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Three-Dimensional Field-Flux Eigenmode Formulation for Periodic Graphene Structures

Vasilis Salonikios, Michalis Nitas, Savvas Raptis and Traianos V. Yioultsis
Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, 54124 Greece,
traianos@auth.gr

Introduction

✓A precise 3-d Field–Flux FEM Formulation for Periodic GRAPHENE structures is implemented

✓The formulation is spurious free and results in a linear Eigenvalue problem. Allows the examination of the wave inside passbands and stopbands of periodic Graphene structures.

✓All computed Fields are of the same order of approximation

Field-Flux Eigenmode Formulation

$$\nabla \times \mathbf{E} = -j\omega \mathbf{B}$$
$$\nabla \times \bar{\bar{\mu}}^{-1}\mathbf{B} = j\omega\epsilon_0\bar{\bar{\epsilon}}_r\mathbf{E}$$

$$\tilde{\mathbf{B}} = -jc_0\mathbf{B}$$

Scaling of **B** to avoid ill-conditionining of the final system of equations

$$\nabla \times \mathbf{E} = k_0\tilde{\mathbf{B}}\,,$$
$$\nabla \times \bar{\bar{\mu}}_r^{-1}\tilde{\mathbf{B}} = k_0\bar{\bar{\varepsilon}}_r\mathbf{E}$$

$$\mathbf{E} = \mathbf{e}e^{-jk_0n_{eff}\hat{\mathbf{k}}\cdot\mathbf{r}}\,,$$
$$\tilde{\mathbf{B}} = \tilde{\mathbf{b}}e^{-jk_0n_{eff}\hat{\mathbf{k}}\cdot\mathbf{r}}$$

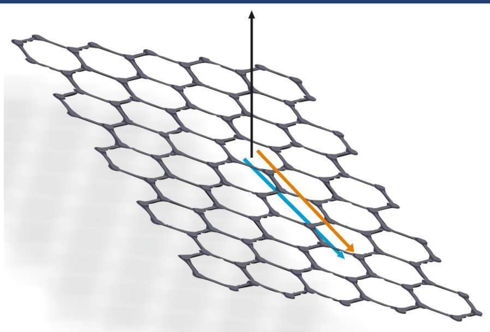
Transformation of Maxwell's equations according to Bloch-Floquet theorem

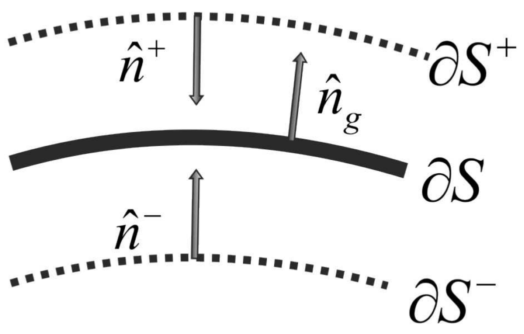
$$\nabla \times \mathbf{e} - jk_0n_{eff}\hat{\mathbf{k}}\times\mathbf{e} = k_0\tilde{\mathbf{b}}\,,$$
$$\nabla \times \bar{\bar{\mu}}_r^{-1}\tilde{\mathbf{b}} - jk_0n_{eff}\hat{\mathbf{k}}\times\bar{\bar{\mu}}_r^{-1}\tilde{\mathbf{b}} = k_0\bar{\bar{\varepsilon}}_r\mathbf{e}$$

$$\iiint_\Omega \tilde{\mathbf{b}}'\cdot\nabla\times\mathbf{e}dv - k_0\iiint_\Omega \tilde{\mathbf{b}}'\cdot\tilde{\mathbf{b}}dv - jn_{eff}k_0\iiint_\Omega \tilde{\mathbf{b}}'\cdot\hat{\mathbf{k}}\times\mathbf{e}dv = 0\,,$$
$$\iiint_\Omega \nabla\times\mathbf{e}'\cdot\bar{\bar{\mu}}_r^{-1}\tilde{\mathbf{b}}dv + \oiint_{d\Omega}\mathbf{e}'\cdot\hat{\mathbf{n}}_{ext}\times\bar{\bar{\mu}}_r^{-1}\tilde{\mathbf{b}}ds - k_0\iiint_\Omega \mathbf{e}'\bar{\bar{\varepsilon}}_r\mathbf{e}dv$$
$$-jn_{eff}k_0\iiint_\Omega \mathbf{e}'\cdot\hat{\mathbf{k}}\times\bar{\bar{\mu}}_r^{-1}\tilde{\mathbf{b}}dv = 0$$

