Group of Optical Micromanipulation Techniques

Department of Optical Micromanipulation Techniques

THEMATIC RESEARCH FOCUS

Research area
- Optics
- Lasers
- Micro(nano)technologies
- Laser spectroscopy
- Biophotonics
- Nanophotonics and plasmonics
- Lab-on-a-chip systems
- Optofluidics

Excellence
- Force interaction between light and objects (theoretically and experimentally)
- Applications of focused laser beams: laser microdissection, optical tweezers, optical cell sorters, long-range optical delivery of micro(nano)objects, polymerization of microstructures
- Raman spectroscopy combined with optical manipulations (Raman tweezers)
- Laser beam shaping by spatial light modulators
- Design and manufacturing of on demand systems that employ laser beams

Mission
To be at the forefront in developing new optical methods appropriate for contact-less, nondestructive investigation of living or inanimate parts of the micro, nano and quantum worlds.

UP-TO-DATE ACTIVITIES

Research orientation
- Investigation of underdamped and overdamped stochastic object motion in nonlinear optical potentials
- Laser cooling of nanoparticles at low pressures
- Optically-induced rotation and self-arrangement of several objects
- Optical trapping and characterization of plasmonic nanoparticles
- Characterization of living microorganisms (e.g. bacteria, yeast and algae cells) using Raman microspectroscopy, Raman tweezers and microfluidic chips.
- Optical monitoring of chemical reactions in emulsion droplets and lab-on-a-chips
- Mastered technology of photopolymerization, soft-lithography, reactive ion etching, micro-opto-electro-mechanical systems

Main capabilities
Basic research
- Theoretical and experimental activities related to optical manipulations with micro and nanoobjects
- Characterization of living microorganisms using Raman microspectroscopy combined with optical micromanipulation and microfluidic techniques

Applied research
- Manufacturing of on-demand opto-mechanical systems using laser beams

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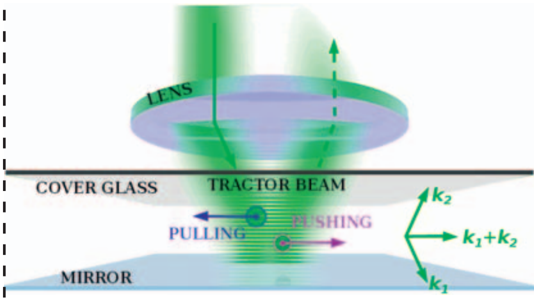
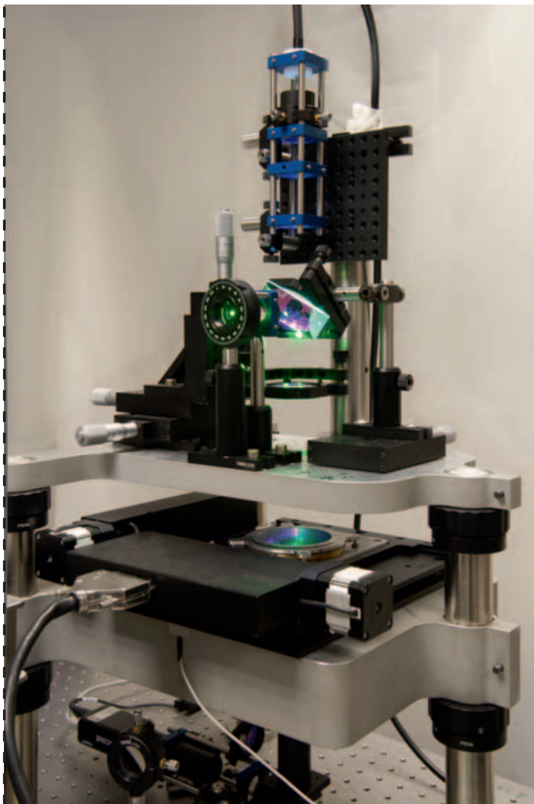


Geometrical configuration of the tractor beam setup and visualization of the pulling and pushing optical force acting upon particles of different sizes

Experimental setup of the tractor beam



– Design and manufacturing of microfludic chips by soft-lithography
– Photopolymerization of microstructures
– Employment of reactive ion etching for surface modifications

Innovations
– Licence agreement on compact optical tweezers and sorters

Sub-fields of group activities
– Optical microscopy
– Microtechnology, nanotechnology and quantum technology
– Biophotonics
– Laser spectroscopy
– Microfluidics
– Lab-on-a-chip systems

