Structured light: from principles to modern applications

A beam of light holds many properties such as the intensity value and pattern, polarization (denoting spin angular momentum), wavelength (linear momentum), and orbital angular momentum (associated with its phase structure). Structured light refers to the users' ability to engineer the aforementioned degrees of freedom, individually or in combination, in order to enhance or extend their optical capabilities. In the last decade, the possibility to modify and control the intensity and phase distribution of light has fostered this new flourishing research framework, showing disrupting and powerful applications in a wide range of fields, encompassing particle manipulation and tweezing, microscopy, imaging, classical and quantum communications.

The course will introduce to the basic and advanced tools that are necessary to understand and describe the generation, propagation and manipulation of structured light beams, focusing in particular on optical beams carrying orbital angular momentum. The methods to control and detect this unexploited degree of freedom of photons will be presented in the light of cutting-edge applications in classical and quantum telecommunications both in free-space and through optical fibres, describing also how this novel optical framework is associated with a new paradigm in optical elements design, the so-called metasurfaces. Experimental demonstrations will be done in order to apply the fundamental concepts to specific cases of interest. A significant part of the course will be devoted also to introduce the nanofabrication techniques and protocols to fabricate the state-of-the-art optical elements required to generate and control structured light beams.

Period: February-March 2021, 24 hours, 6 weeks

Dr Gianluca Ruffato (16 hrs), Prof. Filippo Romanato (8 hrs)

TIMETABLE and CONTENT:

Optical beams propagation in free space (4 hrs)

- From Maxwell's equations to Fresnel-Kirchhoff's integral
- Optical beams in the paraxial regime: definitions and properties
- Optical beams carrying orbital angular momentum (OAM)
- Vortex beams: combining orbital and spin angular momentum of photons

Structured light generation, detection, and control (4 hrs)

- Methods for OAM beams generation and detection
- Conformal transformation optics: theory and applications
- Caustics of light
- Arithmetic of light

From refractive/diffractive optics to metasurfaces (2 hrs)

- Diffractive optics
- Pancharatnam-Berry geometric phase
- The metasurface optical (r)evolution
- From plasmonic to dielectric metasurfaces

Structured light in optical fibres (2 hrs)

- Introduction to fibre optics
- Modal solutions in optical fibres
- Special fibres for mode-division multiplexing and high-dimensional QKD

Applications of structured light in microscopy, astronomy, imaging, classical and quantum communication, quantum key distribution (QKD). From photons to matter waves. (2 hrs)

Experimental demonstration in the lab with optical toolkits: (2 hrs)

- Introduction to spatial light modulators and beam shaping
- Generation and interferometry of OAM beams
- Computer-generated holograms

Heuristic reasons and nanofabrication of nano optical devices (8 hrs)

- Introduction to nano optics: interaction with nanostructured photonic materials.
- Design and realization of a photonic material
- Examples of photonic nanodevices
- Nanofabrication techniques: bottom-up and top-down processes
- Electron-beam lithography and Focused Ion Beam
- Etching techniques: from masters to mass production