Terahertz Emission and Detection in Graphene-Based van der Waals Heterostructures

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The terahertz (THz) frequency band of the electromagnetic spectrum, located between radio waves and light waves, offers many applications within non-invasive screening technologies and ultra-broadband communications. Some devices are capable of operating within this band, but due to limitations, there are no commercially viable devices that can operate across the THz range. Here, we investigate the gated double graphene layer heterostructure (G-DGL) for emission and detection of THz radiation by photon-assisted quantum mechanical resonant tunneling. To examine the phenomena, we use two different experimental setups. In our photo-detection setup, we use a uni-traveling-carrier photodiode (UTC-PD)-type photomixer to generate continuous THz waves at 0.3, 0.5, and 1.0 THz. The generated THz radiation is directed to the sample by an adjustable Indium Tin Oxide (ITO) mirror. By adjusting the angle of the ITO mirror, we alter the photonic and plasmonic responses in the G-DGL, and then measure the tunneling current. For the stimulated emission setup, we considered electro-optic sampling (EOS) of time-domain spectroscopy to optically pump G-DGL. To calibrate the EOS system, we first observed the stimulated THz emission in monolayer graphene using a CdTe crystal. A 1.55-μm, 80-fs pulsed laser pumps the graphene sample and CdTe crystal. The optically rectified CdTe generates a THz probe pulse along the Cherenkov angle and is reflected at the top surface of the CdTe back to the graphene sample. These results characterize the in-plane spatial distribution of the polarization-sensitive regions where the graphene plasmons are strongly excited for future G-DGL samples.

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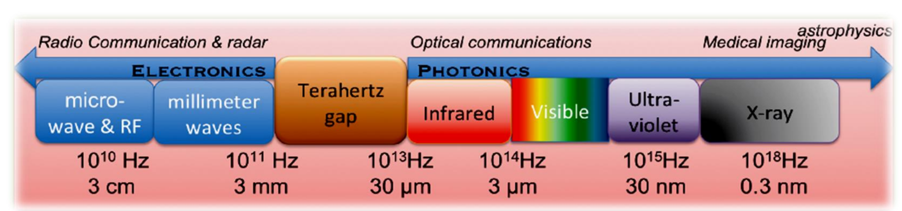
Introduction



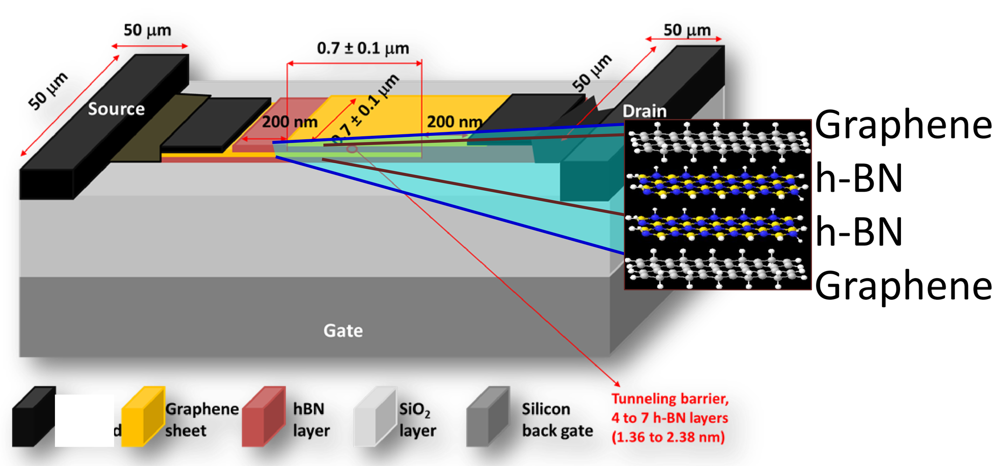
THz Applications
- Food screening
- Homeland security
- Ultra-Broadband Communications

Motivation: Current devices have operating limitations in the terahertz (THz) range.

