Graphene-Based Optical Modulators for Next Generation Datacom

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Abstract

In this paper, we present a review of our work on graphene electro-absorption modulators for datacom applications.

1. Introduction

As cloud computing, big data applications and social networking are expected to keep growing exponentially, the amount of annual global data center traffic is set to increase considerably [1]. To meet this demand, new technologies based on optical communications have been developed, including electro-optical modulators. These modulators play a key role in optical transceivers by converting the output signal from an electric one to an optical one, therefore allowing to connect short-haul electronic circuits with long-haul optical communication systems. An ideal optical modulator requires high modulation speed, small device footprint, large optical bandwidth, low power consumption, low insertion loss and acceptable thermal tolerance.

State of the art modulators are based on silicon (Si) or germanium (Ge). Si-based Mach-Zender modulators (MZM) offer wide optical bandwidth, but suffer from high power consumption [2]. Si-based microring modulators, at the opposite, have low power consumption, but suffer from low optical bandwidth and tight fabrication tolerance [3]. As a consequence, thermal stabilization is necessary to correct fabrication errors, therefore increasing the total power consumption. Ge-based Franz-Keldysch (FK) modulators benefit from a wider optical bandwidth than MZM and have lower power consumption than microring modulators, but at the expense of a higher insertion loss [4].

In recent years, graphene-based modulators have attracted great interest due to graphene's characteristic broadband absorption, from the visible to the infrared. Graphene's absorption can be tuned through capacitive charging by applying an electric field, and can therefore be used to build single-layer electro-absorption modulators (EAM) (Fig. 1). Graphene EAMs offer potentially low power consumption, low insertion loss and high speed operation, due to graphene's high carrier mobility [5].

Demonstration of graphene EAMs shows good promise, however the demand for networks operating at ever higher data rate can't be fulfilled by single devices. Wavelength division multiplexing (WDM) is a technology exploited to increase the bandwidth by combining multiple data streams, transferred at different wavelengths, on a single optical fiber simultaneously.

In this paper, we show our work on improving the operating speed of graphene-silicon EAMs, by optimising the parasitic RC constant of the devices [6, 7]. We then present the first demonstration of WDM transmitters based on graphene-silicon EAMs, showing potential for multi-channel data transmission using graphene technology [8].

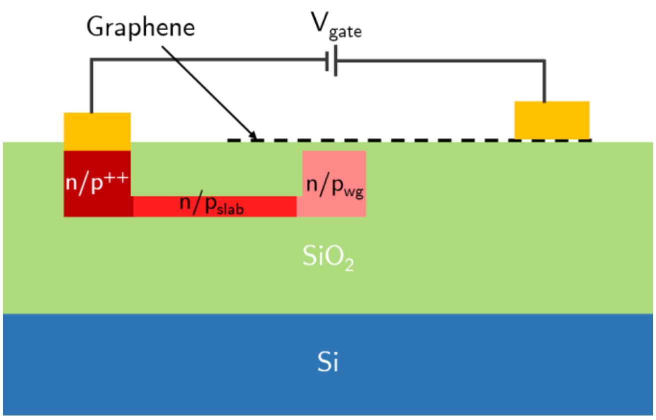

Fig. 1 Schematic cross section of the graphene EAM.

2. Graphene-silicon electro-absorption modulators

In our previous work [6], we studied the influence of the

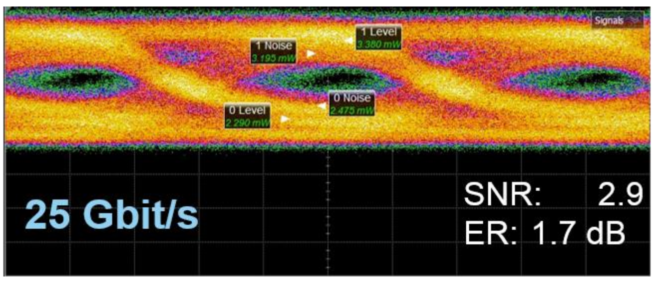

Fig. 2 Optical 2^7-1 PRBS eye diagrams measured at 1560 nm, with a drive voltage of 2.5 V_{pp} and a voltage bias of 2 V, at 25Gbit/s.

