An array scalable far-IR detector with NEP < 10^{-20} W/Hz$^{1/2}$

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Abstract— As more powerful instruments are being planned for the next generation of submillimeter telescopes (e.g., Origins Space Telescope), 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} 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 coupling in a micron- or submicron-size device. Using this approach, the targeted low NEP values have been confirmed via direct optical measurements. The kinetic inductance detector and the quantum capacitance detector also demonstrated recently high sensitivity. The next challenge is to arrive to a sizable array (1000s pixels) of such detectors. Many hurdles associated with electrical and thermal crosstalks, wire management, and readout noise should be addressed.

A novel hot-electron bolometric direct detector presented here uses a submicron size normal metal (e.g., non-superconducting Ti) patch coupled to a planar microantenna. The detector does not require any bias (dc or rf). The Johnson Noise Thermometry using a quantum noise limited microwave amplifier (LNA) allows for the direct read of an increase of electron temperate caused by the absorbed far-IR radiation. At 50 mK, the Noise Equivalent Power (NEP) is less than 10^{-20} W/Hz$^{1/2}$ whereas the dynamic range is 60-100 dB. Multiplexing of a 1000-pixel array is feasible using a single LNA with a bank of narrowband bandpass filters.

The NEP depends on the noise temperature of the readout amplifier and is not very sensitive to the electro-phonon coupling strength. However, materials with weak electron-phonon coupling (Bi, graphene) may provide a larger usable microwave bandwidth and thus will allow for more pixels per a single amplifier.

Although, the primary application is envisioned on a telescope with cryogenically cooled mirror (Origins Space Telescope), this detector can be employed on high-background suborbital and ground based platforms since the detector does not exhibit hard saturation with an increase of the radiation power. This can be important for gradual advancing the technology towards space applications. For such less sensitivity demanding applications, various simplifications of the detector array architecture are possible. For example, an NEP < 10^{-19} W/Hz$^{1/2}$ can be achieved with commercially available LNA (T_A ~ 2 K). Also, operating temperature can be increased for the use of the detector in photometers and polarimeters where the background is higher (NEP = 10^{-18}- 10^{-16} W/Hz$^{1/2}$).

In this paper, we will present an initial experimental study of a normal metal HEB made from a 1-square-micron normal metal Ti 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 were used for readout. Electrical NEP was 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 was ~ 10^{-19} W/Hz$^{1/2}$. The data were 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.