Design and Performance of the Terahertz Photon Counting System: Detectors and Cryogenics

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***Abstract*— Development of a Terahertz photon counting system is ongoing. Among various components, this presentation will describe the detector device and the cryogenic system. The detector is designed for lab experiments with relatively narrow bandwidth. Low leakage SIS junction, which forms a PCTJ, is integrated as an antenna coupled photon detector. Two compact helium-4 sorption fridges are integrated into a cryostat with a pulse tube cooler, to provide continuous cooling to 0.8 K by altering their cool-down operation.**

Keywords*— Superconducting tunnel junction, Terahertz detector, Photon counting, Cryogenics, Sorption fridge

I. Introduction

Fast detectors sensitive to Terahertz photons may have wide range of applications, including those for observations of astronomy and astrophysics. In general, photon counting detectors will realize high sensitivity by resolving each photon arrivals. Fast photon detectors may also be used for high-precision measurements to study the physical condition of the sources by evaluating the photon statistics.

II. Developments

We are developing a detector system for photon counting experiments at terahertz frequencies. SIS junction (or STJ) is a good candidate as a device for fast photon detection. In order to realize the photon counting capability at Terahertz frequencies, low noise equivalent power (NEP) at the order of $10^{-17}\ \mathrm{W}/\sqrt{\mathrm{Hz}}$ is required. Recently we have developed an antenna coupled detector with SIS junctions (or STJs) of Nb/Al/AlOx/Al/Nb, which exhibit low leakage current of 2 pA at a cryogenic temperature of $T \leq 0.8\ \mathrm{K}$ [1]. The SIS junction is 3 μm × 3 μm in size with critical current density of $J_\mathrm{c} = 300\ \mathrm{A/cm^2}$. While wide bandwidth is preferable to realize high sensitivities for astronomical observations, the fabricated detector is designed to have a relatively narrow bandwidth for lab experiment purposes, in order to limit the contribution of the background photons. Two SIS junctions form a PCTJ (parallel connected twin junction) which is designed for 500 GHz, and connected to a twin-slot antenna [2]. The detector was processed at the CRAVITY facility [3] at National Institute of Advanced Industrial Science and Technology (AIST). Detector improvement studies are undergoing; so far we have realized a detector with center frequency of 530 GHz with an improved sensitivity.

The cryogenic system is also being developed. The system is designed to realize a cryogenic environment of 0.8 K, where the detector exhibits the low leakage current. We have developed a compact helium-4 sorption fridge [4], which can operate with less heat load per cool-down cycle to the condensation temperature stage. Two sorption fridges are prepared to alternate their operation, in order to realize continuous cooling to 0.8 K. Recently, the performance of the sorption fridge itself was studied; a single sorption fridge of this design exhibited a hold time of approximately 3 hours, which was shorter than its cycle time of approximately 40 minutes [5]. Following these developments, we are now integrating the sorption fridge into a cryogenic system. The cryostat is cooled with a pulse tube cooler to 3-4 K, which is the condensation temperature of the sorption fridge. So far the initial design of the cryostat has been completed, and integration and evaluation are ongoing.

The design and performance of the detector and cryogenics will be discussed in the presentation. Studies for optics and cryogenic readout circuits are also ongoing, which will be discussed in another presentation.

References

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