Enhanced terahertz emission from monolayer graphene with metal mesh structure

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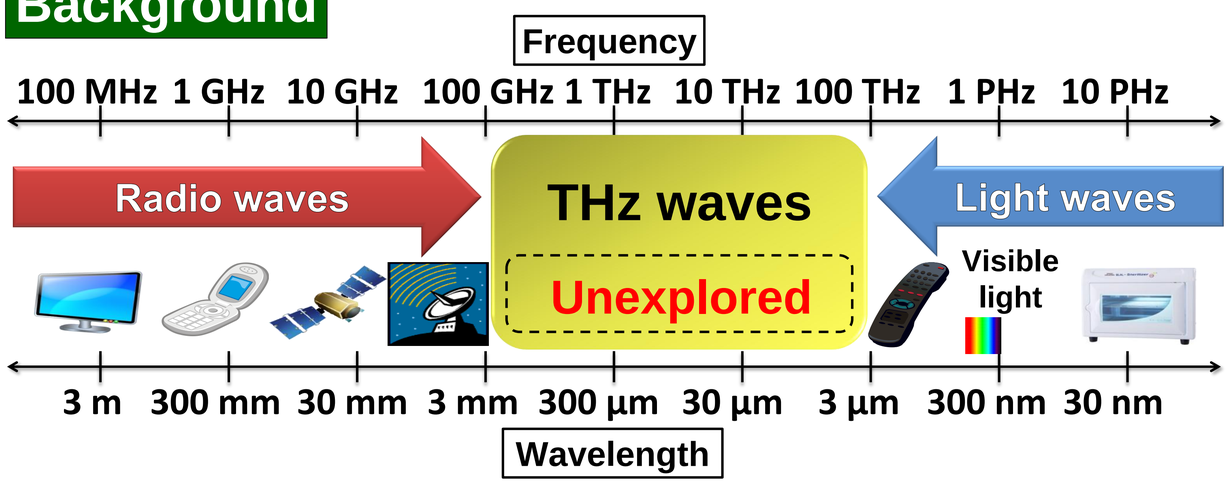
Background



Terahertz gap

1. Maximum operating frequency of electronic devices:
   ➡ Limited by electron velocity
2. Minimum operating frequency of optical devices:
   ➡ Restricted by thermal noise at room temperature