Device

Gated Double Graphene Layer Heterostructure (G-DGL)[1,2]

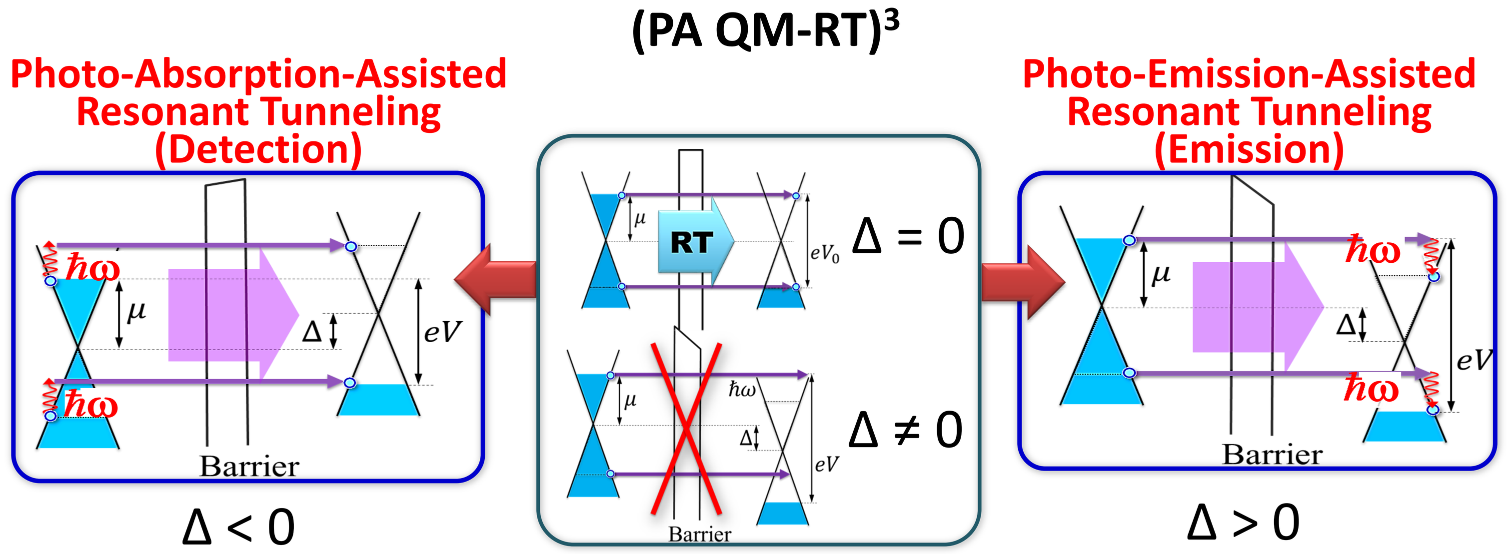
- DGL capacitor sandwiched between thin tunneling barrier h-BN.
- Fabricated on SiO_2 substrate.
- Si gate electrode tunes band offset for bottom graphene layer.

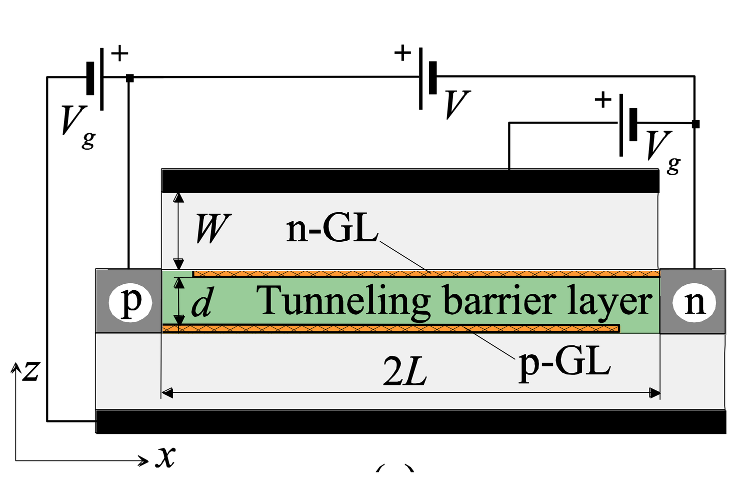


Goal: Observe terahertz emission and absorption in G-DGL heterostructures

Theory

Photon-Assisted Quantum Mechanical Resonant Tunneling (PA QM-RT)[3]