Final FEM Galerkin Formulation

Implementation of Graphene





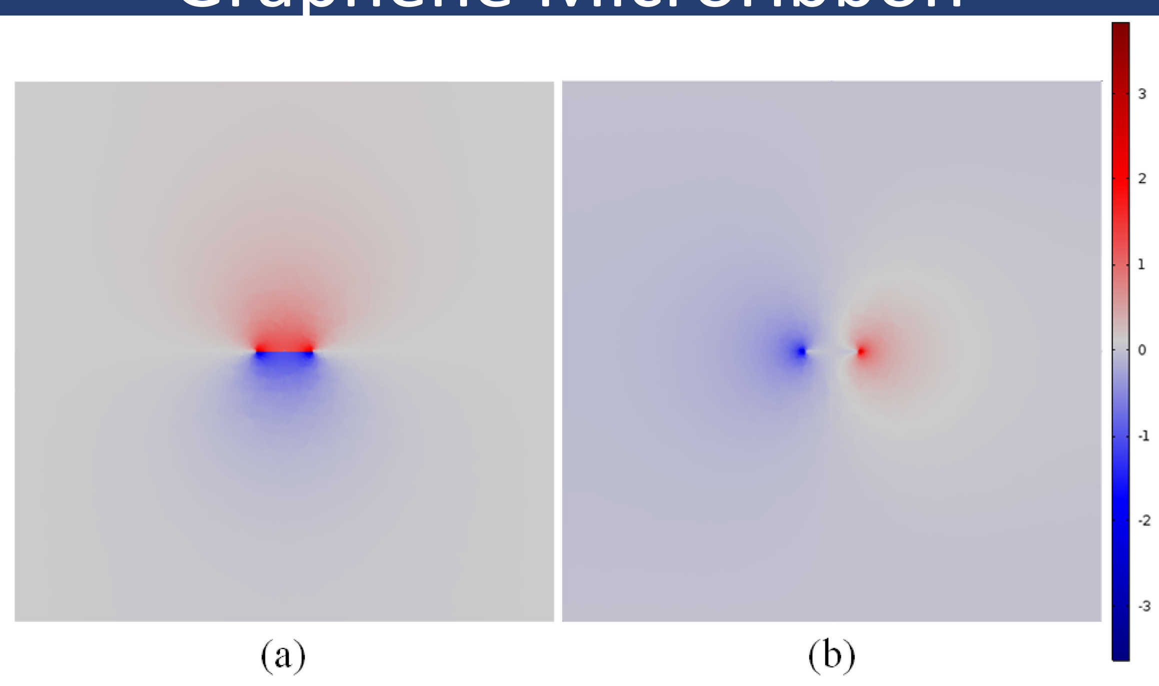
✓ Graphene is treated as a finite conductivity boundary

$$\hat{\mathbf{n}}_g\times\bar{\bar{\mu}}_r^{-1}\tilde{\mathbf{b}}^+ - \hat{\mathbf{n}}_g\times\bar{\bar{\mu}}_r^{-1}\tilde{\mathbf{b}}^- = -j\eta_0\sigma_g\mathbf{e}_{tg}$$

✓ The Graphene's Surface is considered as an exterior boundary

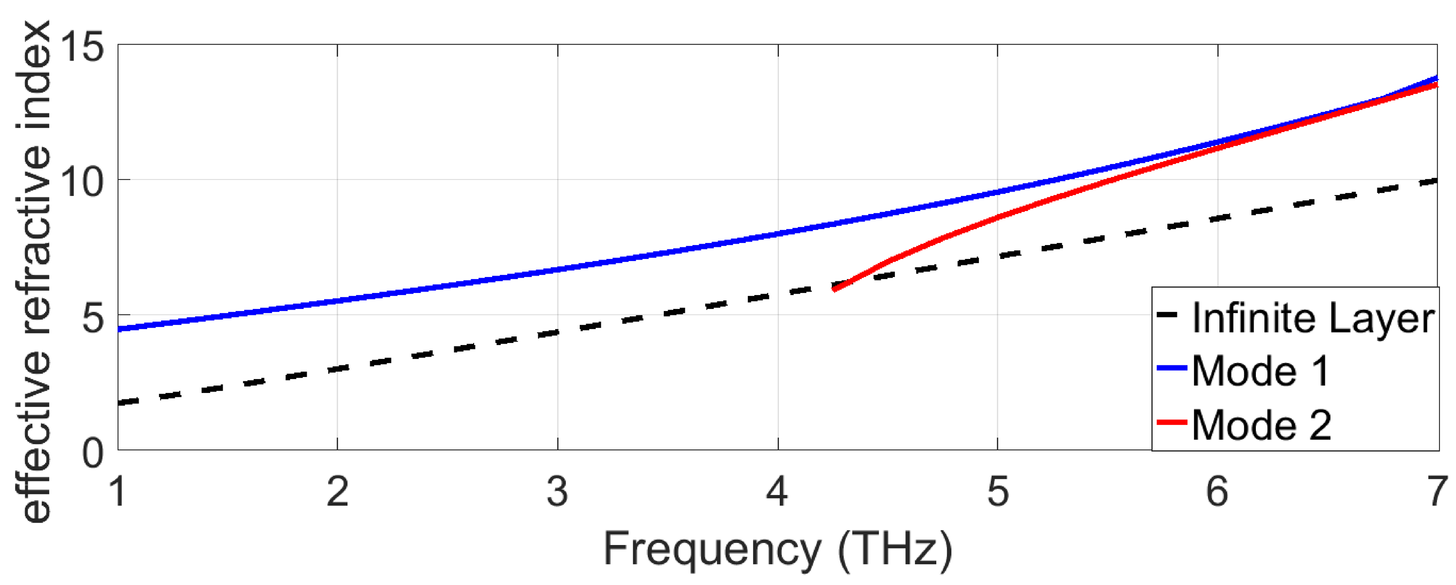
$$\iint_{S_g}\mathbf{e}'\cdot(\hat{n}_{ext}\times\hat{\mu}_r^{-1}\tilde{\mathbf{b}})ds = j\eta_0\iint_{S_g}\mathbf{e}'_{tg}\cdot\sigma_g\mathbf{e}_{tg}ds$$

