Towards a Mid-infrared Lab-on-chip Sensor Using Ge-on-Si Waveguides

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For the last decade, germanium has been proposed as an excellent material for passive mid-infrared (MIR) integrated photonics. This technology allows for label-free sensing in the molecular fingerprint regime (6.7 - 20 μm), where molecules can be uniquely identified by their absorption spectra. Such a platform has the potential to enable low cost, miniaturized mid-infrared sensors for use in crucial applications such as explosives detection, pollution monitoring and detection of breath biomarkers for point of care diagnostics. There have now been a number of demonstrations of waveguides up to 8.5 μm wavelength using Ge [1] and SiGe [2] waveguides. Previously, we have demonstrated the first low loss Ge-on-Si waveguides from 7.5 to 11 μm, with losses as low as ~1 dB/cm [3]. Here, we demonstrate their potential for sensing applications by evanescently sensing unique vibrations in poly(methyl methacrylate) (PMMA) polymers, in the spectral region of 7.5–10 μm wavelength.

Commercial Ge-on-Si material was used for waveguide fabrication, with 2 μm thick Ge grown on (100) Si by reduced-pressure chemical-vapour-deposition. Single mode, rib-waveguides were patterned by electron beam lithography (4 μm wide) and etched to 1 μm depth, Fig. 1(a). The waveguides were spin-coated with PMMA and patterned with a shadow mask and an oxygen plasma etch to leave ~1 mm strip coating a Ge waveguide, Fig. 1(a). The waveguide transmission was measured before and after coating with PMMA, by stepping the emission wavelength from a Quantum Cascade Laser (QCL) wavelength in 10 nm increments. The spectra before and after the polymer coating are subsequently divided to produce the PMMA transmission spectrum. This is compared with a surface normal PMMA transmission measurement taken on a Bruker IFS 66 V Fourier Transform Infrared (FTIR) spectrometer, Fig 1(b-d). Clearly, spectral features are observable in the measurement range, which include stretching modes from a C–O–C vibration [4].

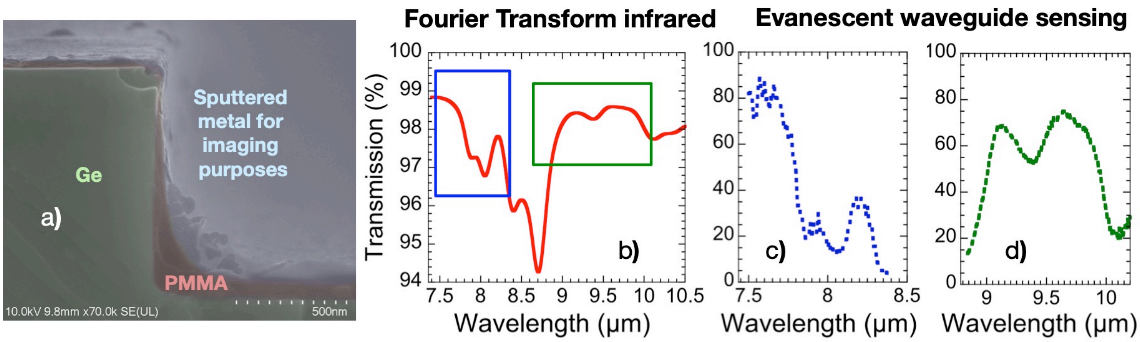

Fig. 1 a) A scanning electron microscope image of a PMMA coated Ge waveguide. b) The transmission measurement from surface normal FTIR spectroscopy on a PMMA film. c) & d) Evanescent sensing from a Ge-on-Si waveguide of a PMMA film coating a ~ 1 mm section of waveguide.

The increased attenuation observed in the waveguide measurement, Fig. 1(b-d), highlights the potential advantage of evanescent sensing in this geometry, compared to single pass transmission in the surface normal configuration. The low modal overlap with the analyte in the waveguide can be fully compensated by increased propagation length in low loss waveguides. For maximum sensitivity, the waveguide length should be approximately $1/\alpha$ where α is the waveguide loss (cm^{-1}) [5]. This means that with lower propagation losses, longer waveguides can be used to increase the interaction length with the analyte, improving the minimum concentration detectable for a given source power and detector. For certain applications, such as label free study of proteins or DNA this could hold significant advantages, where single pass measurements are not feasible.

Example References

[1] M. Nedeljkovic, J. S. Penadés, C. J. Mitchell, A. Z. Khokhar, S. Stankovic, T. D. Bucio, C. G. Littlejohns, F. Y. Gardes, and G. Z. Mashanovich, "Surface-grating-coupled low-loss Ge-on-Si rib waveguides and multimode interferometers," IEEE Photonic Tech L 27, 1040–1043 (2015).

[2] J. M. Ramirez, Q. Liu, V. Vakarin, J. Frigerio, A. Ballabio, X. Le Roux, D. Bouville, L. Vivien, G. Isella, and A. D. Marris-Morini, "Graded SiGe waveguides with broadband low- loss propagation in the mid infrared," Opt. Express, vol. 26, no. 2, p. 870, 2018.

[3] K. Gallacher, R.W. Millar, U. Griskeviciute, L. Baldassarre, M. Sorel, M. Ortolani and D. J. Paul, "Low loss Ge-on-Si waveguides operating in the 8 μm to 14 μm atmospheric transmission window" Opt. Exp. 26, 25667–25675 (2018).

[4] A. Dazzi,A. Deniset-Besseauaand, P. Lasch,"Minimising contributions from scattering in infrared spectra by means of an integrating sphere" Analyst 138, 4191–4201 (2013)

[5] H. Lin, Z. Luo, T. Gu, L. C. Kimerling, K. Wada, and A. Agarwal, "Review article Mid-infrared integrated photonics on silicon: a perspective," vol. 7, no. 2, pp. 393–420, 2018.