# PhD thesis project

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## « Controlling the nonlinear properties of photonic waveguides and planar metamaterial-like media in silicon photonics with regresssion and learning techniques »

**Research project description:**

Integrated photonics is a platform of choice for the realization of various experiments in physics and rich in numerous applications. Among these, one of its branches, **silicon photonics**, has developed considerably in recent years, specializing in the development of optoelectronic and optical components for integration with silicon microelectronics. In recent years, there has been a trend towards a **strong diversification of silicon photonics to various fields** such as quantum optics on a chip, metrology or spectroscopy on a chip at mid infra-red wavelengths (2µm-20µm), and the development of all-optical signal processing functions through the exploitation of second or third order non-linear optical effects. The use of nonlinear effects, particularly of the third order, indeed opens up a whole range of possibilities from the realization of optical sources based on the supercontinuum generation effect to Kerr frequency comb generation, or the ultra-fast switching of signals without conversion to electrical signals.
**Theses nonlinear effects are particularly interesting but difficult to control**. For instance, the dynamics of the generation of a supercontinuum **[1,2]** is difficult to predict. A high-power optical pump signal allows to reach, under the effect of third-order nonlinear optical mechanisms, the parametric gain conditions. Under the combined effects of the phase self-modulation mechanism and the chromatic dispersion of the waveguide, which also plays a critical role, the spectrum of the pump signal widens as the light propagates along the waveguide. However, the **very complex and unpredictable global dynamics between the contributions of the different effects** (Kerr effect, waveguide chromatic dispersion, single or multiple phase matching conditions, possible fissions of solitons, etc) **makes it extremely difficult to predict the optical pulse spectral enlargement, the shape itself of this spectrum, and its level of phase coherence**.
One possible way to solve this problem and to be able to predict the configurations corresponding to a given spectrum expanded by the **supercontinuum** effect is to rely on statistical regression and/or learning methods **[3,4]**. This will thus involve determining the geometry of the waveguides (core/cladding optical index contrast, section), length, as well as that of the input and output optical accesses (light coupling by diffraction gratings) to obtain a pre-determined expanded optical spectrum, i.e. to solve the inverse problem: **[Considering a desired optical spectrum => Which photonic waveguide structure should I choose?]**. The study of the nonlinear propagation of picosecond optical pulses is based on the resolution of the so-called nonlinear Schrödinger equation in photonic waveguides (in our case, mainly in silicon, $Si_3N_4$, or Silicon-rich nitride waveguides). **One of the main degrees of freedom to be exploited will be to consider a lateral variation in the width of the waveguide throughout the propagation of light**. Given the number of study parameters (shape and peak power of the input optical pulses, central wavelength of this optical pump, shape of the waveguide throughout the propagation, choice of materials among those mentioned above), learning techniques will be used and exploited to solve the desired inverse problem.

By capitalizing on the regression (KNN, randomforest, etc) and learning methods (deep learning) developed, a second part of the thesis project will consist in extending the effects studied to **gradual periodic planar structures made of a regular and/or random arrangement of patterns, eg of generalized optical gratings/graded-photonic-crystals/metasurfaces for the control of light on demand, in the plane and out of the plane, first in the situation of optically linear materials, and also by considering nonlinear optical materials** **[5,8]**. The ambitious objective of this second part of the thesis is to set up a methodology for modelling the propagation (in plane) and diffraction of light (out of the plane) within a general framework for its application to various application domains: light in/out couplers from/into optical circuits, novel kinds of lenses, realization of chaotic optical effects, spatial light modulation, etc.

All this modelling part of the thesis will lead to the design of structures. The PhD candidate will be strongly involved in the design of structural masks (GDSII masks) for their fabrication by micro-nano-fabrication clean room techniques (lithography, etching, etc), then in their various optical linear and nonlinear characterizations within the Minaphot research team.

