Ultra-Sensitive Hot-Electron Nanobolometers for THz Astrophysics

Boris. S. Karasik[a], Sergey V. Pereverzev[a], Jian Wei[b], David Olaya[b], Michael E. Gershenson[b], Andrei V. Sergeev[c], and Robin Cantor[d]

[a] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA
[b] Rutgers University, Piscawataway, NJ 08854, USA
[c] SUNY at Buffalo, Buffalo, NY 14260, USA
[d] Star Cryolectronics, Santa Fe, NM 87508, USA

***Abstract*—The background-limited spectral imaging of the early Universe requires terahertz (THz) detectors with the sensitivity 2-3 orders of magnitude better than that of the state-of-the-art bolometers. To realize this sensitivity without sacrificing the operating speed, the sensing element of a bolometric detector should have an exceptionally high thermal isolation from the environment combined with an ultrasmall heat capacity. We have demonstrated that this goal can be achieved by realizing a superconducting hot-electron nanobolometer whose design blocks photon and phonon energy exchange through its contact leads. The remaining coupling due to electron-phonon interaction provides thermal control at a level of one thousandth of the quantum of thermal conductance $G_Q \approx 1$ [pW/K] × *T*. These hot-electron nanobolometers with a heat capacity of ~ 0.1 aJ/K will be sufficiently sensitive for registration of single THz photons. These devices are very promising for submillimeter astronomy and other applications based on quantum calorimetry and photon counting.**

I. Introduction And Background

ALTHOUGH being one of the oldest radiation detectors, bolometer still has a great potential for achieving the most challenging goals. However, the realization of an ultra-high sensitivity bolometer requires unprecedented thermal isolation. In the flux-integrating regime (where the bolometric time constant $\tau >> N_{ph}^{-1}$), the minimum *NEP* is determined by the thermal energy fluctuations in a bolometer, and the corresponding value of $NEP_{TEF} = \sqrt{4k_B T^2 G}$ is controlled by the thermal conductance *G* between the bolometer and its environment. In a traditional "geometrically isolated" bolometer, *G* is determined by the number of relevant phonon and photon "channels" (modes) participating in thermal transport between the sensor and its environment. It has been shown recently for both photons and phonons that the thermal conductance of a short single channel is determined by the universal value $G_Q = \pi^2 k_B^2 T/3h$ known as the quantum of thermal conductance. Nevertheless, even a thermal conductance at the level of G_Q is too large for the realization of the required bolometer sensitivity in the temperature range accessible for future space instruments (≥ 50 mK).

Some time ago we proposed an alternative approach to enhance the sensitivity of bolometers based on using the hot-electron effect in superconducting nanostructures. Recently we have fabricated hot-electron superconducting nanobolometers with an electron-phonon thermal conductance on the order of G_Q and showed that this approach can both significantly increase the sensitivity and reduce the response time.[1]

II. Results

In the present work, we expand the limits of thermal isolation of electrons in a nanosensor to an unparalleled "milli-quantum" level. Effective suppression of outdiffusion of hot electrons and emission of photons allows us to realize values of thermal conductance far below G_Q: at $T = 40$ mK, we have observed $G \approx 0.003 G_Q$ along with $\tau \approx 0.5$ ms in titanium nanobolometers. This thermal conductance is the lowest ever measured and is sufficient for realization of the ultralow NEP meeting any requirements for future SMM applications in space (Fig. 1). Using micron-size structures, we have demonstrated detection of single NIR photons. An ultra-small electron heat capacity of nanobolometers ($C \sim 10^{-19}$ J/K at $T = 100$ mK) should make it possible to detect single THz photons.

The on-going experimental work is aimed at the direct measurements of optical NEP in antenna-coupled devices and demonstration of single THz photon detection.

The research at the Jet Propulsion Laboratory, California Institute of Technology, was carried out under a contact with the National Aeronautics and Space Administration.

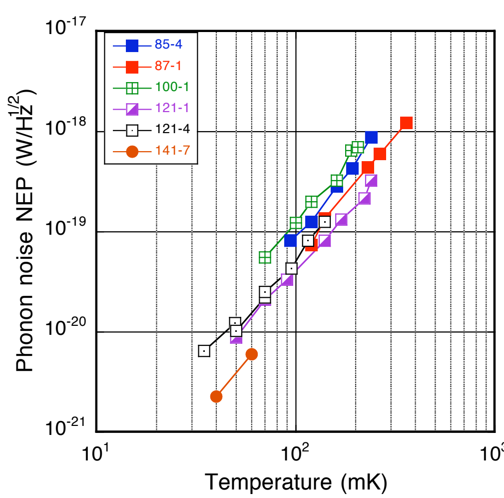

Fig.1. Phonon-noise NEP in titanium nanobolometers.

References

[1] B.S. Karasik et al., "Record low NEP in the hot-electron titanium nanobolometers", *IEEE Trans. Appl. Supercond., Vol.*17, pp.293-297 (2007).