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Light Propagation in the Electro-Optic Modulators based on Graphene-Slot Silicon Waveguides

E. Khoobjou*

Department of Electrical Engineering, Islamic Azad University, South Tehran Branch, Tehran, Republic of Iran; Elhamkhoobjou@yahoo.com

Abstract

Background/Objectives: In this study we have investigating light propagation in the electro-optic modulators based on graphene-slot silicon waveguides. **Methods/Statistical Analysis**: In this simulation, μ_c = 0 eV and 0.515 eV is considered and the dielectric constants of the graphene for each μ_c is taken from the reference above. Since we consider a single telecom wavelength at 1550 nm, we use (n, k) material model to input the optical constant of the graphene. The materials in the material database correspond to the chemical potential of 0 eV and 0.515 eV, respectively. **Findings:** The field profiles are drastically changed as a function of a chemical potential. The field profile for μ_c = 0 eV keeps almost the same intensity after traveling 800 nm, while that for μ_c = 0 eV is considerably decayed. The results are about 96% and 45 % for μ_c = 0 eV and 0.515 eV, respectively and finally the loss for μ_c = 0.515 is considerably higher than that for μ_c = 0 eV.

Keywords: Electro-Optic, Graphene-Slot, Modulators, Silicon, Waveguides

1. Introduction

One of the most important devices in optoelectronic integrated circuits is the Electro-Optic (EO) modulator[1,2], which converts electronic signals into high bit-rate photonic data. Recent years have witnessed breakthroughs in the development of EO modulators[3–7]. However, the lack of ultra high speed compact EO modulators remains a critical technical bottleneck impeding the wide deployment of the on-chip optical interconnects. Because of the poor EO properties of regular materials[8], a conventional EO modulator has a very large footprint[3,5,7,9]. Employment of a high-Q resonator may significantly reduce the footprint, but it simultaneously decreases the operation bandwidth and thermal stability[4], which demand additional components to improve[10,11]. Hybrid of novel semiconductors[12–16] using sophisticated techniques may partially resolve these issues, but the involved waveguides are still tens to hundreds of micrometers long. Plas MO Stors[17] can be very compact, but have inherently large insertion loss and limited operation speed. Recent research on graphene has provided unprecedented opportunities to meet the challenges.

Graphene[18,19] has attracted a great deal of interest because its exceptional electronic transport properties show great potential applications in the field of nanoelectronics[20] with the highest intrinsic mobility[21] and the largest current density at room temperature[22]. Graphene also has remarkable flexibility, robustness and environmental stability, as well as extraordinary thermal conductivity[23]. Research on graphene has revealed its unique optical properties [24], including strong coupling with light[25], high-speed operation[26] and gate-variable optical conductivity[27], which promise to satisfy the needs of future EO modulators. The application of graphene in EO modulation was studied in[28] at long wave infrared frequencies. A more recent work[29] demonstrated a broadband EO modulator at telecom wavelengths based on the inter band absorption of grapheme with overall length only 40 μm. However, compared with the size of on-chip electronic components it is still bulky. On-chip optical interconnects require EO modulation at the nanoscale. The key to achieve nanoscale graphene EO modulation

**Author for correspondence*

is to greatly enhance light–graphene interaction based on novel waveguides and platforms.

Integrated optical modulators with high modulation speed, small footprint and large optical bandwidth are poised to be the enabling devices for on-chip optical interconnects[30,31]. Semiconductor modulators have therefore been heavily researched over the past few years. However, the device footprint of silicon-based modulators is of the order of millimeters, owing to its weak Electro-Optical properties[32]. Germanium and compound semiconductors, on the other hand, face the major challenge of integration with existing silicon electronics and photonics platforms[33–35]. Integrating silicon modulators with high-quality-factor optical resonators increases the modulation strength, but these devices suffer from intrinsic narrow bandwidth and require sophisticated optical design; they also have stringent fabrication requirements and limited temperature tolerances[36]. Finding a Complementary Metal-Oxide Semiconductor (CMOS)-compatible material with adequate modulation speed and strength has therefore become a task of not only scientific interest, but also industrial importance. Here we experimentally demonstrate a broadband, high-speed, waveguide integrated electro absorption modulator based on monolayer grapheme[37,38]. By electrically tuning the Fermi level of the graphene sheet, we demonstrate modulation of the guided light at frequencies over 1 GHz, together with a broad operation spectrum that ranges from 1.35 to 1.6 under ambient conditions. The high modulation efficiency of graphene results in an active device area of merely 25 , which is among the smallest to date. This graphene-based optical modulation mechanism, with combined advantages of compact footprint, low operation voltage and ultrafast modulation speed across a broad range of wavelengths, can enable novel architectures for on-chip optical communications.

