Internship subject

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Artificial intelligence for the design of optical 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 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 elementary building blocks arranged at distances of a few hundreds of nanometers – has been 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 (1 µm or less) 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 interestingly, 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.

Common metasurfaces are designed exploiting relatively simple geometries (cylindrical or rectangular building blocks) that are designed by hand, which however results in limited performance. On the contrary, one of the most active research topics in the field focuses on the possibility of using **non-intuitive shapes and complex material distributions** . The way light interacts with matters in such structures is not easy to describe with commonly available models and their design requires **developing innovative design methodologies**. **These challenges stimulated a large research effort in the direction of artificial intelligence and data-driven methodologies which have been demonstrated as a viable solution to handle thousands of design variables simultaneously**. Machine learning algorithms can build complex physical models directly from a set of training data, models that can then be used to very efficiently design novel photonic structures with desired optical properties.

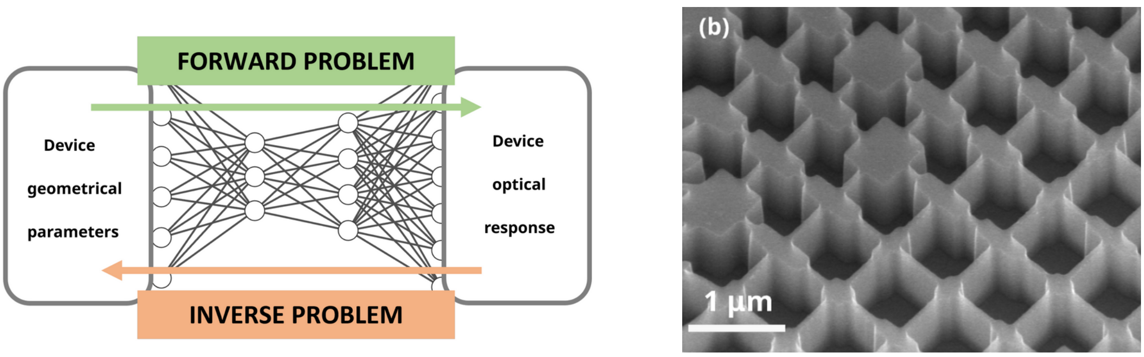

Fig.1: (left) Schematic representation of a neural network capable of predicting the optical response of a photonic device from its geometrical parameters (forward problem) or providing the geometrical parameters for a desired response (inverse problem). (right) Top view of a fabricated metasurface [4].

The goal of this internship is the exploration of innovative design tools for the development of metasurfaces with improved performance and advanced functionalities. Models based on neural networks and their potential combination with optimization techniques will be investigated to efficiently optimize the design of complex elementary building blocks and realize large metasurfaces. Depending on the results of the design phase, metasurfaces could then be fabricated in the C2N cleanroom and tested to demonstrate their performance.

The research activity will include:

- **Bibliography study** to familiarize with the use of machine-learning-based algorithms in the field of optical metasurfaces and the existing challenges.
- **Set-up of machine learning algorithms** linked to optical simulators (using available software and packages) capable of predicting the optical behavior of a given material geometry (forward problem) and, eventually, generate new geometries for a desired functionality (inverse problem).
- **Evaluate the performance** of these algorithms with respect to other available design techniques.
- **Comparison of the desired performance of the metasurfaces with those obtained through optimization** on key performance metrics (efficiency, bandwidth, reflections...).

During the internship, the student will be actively involved in the on-going research activity in the described topic, collaborating with PhD students, postdocs and researchers of different research backgrounds and nationalities. **The research work in this topic can be continued and expanded as a PhD thesis**.

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] P. R. Wiecha et al., 'Deep learning in nano-photonics: inverse design and beyond', Photon. Res., PRJ, vol. 9, no. 5, pp. B182–B200, May 2021, doi: 10.1364/PRJ.415960.

[2] W. Ma et al., 'Deep learning for the design of photonic structures', Nature Photonics, pp. 1–14, Oct. 2020, doi: 10.1038/s41566-020-0685-y.

[3] D. Melati et al. 'Mapping the global design space of nanophotonic components using machine learning pattern recognition', Nat Commun, vol. 10, no. 1, pp. 1–9, Oct. 2019, doi: 10.1038/s41467-019-12698-1.

[4] Y. Liu, Y. Liu, J. Zhang, X. L. Roux, E. Cassan, D. Marris-Morini, L. Vivien, C. Alonso-Ramos, and D. Melati, 'Broadband behavior of quadratic metalenses with a wide field of view', *Opt. Express*, vol. 30, no. 22, pp. 39860–39867, Oct. 2022, doi: 10.1364/OE.466321.