Design and Evaluation of SIS Photon Detectors at Terahertz Frequencies

Hajime Ezawa[1,2], Hiroshi Matsuo[1,2], Masahiro Ukibe[3], Go Fujii[3], and Shigetomo Shiki[3]

Demands for better sensitivity and higher angular resolution are increasing in observational astronomy and astrophysics. ALMA has successfully revealed its high observation capability among millimeter and submillimeter wavelengths, which includes detection of high redsifted [OIII] 88 μm emission line from distant galaxies, or resolving the detailed structure of proto-planetary disks. Photon counting detectors would be one of the next generation technologies for high sensitivity terahertz observation. Fast detectors may resolve each photons to realize high signal to noise ratio. Moreover, they will enable us to introduce "photon statistics" to terahertz astronomy to realize high precision measurements [1].

We are considering SIS junctions with low leakage current to be integrated into photon counting detectors at terahertz frequencies. The requirements to the SIS junction to realize photon counting capability has been discussed recently [2]. When we consider to observe an astronomical source of 1 Jy through a 10 m telescope at 1 THz with 100 GHz bandwidth, the photon rate is expected to be in the order of 100 M photons/s. In order to resolve these photons, the detector should be as fast as 1 GHz with the noise equivalent power (NEP) of < 3×10^{-17} $\mathrm{W}/\sqrt{\mathrm{Hz}}$. When the SIS junction operates in photon-assisted tunneling mode, this NEP requirement can be achieved with leakage current of 1 pA (assuming η =0.5).

Recently we have successfully developed an SIS junction with Nb/Al/AlOx/Al/Nb which exhibits its leakage current as low as 1 pA at a cryogenic temperature of $T \leq 0.7$ K. The junction was developed using the CRAVITY facility in AIST [3]. Following the success, we have integrated this junction into an antenna coupled SIS detector, in order to realize photon counting experiments in the lab. The detector consists of a twin slot antenna which feeds the RF signal into the SIS junction through a coplanar wave guide. The photo-current from the SIS junction will be fed to the first-stage readout circuit (FET) through a choke filter which suppresses the RF signal. The SIS is designed as a parallel connected twin junction (PCTJ) in order to match its impedance with that of the coplanar wave guide. The detector design is tuned for lab experiments: The antenna is optimized for 500 GHz, and the critical current density of the SIS junction is designed to be 300 A/cm^2. This design aims for relatively narrow bandwidth to limit the contribution of background photons in lab experiments.

The designed SIS detector was fabricated at CRAVITY, and its evaluation is undergoing. The temperature dependence of the leakage current was evaluated utilizing a ^{3}He-^{4}He sorption cooler, to confirm the low leakage feature of 1-2 pA at T < 0.7 K. The photo-response will be evaluated with the Fourier Transform Spectrometer.

Considering the system design, we are planning to utilize a ^{4}He sorption cooler, which exhibits a larger cooling capacity compared with ^{3}He based sorption fridges. This allows us to locate the first-stage FET adjacent to the SIS detector on the cryogenic stage. For this purpose we are tuning the SIS junction for higher operation temperature to exhibit low leakage current even at $T \geq 0.8$ K.

The concept of the detection system, as well as the design and performance of the developed detector will be discussed in the presentation.

References

[1] H. Matsuo, J. Low Temp. Phys. 167, 840-845 (2012), DOI: 10.1007/s10909-012-0579-6.

[2] H. Ezawa, H. Matsuo, M. Ukibe, G. Fujii, S. Shiki, J. Low Temp. Phys. 184, 244-249 (2016), DOI: 10.1007/s10909-015-1465-9.

[3] M. Ukibe, S. Shiki, Y. Kitajima, M. Ohkubo, JJAP 51, 010115 (2012), DOI: 10.1143/JJAP.51.010115.

[1] National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan.

[2] Department of Astronomical Science, The Graduate University for Advanced Studies (SOKENDAI), Mitaka, Tokyo 181-8588, Japan

[3] National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8568, Japan

NOTES: