Rigorous retrieval of linear and nonlinear parameters in graphene waveguides

A. Pitilakis[1,*], D. Chatzidimitriou[1], E. E. Kriezis[1]

[1]*Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Greece*

*alexpiti@auth.gr

We outline a framework for the electromagnetic modelling of arbitrary cross-section nanophotonic waveguides that comprise both bulk and sheet materials, like graphene, based on the finite element method (FEM). Our formulation is extended to the analysis of third-order nonlinear effects in these waveguides.

Introduction

Graphene is a quasi-2D (sheet) material exhibiting remarkable thermal and electric conductivity with an ample tuning range in the optical and THz bands. Graphene has been successfully utilized in a number of guided-wave components like photodetectors, polarizers and modulators [1] and very recently its nonlinear response has started generating significant interest.

Summary

The optimal representation of a graphene sheet in the context of FEM modelling is effectuated by attributing a complex-valued surface conductivity to appropriate edges (or faces) shared by two surface (or volume) finite elements of the mesh. Furthermore, it is shown that the representation of graphene as a bulk medium of finite sub-nanometre thickness is inappropriate for the modelling of inherently anisotropic, arbitrarily oriented, sheet materials in $\mathbf{R}^3$ vector spaces and further requires substantially increased computational resources to mesh ultra-thin bulk layers. We extend our formulation to provide rigorous expressions for the calculation of the nonlinear parameter (γ) of arbitrary cross-section graphene-comprising waveguides. The third-order nonlinear part of the surface conductivity of sheet materials $\sigma^{(3)}$ complements the nonlinear susceptibility of bulk materials $\chi^{(3)}$ [2] and the contributions of the two nonlinearities to the overall γ are assessed.

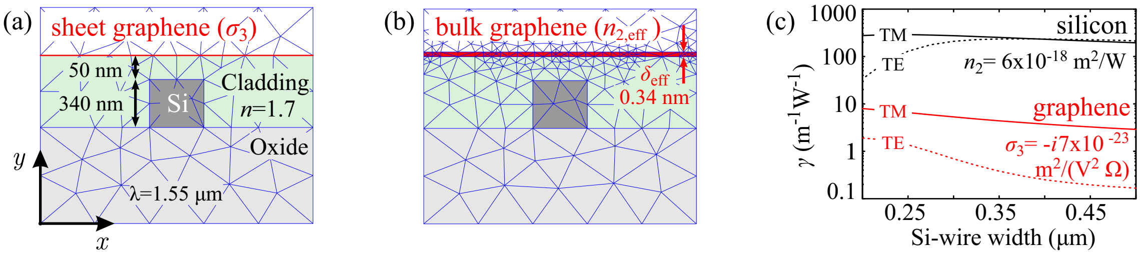

Fig. Sample finite element meshing of a Si-wire waveguide covered with a graphene monolayer, in its (a) sheet and (b) bulk representation. (c) Si-wire and graphene-sheet contributions to the nonlinear parameter.

Overall we provide a robust framework for the FEM modelling of graphene-comprising waveguides, in the linear and nonlinear regime. The natural and superior sheet representation of graphene is employed, thus circumventing the pitfalls of the effective bulk medium approach.

Acknowledgements

This work has been supported by European Union (European Social Fund) and Greek national funds through the Research Funding Program THALES (Project ANEMOS) and by the “IKY Fellowships of Excellence for Postgraduate Studies in Greece – Siemens Programme”.

References

[1] M. Liu, X. Yin, X. Zhang, “Double-layer graphene optical modulator,” *Nano Lett.*, vol. 12, no. 3, pp. 1482–5, 2012

[2] A. Pitilakis, E. E. Kriezis, “Highly nonlinear hybrid silicon-plasmonic waveguides: analysis and optimization,” *J. Opt. Soc. Am. B*, vol. 30, no. 7, pp. 1954–65, 2013