Emission and Detection of Terahertz Radiation in Double-Graphene-Layer Van der Waals Heterostructures

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***Abstract*—We report on experimental observation of terahertz emission and detection in a double graphene layer heterostructure with two independently contacted graphene layers separated by a thin h-BN tunnel-barrier layer. The bias voltages/doping causes the inter-graphene-layer population inversion with the possibility of photon-assisted resonant-tunneling transitions between the conduction bands and valence bands of the two graphene layers. We demonstrate that this can enable the realization of devices such as resonant terahertz detectors and emitters.**

I. Introduction

DOUBLE-graphene-layer (DGL) heterostructures have recently attracted much attention due to their potential applications in high speed modulators of terahertz (THz) and infrared (IR) radiation, transistors, and THz photomixers [1]. In this work we report the first experimental observation of THz emission and detection in the DGL device structures. We demonstrate that the photon-assisted inter-GL resonant tunneling (RT) radiative transitions enable the applications of such devices for THz/IR lasers [2-4] and photodetectors (PDs) [5,6]. The fabricated devices consist of two independently contacted graphene layers separated by the thin transparent hexagonal Boron Nitride (h-BN) tunnel-barrier layer. The bias voltage V applied between the GL's contacts induces the electron and hole gases in the opposing GLs. The electron and hole densities in GLs are also modulated by the gate voltage Vg.

II. Results

The bias voltage V gives rise to the tunnel current through the thin h-BN barrier. Figures 1(a) and (b) show the measured I-V curves of fabricated devices exhibiting a clear trace of negative dynamic conductivity (NDC) at 100 K due to nonlinear inter-GL RT transitions. The NDC is not temperature- dependent but strongly depends on the relative crystallographic orientation between the two GLs. In order to observe the NDC the two GLs have to be aligned so that their crystallographic axes are in parallel.

The bias voltages cause the inter-GL population inversion and photon-assisted RT radiative transitions between the conduction bands and the valence bands of the two GLs. We conducted THz emission experiments using a Fourier transform far-infrared spectrometer, and observed the spontaneous THz emissions associated with the photon-assisted RT transitions. Figure 1(c) shows the measured emission spectra at different gate bias voltages. For biasing conditions when the energy of the final states of the inter-GL RT transition are lower than the initial states, the RT is associated with emission of the photon radiation. Our results show the THz emission exclusively in this case, when the energy of the final states are higher, the RT is preceded by an absorption of photons.

The detection experiments were done in an oblique incidence configuration to maximize the THz electric field perpendicular to the GLs and thus to maximize the RT transitions associated with the absorption of the THz photons. Figure 1(d) shows the tunneling current vs. DGL bias voltages for different gate biases under 1-THz photon irradiation at 300K. The photocurrent increases with increasing the DGL bias both positively and negatively. The increase of the DGL current in the positive (negative) DGL biases are induced by the RT associated with absorption (emission) of THz photons. The results show clear manifestation of the detection and emission of THz radiation.

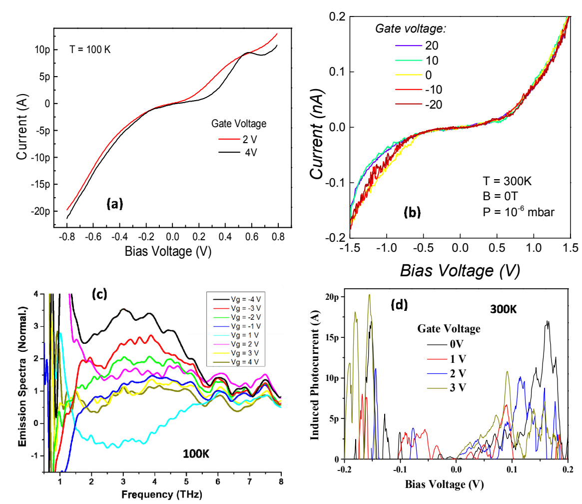

Fig. 1. Measured I-V curves of the fabricated devices at 100K (a) and 300K (b). Measured THz emission spectra at different gate bias voltages (c) and the measured tunneling current induced by the incoming THz beam at different gate bias voltages (d).

III. Summary

Double-graphene-layer based devices can exhibit advantages over the devices exploiting the intra-GL interband vertical radiative transitions proposed and analyzed previously [7-10]. These advantages are: (1) resonant voltage-tunable spectrum, (2) the possibility of operation in the frequency range between 2 and 10 THz (not accessible for quantum cascade lasers and quantum-well- and quantum-dot infrared PDs due to high absorption by the optical phonons), (3) the suppressed Drude absorption (due to the radiation polarization perpendicular to the GL plane), and (4) a lower dark current (due to its non-resonant tunneling nature).

References

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