We are currently developing THz devices by using a novel operating principle

Operation principle

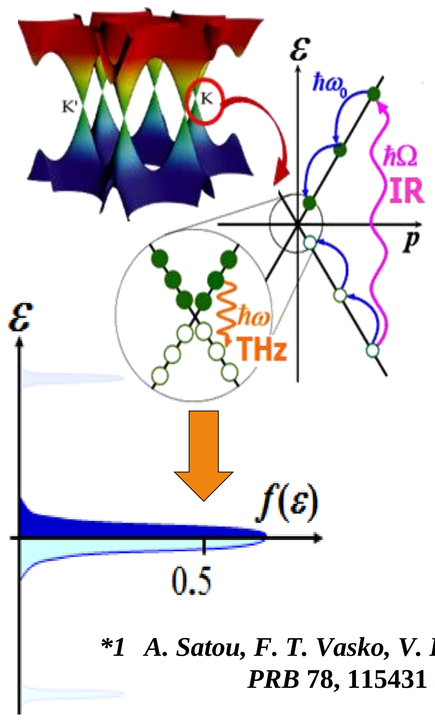
Photo-excited graphene

Irradiation of graphene with infrared laser

Formation of population inversion from generated electron-hole pairs

Emission of THz waves by recombination

Amplification of 1-10 THz waves

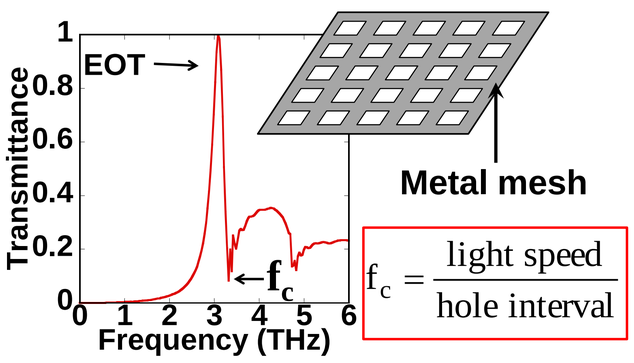


**1 A. Satou, F. T. Vasko, V. Ryzhii, PRB 78, 115431 (2008)*

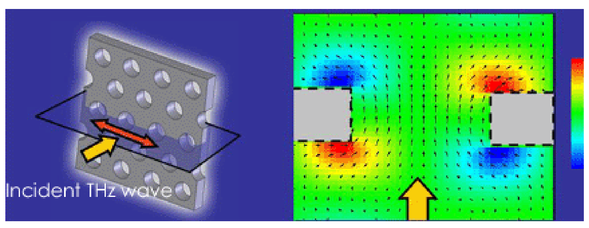
Metal mesh structure

- Extraordinary optical transmission (EOT)
- Field enhancement effect caused by spoof surface plasmon polaritons (SPPs)

Transmission characteristics of metal mesh structure



Field enhancement effect due to SPPs[*2]



**2 Optical Physics Laboratory, Department of Physics, Faculty of Science, Shinshu University.*

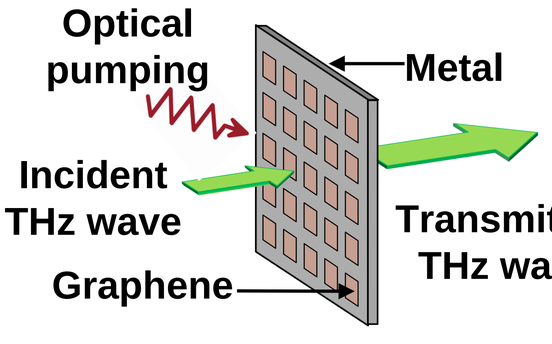
Purpose

Concept of THz amplifier

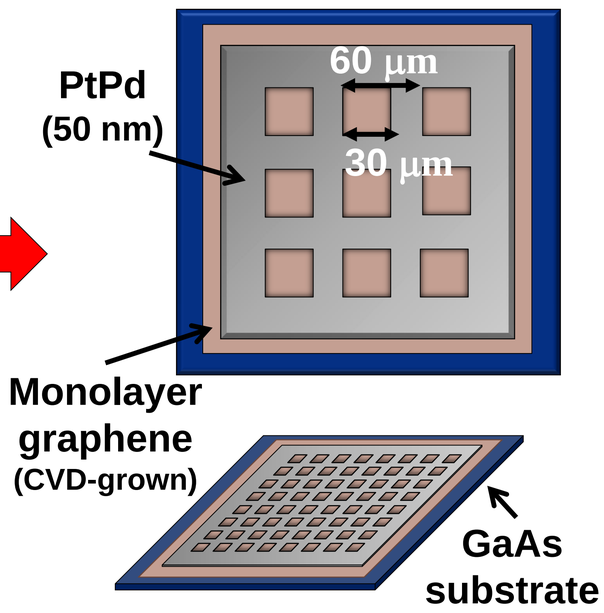
Graphene (THz wave gain medium)