2. Simulation Setup

The modulator we're considering is show in the Figure 1. A 800 nm long graphene sheet is embedded in a silicon waveguide and an external bias is applied to adjust the chemical potential μ_c of the graphene sheet. In this simulation, $\mu_c = 0$ eV and 0.515 eV is considered and the dielectric constants of the graphene for each μ_c is taken from the reference above. Since we consider a single telecom wavelength at 1550 nm, we use (n, k) material model to input the optical constant of the graphene. The materials in the material database correspond to the chemical potential of 0 eV and 0.515 eV, respectively.

3. Results

The Figures 1-3 show electric field profiles on the cross section of the waveguide when the light travels half a way along the graphene sheet. A field profile monitor records this profile. The Figures 2 and 3 shows the profile when the chemical potential is set to 0 eV and 0.515 eV, respectively. The field profiles are drastically changed as a function of a chemical potential.

The Figures 4 and 5 show the electric field distribution inside the graphene sheet. A field profile monitor records this profile. The field profile for $\mu_c = 0$ eV keeps almost same intensity after traveling 800 nm, while that for $\mu_c = 0$ eV is considerably decayed.

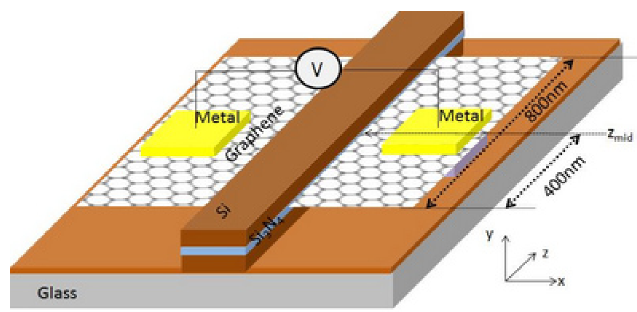

Figure 1. The modulator we're considering.

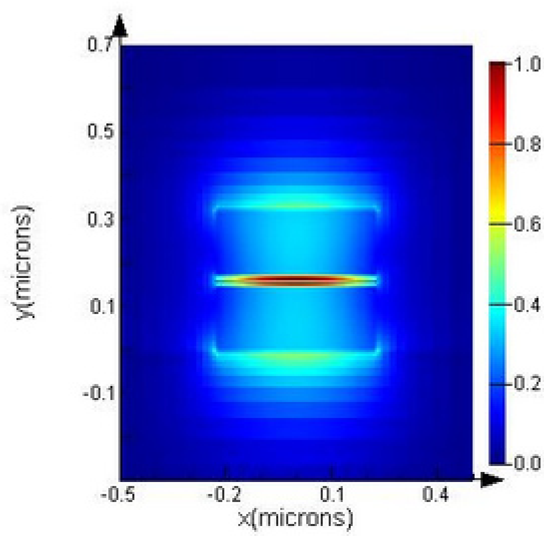

Figure 2. Profile when the chemical potential is set to $\mu_c = 0$ eV.

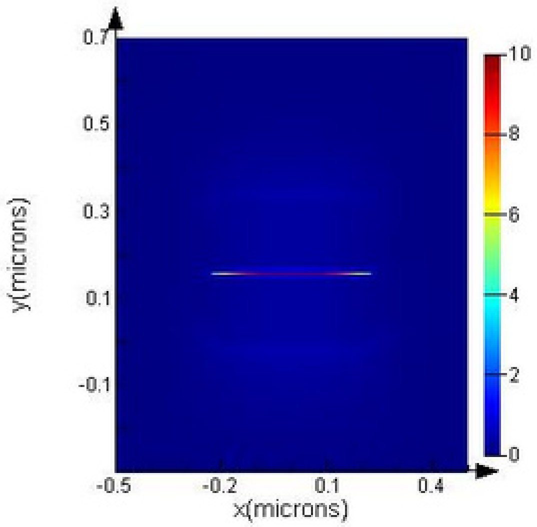

Figure 3. Profile when the chemical potential is set to $\mu_c = 0.515$ eV.