Computational Results I : 5μm Free-Standing Graphene Microribbon



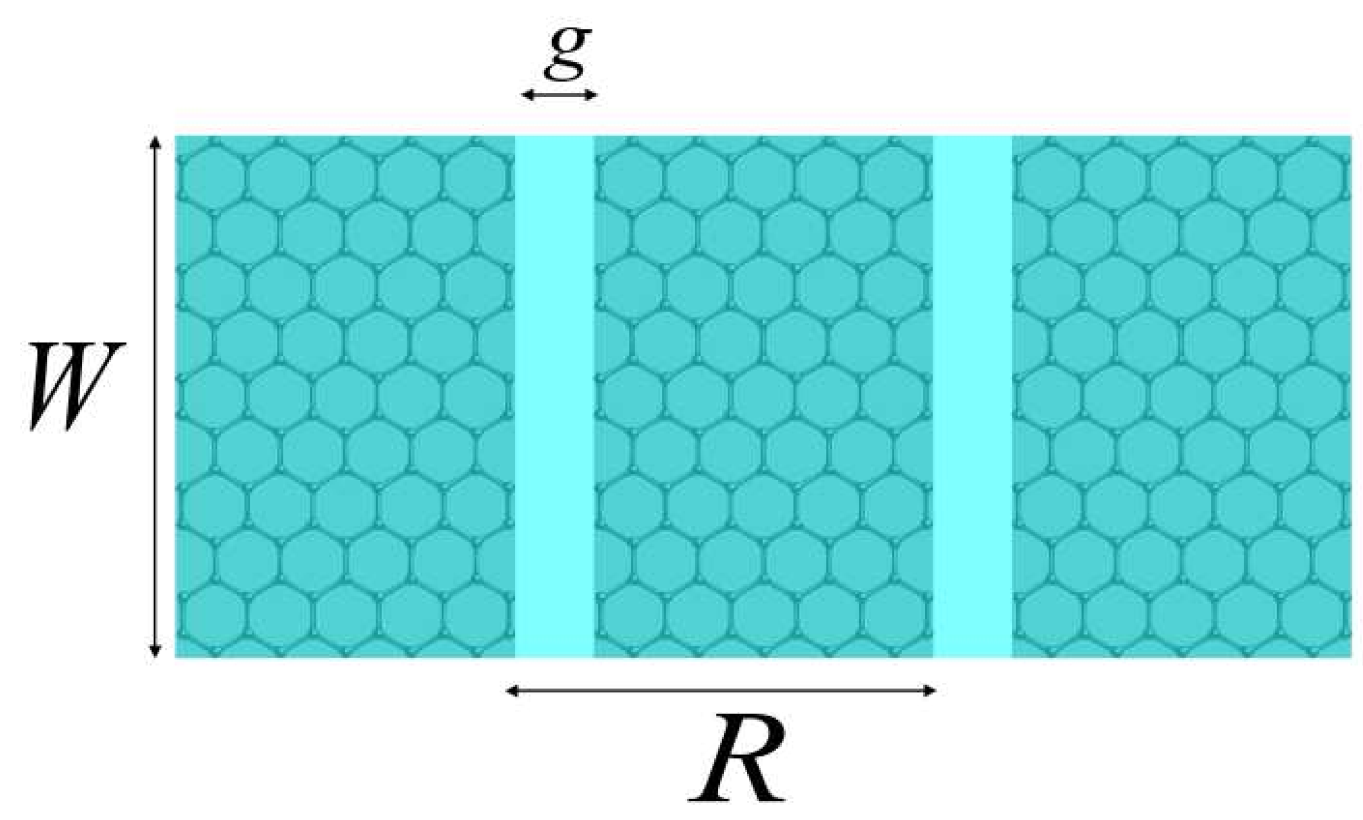
(a) (b)

