Design of Hybrid Integrated Graphene Optical Switch with an III-V-on-Si laser

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Monolithic integration of photonic devices such as switches and modulators with lasers is a complex process. Often these devices require materials with different band-gaps, which makes their co-integration costly and complicated. As an alternative, materials exhibiting interesting optical and electronic functionality such as graphene and other 2D-materials can be hybridly combined with Si and III-V platforms, simplifying the fabrication process and providing complex integrated optical systems on a smaller footprint. A big advantage of graphene is its optically broadband operating window and the fact that its optoelectronic properties are tunable by electrical gating or chemical doping.

In this paper we propose a novel approach to integrate a graphene modulator or switch with a hybrid III-V on silicon laser device [3,5]. The most straightforward approach would be to integrate the graphene device next to but separate from the III-V amplifier, directly on the silicon waveguide. However, in most of the investigated graphene-on-Si waveguide based devices, the quasi-TM polarization is the dominant mode having the highest interaction with the graphene layer [1,2]. The quasi-TE mode, used in the III-V amplifiers has considerably less overlap with the graphene layer and results in very inefficient devices. This is certainly the case taking into account the 400nm thick silicon waveguides used in typical hybrid III-V on silicon lasers [5]. Therefore, a design resulting in enhanced interaction of the TE-like mode with the graphene optical device is needed. In addition our approach inherently provides the possibility to gate or modulate the Fermi-level in the graphene layer, without the need for any further processing steps thereby considerably simplifying the integration process.

Our approach is sketched in Figure 1. Most hybrid III-V on silicon lasers contain a taper section where the light is adiabatically coupled from the III-V gain section to the silicon waveguide (Figure 1, left [3]). We propose to integrate the graphene layer in this taper section. Figure 1, right shows the cross section of our structure. The InP epitaxial layers are chosen similar to that of a standard heterogeneously integrated laser design [5]. A single layer of graphene is included on the 400 nm Si rib waveguide. The InP mesa is placed above of graphene with an insulating layer of DVS-BCB in between. The latter has now two roles in this design. First, it serves as the adhesive bonding layer between the III-V and the Si chips. Second, it acts as a dielectric layer for the switch. Applying a voltage between the metal contact on the graphene and the doped bottom InP cladding layer of the laser allows controlling the chemical potential and hence the transparency of the graphene layer [1,2]. In Figure 2, the TE mode absorption is plotted as function of the InP mesa width and Si waveguide width as they vary along the taper. It shows that the absorption level changes drastically along the taper length and can be controlled by varying the respective waveguide widths. The graph also compares the absorption in the modulator with that of a layer of graphene directly deposited on the silicon waveguide. In the latter design, the Si waveguide has to be doped in order to apply a voltage over the graphene layer. This increases the complexity of the process and as the graph shows also has considerably lower performance. According to Figure 2, the TE mode absorption in the taper design is almost 4 times higher than for the standard device. The total absorption for a taper length of 150 μm is about 6dB in the Dirac point of graphene, sufficient for datacom applications. The figure also shows the effect of the thickness of the bonding layer. A thicker BCB-layer, pushes the mode toward the Si waveguide and reduces its interaction with the graphene. Thinner bonding thickness not only increases the absorption (and hence the modulation efficiency, see [4] for details) but also is beneficial to boost the coupling from the III-V mesa to the Si waveguide and enhance the laser performance [5]. Figure 3 shows three cross sections along the taper length.

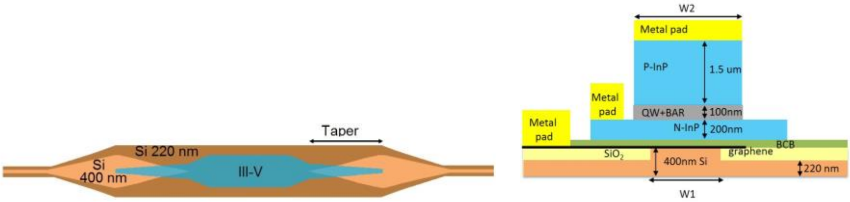

Fig. 1. Left: III-V on Si laser design, top view, Right: Schematic of the graphene device integrated with an InP/Si laser. The structure is on the taper section in the left image, therefore the width of Si waveguide and P-InP is varied.

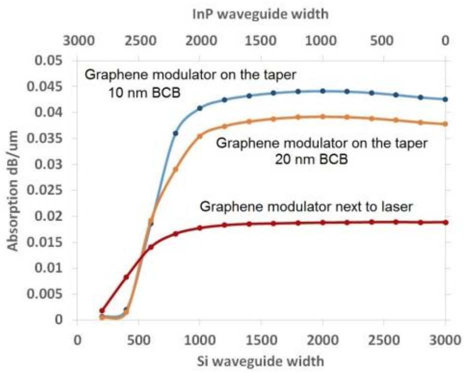

Fig. 2. The TE mode absorption as function of the InP taper width and Si waveguide width for two designs of graphene modulator next to laser and graphene modulator on the tapered Si integrated with laser.

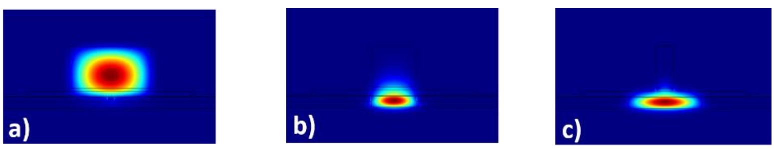

Fig. 3. Three cross section from the taper with a) P-InP width 3000nm, Si width 200 nm b) P-InP width 1600nm, Si width 1600 nm c) P-InP width 600nm, Si width 2.6 um.

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