17a-C3-5

A New Simulation Method of Graphene-Coated SOI Wire Waveguides

Goran Kovacevic, Shinji Yamashita

Research Center for Advanced Science and Technology (RCAST), The University of Tokyo
E-mail: gorank@cntp.t.u-tokyo.ac.jp

In this work, we propose a novel method to numerically calculate the optical absorption of a graphene coated SOI wire waveguide based on the 2D Finite Difference Method.

In any approach, graphene has to be incorporated as a kind of approximation and usually, even though it is a 2D structure, it is represented as a 3D one with provisionally small thickness (~1nm) [1]. In our proposed method, graphene retains its 2D form which we believe yields lower numerical error and higher correspondence with experimental results.

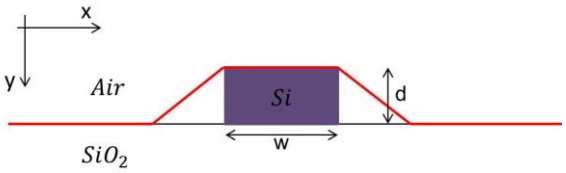

Figure 1 SOI Wire waveguide coated with a graphene layer (red line) used in simulations

Optically, graphene is described by its surface dynamic conductivity σ. We assume that graphene is undoped in simulations which accounts for the dynamic conductivity of around 60μS [2].

We initially employ the standard 2D FDM to describe the light propagation in the rectangular waveguide, with the goal being the calculation of the propagation wavevector β and the optical mode profiles. By taking the graphene's dynamic conductivity into account, β becomes complex and its imaginary part corresponds to the attenuation of the field – the absorption of the graphene sheet.

The main idea is to start with the physical boundary condition of the tangential magnetic field at the graphene interface $\boldsymbol{n}\,x\,(\boldsymbol{H_2}-\boldsymbol{H_1})=\sigma\boldsymbol{E}$. We explicitly implement this boundary condition by modifying the FDM matrices representing the differentials in the direction normal to the boundary (y direction) of the tangential magnetic fields. Main characteristic of FDM is that every differential is represented as a subtraction of neighboring points in the grid in special matrix equations, and those equations are modified with respect to the physical boundary condition.

This approximation also introduces a certain error into the numerical result, as the differential of the field is skipped at the points around the boundary, but if the points are close enough (the grid resolution is high) this error should be negligible. We prove this statement through numerical results.

First we inspect the validity of the introduced approximations by simulating a typical wire waveguide of width w=600nm and thickness d=210nm. We compare two simulations: In the first, approximations are introduced but graphene's conductivity is set to zero and in the second we simulate a regular wire waveguide without graphene. The propagation wavevectors of the TE like and TM like modes with approximations are found to be $\beta_{TE}=9.98\mu m^{-1}$ and $\beta_{TM}=6.72\mu m^{-1}$, while with no approximations they are $\beta_{TE}=9.99\mu m^{-1}$ and $\beta_{TM}=6.79\mu m^{-1}$. We observe a very slight deviation in the results which proves that the proposed method is valid. When we include graphene to these simulations we obtain $\beta_{TE}=9.98-j0.009\mu m^{-1}$, $\beta_{TM}=6.72-j0.0133\mu m^{-1}$, which shows that graphene only introduces the absorption (imaginary part of β).

Next, we find the optimal structure dimensions to maximize absorption: d=240nm and w=600nm. The obtained values in this case are: $\beta_{TE}=10.4-j0.007\mu m^{-1}$, $\beta_{TM}=7.62-j0.0165\mu m^{-1}$. Absorption is maximized for the TM mode and can be expressed as 0.143 dB/μm, which means that the device length of only around 20μm is required for the 3dB extinction ratio, the highest reported for this type of device. In Figure 2 we can clearly observe this maximum value, and we can also observe very high absorption coefficients for the TE mode at low waveguide thicknesses and a reversal in the dominantly absorbed mode not previously reported with thickness variation.

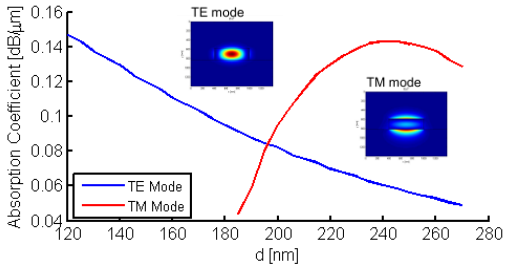

Figure 2 Absorption dependency on the thickness of the waveguide d (with width w constant at 600nm) and the optical mode profiles at d=240nm (inset)

Finally we compare our simulation results with the experimental results reported in [3]. R. Kou et al. reported absorption coefficients of 0.09dB/μm for the TE and 0.05dB/μm for the TM mode using a waveguide of dimensions d=200nm and w=400nm. Using our simulations we obtain 0.0882dB/μm for the TE and 0.055dB/μm for the TM mode which proves a very high order of correspondence between simulation and experiments.

References

[1] M. Liu et al., Nature **474** (2011) 64-67.
[2] F. Bonaccorso et al., Nat. Phot. **Vol 4** (2010) 611-622.
[3] R. Kou et al., Jpn. J. Appl. Phys. **52** (2013) 060203.