+

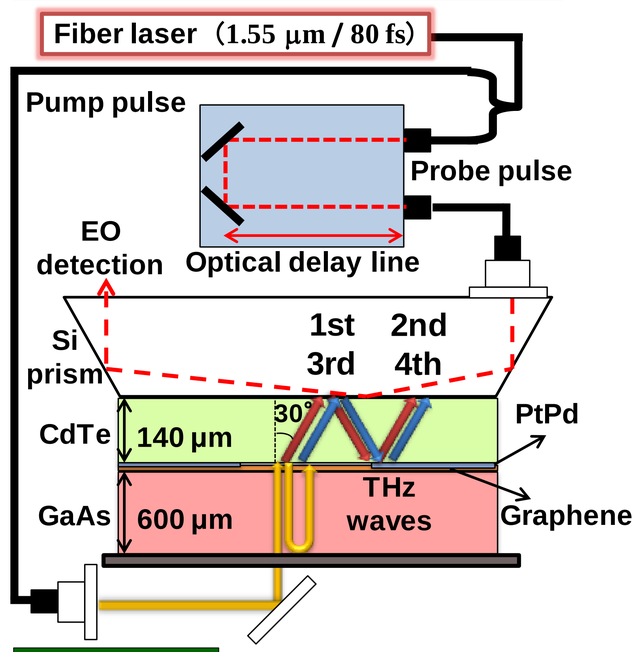
Metal mesh structure (Field enhancement & EOT)



Prototype THz amplifier (GaAs + Metal + Graphene)



Measurement system



Reflective Electro-Optic Sampling

➢ **Pump pulse**

✓ Photoexciting the sample and CdTe crystal

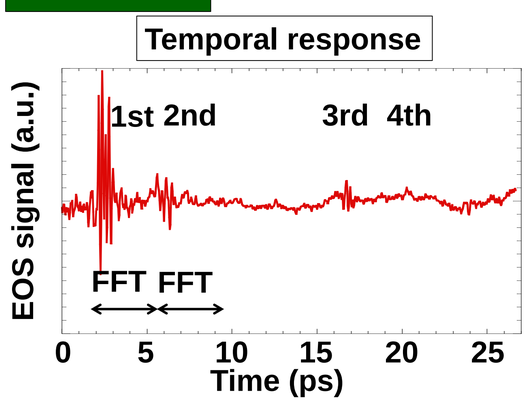
✓ Generating THz waves in GaAs substrate and CdTe crystal by optical rectification

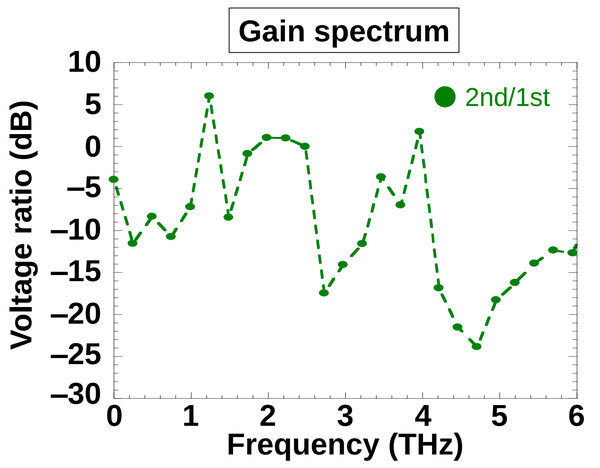
➢ **Probe pulse**

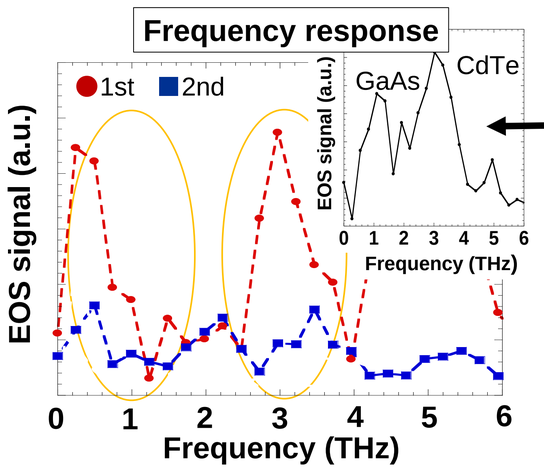
Sensing electric field by electro-optic crystal (refractive index change due to electric field)