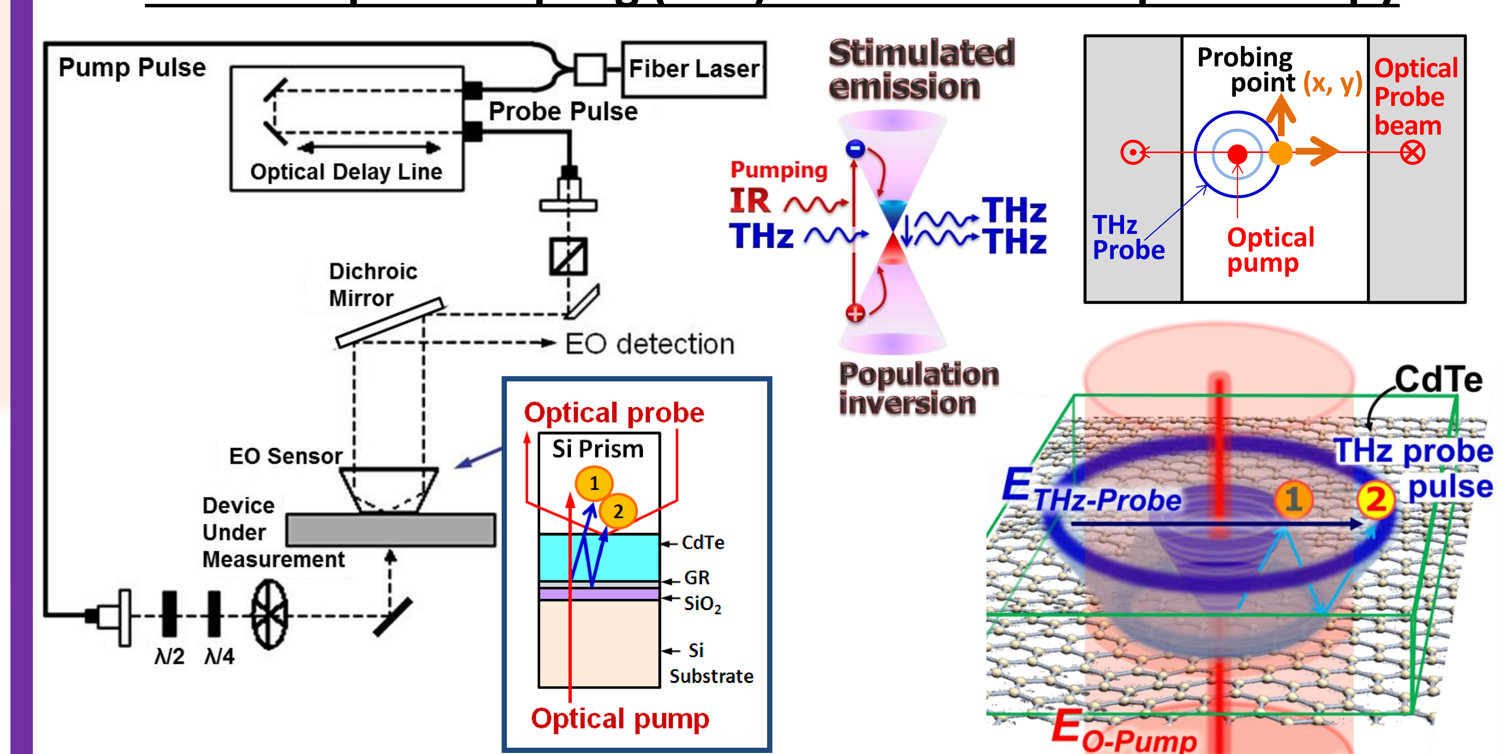


- DC bias V_g creates tunable band offset Δ.
- If Δ = 0, electrons tunnel through barrier by QM-RT.
- If Δ ≠ 0, electrons tunnel by emitting or absorbing photons (PA QM-RT).

