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

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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 $\lambda = 8$ 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 [8-10]. 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.

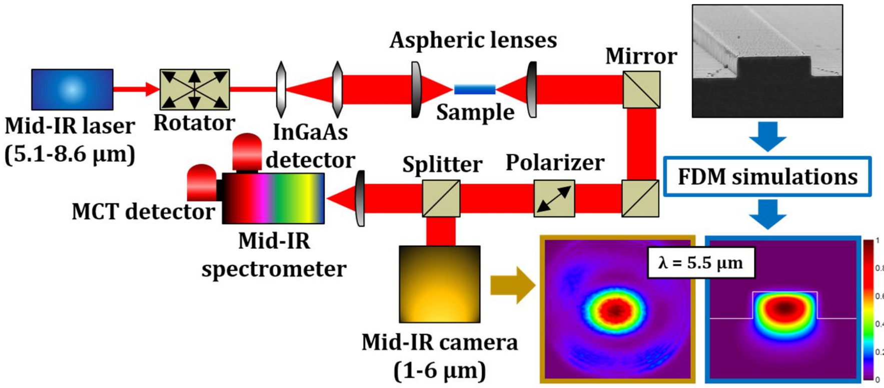

Fig. 1. Experimental setup used to characterize the broadband mid-IR Ge-rich SiGe waveguides. The SEM image located at the upper-right hand side shows a typical waveguide cross-section, with an etching depth of 1.5 μm and a waveguide width of 8 μm. Pictures at the bottom-right hand side compare the measured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

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