Graphene devices for outperformed optical interconnects

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Optical On-Off keying based on graphene has received great attention in the past years for communication applications. However, most studied devices suffer from a low extinction ratio. Here we introduce a design based on the integration of graphene (two layers of graphene with a dielectric in between) on a silicon slot waveguide. It has an extinction ratio over 20 dB for a 100 um device length with an applied voltage of 6 Volt and operates with TE polarized light. The insertion loss, another key parameter for optical switches, is only 1 dB, assuming high quality graphene.

Introduction

Optical communication devices are being developed to enhance the performance in the energy, speed, footprint, etc. Graphene with its extraordinary properties is a proper candidate to this end. For many applications a strong interaction of graphene and light is required in order to modify the device performance. This can be achieved by integrating graphene on the optical waveguide so that light travels along the graphene layer.

Using such an arrangement, different graphene based devices such as photodetectors, modulators and switches have already been demonstrated [1-5]. For most of the investigated graphene-on-Si waveguide based devices, the quasi-TM mode has the highest interaction with the graphene layer [3,4], while the quasi-TE mode is the most common polarization for the guiding mode in other optical devices. Hence graphene-on-Si based devices that are operating with the TM-like mode lead to a complicated design when integration with other optical components is desired.

In this paper, we propose a double layer graphene-on-Si slot waveguide based optical switch. Our simulation results show that the TE mode interacts more strongly with graphene, which addresses the difficulty of integration with other optical devices. A relatively high absorption is achieved at the Dirac point by transferring double layers of graphene with a 5 nm dielectric spacer between them on the Si slot waveguide (DLG-Si-Slot). This solves the issue of poor extinction ratio in previous graphene based devices operating with the TE-mode. The mechanism of switching is based on moving the fermi level away from the Dirac point (off-state) by applying a voltage between the two graphene layers, making these layers transparent through Pauli-blocking (on-state).

In the next section, we present the results for the optimum design of the waveguide width, capacitor width, impact of polarization, metal pads distance from the waveguide and finally graphene quality on the absorption of graphene. The most important parameters are compared with our previous work on Si strip waveguides with double layer graphene on top (DLG-Si) [5].

Results and discussion

The presented structure is a Si slot waveguide with a graphene-dielectric-graphene stack on top. A voltage can be applied through metal contacts on both graphene layers (Figure1).

This graphene based switch has been investigated using the finite element solver COMSOL where the conductivity of graphene (including inter-band and intra-band effects) as function of the temperature, wavelength, fermi level and graphene scattering time is implemented. The results presented in this paper are for an operating wavelength of 1550 nm and a temperature of 300 K.

Figure 2a shows the absorption of the TE mode versus width of the slot waveguide with a double layer graphene on top. In this design the width of slot section is fixed to a constant value of 120 nm and the width of the Si is varied. The optimum absorption of 0.27dB/µm is found for a waveguide width of 620 nm. Figure 2a shows the absorption of the TE mode of the DLG-Si-Slot waveguide is much higher than that for the DLG-Si strip waveguide, which is due to the high confinement of the mode in the graphene layers for the slot configuration.

In order to assess the effect of graphene quality on the absorption, we simulated the graphene loss for two different types of graphene (the higher scattering time is equivalent with a better graphene quality) as function of the applied voltage. It is shown in Figure 2b, that the high quality graphene has a smaller insertion loss (the smallest absorption for a given voltage) and thus a higher extinction ratio. According to this graph, a remarkably high extinction ratio of 23 dB can be accomplished with only 1dB insertion loss for a device with 100 µm length. These parameters can be improved linearly for the longer devices. V_0 in this curve takes into account effects of background doping of graphene caused by the fabrication processes or environment.

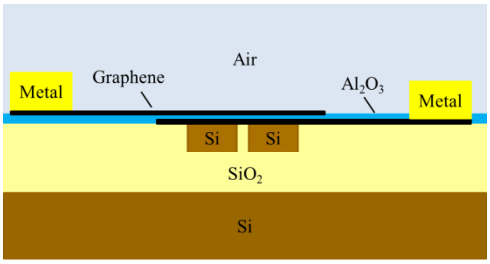

Figure1. A schematic of the double layer graphene-on-Si slot waveguide optical switch.

