Designing and Characterization of Graphene-on-Silicon Waveguides

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***Abstract** -We report a simple and strong method for designing and analysis of the graphene-on-silicon waveguides. The waveguides consist of a silicon core covered by a thin graphene layer whose width exactly matches with the width of the silicon core. The analysis of the waveguides showed that the graphene layer retained its high quality even after the wave processing. Transmission measurements of the Graphene-on-Silicon waveguides showed less propagation losses in transverse-electric mode and transverse-magnetic mode.*

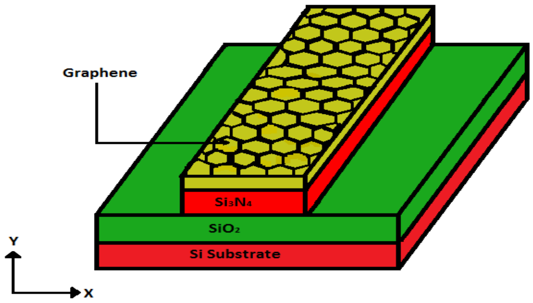
***Key Words*: Graphene, Waveguides, Silicon Waveguides, Graphene-on-Silicon Waveguides, OptiFDTD Software.**

1.INTRODUCTION

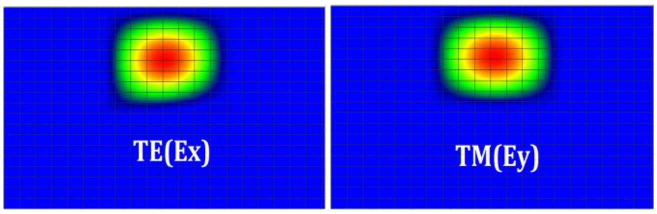
Graphene is a form of carbon consisting of a single layer of carbon atoms arranged in a hexagonal array. Graphene has many, interesting and useful electrical and optical properties. It is the strongest material, conducts heat and electricity efficiently, and is nearly transparent. With the emergence of silicon photonics as a prominent platform for integrated optics, there has been a lot of interest in integrating graphene with silicon waveguides to realize novel optoelectronic and nonlinear optics devices. Given the high interest in Graphene-on-Silicon devices, it is of practical importance to developing solid and simple methods for designing these photonics devices. The simplest method/procedure for realizing Graphene–on-Silicon waveguides is to first fabricate the silicon waveguides on a silicon substrate, depositing a cladding layer of SiO2 on top, then transfer a thin layer of the graphene over the waveguides. Also, for waveguides without a cladding, the graphene may hold non-uniformly to the waveguides sidewalls. This non-uniform coverage may lead to extra absorption and scattering losses. In this letter, we report a method for designing Graphene-on-Silicon waveguides where the width of the thin graphene layer conforms the width of the silicon waveguides and the length of the graphene coverage can be controlled. We call such waveguides edge-conformed Graphene-on-Silicon waveguides. Since the graphene is designed only over the core of the waveguide, device characteristics can be controlled accurately, and adjacent waveguides can be placed closer to each other lead to high integration density. The main advantage of our designing and analysis method is that it does not require precise alignment of the graphene layer with the silicon waveguides core. We are using the OptiFDTD software for the characterization and analysis of the Graphene-on-Silicon Waveguides. We also performed measurement and analysis of the propagation losses of edge conformed Graphene-on-Silicon waveguides to quantify the effect of graphene optical absorption on the waveguides loss.

2. PROPERTIES OF GRAPHENE-ON-SILICON WAVEGUIDESS

Graphene is a form of carbon consists of a single layer of carbon atoms arranged in a hexagonal lattice. It is the basic allotropic structure of carbon. Graphene has many interesting electrical and optical properties. Graphene is one of the strongest materials ever produced. Also, it is a good conductor of heat and electricity and it is nearly transparent. Graphene is a different physical form of carbon with two-dimensional properties. It's carbon atoms are packed tightly in a regular hexagonal pattern. Fig.1. shows a schematic of Graphene-on-Silicon waveguides. The waveguides consist of a Silicon core of 3µm thickness and 8µm width lying on top of a 2µm thick oxide layer. A small section of the Silicon waveguides is covered with a graphene layer whose width exactly conforms to the width of the Silicon core. At the 1.55µm wavelength, the waveguides give a refractive index value of 2.70. Thus graphene can be regarded as a strongly absorbing dielectric at optical frequencies with bulk absorption of about 100dB/µm.



(a)



(b)

Fig.1 (a) Schematic Layout of Graphene-on-Silicon Waveguide. (b) Field distributions TE and TM modes of the Graphene-on-Silicon waveguides in the x-y plane.

We perform a simulation and analysis of the Graphene-on-Silicon waveguides using the OptiFDTD software. The OptiFDTD software based on the Finite Difference Time Domain. The total effective index and the propagation loss of the Graphene-on-Silicon waveguides are measured over the 1.55μm wavelength. The effective index of Graphene-on-Silicon waveguides is also very close to that of the bare silicon waveguides but the propagation loss is strongly influenced by the optical absorption property of the graphene layer. It is also observed that the propagation loss is higher in the TM mode than the TE mode.

2. OptiFDTD SOFTWARE

OptiFDTD is a powerful, highly integrated, strong software designing and simulation of photonic devices. The OptiFDTD software is based on the finite-difference time-domain(FDTD) method. The FDTD method is a powerful engineeringtool for integrated and diffractive optics device simulations. The FDTD method has uniquecombination of features, such as the ability to model light propagation, scattering, diffraction, reflection and polarization effects.

