Terahertz sensing and imaging based on carbon nanotubes: frequency-selective detection and near-field imaging

(Yukio Kawano)

Abstract :

The advantageous properties of terahertz (THz) waves - permeability through objects opaque for visible light, the important energy spectrum in the meV range, etc. - potentially enable various applications of sensing and imaging in this band. Low-dimensional electronic structures open up novel THz technologies, such as quantum cascade laser and THz time-domain spectroscopy.

In this work, by employing a carbon nanotube (CNT) and a GaAs/AlGaAs heterostructure, we have succeeded in developing a new type of THz sensing and imaging devices: a frequency-selective THz detector and a near-field THz imaging probe. Moreover, as an application of THz imaging to materials science research, we have achieved electron density mapping for each Landau level in a two-dimensional electron system by the use of simultaneous imaging of THz radiation and voltage. I will present the following three topics: (1) detector, (2) imaging, and (3) application of imaging.

(1) THz photon-assisted tunneling in a carbon nanotube quantum dot

In order to achieve ultra-highly sensitive and frequency-selective THz detection, we have studied THz response of CNT quantum dots (QDs). A charging energy of the CNT-QD is typically as large as 10-50meV, which corresponds to a THz frequency. This advantageous property has allowed us to observe a photon-assisted tunnelling in the THz region, whose frequency is two or three magnitudes higher than the microwave (GHz) frequency, previously observed for conventional semiconductor QDs.

We have observed THz-induced currents, whose peak position relative to a gate voltage linearly depends on THz photon energy[1]. This provides direct evidence of THz photon-assisted tunneling in the CNT-QD.

(2) On-chip near-field THz imaging probe integrated with a detector

Contrary to the well-established, other frequency regions, the development of near-field imaging technique in the THz region has been hindered by the lack of high transmission wave line and the low sensitivity of the commonly used detector. This issue is therefore one of the most formidable and challenging tasks of contemporary photonics research. Here, we present a new designed THz near-field imaging device, in which all components: an aperture, a probe, and a THz detector are integrated on one GaAs/AlGaAs heterostructure chip[2]. The development of this device has made it possible to sense the evanescent field very efficiently and to avoid the influence of the far-field wave, which was not possible with other previous systems.

(3) Simultaneous imaging of THz radiation and voltage in a 2D electron system

We have developed a tunable and highly sensitive THz detector[3] and a scanning electrometer[4,5] based on quantum Hall effect (QHE) devices. Using the two sensing devices, we have constructed a combined system of THz microscope[6,7] and electrometer, which can work in a cryogenic and strong magnetic field environment. With this unique microscope, we have been able to map simultaneously spatial distributions of THz cyclotron emission and voltage in another QHE sample. Comparing the mapped data of the emission intensity and the voltage has enabled us to investigate separately spatial distributions of ground-state electrons and excited-state electrons in Landau levels[8]. The resulting data clearly reveal that the two distributions are strikingly different. This indicates substantial differences in the scattering processes involved and in their characteristic length scale.

[1] Y. Kawano *et al.*, J. Appl. Phys., in press.

[2] Y. Kawano *et al.*, submitted.

[3] Y. Kawano *et al.*, J. Appl. Phys. **89**, 4037 (2001).

[4] Y. Kawano *et al.*, Appl. Phys. Lett. **84**, 1111 (2004).

[5] Y. Kawano *et al.*, Appl. Phys. Lett. **87**, 252108 (2005).

[6] Y. Kawano *et al.*, Phys. Rev. B **68**, 085328 (2003).

[7] Y. Kawano *et al.*, Phys. Rev. Lett. **95**, 166801 (2005).

[8] Y. Kawano *et al.*, Phys. Rev. B (Rapid Commun.) **70**, 081308(R) (2004).