Normal Metal HEB Detector with Johnson Noise Thermometry Readout

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Next generation submillimeter telescopes will require more sensitive detectors for spectroscopy and imaging. Several advanced concepts have been pursued in the recent years with the goal to achieve a detector Noise Equivalent Power (NEP) of the order of 10^{-20} - 10^{-19} W/Hz$^{1/2}$ that corresponds to the photon noise limited operation of the future space borne far-IR spectrometers under an optical load ~ 10^{-19} W. Our recent work has been focusing on the hot-electron Transition-Edge Sensor (TES) where a much lower thermal conductance than in a SiN membrane suspended TES has been achieved. This is due to the weak electron-phonon (e-ph) coupling in a micron- or submicron-size hot-electron Ti TES. Using this approach, the targeted low NEP values have been confirmed via direct optical measurements [1]. The kinetic inductance detector [2] and quantum capacitance detector [3] demonstrated recently a similar sensitivity as well.

We see nevertheless the possibility to push the state-of-the-art even further. Increase of the operating temperature and the saturation power, and simplification of the array architecture are believed to be important areas of improvement not only for the ultrasensitive detectors but also for far-IR detectors intended for use in photometers and polarimeters where the background is higher (NEP = 10^{-18} - 10^{-16} W/Hz$^{1/2}$). Recently, graphene has emerged as a promising material for hot-electron bolometers (HEB) due to its weak e-ph coupling, very small volume of a single-atom thick sensing element and strong Drude absorption of far-IR radiation. Since the monolayer graphene has a temperature independent resistance its readout is problematic. In recent works [4, 5], Johnson Noise Thermometry (JNT) has been employed as the readout technique.

In this paper, we give a detailed analysis of the expected sensitivity and operating conditions in the power detection mode of a hot-electron bolometer made from a few μm^2 monolayer graphene flake which can be embedded into either a planar antenna or waveguide circuit via NbN (or NbTiN) superconducting contacts with critical temperature ~ 10 K. The most recent data on the strength of the e-ph coupling are used in the present analysis and also the contribution of the readout noise into the NEP is explicitly computed. The readout scheme utilizes the JNT allowing for Frequency-Domain Multiplexing (FDM) using resonator coupling of HEBs. In general, the resonator bandwidth and the summing amplifier noise make a significant effect on the overall system sensitivity. The analysis shows that the readout contribution can be reduced to that of the bolometer phonon noise if the detector device is operated at 0.1 K and the JNT signal is read at about 10 GHz where both the Johnson noise and the microwave photon mediated thermal conductivity weaken greatly. Beside the high sensitivity, this bolometer does not have any hard saturation limit and thus can be used for imaging with arbitrary contrast. By changing the operating temperature the bolometer sensitivity can be fine tuned to the background noise in a particular application. Using a quantum noise limited kinetic inductance parametric amplifier [6], 100s of graphene HEBs can be read simultaneously without saturation of the system output and deterioration of the sensitivity. We will also compare the expected performance of graphene with several conventional normal metal materials for HEB (e.g., W, TiN, Pd). A relative simplicity of the normal metal HEB compared to the TES version (no need in bias, tuning of critical temperature, and dc SQUID amplifiers) can make this approach an attractive alternative for the low-background far-IR arrays.

References

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