KEY RESEARCH EQUIPMENT

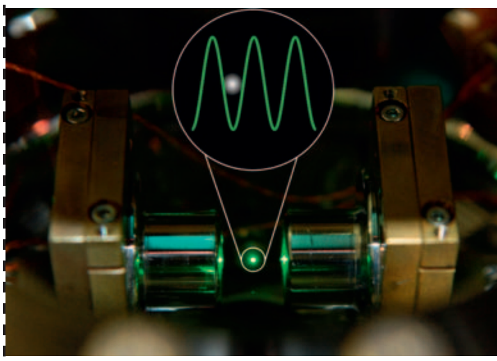
List of devices
– Various CW high power lasers working at 1064 nm, 980 nm, 785 nm, 532nm, 680–1000 nm (Coherent, Spectra Physics, IPG, Sacher)
– Femtosecond laser systems Mira 800 HP, Mai Tai HP Deep See
– Renishaw In Via Reflex Raman microspectrometer
– Raman tweezers developed in house by the research team
– Optical cell sorters developed in house by the research team
– Several different flexible systems for advanced optical micromanipulation experiments (holographic tweezers, dual-beam holographic traps)
– Fast CCD cameras (thousands fps)
– Reactive ion etching system (Plasmalab System 100)
– Photopolymerization system developed in house

ACHIEVEMENTS

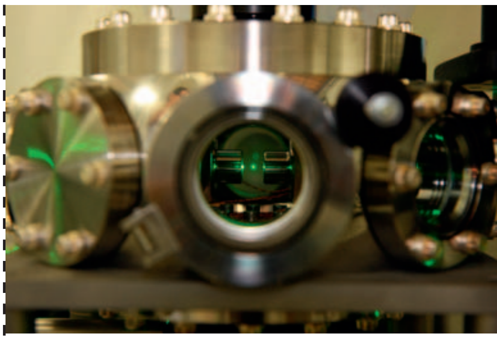
Awards
– Werner von Siemens Excellence Award 2013 for the best result of basic research
– Oto Brzobohatý was awarded the Otto Wichterle Award for talented young scientists by the Czech Academy of Sciences in 2014
– Zdeněk Pilát was awarded the best Ph.D. Thesis in 2015 by the Czechoslovak Microscopy Society
– Jana Damková was awarded Young Scientist Award 2016 by the Czech and Slovak Society for Photonics

Publications
We have deepened the understanding of the mechanical force interaction between light and micro (nano) objects. We have developed original methods to manipulate with individual particles or even thousands of particles and to sort and self-arrange them. We published more than 40 papers in impacted journals with very good citation response in the period 2012–2016.

Experimental demonstration of optical "tractor" beam and its utilization in optical sorting and self-arrangement of microobjects
– O. Brzobohatý, V. Karásek, M. Šiler, L. Chvátal, T. Čižmár, P. Zemánek: *"Experimental demonstration of optical transport, sorting and self-arrangement using a 'tractor beam",* Nature Photon. **7**, 123–127, 2013

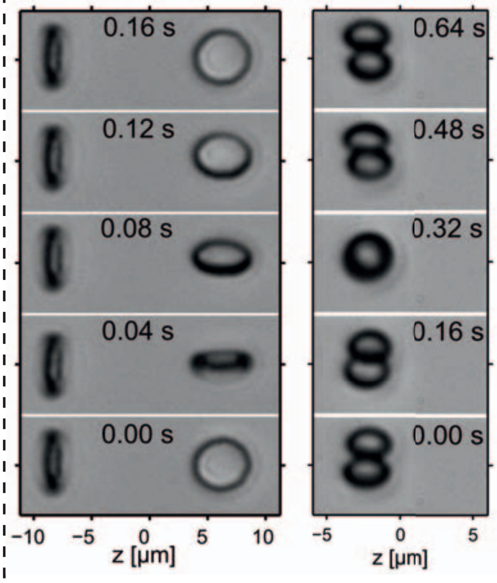


An example of an optically trapped nanoparticle (bright spot) in the optical standing wave of two counter-propagating green laser beams (axial intensity profile is shown in the inset)



An optically trapped nanoparticle inside the vacuum chamber

An example of simultaneous trapping and rotation of disc-like objects in counter-propagating laser beams with circular polarizations



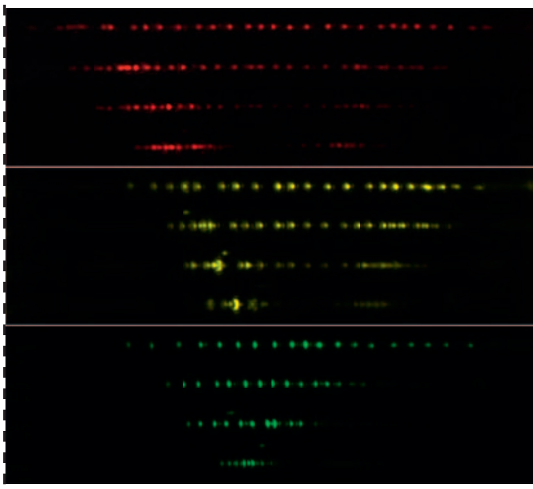
- **A new type of transverse force was confirmed which is directed perpendicularly to the wavevector and is proportional to the optical spin**
  - M. Antognozzi, C. R. Bermingham, R. L. Harniman, S. Simpson, J. Senior, R. Hayward, H. Hoerber, M. R. Dennis, A. Y. Bekshaev, K. Y. Bliokh, F. Nori: *"Direct measurements of the extraordinary optical momentum and transverse spin-dependent force using a nano-cantilever"*, Nature Phys. **12**, 731–735, 2016