Distribution of the normal (a) and tangential (b) electric field at the transverse plane on the propagation axis of the first mode at 1 THz.



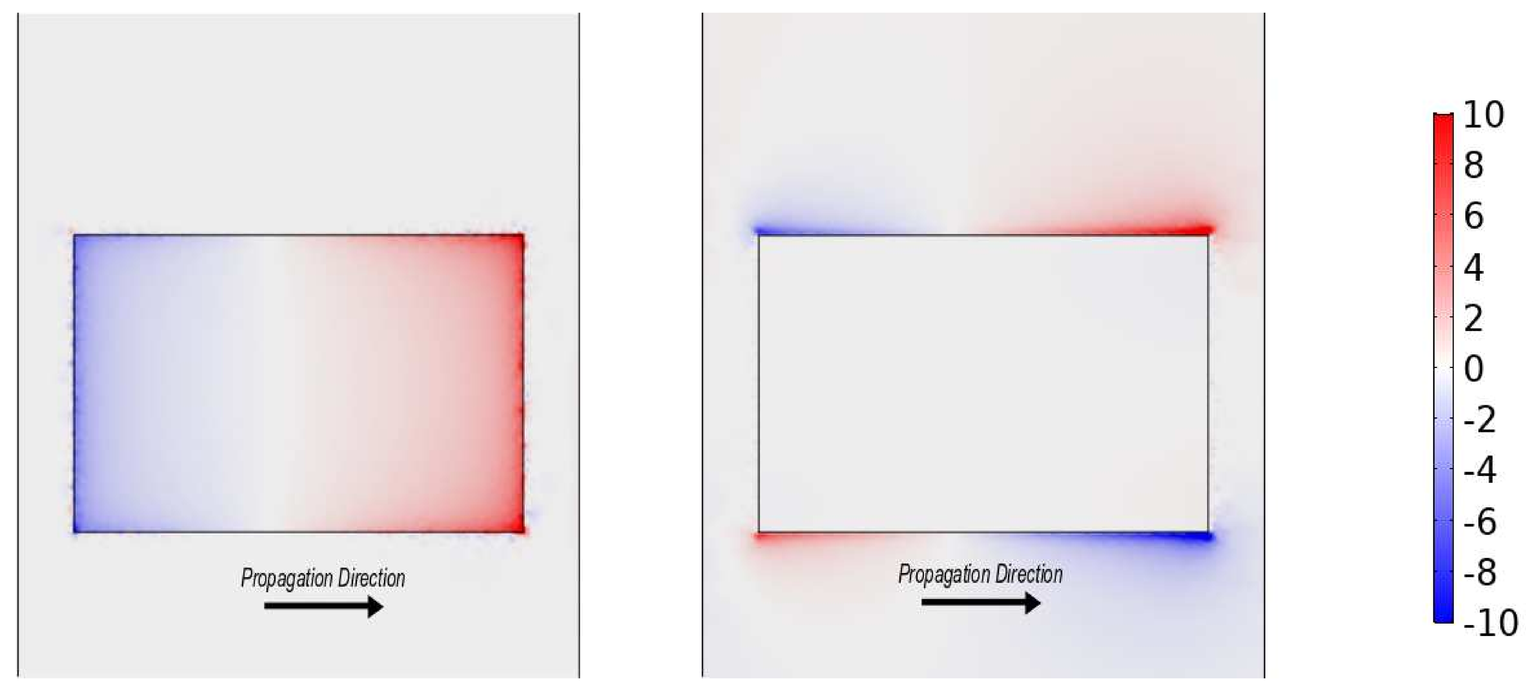
Dispersion curves of the first two modes of a 5μm graphene microribbon compared to the infinite layer [2].

Computational Results II : Periodic Graphene Structure



Periodic Arrangement of Graphene Microstrips

$$W = 5\mu m \quad g = 2\mu m \quad R = 10\mu m$$



(a) (b)

Distribution of the normal (a) and tangential (b) electric field on the plane of the Graphene structure at 2 THz.

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