Complex Photonics Group

Department of Microphotonics

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R&D PROFILE

Research area

- Optics
- Holography
- Microscopy
- *In-vivo* imaging technology
- Endoscopy
- Lasers
- Neuroscience
- Immunology

Excellence

- Light propagation and image formation in optical fibres
- Effects of fibre bending or heating on image formation and recovery
- Laser beam shaping by spatial light modulators and digital micro-mirror devices
- On demand design and manufacturing of imaging systems
- Chemical micro-endoscopy (Raman spectroscopy, CARS or SRS)
- Imaging of biological tissues including brain and lymphoid organs

Mission

Our understanding of (biological) life has huge repercussions for our health and wellbeing. The tremendous complexity of living organisms poses challenging scientific questions. In particular, multiple scattering effects prevent current technologies from retrieving sufficiently detailed information from deep within biological tissue.

Amongst other activities we develop a new class of endoscopes that can break through this barrier. This technology can potentially go as far as reaching super-resolution with instruments having a footprint comparable to the dimensions of a single cell.

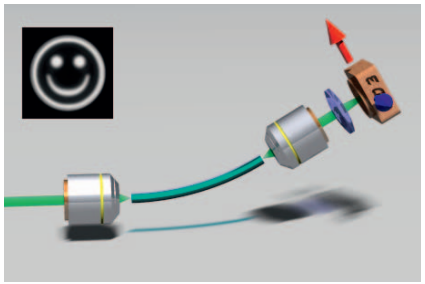
UP-TO-DATE ACTIVITIES

New technologies in holographic endoscopy

- Employ multimode fibres for holographic endoscopic techniques. Study the image formation and degradation due to fibre bending or inhomogeneous heating.
- Software development for fast reconstruction of images obtained by multimode fibres (CUDA, OpenCL, Matlab, LabView).
- Design and employ new types of fibre probes, materials and new endings for broadening spectrum of imaging techniques.
- Design and prototype a new type of Digital Micromirror Device that allows fast modulation of the light spatial phase profile with small phase steps.

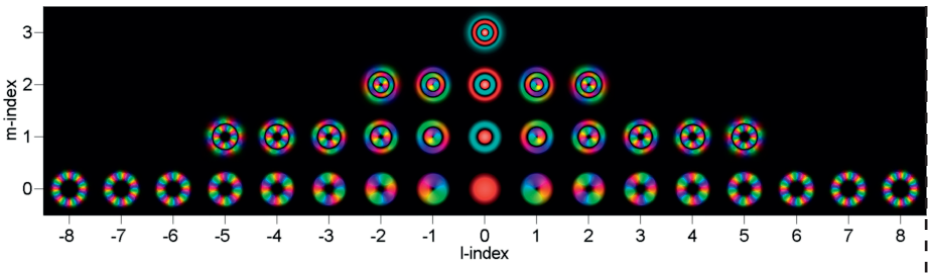
Broadening the understanding and control possibilities of light propagation in optical waveguides

- Linear propagation and shaping of light in ideal, cylindrically symmetric multimode optical fibres including continuous wave and pulse propagation, with applications to non-linear Raman and light sheet imaging.



Schematic description of fibre bending experiments.

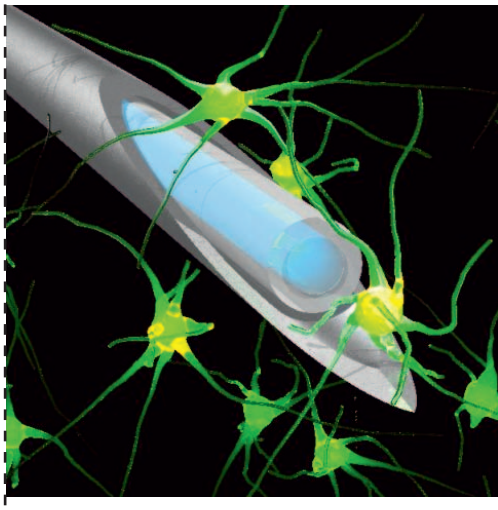
- Effects of small, geometric or optical perturbations, how they influence image formation and how these effects can be ameliorated.
- Methods for efficient optical fibre calibration and measurement.
- Image reconstruction via mode separation and processing.