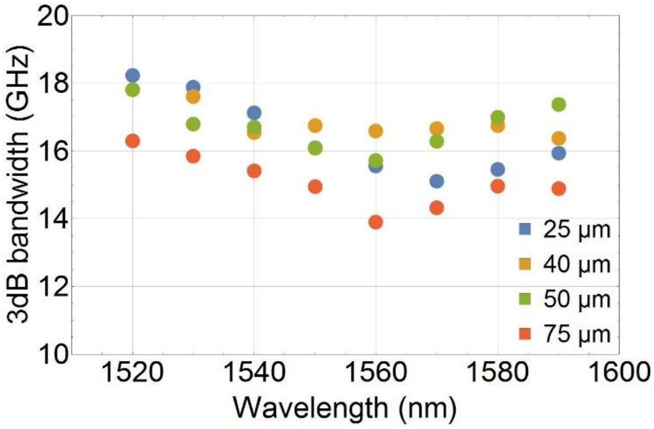

Fig. 3 3dB bandwidth measured at 0 V DC bias from 1520 nm to 1600 nm on graphene EAMs with lengths of 25µm, 40µm, 50µm and 75µm.

waveguide doping type on the operating speed of graphene EAMs. Unpassivated graphene is typically highly p-doped due to environment and polymer contamination. As a consequence, when an electric field is applied across the graphene-oxide-silicon (GOS) capacitor by contacting graphene and Si as shown in Fig.1a, the graphene neutrality point is shifted towards negative voltage bias, leading to low resistance at 0 V or low forward bias. Due to p-doping in graphene, the switching between on and off state in the modulator also occurs in the same voltage range. In order to minimise the capacitance of the GOS capacitor in this same voltage range, a p-doped rather than n-doped Si waveguide can be used.

By using a p-doped Si waveguide combined with p-doped graphene, we demonstrated a 25 µm-long TE-polarised graphene EAM with a 3dB-bandwidth of 17 GHz at 0 V DC bias, 2.6 dB insertion loss and 0.026 dB/µm extinction ratio at 6.5 V_{pp}. This result represents an improvement of 42% compared to the same device built with a n-doped Si waveguide.

Later [7], using the same waveguide-graphene doping combination, we characterized four graphene EAMs (L_{device} = 25, 40, 50, 75 µm) built with TM-polarised waveguides in order to achieve a higher extinction ratio, which is limited when working with TE waveguides. We obtained open eye diagrams up to 25 Gbit/s (Fig. 2) on a 50 µm-long single-layer graphene EAM with 7.7 dB insertion loss, 0.088 dB/µm extinction ratio at 8 V_{pp}, 16 GHz 3dB-bandwidth at 0 V DC bias across 70 nm wavelength range (Fig. 3).

3. WDM transmitters based on graphene electro-absorption modulators

To show the potential of multi-channel data transmission using graphene EAMs, we demonstrated three 5-channel WDM transmitters, each based on five graphene EAMs with n-doped Si waveguides. We achieved 2.2 dB insertion loss, 5.6 dB extinction ratio at 8 V_{pp} and 9.3 GHz 3dB-bandwidth at 0 V DC bias for the 5-channel WDM transmitter with a 600 nm-wide waveguide and 100 µm-lon graphene-silicon EAMs [8]. Open eye diagrams were measured in the C-band at 2.5 V_{pp} on all the 5-channel WDM transmitters, thus allowing data transmission at 5 x 25 Gb/s (Fig. 5).

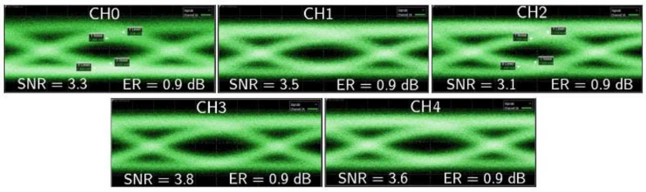

Fig. 5 Eye diagrams measured at 25 Gbit/s on the 5 channels of a WDM transmitter with W_{wg} = 600 nm and L_{device} = 100 µm at 2.5 V_{pp} and -1.2 V DC bias.

4. Conclusions

The telecom and datacom industries are driven by the continuous increase in requirements for the bandwidth of communications. Graphene has shown to be a promising candidate to overcome limiting factors of current silicon photonics technologies, due to its broadband absorption and loose fabrication requirements. An improvement of the graphene quality, and therefore of the graphene mobility, will allow to reduce the graphene resistance, increase the extinction ratio for fixed V_{pp} and reduce the insertion loss of the graphene EAMs.

Acknowledgements

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