Internship subject

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Optical beams generation and control with on-chip metasurfaces

In the same way electronics changed the way we realize and use electrical devices, the possibility of precisely **controlling the behavior of light with nano-scale devices opened the door to an entirely new field of research and innovative applications.** Nowadays, photonics has become a key technology for a wide variety of application fields, including optical communications, sensors, machine learning computation, and imaging.

Among some of the most recent technological advancements in the field of photonics, the study and development of metamaterials – artificial materials consisting of designed building blocks arranged on a subwavelength scale – has represented a major breakthrough. These structures allow to precisely control the interaction between light and matter, offering properties which cannot be obtained with classical materials.

Within this category, **metasurfaces have achieved the largest success**. By carefully designing this artificial surfaces, it is possible to realize the same functionalities of traditional optical elements, such as lenses, but using **ultra-thins device** that can potentially be very easily integrated in a multitude of systems, e.g., compact cell phones cameras or glasses for augmented reality. Even more interesting, **with metasurfaces it is also possible to obtain behaviours that are impossible or very hard to realize with traditional optical elements,** such as aberration-free lensing. Using one of such metasurfaces, **our group has recently demonstrated the undistorted deflection of optical beams over ultra-wide wavelength ranges.**

Because of these great potentialities, metasurfaces have attracted a large interest in the context of classical free-space optics. However, **achieving full-system integration still remains extremely challenging**: the generation and detection of light, as well as the dynamic control of its properties require additional and often bulk devices which do not allow to fully exploit the benefit of integration. To this purpose, **the combination of metasurfaces with other photonic devices integrated on a chip offers a promising solution that has not yet being explored.** On chip devices allows to generate and detect light, dynamically control its phase, amplitude, and polarization, and realize entire photonic circuits with complex functionalities. Combining them with metasurfaces would allow to realize for the first time compact, on-chip photonic systems capable of generating, controlling, and detecting free-space propagating light.

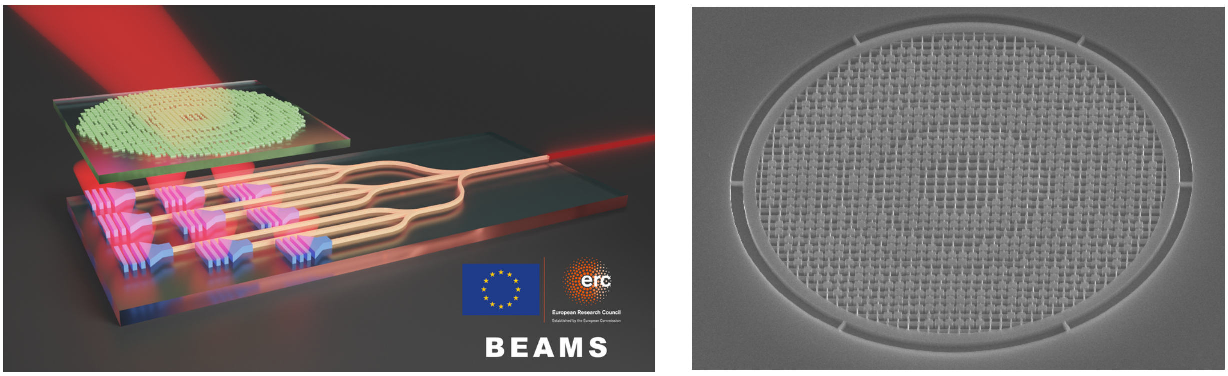

Fig.1: (left) Artistic representation of an integrated system combining a metasurface and photonic antenna to generate and deflect a laser beam propagating in the free-space. (right) Example of a recent metasurface demonstrated by the group.

The goal of this internship is to study and develop silicon-based metasurfaces specifically conceived to be used in combination with photonic integrated antennas in order to demonstrate the generation and steering of optical laser beams in the free space with the sole use of integrated devices.

The research activity will include:

- **Bibliography study** to familiarize with both metasurfaces and their unsolved challenges as well as the different approaches for their design (both classical and machine-learning based).
- **Simulation and design of silicon-based metasurfaces** using available software packages and relying on the results recently demonstrated by the group.
- **Experimental characterization** of the behavior of novel, proof-of-concept metasurfaces and integrated devices, using both free-space and fibre-based optical benches to evaluate their key performance metrics (efficiency, numerical aperture, divergence, bandwidth, ...).

During the internship, the student will be actively involved in the current research activity of the group, collaborating with PhD students, postdocs and researchers of different research backgrounds and nationalities. **This project can be continued and expanded as a PhD thesis within the framework of the project BEAMS funded by the European Research Council (ERC)** which focuses on the development of fully-integrated system for free-space optics and optical communications.

What we expect from you:

- Curiosity for novel research experiences and fields.
- Creativity and pro-activity in the search for innovative solutions and approaches.
- Capability to communicate and share results in a multidisciplinary and multi-nationality environment.

Relevant bibliography

[1] I. Staude and J. Schilling, ‘Metamaterial-inspired silicon nanophotonics’, Nature Photonics, vol. 11, no. 5, Art. no. 5, May 2017, doi: 10.1038/nphoton.2017.39

[2] A. Martins et al., ‘On Metalenses with Arbitrarily Wide Field of View’, ACS Photonics, vol. 7, no. 8, pp. 2073–2079, Aug. 2020, doi: 10.1021/acsphotonics.0c00479.

[3] Y. Liu et al., "Broadband behavior of quadratic metalenses with a wide field of view." arXiv preprint, arXiv:2206.03750 (2022).

[4] D. Melati et al., ‘Design of Compact and Efficient Silicon Photonic Micro Antennas with Perfectly Vertical Emission’, IEEE J. Select. Topics Quantum Electron., vol. 27, no. 1, pp. 1–10, Jul. 2020, doi: 10.1109/JSTQE.2020.3013532.

[5] X. Zhang et al., ‘A large-scale microelectromechanical-systems-based silicon photonics LiDAR’, Nature, vol. 603, no. 7900, Art. no. 7900, Mar. 2022, doi: 10.1038/s41586-022-04415-8.