Hot-electron direct detectors: feasibility of NEP ~ 10^{-20} W√Hz at submillimeter waves

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We present a concept for a hot-electron direct detector (HEDD) capable of counting single millimeter-wave photons. Such a detector will meet the needs of future space far-infrared missions (NEP ≤ 10^{-19} W/√Hz) and can be used for background-limited detector arrays on SPIRIT, the 10-meter space telescope and SPECS. The detector is based on a microbridge (1-μm-size) transition edge sensor fabricated from an ultra-thin film of a superconductor with the critical temperature T_c = 0.1-0.3 K. A very strong temperature dependence of the electron-phonon coupling allows to adjust the electron-phonon scattering time, $\tau_{e\text{-}ph}$, to the desired time constant of the detector ($\tau = 10^{-4}$-10^{-3} s) at T = 0.1 K; further adjustment of $\tau_{e\text{-}ph}$ is possible due to the electron-mean-free-path dependence of $\tau_{e\text{-}ph}$. The microbridge contacts are made from a different superconductor with a higher critical temperature (Nb); these contacts will block the thermal diffusion of hot carriers into the contacts because of the Andreev reflection. The low electron-phonon heat conductance, high thermal resistance of the contacts, and small heat capacitance of electrons in a micron-size bridge determine the noise equivalent power of ~ 10^{-20} – 10^{-21} W/√Hz at T = 0.1 K, which is 10^2 to 10^3 times better than that of the state-of-the-art bolometers. By exploiting the negative electro-thermal feedback, the detector time constant can be made as short as 10^{-5}-10^{-4} s without sacrificing sensitivity.

Preliminary results on hafnium hot-electron bolometers will be reported. The measurements of the electron-phonon relaxation time have demonstrated that the bolometer response time of ~ 0.7 ms at T = 0.1 K is possible without using any high-thermal-resistance suspension of the detector (the Hf films were deposited directly on a bulk sapphire substrate). For a device with lateral dimensions 1×1 μm^2, this would result in a NEP ~ 10^{-20} W/Hz$^{1/2}$ due to the thermal fluctuations. Prototype antenna-coupled devices have been fabricated. These prototypes will be used for testing the spectral properties of the detector up to the THz frequencies. Possible ways of integration of these new devices in large arrays will be discussed.