Results

GaAs + Graphene



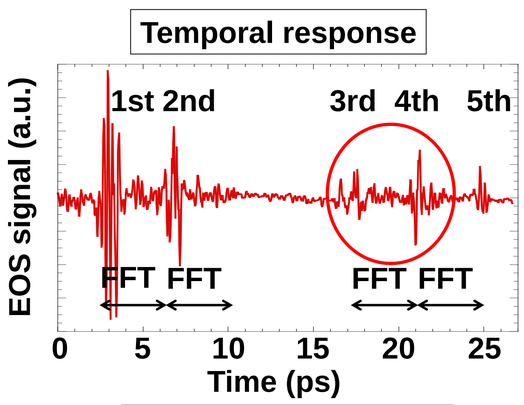


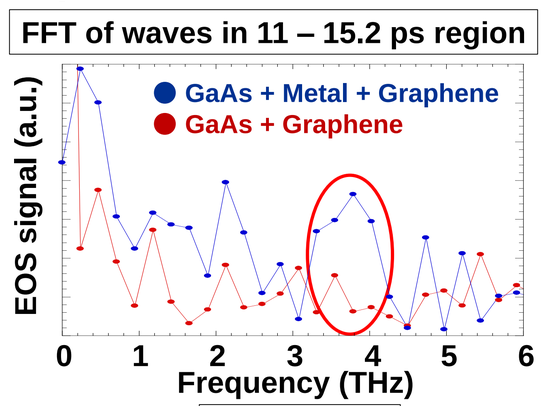


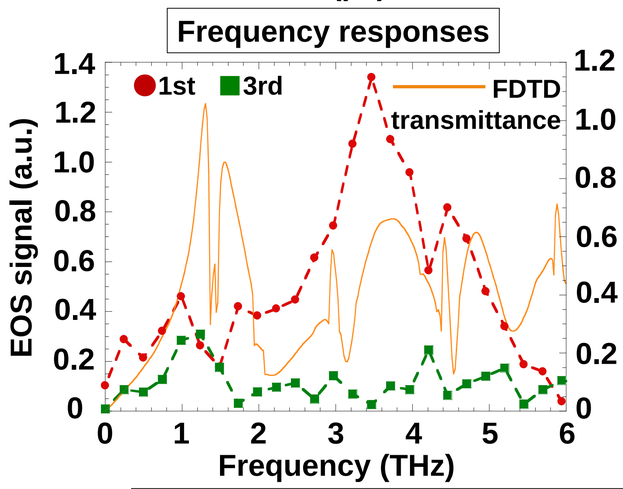
Spectrum of THz waves generated in GaAs and CdTe crystals

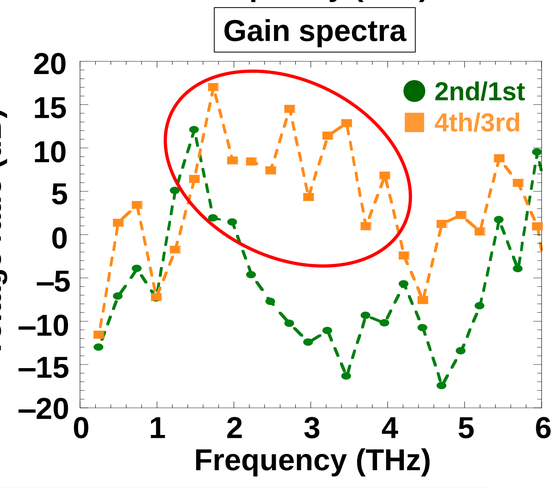
- 1st wave was similar to THz waves generated in GaAs and CdTe crystals
- 3rd and 4th waves were hardly observed
- Amplification was not achieved

GaAs + Metal + Graphene









- Despite the same reflection process as the 1st and 2nd waves, the 4th wave was significantly increased
- Gain in the 1.5 – 4 THz region

These observations suggest (1) the presence of population inversion in graphene, (2) field enhancement due to SPPs (buildup time: several picosec), and (3) Bragg radiation.

Conclusion

✓ Significantly enhanced 1.5 – 4 THz emission from graphene/metal mesh structure

✓ The combined effect of population inversion in graphene and field enhancement due to SPPs enables the amplification of THz waves

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