PhD topic proposal for 2023

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"Physical properties of active and nonlinear optical resonators in silicon photonics"

Research project description:

Silicon photonics is a key field that has developed considerably in recent years [1]. This strong index core/cladding waveguiding platform allows for extremely narrow waveguides: the cross-section of optical waveguides needs to be reduced to around 450nm×220nm to allow single-mode propagation in the near infra-red (e.g. around 1.55µm light wavelength). This raises the need for specific light injection and extraction techniques like optimized grating couplers but provides the strong interest to also reinforce light-matter interactions due to the extremely large electromagnetic density in optical waveguides. A simple rectangular waveguide capped with a 2D material monolayer or few monolayers of active biomolecules can thus present extremely large optical nonlinearities or sensing sensitivity, respectively. Things are even more reinforced in optical dielectric resonators that can be easily realized through different means including micro-ring resonators (folded waveguides wrapped on themselves) or photonic crystal cavities, that are all key elements to reinforce the light-matter physical effects. Placing single emitters placed in optical nanocavities for controlling spontaneous emission and exploiting the Purcell physical effect is one of the possible situations to explore physical mechanisms relying on weak or strong coupling mechanisms [2]. The physics of integrated photonic resonators embedding nonlinear optical materials also gives rise to a rich set of interesting physical mechanisms that are further reinforced by the cavity photon recycling effects [3]. The dynamics of these effects is yet intrinsically difficult to control. Indeed, the cascade of nonlinear optical processes that can occur often depends on a competition between them, which itself depends on the input light source pulse properties as well as on the dispersion regime of the optical waveguides and resonators. A specific focus will be put on the design and realization of Fano resonators in the silicon photonics platform [4,5]. Such resonances occur from the interference between the coupling of the fields decaying from a narrow resonance and a continuum (a spectrally wide resonance is often enough). They can provide extremely asymmetric transmission and reflection spectra which are very useful for a wide range of applications. Additionally, they can be engineered in-plane or out-of-plane with respect to a semiconductor substrate. The challenge is then to design Fano cavities bypassing the present state-of-the-art in terms on-demand control of resonance frequencies, large quality factors, control of the far-field patterns, and to investigate their physical properties.

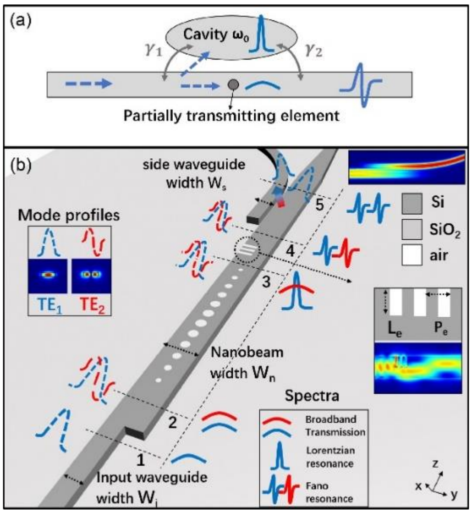

Fig. 1: Folded Fano cavity in a Si waveguide [3]

In this overall context, the **PhD proposal** will conduct the **investigation of resonators and nanoresonators in silicon photonics**, be them dielectric or plasmonic, in view to investigate their **physical effects** when coupled to single-photon emitters or nonlinear materials of second and third orders, respectively:

- In a first direction, the integration of Erbium-based single emitters or 2D materials (e.g. WS_2, MoS_2) containing defects will constitute the basis reference configurations.
- In the second direction, the integration of chalcogenide glasses or 2D materials presenting nonlinear optical properties will be the mainstream goal.

These two families correspond to situations for which collaborations of the PhD supervisor with others teams, be them part of the host laboratory, national, or abroad, can allow the integration of active or nonlinear materials. The silicon photonic waveguides and resonators, for their part, will be designed and fabricated at C2N (host laboratory).

The focus of the PhD topic remains the physical investigation of the active and nonlinear resonators. The development to be carried out will necessitate:

- To conduct an overview of the current state-of-the art of the potential of resonators in silicon photonics for leveraging single-photon emission/quantum communications on a chip, as well as the realization of optical sources based on supercontinuum generation and comb generation processes.
- To develop theoretical and numerical approaches to investigate the related situations. Numerical tools exist at the host group but will have to be extended significantly to take into account the physics underlying the carried out research directions.

Overall, the work will contribute to the understanding of the physical principles suited to the proper integration of emerging materials (eg chalcogenide glasses, Transition metal dichalcogenide monolayers) in silicon photonic cavities and resonators and to explore the physical properties of the associated systems through various experimental techniques (e.g. photoluminescence, monitoring the generation of new frequencies, etc).

The research host laboratory offers itself great opportunities for collaborations (e.g. a department of material science) and the PhD supervisor, Eric Cassan (*) has also established collaborations with other groups abroad.

In terms of abilities, we are looking for an open-minded student, able to work in a group with many collaborators including other PhD and internship students, and having taste and skills for both experiments and modelling. A good level in English is mandatory.

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https://scholar.google.fr/citations?user=Fpsc97gAAAAJ&hl=fr&oi=ao

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