Terahertz Emission and Detection in Graphene Based Heterostructures

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Electromagnetic waves with frequencies in the terahertz (THz) range have potential uses in imaging and ultrafast communication that would be safer, faster, and more accurate than current imaging and wireless communication technology. However, while many devices can operate in frequencies both smaller and larger than THz, it is currently difficult to achieve high power THz emission or sensitive THz detection. Therefore, we study the use of graphene as a THz emitter and detector. Specifically, we use two types of graphene samples: a distributed-feedback dual-gate graphene-channel field-effect transistor (DFB-DG-GFET) for emission and an asymmetrical dual-grated-gate graphene field-effect transistor (ADGG-GFET) for detection. For emission, we use Fourier transform infrared (FT-IR) spectroscopy, which consists of a cryostat containing the graphene sample, and a bolometer to detect the THz radiation. The graphene sample is first excited using current injection, and the carriers in population-inverted graphene can then recombine to emit THz photons. Previously observed single mode emission at 5.2 THz from a DFB-DG-FET suggests that this structure can be viably used as a THz laser. We try to reproduce these results and achieve better operation at higher temperatures. For the detection experiment, we use a uni-traveling carrier photodiode (UTC-PD) as a THz source and place the ADGG-GFET under THz radiation. Using a lock-in amplifier, we look for an increase in the sample's current as a signal of carrier excitation caused by THz radiation. We expect to see a strong photocurrent response, moving us closer to finding a graphene structure with optimal THz detection capabilities.

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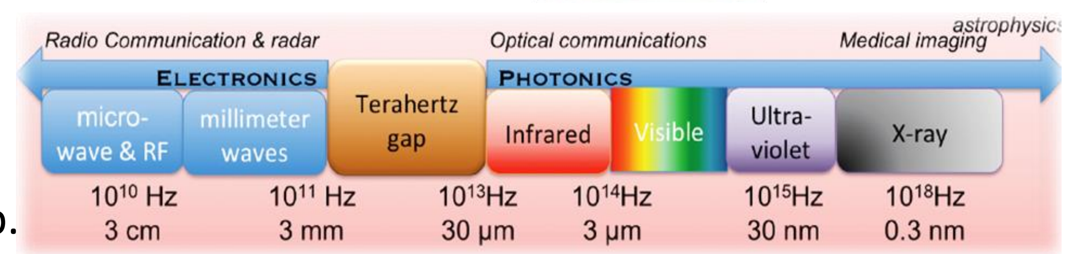
Introduction

- Terahertz (THz) is useful for medical imaging, ultrafast communication, and other technological advancements.
- However, because of "THz Gap," few devices that operate in the THz range.
- Graphene can be used as emitter and detector, bridging the THz gap.

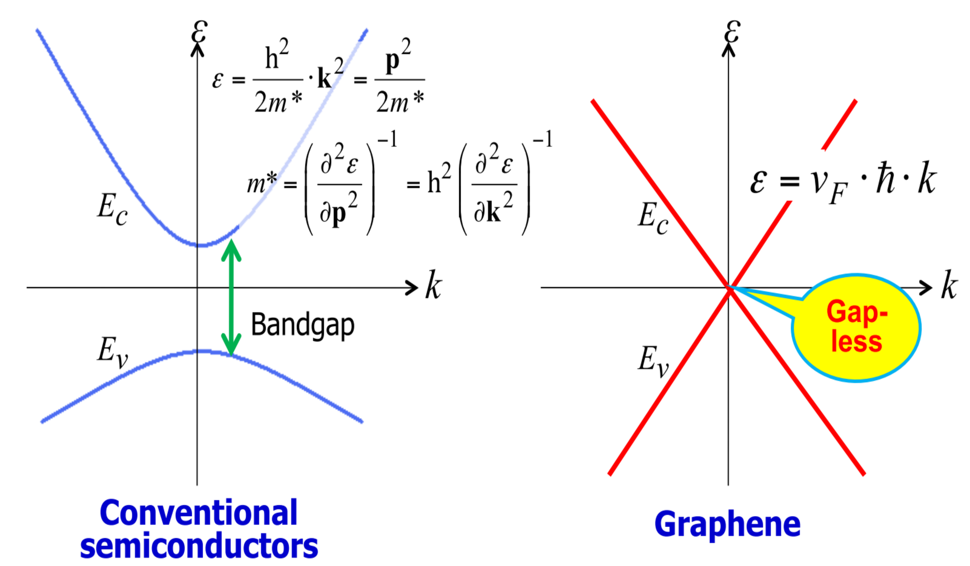
Examples of THz imaging



Purpose

- Study graphene structures viable for graphene-based THz lasers.
- Reproduce high intensity THz emission previously achieved with the proposed structure.
- Study the principles of graphene as a detector of THz radiation.

