Germanium mid-infrared plasmonics for sensing

Paolo Biagioni[1]
J. Frigerio[2], L. Baldassarre[3], G. Pellegrini[1], M.P. Fischer[4], K. Gallacher[5], U. Griskeviciute[5], R.W. Millar[5], A. Ballabio[2], D. Brida[4], G. Isella[2], D.J. Paul[5], M. Ortolani[3]

[1] Dipartimento di Fisica, Politecnico di Milano, Piazza Leonardo da Vinci 32, I-20133 Milano, IT
[2] L-NESS and Dipartimento di Fisica del Politecnico di Milano, Via Anzani 42, I-22100 Como, IT
[3] Department of Physics, Sapienza University of Rome, I-00185 Rome, IT
[4] Department of Physics and Center for Applied Photonics, University of Konstanz, D-78457 Konstanz, DE
[5] School of Engineering, University of Glasgow, Rankine Building, Oakfield Avenue, Glasgow, G128LT, UK

paolo.biagioni@polimi.it

Silicon photonics is an expanding market with an increasing number of applications being demonstrated each year [1]. Plasmonics has not yet made its way to the microelectronic industry, mostly because of the lack of compatibility of typical plasmonic materials like gold and silver with silicon CMOS foundry processes [2]. In this context, we have undertaken the development of heavily-doped germanium thin films as novel plasmonic materials, directly grown on silicon wafers with CMOS compatible processes [3]. Here, we review the Ge components that have been developed in the course of the project GEMINI ('Germanium mid-infrared plasmonics for sensing').

Plasmonic nanoantennas have been realized by electron-beam lithography and reactive ion etching in an inductively-coupled plasma with high selectivity for Ge over Si, starting from heavily-doped Ge films (electron density 10^{19}-10^{20} cm^{-3}) grown by low-energy plasma-enhanced chemical vapor deposition [3]. Their resonances have been predicted by simulations, confirmed by experimental infrared spectra, exploited for molecular sensing [4] and, more recently, for nonlinear frequency conversion [5]. Other nanoantenna designs have been explored, such as suspended Ge membranes with narrow slits, acting as resonant slot antennas in the mid-infrared [6]. Finally, ultrafast optical activation of undoped Ge antennas by femtosecond laser pulses has been demonstrated [7]. Ridge waveguides and rib waveguides have also been developed using similar fabrication processes on insulating Ge wafers to minimize free carrier losses. Propagation losses at mid-infrared wavelengths from 6 to 11 μm were determined to be in the range 1 to 10 dB/cm. A novel near-field diagnostic tool based on an atomic-force microscope and a tunable quantum cascade laser has been developed to image guided mode propagation on-chip in the mid infrared by measuring the local photoexpansion signal on a polymer block positioned at the end of each waveguide.

In conclusion, we developed the components for a chip-scale plasmonic platform technology using Ge on Si in the mid infrared. Envisioned applications include mid infrared spectroscopic sensors for healthcare, security and environmental monitoring. The research leading to these results has received funding from the European Union's Seventh Framework Programme under grant agreement no. 613055.

References

[1] D. Thomson *et al.*, J. Opt. **18**, 073003 (2016).
[2] R. Soref, Nature Photonics **4**, 495 (2010).
[3] J. Frigerio *et al.*, Phys. Rev. B **94**, 085202 (2016).
[4] L. Baldassarre *et al.*, Nano Lett.**15**, 7225 (2015).
[5] M. Fischer *et al.*, arXiv:1802.04152 (2018).
[6] G. Pellegrini *et al.*, (submitted).
[7] M. P. Fischer *et al.*, Phys. Rev. Lett. **117**, 047401 (2016).

Figures

Figure 1. Scanning electron microscope images of Ge antennas supporting localized plasmon resonances (left) and of a Ge waveguide (right).