**BIBLIOGRAPHY:**

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**[2]** **"Octave-spanning coherent supercontinuum generation in a silicon nitride waveguide"**
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**[3]** **"Deep learning"**
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**[4]** **"Deep learning for accelerated all-dielectric metasurface design"**
Christian C. N. Adell et al., Vol. 27, No. 20, 30 Sep 2019, Optics Express 27523

**[5]** **“Dielectric gradient metasurface optical elements”**
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**[7]** **“Light propagation and emission in complex photonic media”**
Willem L. Vos, Ad Lagendijk, Allard P. Mosk
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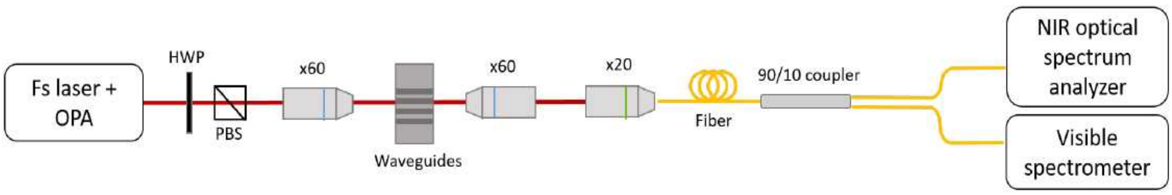
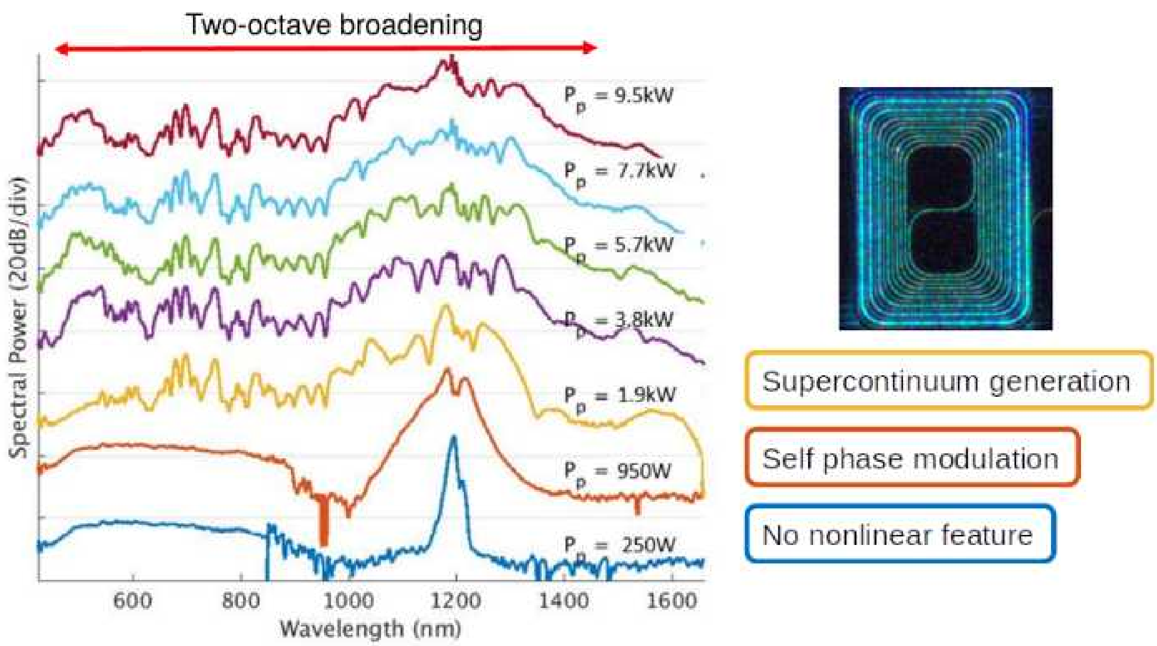
**[8]** **”Controlling light with metamaterial-based nonlinear photonic crystals”**
Nadav Segal, Shay Keren-Zur, Netta Hendler and Tal Ellenbogen
Nature Photonics, 16 FEBRUARY 2015 | DOI: 10.1038/NPHOTON.2015.17

**Send an email to eric.cassan@u-psud.fr if you are interested in these papers.**

Recent experiment carried out in our group :




**We expect from you:**

- **Enthusiasm and involvement**
- **Background in electromagnetism&optoelectronics + Taste for simulation (python, electromagnetic commercial softwares) and optical experiments**
- **Prior knowledge in regression algorithms and/or machine learning methods**
- **Ability to communicate and work in a group (4 researchers/teacher-researchers, and around 10 post-doc fellows and doctoral candidates)**