Graphene-based External Optoelectronic Terahertz Modulators for High Speed Wireless Communications

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Abstract—the realization of terahertz external amplitude modulators with a carrier frequency of 0.8 THz is presented for application in the next generation near-field wireless communications.

Keywords—Terahertz, metamaterials, graphene, wireless communications.

I. INTRODUCTION

Development in the field of terahertz (THz) science and technology is becoming rapidly increasing to fulfill the needs for high data rates transmissions in wireless communication systems beyond 5G. The terahertz (0.1 – 10 THz) frequency band lays between the convention electronics and photonics range. From photonics point of view, external manipulation and modulation of a CW or pulsed THz laser source have a great potential for achieving robust, fast speed, small footprint, low power consumption, ease for chip-scale integration external THz modulators [1-3]. Graphene/metamaterial hybrid optoelectronic devices have demonstrated to be a viable solution for the modulation of THz radiation [4-7] thanks to its efficiency, versatility and integration with well-established fabrication technology. Here we report on a double gate graphene metamaterial array capable to provide > 20% in transmission at 0.8 THz, with a modulation speed exceeding 1GHz.

II. DESIGN AND FABRICATION

The device comprises an approximately 1.3x1.2 mm² array of metallic split ring resonators (SRRs) shunted by graphene patches fabricated on top of a SiO₂/Si (300 nm/500 µm) chip. The Silicon substrate was p-doped to allow electrostatic gating via back gate. A schematic of the final device is shown in Fig 1, together with optical microscope pictures of the final device. The graphene was grown with chemical vapour deposition and then transferred over the substrate. Graphene patches were defined by using lithographic masking followed by Oxygen plasma etching. The SRRs were fabricated via optical lithography, metallic thermal evaporation (Ti/Au, 10/150 nm) and lift off. The graphene areas where encapsulated with a protective Al₂O₃ layer of 150 nm via atomic layer deposition, in order to reduce hysteresis, prevent

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for top gate voltages applied through the Silicon substrate whilst grounding graphene via the drain and source pads, with voltages ranging between -20 V (Dirac point) and +90 V. The position of the resonant feature is around 0.75 THz, in a very good agreement with the simulated one. The modulation depth achievable is larger than 20% in good agreement with previous results achieved for electrostatic gating. Lower frequency components < 1 THz might have an optical spot size larger than the array area. This factor, together with an imperfect alignment might contribute to reduce the measured modulation depth. A leakage towards gate of a few µA might limit as well the achievable modulation depth.

IV. RECONFIGURATION SPEED MEASUREMENTS

The device was then mounted on a high speed board for electrical characterization in a configuration shown in Fig 3. A RF signal from an Agilent RF generator model N9310A, which varied between 100’s MHz to a few GHz was added to a DC voltage by using a bias tee and fed to the top gate. The DC voltage is needed in order to set the working point along the Dirac curve. A constant current < 1 µA was applied between source and drain with a Keithley source-measure unit model 2450, and the voltage across the terminal was amplified and sent to a scope and to a spectrum analyser from Rohde& Schwarz (model FS300). Leakage current between top-gate and drain was in the order of 1-10 nA following no trend with DC voltages applied through the Silicon substrate whilst grounding graphene via the drain and source pads, with voltages ranging between -20 V (Dirac point) and +90 V. The position of the resonant feature is around 0.75 THz, in a very good agreement with the simulated one. The modulation depth achievable is larger than 20% in good agreement with previous results achieved for electrostatic gating. Lower frequency components < 1 THz might have an optical spot size larger than the array area. This factor, together with an imperfect alignment might contribute to reduce the measured modulation depth. A leakage towards gate of a few µA might limit as well the achievable modulation depth.

V. CONCLUSION

In conclusion, we reported on a graphene/metamaterial array based on a double gate architecture operating around 0.8 THz with a modulation depth > 20% and reconfiguration speed of a few GHz. The device was modelled with finite element method software and characterized optically with a fs pulse THz spectrometer yielding a very good agreement with the simulation. This represents an important progress towards high speed next generation of THz wireless communication.
REFERENCES


