A Zero-Bias Ultrasensitive THz Hot-Electron Direct Detector with Large Dynamic Range

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As more powerful instruments are being planned for the next generation of submillimeter telescopes (e.g., the Far-IR Surveyor mission), the need for better detectors is becoming more urgent. 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 was focusing on the hot-electron nanobolometer (nano-HEB), a Transition-Edge Sensor (TES) where a very low thermal conductance was achieved due to the weak electron-phonon (e-ph) coupling in a micron- or submicron-size device. Using this approach, the targeted low NEP values have been confirmed recently via direct optical measurements. The kinetic inductance detector and the quantum capacitance detector demonstrated recently a similar sensitivity.

We see nevertheless the possibility to advance 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 the 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$^{1/2}$). Our recent paper (Karasik et al, IEEE Trans. THz Sci.&Technol. 5, 16 (2015)) analyzed the sensitivity of a normal metal nano-HEB, which uses the Johnson Noise Thermometry (JNT) to read an increase of the electron temperature caused by the absorbed far-IR radiation. Such a detector does not require any bias lines and just needs to be connected to a low-noise microwave amplifier (LNA) via a narrowband filter defining the noise bandwidth. By using a filter bank channelizer, a ~ 1000 detectors can be multiplexed using a single amplifier. The use of normal metal eliminates the need in detector material development (like, e.g., for TES) and provide a ~100 dB dynamic range. The NEP depends on the noise temperature of the readout amplifier and is not very sensitive the e-p coupling strength. An NEP < 10^{-19} W/Hz$^{1/2}$ can be achieved with commercially available LNA.

In this paper, we will present an initial experimental study of a normal metal HEB made from a 1-square-micron normal metal patch coupled to a planar twin-slot microantenna. A SQUID-rf LNA with the noise temperature T_A< 1 K followed by a HEMT LNA with $T_A \approx 5$ K and a large gain are for readout. Electrical NEP is measured by sending a dc current through the device and measuring a change of output noise power caused by the heating. At 50 mK, the NEP is ~ 10^{-19} W/Hz$^{1/2}$. The data are obtained as function of bath temperature and the filter passband and compared with the model. An on-going effort to design a 1000-element bank of narrowband (few MHz) filters needed to array multiplexing will be presented too. We will also discuss various options of LNA (HEMT, parametric superconducting amplifiers, etc.) and associated sensitivity and dynamic range trade-offs.

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