# Resonant Emission and Detection of Terahertz Radiation from Double Graphene Layer Heterostructures

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## 1. Introduction

Double-graphene-layer (DGL) heterostructures have attracted attention due to their various potential applications in optical modulation, terahertz (THz) emission/detection, and THz photo-mixing [1] and many more. Here, we report on experimental observation of the THz emission and detection in the DGL structures and demonstrate that the photon-assisted resonant radiative inter-GL transitions enable the applications of such devices for THz lasers and photodetectors (PDs) [2].

## 2. Methodology

The fabricated devices consist of a thin h-BN tunnel-barrier sandwiched between two crystallographically aligned graphene layers. The bias voltage V applied between the GL's contacts induces the electron gas in one and hole gas in the other GL forming a DGL capacitor. The electron and hole densities in GLs are also controlled by the gate voltage Vg. The voltage-dependent band-offset energy (Δ) between the Dirac points of the GLs and the depolarization shift determine the energies of the photons emitted (in the lasers) or absorbed (in the PDs) in the resonant-tunneling inter-GL transitions[3, 4]. The tunneling causes all excess charges in the n-type GL to recombine with the holes in the p-type GL.

## 3. 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 for fabricated devices having rotation angle misalignment between two GLs of ~30 degree. Figure 1(a) exhibits a clear trace of NDC due to nonlinear inter-GL RT transitions at 100K. In order to observe the negative dynamic conductance (NDC) the two GLs have to be aligned so that their crystallographic axes are in parallel. When the NDC cannot be obtained but only thermionic positive conductance is obtained as seen in Figure 1(b), the tunneling process takes place in a non-resonant manner so that the photon-assisted tunneling may take place in a broadband nature to the incident photon energy. 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 and when the energy of the final states are higher, the RT is preceded by an absorption of photons. Figure 1(c) shows the measured spontaneous emission spectra at different gate bias voltages recorded by using fourier tranform far-IR spectrometer. 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 non-resonant tunneling associated with absorption (emission) of THz photons. The results show clear manifestation of the occurrence of detection and emission of the THz radiation in the DGL.

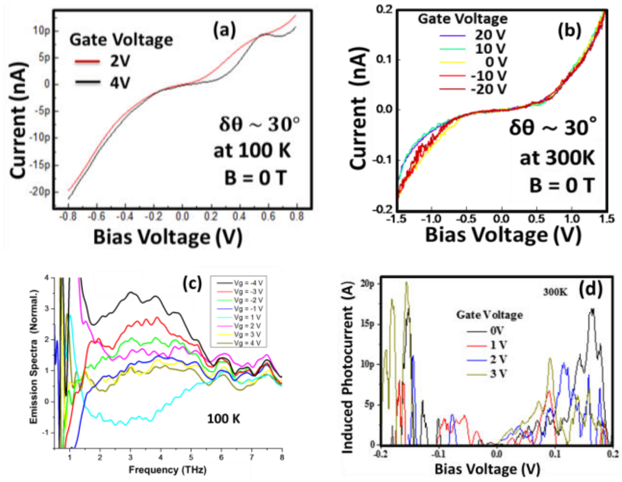


Figure 1. Measured I-V curves of fabricated devices at (a) 100 K and (b) at 300 K. Measured THz emission spectra at different gate bias voltages (c) and the measured tunneling current induced by the incoming THz beam at different gate bias voltages (d).

## 4. Conclusions

DGL devices based on the photon-assisted resonant radiative inter-GL transitions can be exploited to devise highly efficient THz lasers and PDs, with many advantages over the devices based on intra-GL interband radiative transitions proposed and analyzed previously.

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## References

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