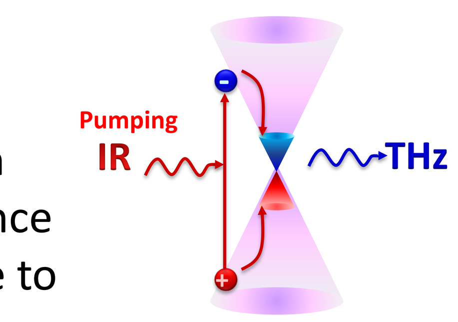
Graphene as a THz Device

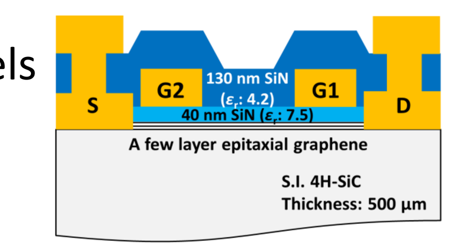


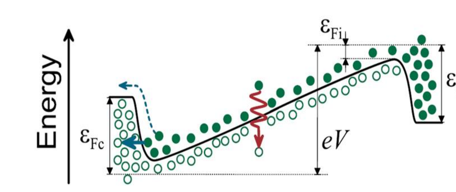
- Unique band structure allows for THz emission and detection.
- No bandgap, linear dispersion relation.
- High carrier mobility, >200,000 cm²/Vs at RT.

Emission

- Population inversion: electrons in conduction band and holes in valence band, which recombine to emit photons.
- No forbidden energy levels in graphene.
- Electrons can be excited to exact energy state (4.1 meV) needed for THz emission upon recombination.

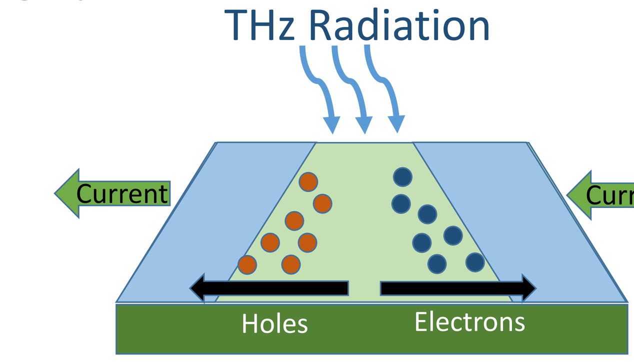






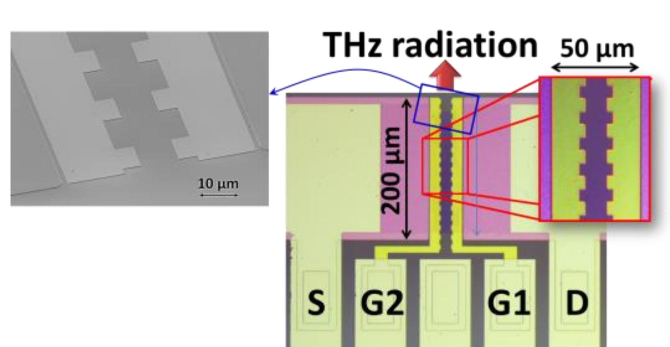
Detection

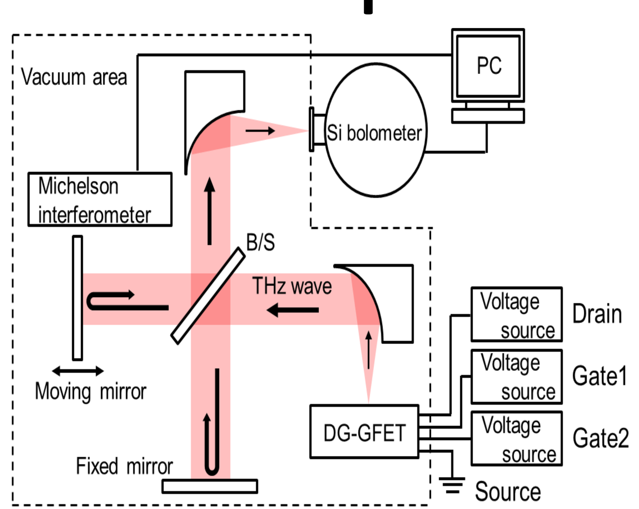
- Since electrons have such a high mobility, it is easy to excite them enough to produce a current, even with low power THz radiation.
- THz can be detected by photothermoelectric or photovoltaic effect in graphene.



