Enhanced Mid -Infrared Reflectance with Graphene Coated Silicon Carbide Nanowires

Patrick Rufangura[1], Arti Agrawal[1, 2], Matteo Bosi[3], Thomas G. Folland[4], Joshua D. Caldwell[4] and Francesca Iacopi[1, 2]
1 School of Electrical and Data Engineering, Faculty of Engineering and IT, University of Technology Sydney, Broadway, 2007 NSW, Australia
2 Australian Research Council Centre of Excellence on Transformative Meta-Optical Systems, University of Technology Sydney, Broadway, 2007 NSW, Australia
3 IMEM-CNR Institute, Parco Area delle Scienze 37/A, 43124 Parma, Italy
4 Department of Mechanical Engineering, Vanderbilt University, Nashville, TN 37212, USA

Abstract: The mid-infrared (MIR) optical spectrum hosts a variety of sought- after photonic applications. Herein we simulate and experimentally demonstrate reflectance enhancement of MIR light using graphene-coated silicon carbide nanowires on silicon, showing promise for on-chip MIR nanophotonics.

The unique optical properties of graphene, which stem from its 2D nature, make it a highly promising material for applications in integrated, miniaturized photonics [1, 2]. Although the transfer of graphene on diverse substrates and pre-fabricated devices is possible [3, 4], a more direct alternative capable of being scaled –up to large surfaces, is the growth of epitaxial graphene on a semiconductor like silicon carbide (EG/SiC) [5-8]. Graphene and SiC have been extensively, but separately, studied for MIR and terahertz (THz) photonics, respectively [9, 10]. The EG/SiC is an ideal platform for investigating exciting physics such as the coupling between graphene plasmons and optic phonons in SiC, which could lead to free-space IR light capture and on-chip manipulation with low-losses and superior confinement [11, 12]. However, the amount of experimental data is still limited in this field.

In this work, we use attenuated total reflectance Fourier transformed infrared (ATR-FTIR) spectroscopy, in combination with electromagnetic simulations using the finite element method (FEM), to reveal a pronounced reflectance enhancement in the MIR when graphene is coated on SiC nanowires (NWs; Fig. 1). The SiC NWs are grown on a silicon substrate as a nanowire forest (see inset in Fig.1a), with an average diameter around 30-50 nm, and are subsequently graphitized according to our catalytic alloy method [13]. In the FEM, a single nanowire of 50 nm diameter was simulated with periodic boundary conditions. The graphene was simulated as an infinitesimal thin conductive layer (0.33 nm) using a transition boundary condition. A TM/p- polarized electromagnetic source was used in the simulation (see Fig. 1c).

From both experimental and simulated spectra, a very low reflectance is found for bare SiC NWs (Fig. 1 blue line), confirmed by the simulated weak electric field intensities (Fig. 2 a-c). This is expected due to the small size and limited amount of SiC NWs being unable to absorb enough light. However, a sharp enhancement in reflectance for the SiC NWs is observed, once they are graphitized (Fig.1a, red line).

The simulation performed on graphene-coated SiC NW/Si (Fig.1b black line) reveals two modes with a substantial field enhancement as compared to bare SiC NWs (Fig. 2 d-f). Our previous observation of this material system indicated the presence of a low-density oxide layer between graphene and SiC NWs [13]. After including an oxide layer in our graphene/SiC NW/Si FEM model, we observe an additional mode and further reflectance enhancements (Fig 1b, red line). There is a satisfactory similarity with the spectra measured experimentally. The field profiles of the electric fields for the different modes (Fig 2 g-i) show maximum field intensities occurring at the interfaces (oxide/SiC NW and graphene/oxide). This extraordinary surface enhancement of about one order of magnitude may be originating from the coupling between graphene plasmon and SiC phonon polariton. We also suggest that the oxide layer could potentially act as a coupling medium.

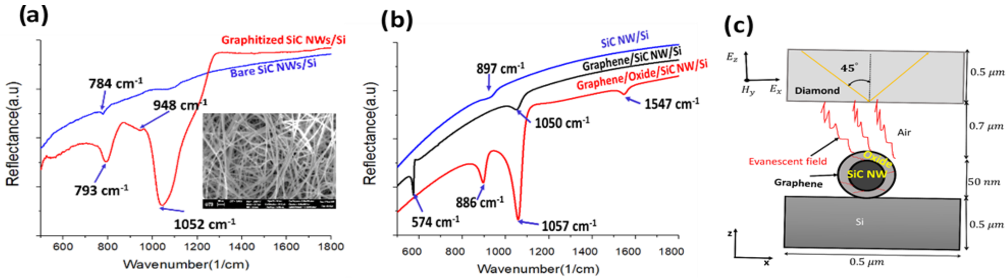

Figure 1. (a) Measured reflectance on bare SiC NWs/Si (blue line), and graphitized SiC NWs/Si (red line), inset shows the SEM image of SiC nanowires/Si. (b) Simulated reflectance on bare SiC NW/Si (blue line), graphene/SiC NW/Si (black line), and graphene/oxide/SiC NW/Si (red line). (c) The schematic of the simulation model with one SiC NW coated with oxide and graphene.

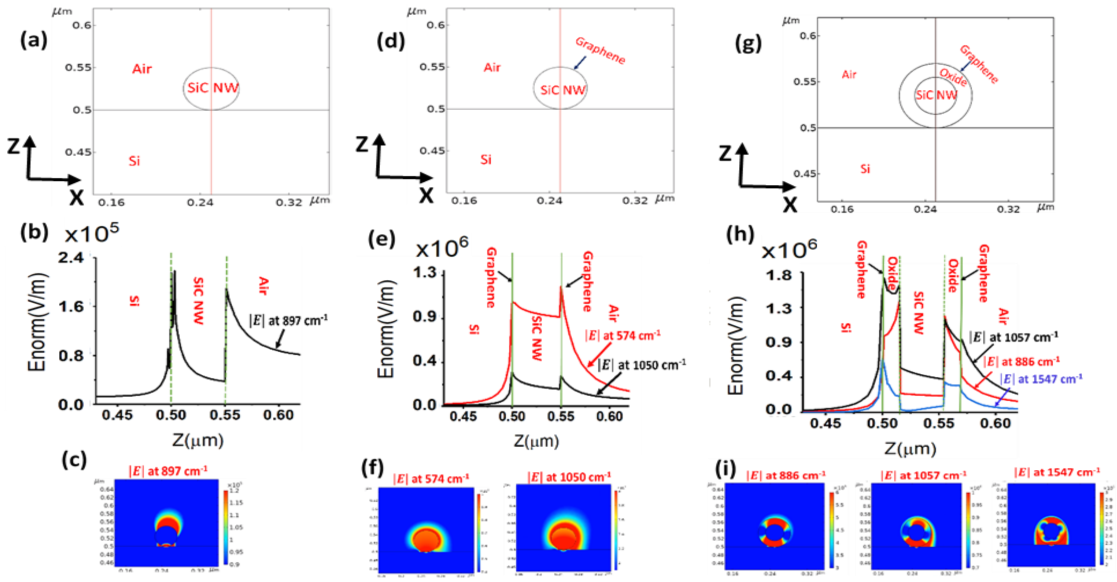

Figure 2. Calculated electric fields along a cut line (Z) and the field map for electromagnetic modes in (a-c) SiC NWs/Si, (d-f) graphene/SiC NW/Si, and (g-i) graphene/oxide/SiC NW/Si.

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