Ge-rich graded-index SiGe waveguides as enabling building blocks for broadband mid Infrared integrated photonics

Joan Manel RAMIREZ[1*], Vladyslav VAKARIN[1], Jacopo FRIGERIO[2], Qiankun LIU[1], Andrea BALLABIO[2], Papichaya CHAISAKUL[1], Xavier LE ROUX[1], Laurent VIVIEN[1], Giovanni ISELLA[2], Delphine MARRIS-MORINI[1]

[1]Centre de Nanosciences et de Nanotechnologies, Université Paris Sud, CNRS, Université Paris Saclay, 91405 Orsay, France

[2]L-NESS, Dipartimento di Fisica, Politecnico di Milano, Polo di Como, Via Anzani 42, 22100 Como, Italy

[*] joan-manel.ramirez@u-psud.fr

The mid-Infrared (mid-IR) photonic integrated platform is recently drawing attention due to its foreseen potential as alternative compact solution to several challenges and limitations taking place in current mainstream technologies [1]. Improved performance is expected in a wide palette of topics such as sensing, thermal imaging, nonlinear optical devices, astronomy or secure datacom, among others [2]. Up to date, different material platforms have been considered to develop mid-IR devices with functionalities beyond the state of the art. In that framework, Si and Ge have risen as promising alternative raw materials to develop mid-IR photonic devices leveraging from the higher refractive index of Ge over Si and their compatibility with the standardized CMOS platform. Also, Si and Ge possess a wavelength transparency window up to λ = 8 µm and 14 µm respectively, in concordance with the spectral range where several substances display their main spectral absorption peaks, hence opening the route towards highly-sensitive and selective label-free chemical sensors. Additionally, none of these materials experience significant nonlinear losses at those wavelengths, as Two-Photon Absorption (TPA) and other related second-order effects are strongly reduced in the mid-IR. This last point in particular, makes SiGe approaches an interesting choice to explore novel nonlinear optical devices operating in the mid-IR range, taking advantage from the commercially available high-power and largely tunable mid-IR quantum cascade lasers.

A large pool of devices using the Ge-on-Si platform have already been reported so far, including waveguides and interferometric devices [3], arrayed waveguide grating multiplexers [4], thermo-optic phase shifters [5] or supercontinuum light sources [6]. Similarly, SiGe alloys with promising nonlinear properties in the mid-IR have been reported [7], and other approaches using graded Ge concentration profiles have also been proposed to obtain low-defect SiGe layer stacks with variable vertical refractive index profiles [8, 9].

Recent advances in graded-index Ge-rich SiGe waveguides operating in the mid-IR will be presented in this work. Main experimental results from passive structures will be detailed first, obtained from an ad-hoc experimental setup that allows precise measurement of the guided mode size and its spectral evolution over a wide wavelength range, as depicted in figure 1. Then, a comprehensive study of the main design parameters that yields optimum nonlinear performance in a broadband mid-IR wavelength range (from 3 µm to 8 µm) will be reported and compared with other state of the art mid-IR integrated platforms, showing that the Ge-rich SiGe graded waveguides have a huge potential as an innovative and powerful platform for the mid IR.

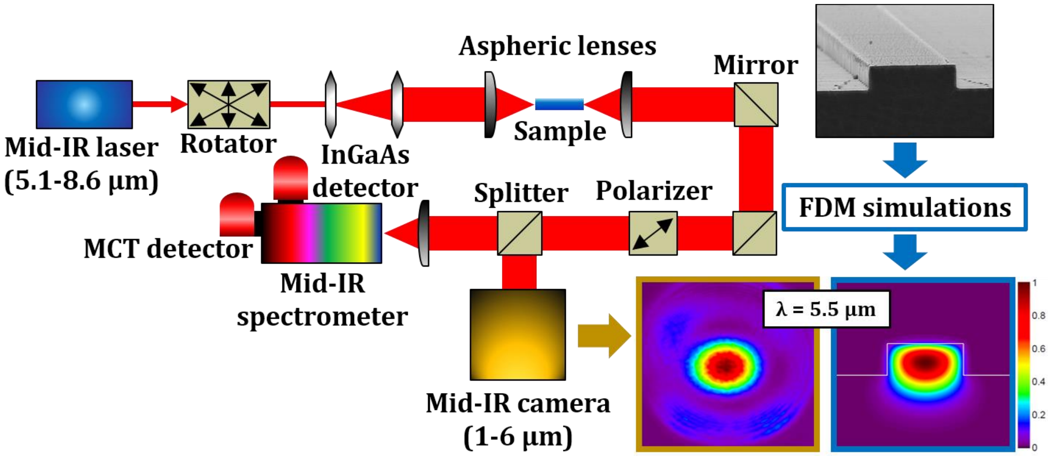

Fig. 1. Experimental setup used to characterize the broadband mid-IR Ge-rich SiGe waveguides. The SEM image located at the upper-right hand side shows a typical waveguide cross-section, with an etching depth of 1.5 µm and a waveguide width of 8 µm. Pictures at the bottom-right hand side compare the measured modal area (left image, boxed in orange) with the simulated one (right image, boxed in blue) using an FDM mode solver.

Acknowledgments

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement N°639107-INsPIRE).

References

[1] R. Soref, "*Mid-infrared photonics in silicon and germanium,*" Nat. Photonics, 4(8), 495-497 (2010).
[2] Editorial "Extending opportunities," Nat. Photonics, 6(7) 407-407 (2012).
[3] A. Malik, M. Muneeb, Y. Shimura, ... , & G. Roelkens, "*Germanium-on-silicon mid-infrared waveguides and Mach-Zehnder interferometers,*" In IEEE Photonics Conference 2013 (IPC-2013) (pp. 104-105). IEEE (2013).
[4] A. Malik, M. Muneeb, S. Pathak, ... , & G. Roelkens, "*Germanium-on-silicon mid-infrared arrayed waveguide grating multiplexers,*" IEEE Photonics Technology Letters, 25(18), 1805-1808 (2013).
[5] A. Malik, S. Dwivedi, L. Van Landschoot, ... , & G. Roelkens, "*Ge-on-Si and Ge-on-SOI thermo-optic phase shifters for the mid-infrared,*" Optics express, 22(23), 28479-28488 (2014).
[6] M. Yang, Y. Guo, J. Wang, ... , & L. Zhang, "*Mid-infrared supercontinuum generation in a low-dispersion Ge-on-Si waveguide using sub-picosecond pulses,*" In Group IV Photonics (GFP), 2016 IEEE 13th International Conference on (pp. 36-37). IEEE (2016).
[7] L. Carletti, P. Ma, Y. Yu, ... , & S. Ortiz, "*Nonlinear optical response of low loss silicon germanium waveguides in the mid-infrared,*" Optics express, 23(7), 8261-8271 (2015).
[8] M. Brun, P. Labeye, G. Grand, ... , & S. Nicoletti, "*Low loss SiGe graded index waveguides for mid-IR applications,* " Optics express, 22(1), 508-518 (2014).
[9] J. M. Ramirez, V. Vakarin, C. Gilles, ... , & D. Marris-Morini, "*Low-loss Ge-rich Si0.2Ge0.8 waveguides for mid-infrared photonics,*" Accepted in Optics Letters.