- **Description of stochastic behaviour of a Brownian particle in nonlinear potential**
  - P. Zemánek, M. Šiler, O. Brzobohatý, P. Jákl, R. Filip: *"Noise-to-signal transition of a Brownian particle in the cubic potential: II. optical trapping geometry"*, J. Opt. **18**, 065402, 2016
  - A. Ryabov, P. Zemánek, R. Filip: *"Thermally induced passage and current of particles in a highly unstable optical potential"*, Phys. Rev. E **94**, 042108, 2016

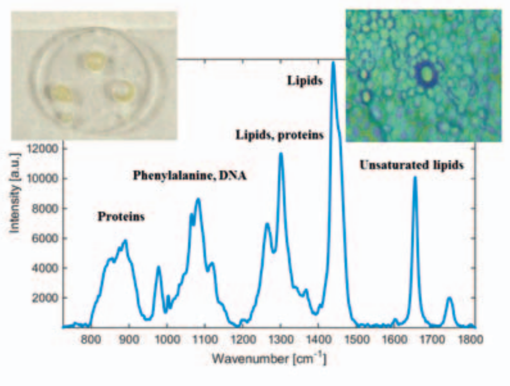
- **Pioneering results related to optically induced alignment or rotation of microobjects and nanoobjects**
  - A. V. Arzola, P. Jákl, L. Chvátal, P. Zemánek: *"Rotation, oscillation and hydrodynamic synchronization of optically trapped oblate spheroidal microparticles"*, Opt. Express **22**, 16207–1622, 2014
  - O. Brzobohatý, A. V. Arzola, M. Šiler, L. Chvátal, P. Jákl, S. Simpson, P. Zemánek *"Complex rotational dynamics of multiple spheroidal particles in a circularly polarized, dual beam trap"*, Opt. Express **22**, 7273–7287, 2015
  - S. H. Simpson, L. Chvátal, P. Zemánek: *"Synchronization of colloidal rotors through angular optical binding"*, Phys. Rev. A **93**, 023842, 2016
  - O. Brzobohatý, M. Šiler, J. Trojek, L. Chvátal, V. Karásek, A. Paták, Z. Pokorná, F. Mika, P. Zemánek: *"Three-Dimensional Optical Trapping of a Plasmonic Nanoparticle using Low Numerical Aperture Optical Tweezers"*, Sci. Rep. **5**, 8106, 2015
  - A. Irrera, A. Magazzu, P. Artoni, S. H. Simpson, S. Hanna, P. H. Jones, F. Priolo, P. G. Gucciardi, and O. M. Marago: *"Photonic Torque Microscopy of the Nonconservative Force Field for Optically Trapped Silicon Nanowires"*, Nano Letters **16**, 4181–4188, 2016

- **Optical sorting of microobjects**
  Optical cell-sorter based on fluorescences or Raman spectra of microorganisms (utility model with Photon Systems Instruments)
  - P. Jákl, A. V. Arzola, M. Šiler, L. Chvátal, K. Volke-Sepúlveda, P. Zemánek: *"Optical sorting of nonspherical and living microobjects in moving interference structures"*, Opt. Express **22**, 29746–29760, 2014

- **Combination of Raman microspectroscopy and optical tweezers offers a unique tool that provides contactless and nondestructive manipulation and diagnostics of living microorganisms**
  Optical tweezers provides 3D manipulation with objects, Raman microscopy represents one of a few contactless and nondestructive methods that provides information about the chemical bonds inside microobjects (even living cells).
  - O. Samek, K. Mlynáriková, S. Bernatová, J. Ježek, V. Krzyžánek, M. Šiler, P. Zemánek, F. Růžička, V. Holá, M. Mahelová: *"Candida parapsilosis biofilm identification by Raman spectroscopy"*, Int. J. Mol. Sci. **15**, 23924-23935, 2014
  - P. Pořízka, P. Procházková, D. Procházka, L. Sládková, J. Novotný, M. Petrilak, M. Brada, O. Samek, Z. Pilát, P. Zemánek, V. Adam, R. Kizek, K. Novotný, J. Kaiser: *"Algal biomass analysis by laser-based analytical techniques—A review"*, Sensors **14**, 17725-17752, 2014
  - S. Bernatová, O. Samek, Z. Pilát, M. Šerý, J. Ježek, P. Jákl, M. Šiler, V. Krzyžánek, P. Zemánek, V. Holá, M. Dvořáčková, F. Růžička: *"Following the mechanisms of bacteriostatic versus bacericidal action using Raman spectroscopy"*, Molecules **18**, 13188–13199, 2013