THz Emission Experimental Setup

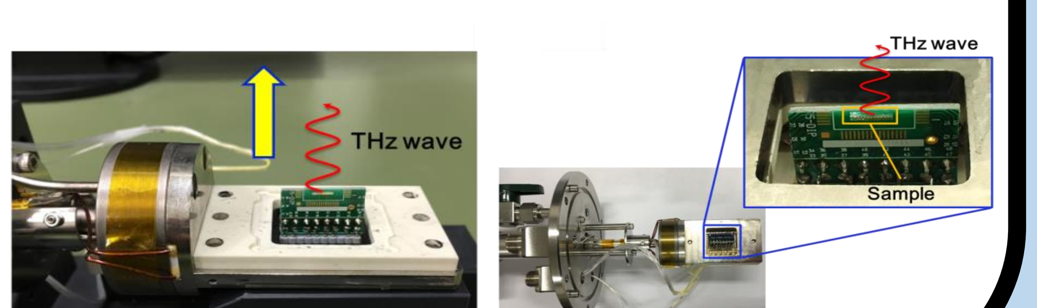
- Distributed-feedback dual-gate graphene-channel field-effect transistor (DFB-DG-GFET) as a THz emission device.
- DFB structure is used to get intense single mode THz emission.





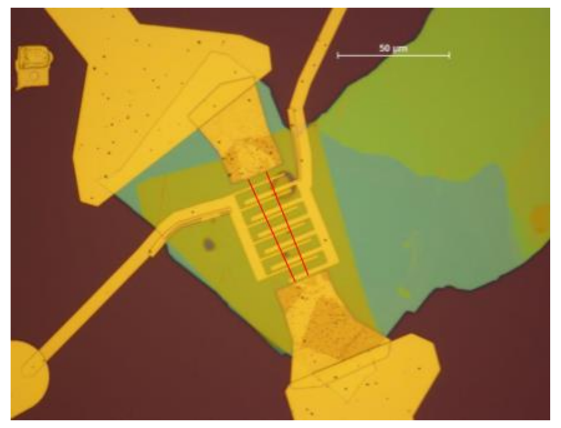
- Fourier Transform Infrared (FT-IR) spectrometer, in which THz emission is detected using a 4.2 K cooled Si-bolometer and analyzed with a Fourier transform.

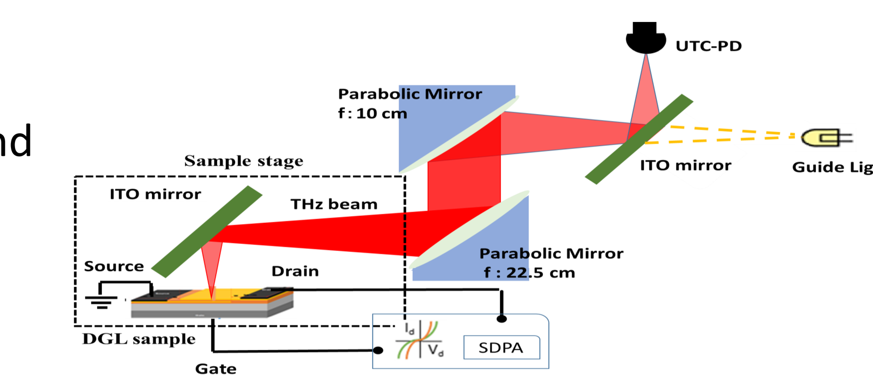
- Electrons excited using current injection.
- After achieving population inversion, carriers then recombine to emit THz photons.
- Graphene sample cooled to 100 K to reduce noise from thermal emission.
- Gate voltages set to induce equal amount of electron and hole carriers.



THz Detection Experimental Setup

- Asymmetrical dual-grated-gate graphene field-effect transistor (ADGG-GFET) used as a broadband THz detector.
- Grated gates create plasmonic regions useful for THz detection.





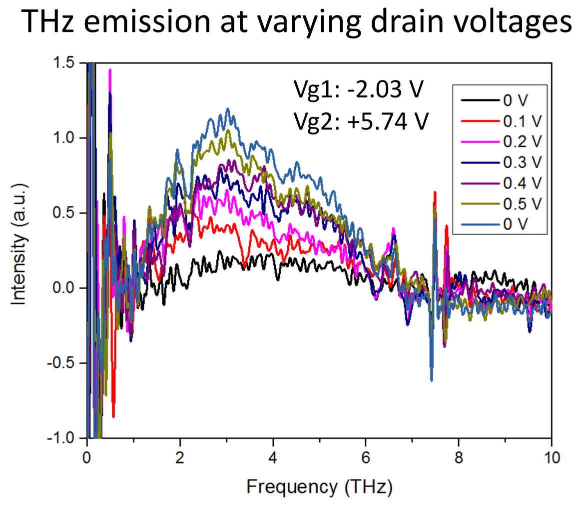
- THz radiation comes from a uni-travelling carrier photodiode (UTC-PD) and travels through a series of mirrors before falling on the sample.

