2020 45th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz) | 978-1-7281-6620-9/20/$31.00 ©2020 IEEE | DOI: 10.1109/IRMMW-THZ46771.2020.9370511

Electrically tunable graphene-on-polyimide Terahertz Modulators

Alessandra Di Gaspare[1], Eva A.A. Pogna[1], Luca Salemi[1], Osman Balci[2], Alisson Cadore[2], Sachin M. Shinde[2], Cinzia di Franco[3], Andrea C. Ferrari[2], Gaetano Scamarcio[3] and Miriam S. Vitiello[1]
[1]NEST, CNR-NANO and Scuola Normale Superiore, 56127 Pisa, Italy
[2]Cambridge Graphene Centre, Cambridge CB3 0FA, United Kingdom
[3]CNR-IFN and Dipartimento Interateneo di Fisica, Università degli Studi di Bari, I-70126 Bari, Italy

***Abstract*—We report a graphene-on-polyimide THz modulator with a tunable-by-design optical bandwidth, a 90% modulation efficiency, a 20 KHz electrical bandwidth and tunable in the 1.9-2.7 THz range. The electrostatic tuning of the THz conductivity is achieved through a grating gate coupler on the top of the polyimide waveguide. By coupling the modulator with a THz quantum cascade laser frequency comb, we show it can fully compensate the cavity dispersion, resulting in stable frequency comb operation over a 45% dynamic range.**

I. INTRODUCTION

The progress of THz photonics is limited by the lack of appropriate technologies for microwave high-speed modulation or switching[1]. Layered materials and their heterostructures are ideal for the development of ultrafast electronic, photonic and plasmonic devices having properties that can be engineered by design [2]. These include saturable absorbers, broadband sources, high-speed photodetectors, near-field components, as well as amplitude and phase modulators, able to manipulate THz waves [1-4].

Here, we report on the design and development of THz modulators based on single layer graphene (SLG) placed on a grating gate double-metal polyimide waveguide (WG), Fig.1a. SLG is ideally suited form this application: its THz optical conductivity can be tuned through electrostatic gating, enabling reconfigurable devices; SLG grown via chemical vapor deposition (CVD) can be transferred on many substrates [5] as well as embedded in cavities or waveguides (WG) [2].

Here, we couple SLG via field-effect to the bottom metal grating, through a dielectric layer. We use a 14µm thick polyimide to match $n\lambda/4$ WG mode within the THz region. The metal grating gate imposes a gate-controlled patterned conductivity on SLG. By engineering the grating gate, we tune the $n\lambda/4$ WG mode resulting in a modulation of the total reflectance. The oscillating behavior of the phase of the reflection field in resonant structures can be exploited to implement an alternative tunable dispersion compensation tool for THz applications.

II. RESULTS

Fig. 1a depicts our modulator layout, with a grating period L_G = 10µm; the grating-gate graphene FET is fabricated with standard micro-pattering techniques for top and bottom metal contacts, followed by deposition of a AlO_x/HfO_2 bilayer. CVD SLG is then transferred on the gate dielectric layer by PMMA-assisted wet transfer [5]. The gate dependence of the total reflectance is measured by time domain spectroscopy (TDS) in a purged environment, Fig.1b, showing a modulation efficiency ~90% and total insertion losses <2dB, in good agreement with simulations based on electrostatic tuning compatible with the field-effect gating of our SLG and an initial Fermi energy~250meV, Fig.1c.

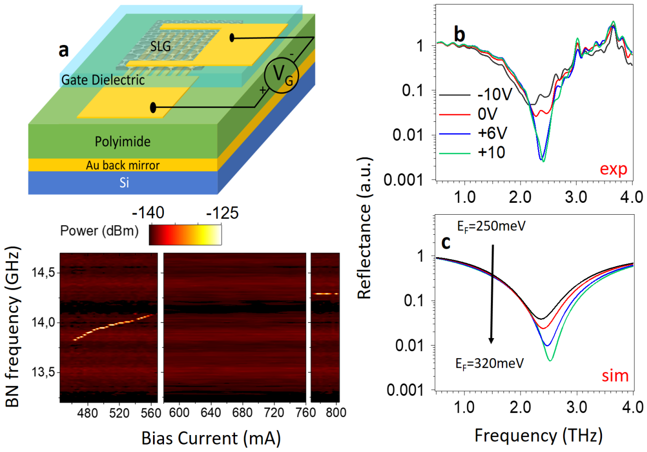

Fig. 1. (a) Device layout. (b) Experimental, (c) simulated reflectance for a SLG modulator with L_G =10µm. Measurements are done by TDS as a function of gate voltage. Simulations are done as function of Fermi energy. (d) Intermode beatnote (BN) map of a QCL frequency comb integrated with the SLG-on polyimide modulator as a function of bias current at V_G=0V.

In order to prove the modulator efficacy in modifying the intracavity mode dynamics and the cavity dispersion of an optical frequency comb synthesizer, we integrate it with a THz quantum cascade laser (QCL) frequency comb [6], defining a Gires-Tournois Interferometer [7] with a 100µm air gap. The QCL intermode beatnote map in Fig.1d shows a single narrow beatnote extending over an operational dynamic range ~45%, significantly larger than the bare laser [6], demonstrating the efficacy of our modulator in compensating the cavity dispersion in a domain in which intra-cavity four wave mixing is ineffective [8] to lock in phase the cavity modes.

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