

# 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  $\sim 10$  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)<sup>1</sup>. This sensing mechanism has allowed us to achieve highly sensitive and frequency-tunable detection of THz photons.

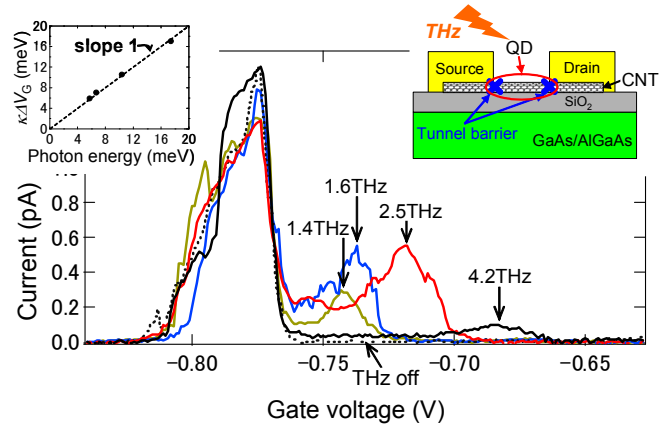
## II. RESULTS

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 <sup>4</sup>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 ( $\sim 30$ K) would be possible thanks to large single electron charging energy ( $\sim 50$ meV) 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<sup>2</sup>, which makes it possible to observe a single electron dynamics<sup>3</sup>. (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<sup>4</sup>, 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,  $k\Delta V_G$ , 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 nanotube quantum dot.**

## REFERENCES

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