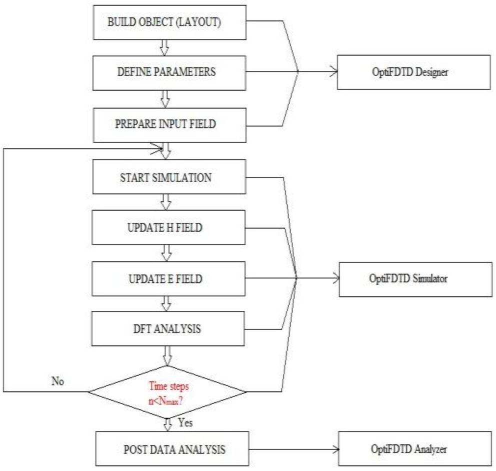
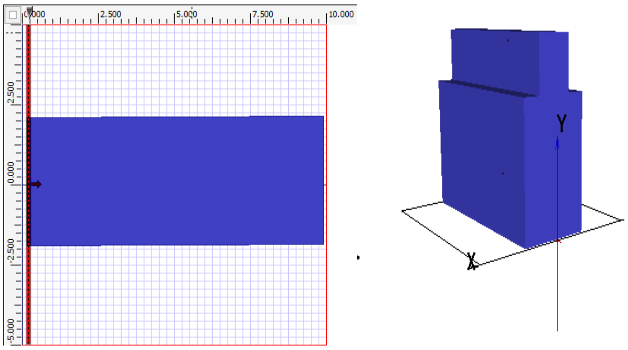


Fig.2. FDTD Simulation Flow Chart

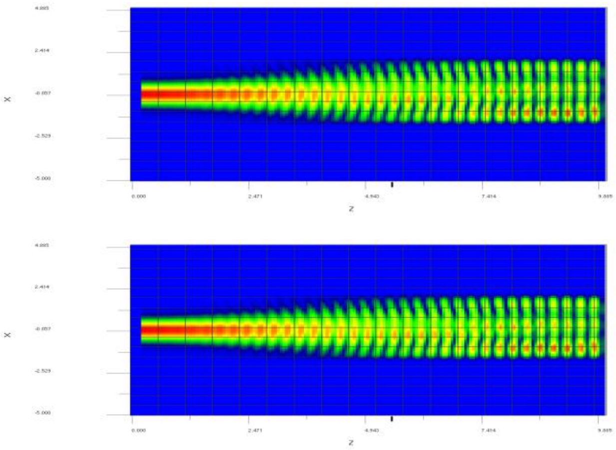
The FDTD method allows for the effective andpowerful simulation and analysis nano-dimension photonic devices with very fine structuralresults. The FDTD approach is based on a direct numerical solution of the time-dependentMaxwell's curl equations. The OptiFDTD analysed the photonics devices in 2-dimensions and 3-dimensions. The main advantages of the FDTD method is the minimum use of approximations data forthe propagating field, light can be modeled with more complexity. The significant advantage of this method is the variety of materials that consistently modeled within the FDTD method. The different variety of materials property also handled by this method, such as Lossy dielectric, non-linear material. OptiFDTD provides post-simulation data simulation and analysis tools in the Simulator and Analyser part of the OptiFDTD software. FDTD can get all the spectral results/responses with a single simulation. To get the spectral results/responses, need to uses the DFT, FFT and Analysis.When DFT runs in the Simulator part of this software, it gives the frequency domain response only for the centre wavelength. Fast Fourier Transform gives the spectral response from the zero frequency to the cut-off frequency.

3. DESIGNING AND CHARACTERIZATION OF GRAPHENE-ON-SILICON

For the designing process at the beginning, Silicon waveguide is being developed. The first layer of the waveguides structure contains the Silicon material. The Silicon substrate having the refractive index 3.45 is developed with the help of the OptiFDTD designer. The Silicon substrate having a width 8.0 μm and the thickness 3.0 μm. The second layer of the waveguides structure consists the Silicon Dioxide (SiO2) material having the refractive index 1.46. SiO2 material having width 8.0 μm and width 2.0 μm. The third layer is of material Silicon Nitride (Si3N4). The Si3N4 material having a width 4.0 μm and thickness 2.0 μm. The fourth and last layer of the waveguides structure is of the graphene. The thin graphene layer of width 4.0 μm and of thickness 0.01 μm.



(a) (b)



(c)

Fig.3. (a) The layout of the Linear Waveguide Model (b) 3D Layout of Waveguide Model (c) DFT response of the waveguide model in TE and TM modes.

First design the Silicon waveguides over the silicon substrate, then transfer the cladding layer of the Silicon Dioxide (SiO2) on the top of the silicon substrate. The thin graphene layer is transferred all over the Silicon waveguide core. The Silicon Nitride (Si3N4) material of width 4.0 µm is placed between the graphene layer and waveguide core for providing the insulation to the device. The propagation loss of the Graphene-on-Silicon waveguides can be decreased by introducing a thin SiO2 layer between the Si waveguide core and the graphene layer. This type of waveguide structures is especially important for non-linear applications where the oxide layer can be tuned to achieve the best balancing between the linear propagation loss and nonlinear interaction of the waveguide core with the graphene layer.

4. CONCLUSIONS

In summary, we demonstrated a simple and strong method for designing and analyzing the Graphene-on-Silicon waveguides in which the graphene layer precisely covers the waveguide core. No degradation in the quality and the properties of the graphene was observed after analysis. Excellent results in measured propagation losses were obtained. We expect the method to be useful for designing densely integrated graphene-based optoelectronic circuits.

5. REFERENCES

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