Bandwidth analysis and optimisation of graphene-Si electro-absorption modulators

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In the past few years graphene has increasingly attracted more attention for applications in photonics, thanks to its potential for high bandwidth and broadband operation [1]. Hybrid waveguide-graphene electro-absorption modulators are particularly promising for datacom applications [2]. Achieving a large operation bandwidth in these devices is possible by reducing the total capacitance of the graphene-oxide-silicon (GOS) capacitor, e.g. by increasing the gate oxide thickness. However, this comes at the expense of higher drive voltages to switch between on- and off-state [3]. An alternative solution to achieve high RF bandwidth is reducing the device series resistance, which is dominated by the graphene related contact and sheet resistance (R_{gC} and R_g) and the silicon sheet resistance (R_{Si}).
In this work, we analyse the total RC time constant of a graphene-Si electro-absorption modulator through rigorous S-parameter analysis. By increasing the doping in the Si waveguide, the impact of silicon-related series resistance is reduced and consequently a higher 3dB bandwidth is obtained. We will present results of TLM measurements on graphene and doped Si structures and fitting of the S_{11} response to understand the contribution of the Si sheet resistance to the total series resistance. In addition, we will present electro-optical simulations demonstrating the impact of the Si waveguide doping on the modulation efficiency along with the speed of the device.

DC bias	f_{3dB} – Std doping	f_{3dB} – High doping
0 V	10.9 GHz	12.0 GHz
1 V	3.5 GHz	7.2 GHz
2 V	4.6 GHz	6.3 GHz

Table 1. 3dB bandwidth of two GOS devices, with standard doped and highly doped Si waveguide. The values are reported at 3 different DC bias voltages for a 25 µm long device.

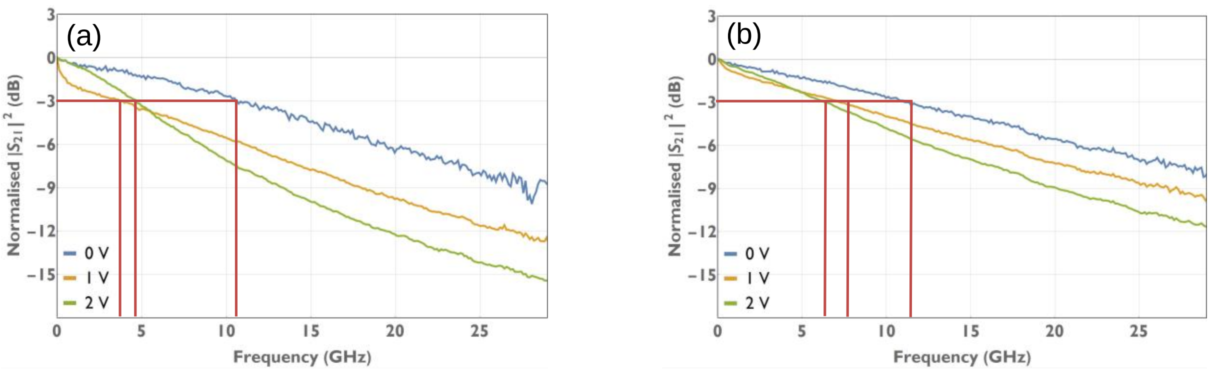

Fig 1. Measured and normalised electro-optical S_{21} frequency response of a 25 µm long device at 0V, 1V and 2V DC bias voltages, for (a) standard doped and (b) highly doped Si waveguide.

References
[1] Bonaccorso, F., Sun, Z., Hasan, T. & Ferrari, A. C. Graphene photonics and optoelectronics. *Nature Photon.* **4**, 611–622 (2010)
[2] Hu, Y., Pantouvaki, M., Van Campenhout, J., Brems, S., Asselberghs, I., Huyghebaert, C., Absil, P. & Van Thourhout, D. Broadband 10 Gb/s operation of graphene electro-absorption modulator on silicon. *Laser & Photonics Reviews*, **10**, 307–316 (2016)
[3] Phare, C. T., Lee Y. D., Cardenas, J. & Lipson, M. Graphene electro-optic modulator with 30 GHz bandwidth. *Nature Photon.* **9**, 511–514 (2015)

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