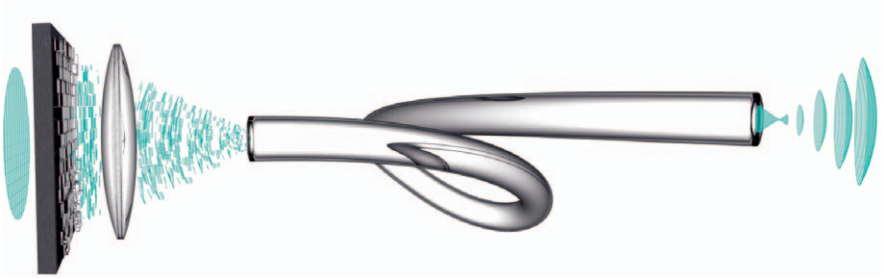
Discrete modes in a multimode optical fibre.

Micro-endoscopy with chemical contrast

- Raman microscopy is a form of label-free imaging with chemical contrast, which means that we can detect the composition of the tissue without staining it.
- Raman imaging and spectroscopy is useful for applications such as identifying bacteria and imaging lipid distribution in cells (relevant for cell metabolism and related disease conditions). Combined with holographic endoscopy, it has promise as a method for diagnosing tumors in situ, without performing a biopsy and associated time consuming histopathology.
- We will implement Raman imaging in a light sheet configuration, for faster imaging than point scanning allows.
- We aim to develop non-linear Raman imaging, in the form of CARS or SRS, through a multimode fibre.
- We aim to apply this for diagnosing tumors in sensitive locations such as the brain or pancreas.



An artist's impression of endoscopic imaging of neurons in the brain. The fibre is inserted using a hypodermic needle.

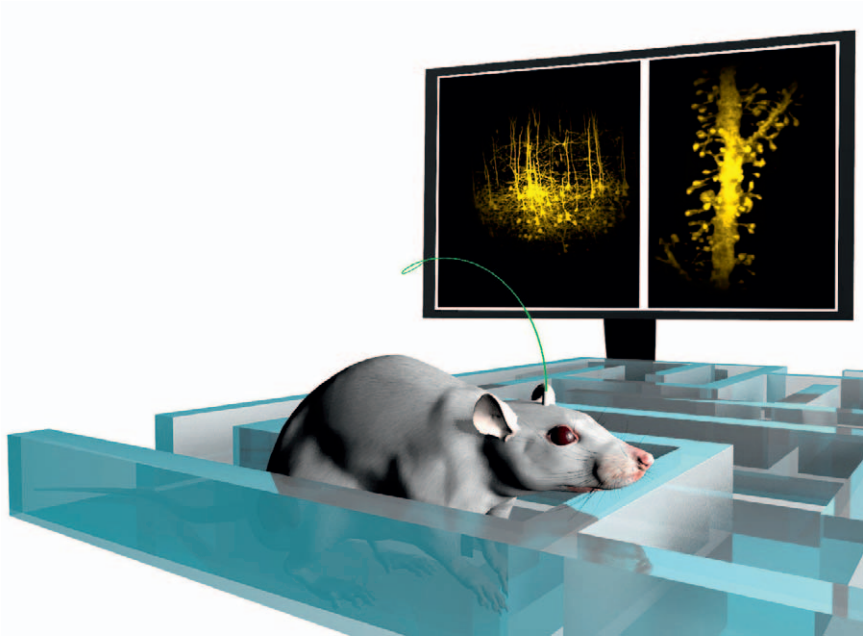


Synthesis of laser focus through a randomizing optical fibre.

In-vivo imaging for neuroscience and immunology

- One of the primary challenges facing bio-medical research today is imaging cells and cell functions in native tissues which is typically absorbing and scattering light and therefore appears opaque.
- Imaging of structures and functions deep in the tissue often requires invasive procedures including removal of the above-lying layers.
- We are developing imaging strategies for multimode optical fibres to be used as endoscopic probes. Such endoscopes have very small footprints and can therefore interrogate and image regions of the sample which would, otherwise, be inaccessible. Simultaneously they provide high-resolution images.
- Using these endoscopes we aim to study the function of two systems *in vivo*: brain and lymphoid organs.
- We will take advantage of well-defined stimulation such as selective, optogenetically-evoked activation of different cell populations, pharmacological manipulations as well as behaviour/memory-related tasks.

– Our ultimate goal is to have a versatile tool for online, high-resolution observation of 1. fundamental neurological processes such as neurovascular coupling, memory formation and neuronal plasticity in awake, freely moving animals; 2. immune processes in tissues inaccessible by classical multiphoton microscopy.