Methods

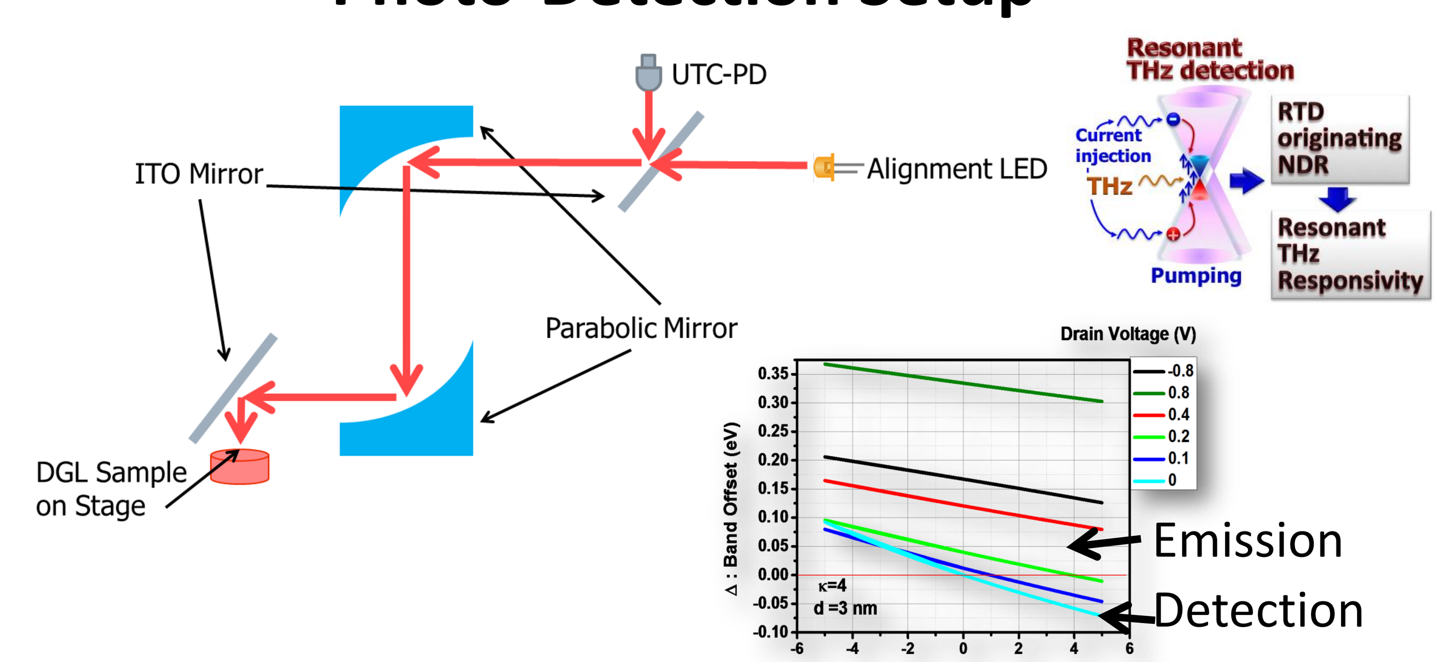
Stimulated Emission Setup[4,5,6,7]

Electro-Optic Sampling (EOS) Time-Resolved Spectroscopy



Procedure
1. Align laser path for pumping and probing.
2. Excite graphene with 1.55-µm, 80-fs pulsed laser.
3. Isolate primary and secondary THz pulse.

Photo-Detection Setup[1,3,4]



Procedure
1. ITO mirror near the DGL sample is tilted at a desired angle.
2. Gate bias V_g is applied to tune the band offset Δ and match the corresponding photon energy.
3. The uni-traveling-carrier photodiode (UTC-PD) emits a continuous THz wave that is absorbed by the sample when Δ < 0.
4. A range of drain biases is applied and the respective tunneling current is to be measured.

