High-speed, low-noise thermoelectric graphene detectors at terahertz frequencies

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***Abstract*—We report room temperature terahertz detection in hBN/graphene/hBN heterostructures, integrated in top-gated field effect transistors. The record combination of high-speed (response time < 1 ns) and high sensitivity (noise equivalent power ~ 100 pWHz$^{-1/2}$) is enabled by the photo-thermoelectric effect and paves the way for the design of ultrafast graphene arrays in the far infrared, opening concrete perspectives for targeting ultrafast applications.**

I. INTRODUCTION

TERAHERTZ (THz) technology is at the center of an ever increasing research effort, due to the ability of THz rays to penetrate materials and due to their non-ionizing nature. Potential applications include biomedical diagnostics, homeland security and imaging. Ultra-fast THz physics and pulsed-laser technology have specific requirements on the detector performances in terms of response time and sensitivity. To date, only cryogenically cooled superconducting hot-electron bolometers [1] and quantum well infrared photodetectors (QWIPs) [2] offer the capability of ultrafast detection (> 1 GHz speed) with high responsivities (> 1 V/W) above 3 THz.

Single layer graphene (SLG) can play an important role for the development of efficient THz detectors operating at room temperature (RT), owing to the absence of energy gap, which allows broadband absorption from the UV to gigahertz frequencies. Interestingly, the broadband nature of SLG perfectly combines with the broadband photo-thermoelectric (PTE) effect, which relies on the thermal gradient within the electronic distribution as a consequence of the absorption of a photon. The PTE effect can be efficient in SLG-based devices because (*i*) the low electron heat capacity allows huge thermal gradients in the electronic distribution, resulting in low noise equivalent powers (NEP < 100 pWHz$^{-1/2}$) and (*ii*) the unique combination of fast carrier heating (~50 fs) and fast electron cooling (~ ps) enables ultrafast response times (τ ~ 50 ps).

II. RESULTS

In this work we prepare high mobility (53000 cm^{2}V^{-1}s^{-1}) hBN/SLG/hBN field effect transistors (FETs), coupled to on-chip planar THz antennas (Fig.1a shows a bow-tie architecture) and integrated with lithographically-patterned high-bandwidth (~100 GHz) chips. This is done for various antenna and transistor architectures whose operation frequency can be in principle extended over the whole 0.1-10 THz range. We engineer either planar bow tie antennas, asymmetrically connected to the source (*S*) and top-gate (*G*) electrodes, or a double split-gates, connected to the two branches of a linear dipole antenna, defining a *p-n* junction at its center. Such antenna geometries are widely used in THz optoelectronics and both enable broadband operation

By optically characterizing the devised THz SLG photodetectors with THz quantum cascade lasers (QCLs) operating in the frequency range 2.7-3.4 THz (Fig.1b), we demonstrate ultrafast detection at RT, and, to the best of our knowledge, with a record combination of speed (τ = 890 ps) and sensitivity (NEP ~ 100 pWHz$^{-1/2}$). Fig.1c reports a representative time trace, showing its capability of characterizing terahertz pulses with a sub-ns temporal resolution.

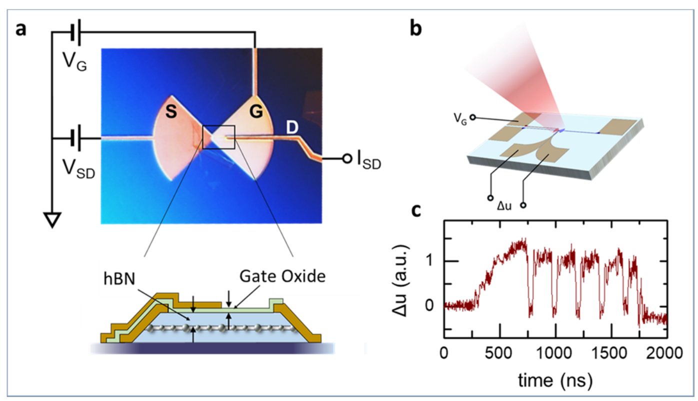

Fig. 1. (a) Van der Waals hBN/graphene/hBN heterostructures are integrated in top-gated FETs. The gate bias (V_G) can be modified to maximize the detector sensitivity. (b) Optical experiment: a THz beam generated by a QCL is focused onto the THz detector. (c) Time trace of the detector signal, recorded during a single THz pulse of 1.6 μs [3]. Fluctuations in the output power of the QCL can be detected with a sub-ns resolution, corresponding to a bandwidth of 150 MHz.

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