; Jonáš, A.; Pilát, Z.; Zemánek, P.; Nedbal, L.; Tříska, J.; Kotas, P. and Trtílek, M.; Raman microspectroscopy of individual algal cells: Sensing unsaturation of storage lipids in vivo. Sensors 10, (2010), 8635–8651
  - Samek, O.; Zemánek, Z.; Jonáš, A. and Telle, H. H.; Characterization of oil-producing microalgae using Raman spectroscopy. Laser Physics Letters 8, (2011), p. 701–709
  - Pilát, Z.; Bernatová, S.; Ježek, J.; Šerý, M.; Samek, O.; Zemánek, P.; Nedbal, L. and Trtílek, M.; Raman microspectroscopy of algal lipid bodies: beta-carotene quantification. Journal of Applied Phycology 24, (2012), p. 541–546
- **Manufacturing of polymer fibres of diameters in units of micrometers and length in centimetres by non-diffracting beams.**
  - Ježek, J.; Čižmár, T.; Neděla, V.; Zemánek, P.; Formation of long and thin polymer fiber using nondiffracting beam. Optics Express 14, (2006), p. 8506–8515
- **Manufacturing of microfluidic chips combined with optical trapping and diagnostics for microfluidic cell-sorters, cell cultivation and droplets generators for discrete microfluidics or droplet lasers**
- **Compact optical tweezers modules compatible with majority of optical microscopes (utility model awarded, in cooperation with Meopta-Optika)**

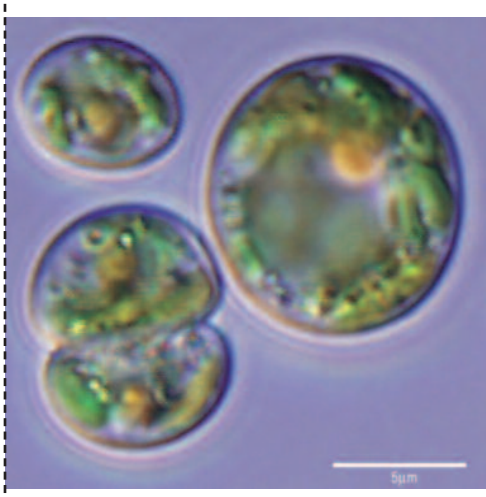


Image of Trachydiscus Minutus from optical microscope

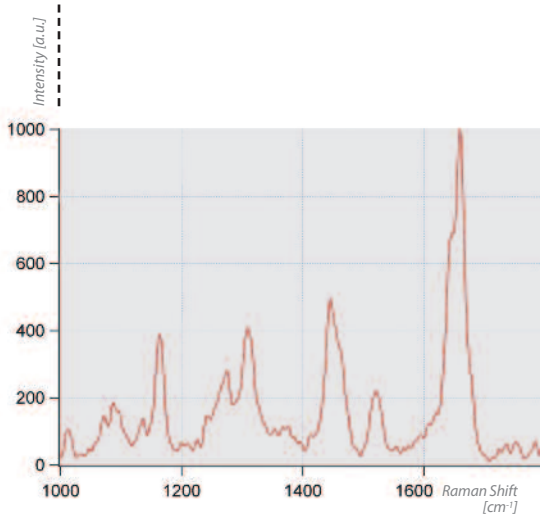
MAIN COLLABORATING PARTNERS

Collaboration with academic partners

- University of St. Andrews (St. Andrews, GB)
- University of Naples Frederico II (Naple, IT)
- University of Texas (Austin, US)
- Universidad Nacional Autonoma de Mexico (Mexico City, MX)
- Koc University (Istanbul, TR)
- Max Planck Institute of Molecular Cell Biology and Genetics (Dresden, DE)
- Lehigh University (Bethlehem, USA)
- Palacky University (Olomouc, CZ)
- Brno University of Technology (Brno, CZ)
- Masaryk University (Brno, CZ)
- Institute of Experimental Physics, Slovak Academy of Sciences (Košice, SK)

Collaboration with companies

- Photon Systems Instruments (Drasov, CZ)
- Meopta-Optika (Přerov, CZ)
- Measurement Technic Moravia Ltd. (Omice, CZ)



Example of Raman spectrum of an optically trapped single living alga Trachydiscus Minutus enabling determination of fatty acid saturation

EXPECTATIONS

Offers

- We offer collaboration in the areas of our expertise
- Partnership in international projects
- Manufacturing of custom-made opto-mechanical laser beam systems
- Theoretical studies based on Mie light scattering, coupled dipoles method, COMSOL multiphysics software

Requirements

We look for cooperation with academic partners as well as companies in the fields of optics, biophotonics, microtechnologies, nanotechnologies, applications of optical methods.