Internship subject

Laboratory: Centre de Nanosciences et de Nanotechnologies (UMR 9001)
Address : 10 Boulevard Thomas Gobert, 91120, Palaiseau

Contact: Daniele MELATI
email: daniele.melati@universite-paris-saclay.fr
https://minaphot.c2n.universite-paris-saclay.fr/en/

"Metasurfaces for free space optical communications"

Photonics has become a key technology for a wide variety of application fields, including both wired and free space optical communications, sensors, computational systems, and imaging. For example, Lidars are foreseen as a vital component of autonomous vehicles; the next generation of communications with satellite and deep space are expected to be empowered by the use of optical links. Among recent technological advancements in the photonic field, 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 and a novel perspective beyond classical waveguide-based architectures. Within this category, metasurfaces – ultrathin artificial surfaces – provide unparalleled controllability over light propagation in free-space and offer ultra-compact flat-optics alternatives to traditional bulky systems used in lensing and beam-shaping.

The tremendous progress in artificially engineered photonic structured also raised the problem of developing appropriate design methodologies. Classical procedures based on analytical modelling and numerical simulations largely rely on the past experience of the designer and known design patterns and are limited in the number of design parameter that can be handled, owing the constraints of computational resources available for simulation. For devices employing metamaterials, not only the number of design parameters vastly increase but often a multitude of figure of merits must be simultaneously evaluated, making this conventional approaches no longer applicable. These challenges stimulated a large research effort in the direction of machine learning 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 properties.

In this context, the objective of the work will be the exploration machine learning algorithms for the design of metasurfaces for free-space optical communications on the Silicon and Silicon Nitride platforms. Deep learning methodologies (e.g. variational autoencoders) will be combined with physics-based models and gradient descent techniques to alleviate the large amount of input data required by classical algorithms. The use of dimensionality reduction will be investigated to describe the physics of the designed metasurfaces.

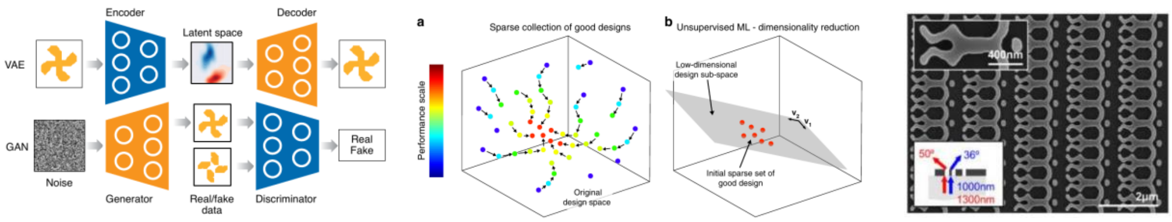

Fig.1: (left) Schematic representation of a Variational Autoencoder and a Generative Adversarial Neural Network [4]. (middle) Photonic design based on machine learning dimensionality reduction [5]. (right) Example of photonic metasurface [2]

The research activity will include:

- Bibliography study to both familiarize with metasurfaces and their unsolved challenges and understand machine-learning-based optimization.

- Set up of machine learning models linked to optical simulators (using available software and packages) capable of generating new metasurface designs and evaluation of their performance compared to available techniques

- Propose proof-of-concept metasurface designs (including masks) for fabrication and experimental demonstration

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] D. Sell, J. Yang, S. Doshay, R. Yang, and J. A. Fan, ‘Large-Angle, Multifunctional Metagratings Based on Freeform Multimode Geometries’, Nano Lett., vol. 17, no. 6, pp. 3752–3757, Jun. 2017, doi: 10.1021/acs.nanolett.7b01082.

[3]Z. Liu, D. Zhu, S. P. Rodrigues, K.-T. Lee, and W. Cai, ‘Generative Model for the Inverse Design of Metasurfaces’, Nano Lett., vol. 18, no. 10, pp. 6570–6576, Oct. 2018, doi: 10.1021/acs.nanolett.8b03171.

[4] W. Ma, Z. Liu, Z. A. Kudyshev, A. Boltasseva, W. Cai, and Y. Liu, ‘Deep learning for the design of photonic structures’, Nature Photonics, pp. 1–14, Oct. 2020, doi: 10.1038/s41566-020-0685-y

[5] 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.