KEY RESEARCH EQUIPMENT

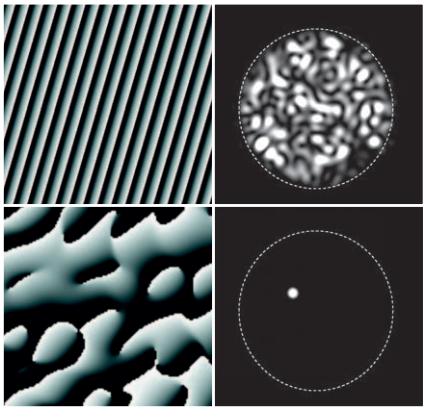
List of devices

- High power CW laser & tunable single frequency Ti:sapphire laser
- Multiphoton/confocal microscope centre (2019 onwards)
- Femtosecond laser system (2019 onwards)
- Various liquid crystal Spatial Light Modulators and Digital Micromirror Devices
- Centre of 3D printing enabling various 3D print techniques: Polyjet printing (Stratasys Objet Prime) including biocompatible materials, Fused Deposition Modelling (Zortax M300, Felix Pro 2) and Digital Light Processing (Dwarf 3)
- Surgical equipment for *in-vivo* imaging studies (IVC rack, isofluorane anaesthetic centre, stereotactic frame, stereo microscope, autoclave, homeothermic blanket, MouseOx mouse monitoring system, dental drill)
- Cell-culture equipment (laminar flow-box, CO_2 incubator, centrifuge)
- Equipment for *in-vivo* microscopy and endoscopy (pneumatic pico pump, pulse stimulator, pipette puller, micro-manipulators)

ACHIEVEMENTS

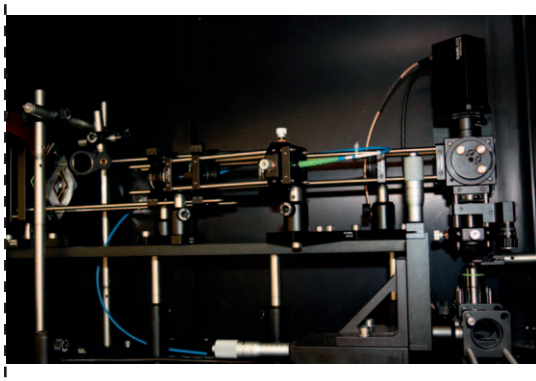
- **Sergey Turtaev, Ivo T. Leite, Kevin J. Mitchell, Miles J. Padgett, David B. Phillips, & Tomáš Čižmár, "Comparison of nematic liquid-crystal and DMD based spatial light modulation in complex photonics," Opt. Express 25, 29874-29884 (2017)**

- **Ivo T. Leite, Sergey Turtaev, Xin Jiang, Martin Šiler, Alfred Cuschieri, Philip St.J. Russell, & Tomáš Čižmár, "3-D holographic optical manipulation through high-NA soft-glass multimode fibre," Nature Photonics 12, 33-39 (2018)**



The fibre scrambles the light from a plane wave illumination to a speckle pattern (↗). The plane wave is created by the phase grating on the SLM (↖). By applying an appropriate pattern on the SLM (↙) we create a focus at the output of the fibre (↘).

Experimental setup for fibre imaging



Dirk E. Boonzajer Flaes, Jan Stopka, Sergey Turtaev, Johannes F. de Boer, Tomáš Tyc, & Tomáš Čižmár, "Robustness of Light-Transport Processes to Bending Deformations in Graded-Index Multimode Waveguides," Phys. Rev. Lett. 120, 233901 (2018)

MAIN COLLABORATING PARTNERS

Collaboration with academic partners

- Leibniz-Institut für Photonische Technologien (Jena, DE)
- University of Edinburgh (Edinburgh, UK)
- Oxford University (Oxford, UK)
- University of Exeter (Exeter, UK)
- Stanford University (Stanford, USA)
- Max Planck Institute for the Science of Light (Erlangen, DE)
- Vrije Universiteit Amsterdam (Amsterdam, NL)
- Masaryk University (Brno, CZ)
- University of Dundee (Dundee, UK)
- University of Glasgow (Glasgow, UK)
- University of St. Andrews (St. Andrews, UK)

EXPECTATIONS

Offers

We offer to share our expertise in the areas of waveguide optics, fluorescence imaging, nonlinear microscopy and digital holography.

Requirements

We look for cooperation with academic partners in the fields of *in-vivo* imaging, neuroscience, & optical manipulation.

FUNDING

European Regional Development Fund,
Project No. CZ.02.1.01/0.0/0.0/15_003/0000476

EUROPEAN UNION
European Structural and Investing Funds
Operational Programme Research,
Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS