Saturable absorption of a double layer graphene modulator on a slot waveguide

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Abstract

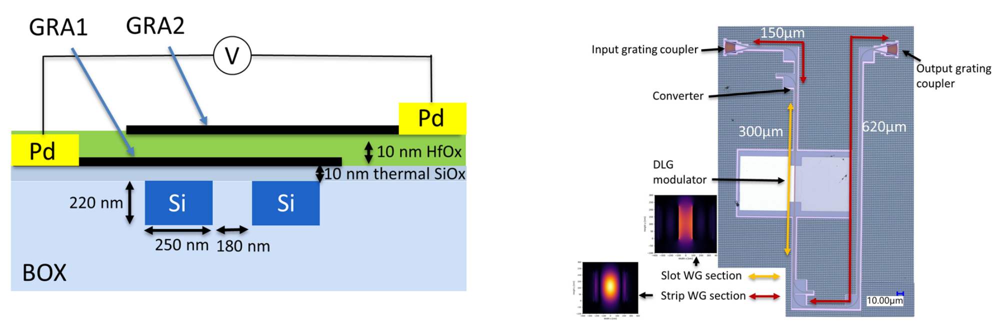
The saturable absorption of a double-layer graphene modulator is experimentally demonstrated on a silicon slot waveguide platform. Saturation was found to start at ∼0.8W with a maximum saturation depth of 1.9 dB for a 50 μm long graphene modulator.

I. Introduction

Graphene has received significant attention in the (integrated) optics community thanks to many attractive optical properties such as its strong tunable and saturable broadband light absorption [1][2]. The saturable absorption (SA) of graphene has been proposed to be a promising candidate for use in integrated mode-locked lasers, after successful reports of its use in creating ultra-fast mode-locked fibre lasers [3].

Thanks to the electrical tunability of graphene, graphene layers have already been successfully incorporated on top of silicon waveguides to create efficient integrated electro-absorption modulators (EAM) [1][4]. However, it has proven challenging to saturate these modulators at optical powers below 1W, caused by the weak interaction of the transverse electric (TE) mode of a strip waveguide with the graphene layer(s) on top of the waveguide [5][6]. The SA was improved by moving to waveguides guiding transverse magnetic (TM) polarised light which improves the optical interaction with graphene, after which the SA was further enhanced through electrical gating of the graphene layer [7]. The benefit of having the ability to electrically gate the graphene SA is that this enables electrical control over the light absorption and saturation depth in the graphene layers through control of the Fermi-level of graphene [7].

By using a slot waveguide, it is expected that the saturable absorption (and modulation efficiency) is improved further due to an increase in optical interaction of the guided mode with the graphene layers. Thanks to this improved optical interaction of graphene via the slot waveguide topology, a double-layer graphene (DLG) modulator was recently demonstrated having an enhanced modulation efficiency reaching 0.2 dB/μm [8]. This improved modulation efficiency is a clear indication that the optical interaction with graphene is improved which should result in a reduction of the optical power required to saturate the graphene layers, as was demonstrated previously using a non-gated graphene approach on slot waveguides [9]. In this report, the electrically tunable saturable absorption of a DLG modulator on a slot waveguide is investigated.



a) Schematic cross section of the double-layer graphene modulator on a slot waveguide cross-section

b) Top view microscope image of the measured device with a 50 µm long slot modulator

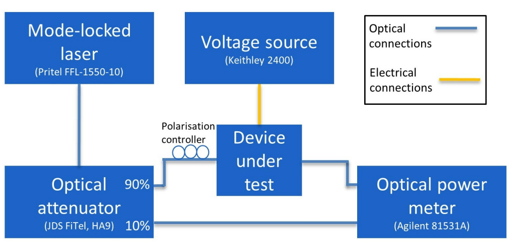
Fig. 1: Double-layer graphene modulator cross-section (left image). And a top down microscope image of the DLG structure measured, in which the red coloured arrows indicate the locations of strip waveguides, and the yellow arrows slot waveguides with the corresponding numbers indicating the respective lengths.

II. Fabrication and measurement setup

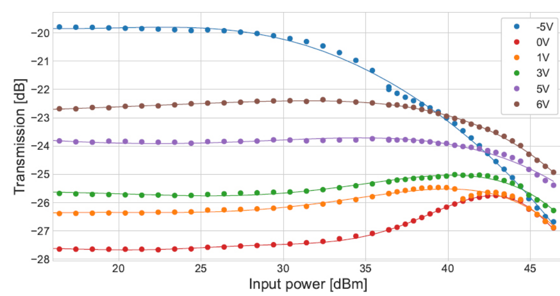
The modulator cross-section is schematically shown in figure 1a. The slot waveguide was fabricated in imec's 200mm pilot line. The DLG modulator consists of two graphene layers which were grown by chemical vapor deposition (CVD) on a Si/SiO_2/Pt substrate and is separated by a 10 nm HfOx gate oxide forming a capacitor. The Fermi level of graphene can be changed by applying a voltage between the two graphene layers using Paladium contacts. More details on the fabrication and EAM modulation performance of the device measured can be found in [8].
The top-side view of the device measured is shown in figure 1b which consists of both TE strip and slot waveguides. Coupling between the strip and slot waveguide is achieved using a 10 μm long adiabatic mode converter. Coupling to and from the device is performed using grating couplers having 5-6 dB loss each.
The measurement setup used to measure the saturable absorption is shown in figure 2a. A Pritel Inc. FFL-1550-10 laser is used to generate 8 ps pulses with a repetition rate of 10 MHz at a centre wavelength of 1550 nm. These pulses are attenuated using a JDS FiTel HA9 tunable attenuator in which a splitter divides the beam of light providing a monitor signal. After a polarisation controller, the transmission of the device under test (DUT) and the monitor ports are measured using Agilent 81531A optical power sensors.

III. Experimental results

The measurement results are shown in figure 2b. This figure shows a saturable absorption depth of 1.9 dB for an input peak power of 19W (prior to coupling) for a 50 μm long modulator, with saturation starting at $\sim$0.8W. By shifting the Fermi-level of graphene the absorption and saturation depth are reduced. When the absorption of the graphene layers is reduced however, two-photon absorption is increased caused by the higher optical intensity in the strip waveguide after the graphene modulator. The results reported show an improved saturation compared to previously published graphene saturable absorbers on TE and TM based strip waveguides. From these results a saturable absorber based on a DLG modulator on a slot waveguide seems to be a promising option for use in integrated mode-locked lasers.



(a) The measurement setup used to measure the saturable absorption of the graphene modulator.



(b) Measurement results of the graphene saturable absorption of a 50 μm long graphene modulator. Each line corresponds to a different voltage applied over the DLG modulator. The input peak power refers to the pulse peak power before coupling using a grating coupler. The transmission refers to the transmission of the device including grating coupler losses.

Fig. 2: Saturable absorption measurement setup and results for a DLG saturable absorber.

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