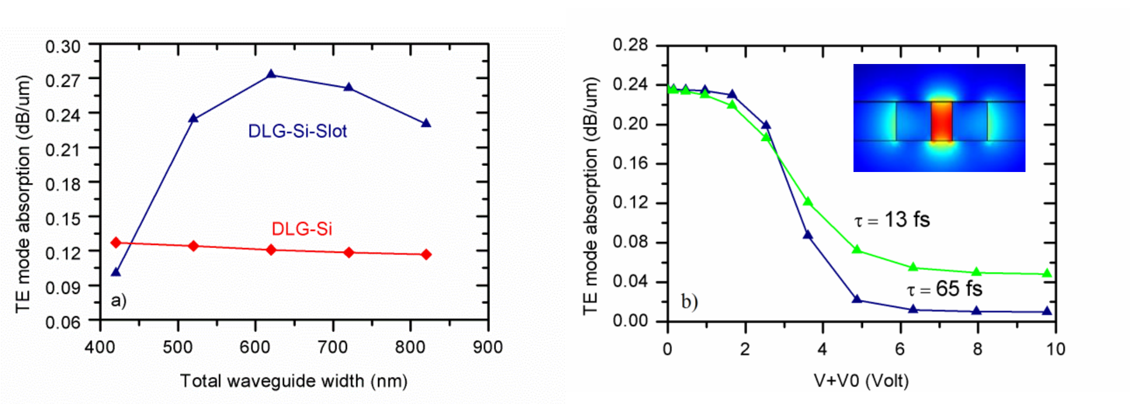

Figure 2. a) The TE mode absorption at the Dirac point versus the total waveguide width (2×Si section width + slot section width), the graphene scattering time is 65 fs b) The TE mode absorption for the

scattering time of 65 and 13 fs. Si section width= 200 nm, slot section width = 120 nm, thus the total waveguide width is 520 nm.

The capacitor width is another effective parameter in the device absorption. The loss (i.e. interaction between light and graphene layer) increases by widening the width of capacitor. For widths more than 1 µm the increase saturates (Figure 3a). The minimum point is a configuration where graphene layers are just covering the slot and interestingly the absorption is still a notable value of 0.16dB/µm. Therefore for a device with the length of 100 µm the extinction ratio can be about 16 dB, a quite large value. In addition, this design allows for improved dynamic performance, through lowering the capacitance of the device considerably (see [5] for details).
For the real device we also have to consider the extra loss due to the metal pads and the resistive part of the graphene. To evaluate this effect Figure 3b plots the influence of the distance between the metal and the waveguide. It is seen that insertion loss originating from the metal pads is suppressed by enlarging the distance between metal and the waveguide over 1µm. The remaining loss is due to the resistive graphene which is an absorber. Since the two configurations, the DLG-Si strip and the DLG-Si-Slot, have almost the same length of resistor, their insertion loss evolves to the same value in Figure 3b.
The mode profiles for the structures exhibiting maximum and minimum insertion loss for the DLG-Si-Slot waveguide are also shown in Figure 3b. These show clearly that the mode tends to confine in the metal area if these pads are close to the waveguide (spacing = 0.35µm). On the other hand, the mode only exists in the waveguide-graphene section with no leakage towards the metal pads for the low insertion loss state (3µm spacing).

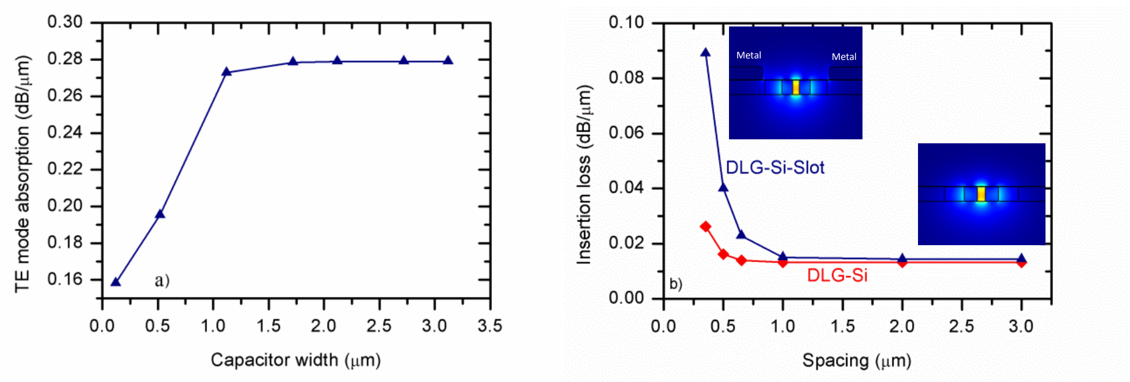

Figure3. a) The TE mode absorption at Dirac point for the scattering time of 65 as function of capacitor width b) The insertion loss as function of the distance of metal edge and the waveguide edge (spacing). In the case of DLG-Si-Slot, the total waveguide width is 520 nm.

Conclusion

In this work we have investigated the performance of an optical graphene switch based on a Si slot waveguide. The proposed structure has absorption of 0.27dB/µm at the Dirac point for the optimum geometry, a high value compared to that for a standard TE strip waveguide, and leads to a proper design with a high extinction ratio. For the high quality graphene with scattering time of 65 fs and total waveguide width of 520 nm, a 100 µm long device can provide an extinction ratio of 23 dB with an insertion loss of only 1dB. A wider capacitor improves the absorption characteristic but it limits the switching speed. The metal contacts should be at least 1 μm away from the mode confined region to avoid the extra insertion loss. The device operates with the TE polarization, which enables to integrate this type of switch with other optical components.

Acknowledgements

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