Results

EOS Mapping Results

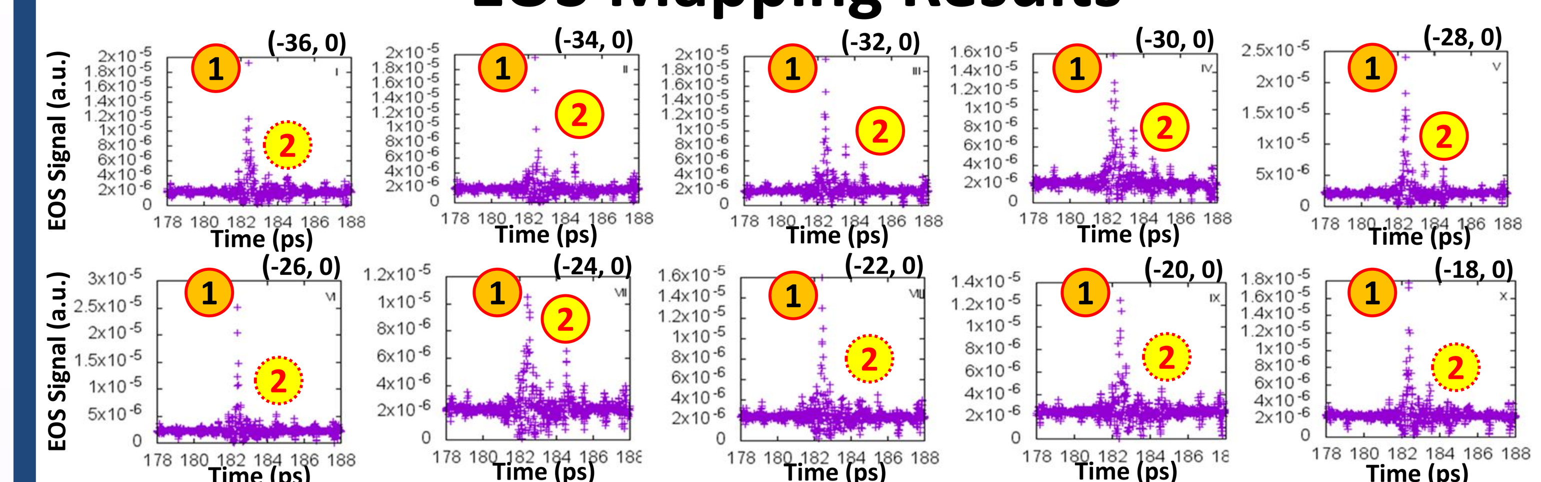
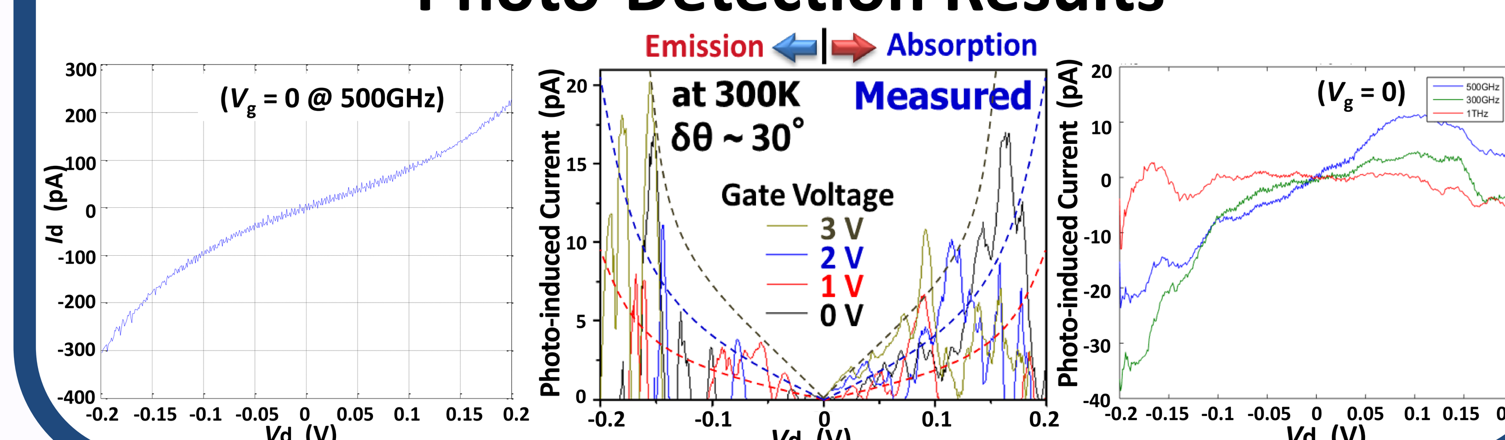


Photo-Detection Results



Conclusions

- We observed the primary and secondary THz pulse from EOS system at consistent positions.
- DGL has increasing photo-induced tunneling current for increasing drain biases for different gate voltages.
- The dependence of the photo-induced tunneling current on THz photon energy is yet to be interpreted.

Future Work

- Alter ITO mirror to observe the DGL photo-response at different angles.
- Improve signal-to-noise ratio on the EOS system.
- Measure stimulated emission from DGL sample.
- For both experiments, use DGL sample with 0° alignment for greatest THz response.

Citations

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Acknowledgements

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