New photonic platforms for the mid-infrared

(Invited paper)

Milos Nedeljkovic[1,*], Ahmed Osman[1], Jordi Soler Penadés[1], Tiantian Li[2], Callum G. Littlejohns[1,4], Zhibo Qu[1], Yangbo Wu[1], Wei Cao,[1] Alejandro Sanchez Postigo[3], Alejandro Ortega-Moñux[3], Gonzalo Wangüemert-Pérez[3], Robert Halir[3], Íñigo Molina-Fernández[3], Hong Wang[4], Zhiping Zhou[2], Graham T. Reed[1], and Goran Z. Mashanovich[1]

[1] *Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ United Kingdom*

[2] *State Key Laboratory of Advanced Optical Communication Systems and Networks, School of Electronics Engineering and Computer Science, Peking University, Beijing, 100871 China*

[3]*Universidad de Málaga, Departamento de Ingeniería de Comunicaciones, ETSI Telecomunicación, Spain*

[4] *Silicon Technologies Centre of Excellence, Nanyang Technological University, 639798 Singapore*

**e-mail: m.nedeljkovic@soton.ac.uk*

ABSTRACT

Mid-infrared (MIR) group-IV photonics has seen rapid development in recent years amidst interest in developing integrated photonic systems that could be used for applications in sensing and free-space communications. In particular there is a focus on mid-infrared absorption spectroscopy, since many gases, chemicals, and biological molecules exhibit strong and unique absorption features in this part of the electromagnetic spectrum (approximately 3-16 μm). To achieve this low loss waveguide platforms must be developed that span the MIR. To this end we have investigated suspended silicon, germanium-on-silicon, and suspended germanium waveguides, which are expected to be transparent throughout the MIR range. Optical absorption and phase modulators may also be useful in a variety of integrated MIR systems, but modulation in Si and Ge in the MIR is not yet well understood. We have therefore fabricated and tested silicon-on-insulator free carrier injection modulators for 3.8 μm, and germanium-on-silicon carrier injection modulators for 3.8 μm and 8 μm.

Keywords: silicon photonics, mid-infrared, waveguides

1. GROUP-IV MATERIAL PLATFORMS FOR PHOTONICS

Silicon-on-insulator (SOI) is the most popular platform for Silicon Photonic in the near-infrared, but SiO_2 has high absorption above 4 μm, therefore alternative group-IV waveguide platforms are required to access longer wavelengths. We have demonstrated low loss suspended Si waveguides, in which the SiO_2 below the Si core in SOI waveguides is removed by wet etching with hydrofluoric acid, at wavelengths up to 7.7 μm [1]. Unfortunately, this is near the end of the transparency region of Si, so to reach even longer wavelengths the Si waveguide core can be replaced with germanium, which is transparent up to 16 μm. We have demonstrated germanium-on-silicon (GOS) waveguides at up to 8.5 μm [2], and suspended Ge waveguides at 7.7 μm [3]. Both of these platforms are expected to provide access to almost the whole transparency range of Ge. The GOS waveguides benefit from a simpler fabrication process, but due to their more symmetrical refractive index profile suspended Ge waveguides can be engineered for a stronger evanescent field, which would benefit sensing applications in which a high mode overlap with an external analyte would be desirable.

2. MID-INFRARED MODULATORS FOR GROUP-IV PLATFORMS

Looking beyond waveguides and other passive devices, in the longer term active devices, namely light sources, modulators, switches, and detectors, will also be required to make integrated sensing systems.

Until recently there has been little exploration of modulation in the mid-infrared in group-IV materials. Nevertheless, intensity modulation or phase shifting may be important in MIR sensing circuits for on-chip signal processing and switching, or in phased arrays for beam steering, or in a MIR free-space communication system for modulating a light beam. We have previously published equations that predict the strength of the free-carrier plasma dispersion effect in both Si and Ge in the MIR. We have used those equations to design SOI free carrier injection modulators for 3.8 μm [4], and GOS modulators for 3.8 μm and 8 μm, and fabricated and tested each device. SOI electroabsorption modulators exhibited modulation depths of up to 34 dB, while electrorefraction modulators achieved a modulation efficiency $V_\pi L_\pi$ of 0.052 V.mm with a modulation depth of 22 dB and data rate of 125 Mbit/s. GOS electroabsorption modulators achieved a modulation depth greater than 35 dB at 3.8 μm, and it was found that the free carrier absorption is approximately 4.9 times stronger at 8 μm.

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