

PhD project : Reconfigurable photonic devices for mid IR photonic integrated circuits

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Mid-infrared (mid-IR) integrated photonics (i.e. with $2\mu\text{m} < \lambda < 20\mu\text{m}$) is actually a subject of increased emphasis, with a strong potential to revolutionize different application fields. As an example mid IR spectroscopy is a nearly universal way to identify chemical and biological substances, as most of the molecules have their vibrational and rotational resonances in this wavelength range. Commercially available mid-IR systems are based on bulky and expensive equipment, while lots of efforts are now devoted to the reduction of their size down to chip-scale dimensions. The demonstration of mid-IR photonic circuits on silicon chips would benefit from reliable and high-volume fabrication to offer high performance, low cost, compact, low weight and power consumption photonic circuits, which is particularly interesting for mid-IR spectroscopic sensing systems that need to be portable and low cost. Mid-IR photonic circuits on silicon chips can also have important applications for free space telecommunications or military applications.

In this context, we develop a new route for the development of chip-scale integrated circuits on silicon for the mid-IR wavelength range, based on **Ge-rich SiGe materials**. We recently demonstrated **the strong potential of this platform for broadband operation in the mid-IR**. We also studied nonlinear properties of Ge-rich SiGe waveguides, showing that **band-gap engineering can be used to tune the non-linear effects** and to exploit diverse phenomena based on nonlinear effects.

As a next step we would like to investigate the possibility to command electrically the properties of these integrated devices (by applying an electrical voltage). While electro-optical control of Si based devices in the near IR has been largely studied, very little work has been reported up to now in the mid-IR wavelength range. The main idea will be to use **refractive index/absorption coefficient variations by free carrier concentration variations, in order to develop reconfigurable devices**.

Targeted devices cover (i) optical modulator based on ring resonator/Mach Zehnder interferometer for synchronous detection systems, (ii) reconfigurable spectrometers to finely tune the spectral response of an on-chip spectroscopic detection platform.

Besides these objectives, the development of active devices in the mid-IR can also have a strong impact for other application such as free space communications.

The goal of this PhD project will be to develop electrically-controlled optical devices based on Ge-rich SiGe waveguides, from 5 to 8 μm wavelength.

The research activity will include:

- **theoretical study and electro/optical simulations** (using commercial software) to evaluate the key metrics for tuning the optical properties of the waveguide modes
- **clean-room fabrication** based on classical fabrication process (lithographie, etching, ...)
- **experimental characterizations** using mid-IR optical bench developed within the group

The work is done in the framework of the ERC INSPIRE project, in a strong collaboration with Giovanni Isella's group (L-Ness lab (Politecnico di Milano)).

During his PhD, the student will be actively involved in the current research activity of the group, collaborating with PhD students, postdocs and researchers of different research backgrounds and nationalities.

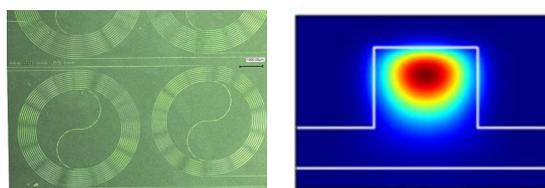


Fig. 1: left: picture of integrated mid-IR photonic integrated circuit based on Ge-rich SiGe platform / right: optical mode calculation showing the strong confinement of light in the core of a graded waveguide.

VALUED QUALITIES IN THE STUDENT

- 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.

BIBLIOGRAPHY RELATED TO THE TOPIC

[1] J.M. Ramirez, V. Vakarin, C. Gilles, J. Frigerio, A. Ballabio, P. Chaisakul, X. Le Roux, C. Alonso-Ramos, G. Maisons, L. Vivien, M. Carras, G. Isella, D. Marris-Morini, "Low-loss Ge-rich Si_{0.2}Ge_{0.8} waveguides for mid-infrared photonics", *Optics Letters* 42 (1) 105 (2017).

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[2] J.M. Ramirez, V. Vakarin, J. Frigerio, P. Chaisakul, D. Chrastina, X. Le Roux, A. Ballabio, L. Vivien, G. Isella, D. Marris-Morini, "Ge-rich graded-index Si_{1-x}Ge_x waveguides with broadband tight mode confinement and flat anomalous dispersion for nonlinear mid-infrared photonics", *Optics Express* 25 (6) 6561 (2017)

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[3] V. Vakarin, J-M. Ramirez, J. Frigerio, A. Ballabio, X. Le Roux, Q. Liu, D. Bouville, L. Vivien, G. Isella, D. Marris-Morini, "Ultra-wideband Ge-rich silicon germanium integrated Mach-Zehnder interferometer for mid-infrared spectroscopy" *Optics Letters* Vol. 42 n°17, 3482-3485 (2017)

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