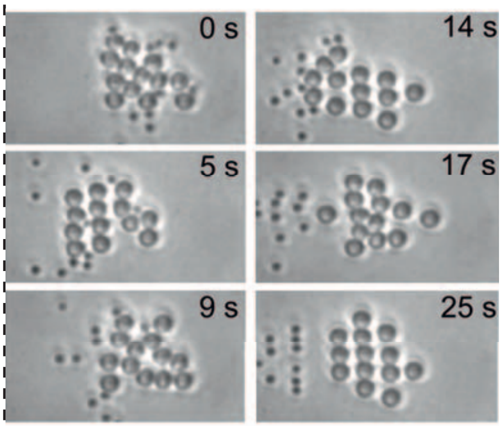


An example of optically self-arranged colloidal waveguide. The distance between the particles is tuneable by the width of two counter-propagating beams which is followed with different spectral properties of the whole structure shown at red, yellow and green wavelengths



Raman spectrum of an oil drop produced by yeast Metschnikowia. Left inset shows pipetted sample, magnified detail is shown on the right inset

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



- Z. Pilát, J. Ježek, M. Šerý, M. Trtílek, L. Nedbal, P. Zemánek: *"Optical trapping of microalgae at 735-1064 nm: Photodamage assessment"*, J. Photochem. Photobiol. B Biol. **121**, 27–31, 2013
- Z. Pilát, S. Bernatová, J. Ježek, M. Šerý, O. Samek, P. Zemánek, L. Nedbal and M. Trtílek: *"Raman microspectroscopy of algal lipid bodies: beta-carotene quantification"*, J. Appl. Phycol. **24**, 541–546, 2012

Optical monitoring of biochemical reactions running in emulsion droplets in microfluidic chips

Compact optical tweezers modules compatible with majority of optical microscopes (utility model in cooperation with Meopta)

MAIN COLLABORATING PARTNERS

Collaboration with academic partners

- Brno University of Technology (Brno, CZ)
- Consiglio Nazionale delle Ricerche (Messina, IT)
- Institute of Experimental Physics, Slovak Academy of Sciences (Košice, SK)
- Istanbul Technical University (Istanbul, TR)
- Koc University (Istanbul, TR)
- Lehigh University (Bethlehem, USA)
- Masaryk University (Brno, CZ)
- Max Planck Institute of Molecular Cell Biology and Genetics (Dresden, DE)
- Palacký University Olomouc (Olomouc, CZ)
- Universidad Nacional Autonoma de Mexico (Mexico City, MX)
- Universität für Bodenkultur (Wien, Austria)
- University of Bristol (Bristol, UK)
- University of Dundee (Dundee, UK)
- University of Glasgow (Glasgow, UK)
- University of Graz (Graz, Austria)
- University of Life Sciences (As, Norway)
- University of Naples Frederico II (Naples, IT)
- University of St. Andrews (St. Andrews, UK)

Collaboration with companies

- IQ Structures (Praha, CZ)
- Measurement Technic Moravia Ltd. (Zastávka u Brna, CZ)
- Meopta (Přerov, CZ)
- Photon Systems Instruments (Drásov, CZ)
- Tescan Orsay Holding (Brno, CZ)

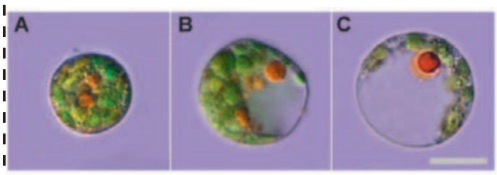
EXPECTATIONS

Offers

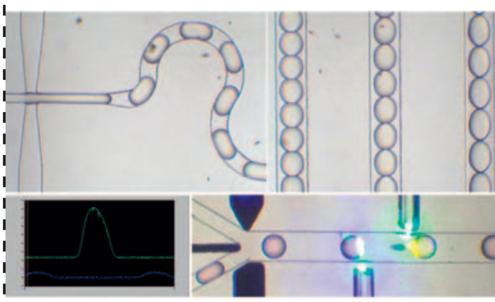
- Collaboration in the areas of our expertise
- Partnership in international projects
- Custom manufacturing of opto-mechanical systems using laser beams

Requirements

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



Living alga cells Trachydiscus minutus cultivated at different light conditions and having different contents of lipid bodies



An example of droplet microfludics. Top left: droplet generation, top right: parallel channels, bottom: fluorescence-based droplet sorting

An example of compact optical tweezers developed in collaboration with Meopta company

Custom-made selective plane illumination microscope (OpenSPIM) delivered to CEITEC laboratories