- THz radiation excites carriers enough to create a current.
- A lock-in amplifier is used to measure the current, checking for a response caused by THz radiation.
- Bias voltage and current are kept low to enable easier detection of THz induced current.

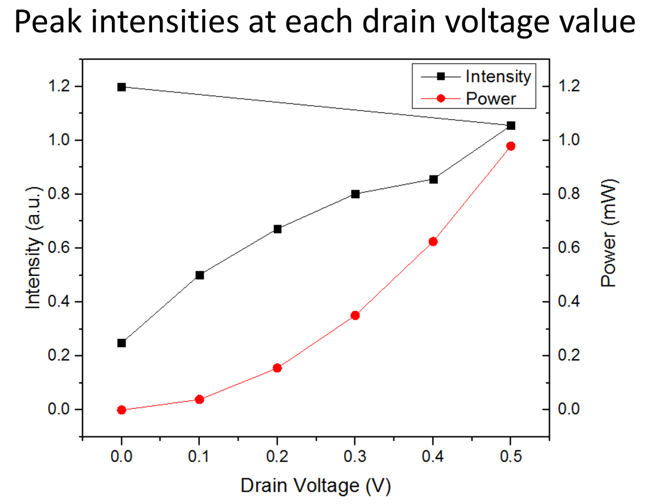
Results

Sample 1

THz emission at varying drain voltages



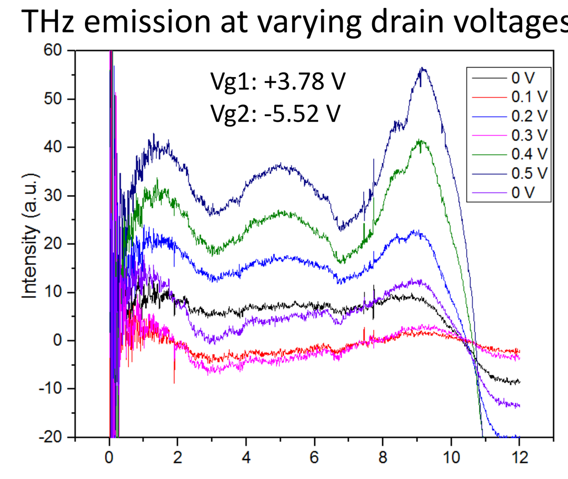
Peak intensities at each drain voltage value



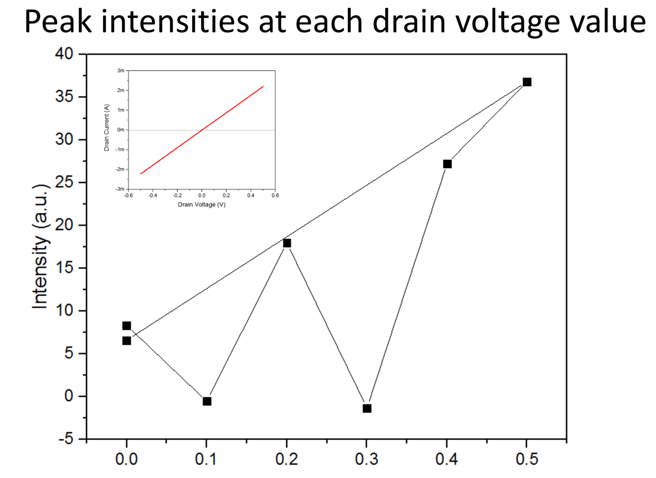
- One sample showed increasing THz emission as its drain voltages were increased, but the THz emission continued to increase even after the drain voltage was set to 0 V.
- Since the emission increased with time as the sample heated up, and was not affected by the reduction in drain voltage, this sample's detected emission was only black body radiation.

Sample 2

THz emission at varying drain voltages



Peak intensities at each drain voltage value



- The second sample showed strong THz emission that had an increasing trend with increasing drain voltage.
- While the slope is not always positive, the trend is increasing with voltage and clearly decreases when the voltage is zero.

Conclusion

- Observed THz emission that increased with increasing bias voltage.
- Observed broadband THz emission with 4 to 6 THz peaking.
- Since emission decreased at zero bias, emission was in fact due to current injection pumping and not just thermal radiation.

Future Work

- Achieve stronger emission in narrow frequency range, working toward the creation of single mode THz emitting GFETs.
- Study broadband THz emission from ADGG-GFET samples.
- Modify GFET structure for stronger THz detection response by employing antenna couplers.

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Acknowledgements

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