Highly sensitive and frequency-tunable THz detector using carbon nanotube quantum dots

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Abstract—**We have developed a new type of THz detector using carbon nanotube quantum dots. We found that THz illumination generates new-side currents, whose peak position linearly depends on the THz-photon energy. This observation leads to highly sensitive and frequency-tunable detection of THz photons.**

I. Introduction And Background

A highly sensitive and frequency-tunable detector in the terahertz (THz) range is in strong demand in various research fields, such as radio astronomy, biochemical spectroscopy, medicine, and solid-state physics. Nevertheless, the photon energy of the THz wave, typically ~10 meV, is two to three magnitudes lower than that of the visible light, thus making the development of a high-performance THz detector a difficult task. Recent progress in the fabrication of nanoscale devices, however, opens up a new possibility of significantly enhancing detector performance. Here, we experimentally present a novel THz detector using photon-assisted tunneling (PAT) in carbon nanotube quantum dots (CNT-QDs)[1]. This sensing mechanism has allowed us to achieve highly sensitive and frequency-tunable detection of THz photons.

II. Results

The right inset of Fig. 1 displays the schematic drawing of the device structure. Single-wall CNTs, placed on a GaAs/AlGaAs heterostructure chip, have source and drain electrodes made from Ti/Au films. The CNT-QD devices were immersed into a ^{4}He cryostat and single-electron transport measurements were performed at 1.5 K without and with THz irradiation.

Figure 1 shows that THz irradiation causes an appearance of new-side peaks in the Coulomb blockade regime, and that the energy spacing between the new-side peaks and the original peaks is proportional to the photon energy of the incident THz wave in the range of 1.4-4.2 THz. These observations provide direct evidence of THz photon-assisted tunneling. This result means that the CNT-QDs can be utilized as a frequency-tunable THz detector. We observed that the CNT-QD detector functions at 4K properly, which are inaccessible via earlier THz detectors using GaAs- and Aluminum-based QDs. This shows that our device can be used in a liquid-He-free, Gifford-McMahon type or pulse-tube type compact refrigerator, allowing a wide range of practical uses. We expect that higher-temperature operation (~30K) would be possible thanks to large single electron charging energy (~50meV) of the CNT-QD.

As the next step, we are currently trying to improve detector performance in the following three points: (i) *Sensitivity*: A much more sensitive readout of the PAT signal could be achieved by capacitively coupling a CNT-QD with a quantum point contact device on a GaAs/AlGaAs heterostructure[2], which makes it possible to observe a single electron dynamics[3]. (ii) *Frequency selectivity*: Its improvement would be realized by using a double-coupled CNT-QD, in which the PAT takes place as a result of electron transitions between two well-defined discrete levels. (iii) *THz camera*: When many CNT-QDs are arrayed in two-dimensional configuration[4], it provides the interesting possibility of a THz "camera" for real-time imaging.

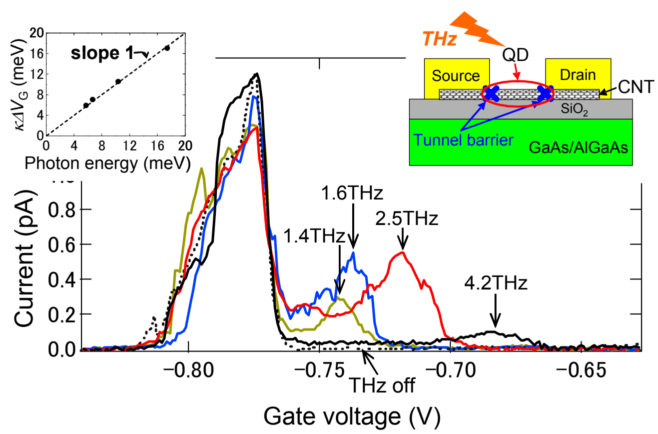

Fig. 1. ***Source-drain current versus gate voltage observed without and with the THz irradiation. The left inset shows the energy spacing, $\kappa\Delta V_G$, between the original peaks and the side peaks as a function of the photon energy of the THz wave. The right inset illustrates device structure of a carbon nanotbue quantum dot.***

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978-1-4244-2120-6/08/$25.00 ©IEEE.