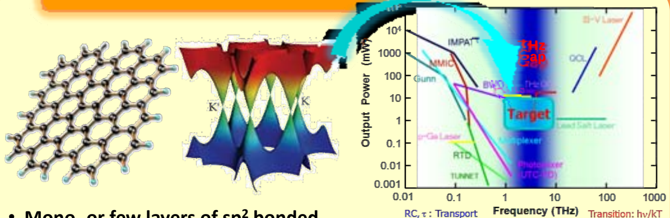
Observation of Terahertz Stimulated Emission of Radiation from Optically Pumped Graphene

Silvia H. Chan[1,2], Stephane Boubanga-Tombet[2], Amine El Moutaouakil[2], Akira Satou[2], and Taiichi Otsuji[2]

[1]NanoJapan Program, Rice University and Department of Materials Science & Engineering, University of Pennsylvania

[2]Research Institute of Electrical Communication, Tohoku University, Sendai, Japan

What's Graphene?



- Mono- or few layers of sp^2 bonded carbon atoms in a honeycomb lattice.
- Massless Dirac Fermions obey linear dispersion relation at K & K' points.
- High carrier mobility of $2 \times 10^5 cm^2/Vs$ at RT. [1]

Due to its unique transport properties, graphene is suitable for implementation in photonic devices.

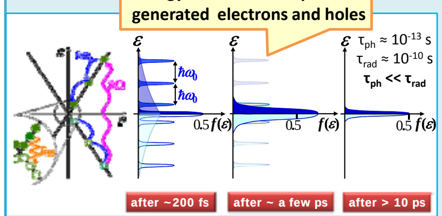
Objective

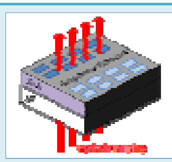
To stimulate terahertz (THz) emission by implementing electro-optic sampling (EOS) time-resolved spectroscopy to optically pump and THz probe exfoliated graphene ribbons (GR) on SiO_2 sample.

Theory

Non-equilibrium Carrier Dynamics in Optically Pumped Graphene[2]

Energy distribution of photo-generated electrons and holes





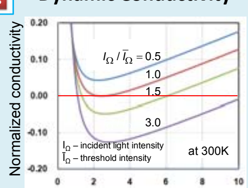
Optical pumping: ħΩ

Optical phonon emission: $\hbar\omega_o$, τ_{ph}

Radiative recombination: ħω, τ_{rad}

=> THz emission

Non-equilibrium Negative Dynamic Conductivity



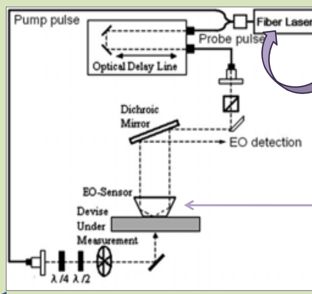
Electrons and holes relax and accumulate near the Dirac point. Due to graphene's negative dynamic conductivity in THz range, population inversion can be achieved for stimulated emission of THz lasing.

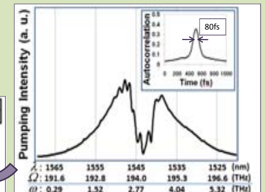
Setup & Method

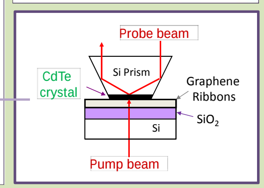
1 Setup Laser Pathway for Pumping and Probing

Pump & Probe Pulses:
1.5µm, 80fs, 2mW

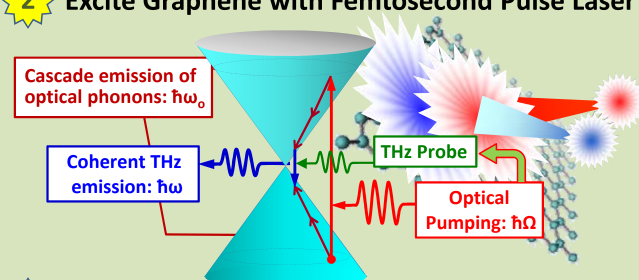
Bandwidth: ~7THz



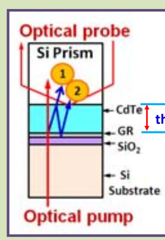


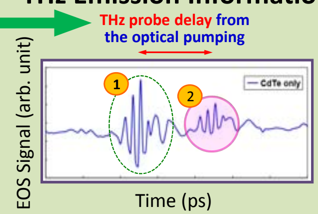


2 Excite Graphene with Femtosecond Pulse Laser



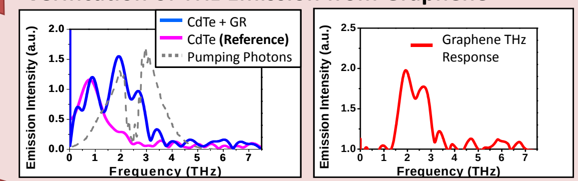
3 Isolate Graphene Response Peak & FFT to Obtain THz Emission Information



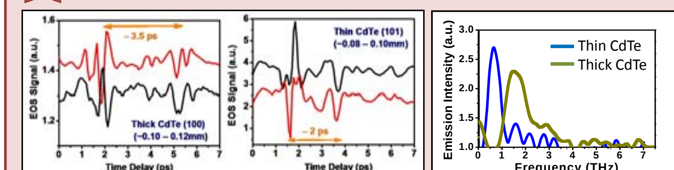


Results

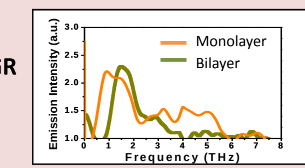
1 Verification of THz Emission from Graphene



2 THz Emission Dependence on CdTe Crystal Thickness



3 THz Emission from Monolayer vs. Bilayer GR



Conclusions

- **THz coherent emission was successfully observed** in optically pumped graphene.
- **Thinner CdTe gives rise to an emission spectra shifted to lower frequencies compared to those of the thicker CdTe.** This discrepancy might be attributed to the usage of a different crystal orientation.
- **The emission spectra of monolayer GR was found to be broader than those of bilayer GR.** The parabolic band structure of bilayer GR accelerate relaxation dynamics and gives rise to narrow spectra at lower frequencies.

Future Work

- Use the (100) crystal orientation CdTe of varying thicknesses to see the effects on the THz spectrum.
- Excite plain exfoliated graphene to verify the effect of plasmonic absorption of THz in GR sample.

Acknowledgements

Research conducted at Otsuji Laboratory of Tohoku University as a participant of the NanoJapan 2010 program, sponsored by Rice University and the NSF-PIRE Grant. http://nanojapan.rice.edu

References

1. S.V. Morozov et al. PRB 100, 016602 (2008)
2. V. Ryzhii, M. Ryzhii, T. Otsuji, J. Appl. Phys. 101, 083114 (2007)

This material is based upon work supported by the National Science Foundation under Grant No. OISE-0530220.