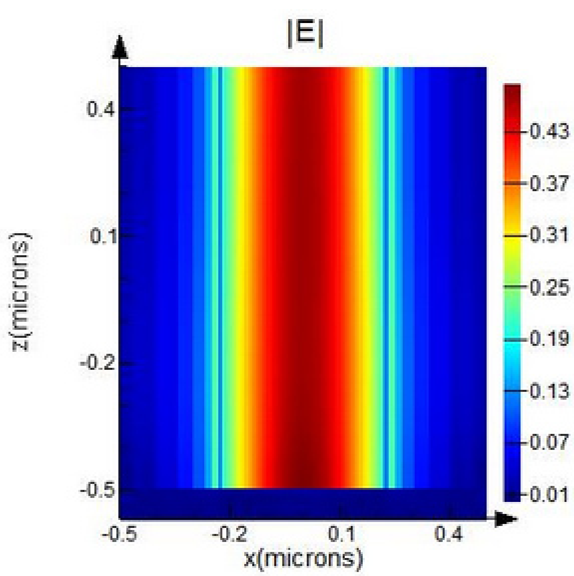

Figure 4. Field profile for $\mu_c = 0$ eV.

Using two power monitors located at the edges of the graphene sheet, transmission thorough the graphene-embedded part can be calculated. The results are about 96% and 45 % for $\mu_c = 0$ eV and 0.515 eV, respectively.

If we use MODE solutions, we can analyze the mode properties of the Si waveguide which include a graphene sheet. The Figures 6 and 7 show the mode profiles and the losses calculated by MODE Solution. As we can expect from the figures above, the loss for $\mu_c = 0.515$ is considerably higher than that for μc = 0 eV.

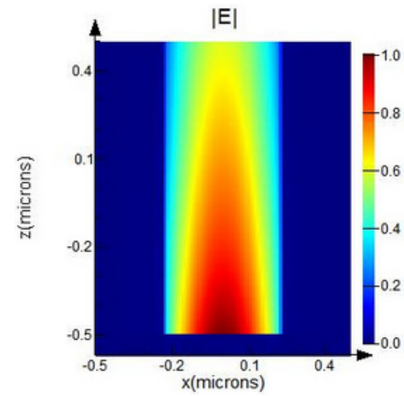

Figure 5. Field profile for $\mu_c = 0.515$ eV.

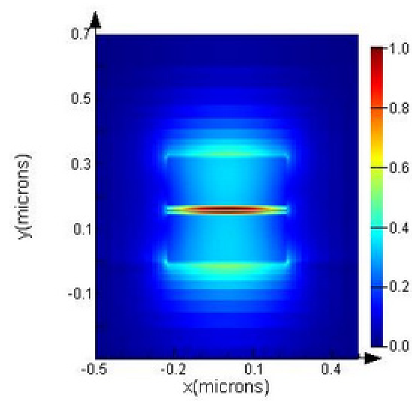

Figure 6. Mode profiles and the losses calculated $\mu_c = 0$ eV, loss = 1638 dB/cm.

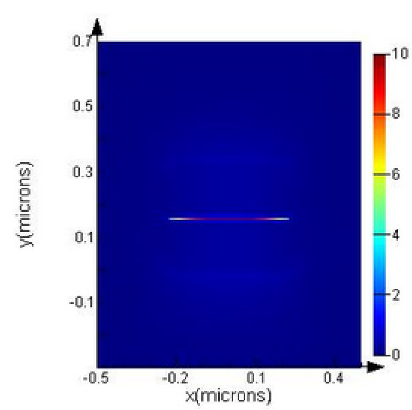

Figure 7. Mode profiles and the losses calculated $\mu_c = 0.515$ eV , loss = 40890 dB/cm.

4. Conclusions

In this simulation, μ_c = 0 eV and 0.515 eV is considered and the dielectric constants of the graphene for each μ_c is taken from the reference above. Since we consider a single telecom wavelength at 1550 nm, we use (n, k) material model to input the optical constant of the graphene. The materials in the material database correspond to the chemical potential of 0 eV and 0.515 eV, respectively. The field profiles are drastically changed as a function of a chemical potential. The field profile for μ_c = 0 eV keeps almost same intensity after traveling 800 nm, while that for μ_c = 0 eV is considerably decayed. Using two power monitors located at the edges of the graphene sheet, transmission thorough the graphene-embedded part can be calculated. The results are about 96% and 45% for μ_c = 0 eV and 0.515 eV, respectively and finally the loss for μ_c = 0.515 is considerably higher than that for μ_c = 0 eV.

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