# PhD Thesis proposal form

Discipline
**PHYSIQUE**

Doctoral School
**Ecole Doctorale STITS (ED 422 ; http://www.ed-stits.fr/)**

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| Thesis subject title: | **GRADED NANOPHOTONIC PERIODICAL STRUCTURES IN THE NEAR AND MID INFRA-RED FOR OPTICAL SIGNAL PROCESSING AND BIOSENSING** |

- Laboratory name and web site: **Institut d'Electronique Fondamentale (UMR CNRS 8622)**
- PhD supervisor (contact person):


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- **Thesis proposal:**

**Keywords**: Silicon nanophotonics, near and mid-infrared wavelengths, periodic structures, photonic metamaterials, electrical and all-optical signal processing, biosensing

**More details at**: *http://silicon-photonics.ief.u-psud.fr/*

**Silicon photonics** has raised an increasing interest in the last years due to the foreseen possibility of merging electronics and photonics on the same chips using large scale wafers and well-established technologies. Significant breakthroughs have been demonstrated on optical waveguides and passive optical devices to distribute light, filter optical signals, add-drop individual wavelength around $\lambda$=1.5$\mu$m, as well as in the field of active structures for light emitters, modulators, and detectors. The main potential applications of the **silicon photonic** technology are datacom for rack-to-rack, chip-to-chip and on-chip interconnects, **optical telecommunications**, and **biophotonics**.

In terms of physical properties, SOI optical waveguides are characterized by a strong refractive index contrast between core and cladding ($\Delta n \approx 2$), leading to a strong miniaturization of the waveguide cross-sections in the deep-submicron scale. The main derived benefits are the small footprint of photonic structures and the possible strengthening of non-linear optical phenomena.

The increase of data bit rates of optoelectronic components beyond 40Gbits.s$^{-1}$, the reduction of their power consumptions and their footprints, and the improvement of the sensitivity of optical bio-sensors are few examples of the main **forthcoming challenges in silicon photonics**. For all of these items, the use of periodically corrugated structures, e.g. sub-wavelength and/or photonic crystal structures producing high-Q cavities, unusual dispersive phenomena, and a tight control of optical beams is perceived as very interesting and promising approach.

**In this general context, the PhD proposed topic will focus on the physical properties and possible applications of *graded periodical nanophotonic structures* in the near ($\lambda \sim$ 1.3-1.6$\mu$m) and mid (2.2$\mu$m $\leq \lambda \leq$ 16$\mu$m) infrared wavelength range for optical signal processing and biosensing.** The choice to extend the wavelength range beyond NIR the telecommunication band stems from recent interesting publications by strong research groups from the USA having pointed out the benefits that can be obtained by working above the 2.2 $\mu$m; these works have indeed pointed out that the non-linear optical properties of silicon are then more interesting because the two-photon absorption (TPA) and free-carrier absorption (FCA) processes are strongly reduced [1,2]. Additionally, we add that working at larger wavelengths also eases the practical fabrication of photonic structures with similar waveguiding and dispersive properties than for smaller wavelength devices due to the scaling rules of the Maxwell's equations.

**The primary item that will be addressed will be the design and fabrication of silicon-compatible** (Si, Ge, SiGe, GeSi, GeSn with $SiO_2$, SiON, $Si_3N_4$ cladding, …) **graded nanophotonic structures to curve light paths following arbitrary trajectories using either sub-wavelength or photonic crystal structures for the realization of new and versatile integrated optical functions**. Theoretical works performed in our research groups have shown the possibility to accurately control light paths by adjusting the graded structure dimensions "on-the-fly" (filling factor, shape of individual scattering elements of the photonic metamaterial) [3]. **These concepts will be extended up to mid-infrared wavelengths** and appropriate waveguiding structures will be defined depending on the targeted wavelength range. The first application that will be envisaged is the design and fabrication of **broadband optical delay lines and sensors** using an idea proposed in our group. Indeed, recently, we theoretically showed the possibility to curve the light path in a semiconductor sample optical slab waveguide following a nearly-closed path (spiral light path) with an ultra-wide bandwidth due to the involved non-resonant mechanism [4]. The light path length is unfolded over several millimeters for optical devices designed in a square of less than $150\mu m \times 150\mu m$. The immediate consequence is a strong increase of both the optical delay and the interaction length between light and matter, while maintaining small footprint devices. Such spiralling effect strengthens non-linear optical effects and can be envisaged for the realization of configurable optical delay lines and buffers that could serve to optical signal processing in a large wavelength range in the mid-infrared.

**The PhD student will be welcomed in the silicon photonics group of the IEF laboratory (*http://silicon-photonics.ief.u-psud.fr/*) under the supervision of prof. Eric CASSAN (eric.cassan@u-psud.fr)**. He/she will use the computing methods/softwares of the group (FDTD, PWE, Silvaco, home-made codes), the silicon clean room of the lab (e-beam lithography, RIE/ICP etching techniques, etc), and the experimental environment provided by four experimental optical benches with nanoalignements and electrical/RF probes to characterize the samples. Additionally, collaborations established with other groups will open the possibility to realize near-field optical and other complementary measurements.


[1] Bahram Jalali, "Silicon photonics, Nonlinear optics in the mid-infrared", Nature Photonics 4, 506 (2010).

[2] Richard Soref, "Mid-infrared photonics in silicon and germanium", Nature Photonics 4, 495 (2010)

[3] E. Cassan, K.V. Do, C. Caer, D. Marris-Morini, L. Vivien, "Short-Wavelength Light Propagation in Graded Photonic Crystals", Journal of Lightwave Technology, vol. 29, n°13, pp. 1937-1943, 2011.

[4] E. Cassan, K. V. Do, "Analytic design of graded photonic crystals in the metamaterial regime", Journal of the Optical Society of America B, vol. 28, n°8, pp. 1905-1910, 2011.


- Publications of the laboratory in the field (max 5): **(5 publications among ours in the 2011 year)**


[1] E. Cassan, K.V. Do, C. Caer, D. Marris-Morini, L. Vivien, "Short-Wavelength Light Propagation in Graded Photonic Crystals", *Journal of Lightwave Technology*, vol. 29, n°13, pp. 1937-1943, 2011.

[2] E. Cassan, K. V. Do, "Analytic design of graded photonic crystals in the metamaterial regime", *Journal of the Optical Society of America B*, vol. 28, n°8, pp. 1905-1910, 2011.

[3] Anatole Lupu, Kamal Muhieddine, Eric Cassan, Jean-Michel Lourtioz, "Dual transmission band Bragg grating assisted asymmetric directional couplers", *Optics Express*, vol. 19 (n°2), pp. 1246-1259, 2011

[4] Jean Dellinger, Damien Bernier, Benoit Cluzel, Xavier Le Roux, Anatole Lupu, Frédérique de Fornel, and Eric Cassan, "Near field direct experimental observation of beam steering in a photonic crystal superprism", *Optics Letters*, Vol. 36, Issue 7, pp. 1074-1076 (2011)

[5] E. Cassan, X. Le Roux, C. Caer, R. Hao, D. Bernier, D. Marris-Morini, L. Vivien, « Silicon slow light photonic crystal structures: present achievements anf future trends », Review paper, *Frontiers of Optoelectronics in China*, vol. 4, n°3, pp. 243-253, Higher Education Press and SPRINGER –VERLAG, 2011.