Noise temperature and IF bandwidth of a 530 GHz heterodyne receiver employing a diffusion-cooled superconducting hot-electron mixer

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ABSTRACT

We report on the first heterodyne measurements with a diffusion-cooled hot-electron bolometer mixer in the submillimeter wave band, using a waveguide mixer cooled to 2.2 K. The best receiver noise temperature at a local oscillator frequency of 533 GHz and an intermediate frequency of 1.4 GHz was 650 K (double sideband). The 3 dB IF roll-off frequency was around 1.7 to 1.9 GHz, with a weak dependence on the device bias conditions.

Keywords: Superconductor, bolometer, submillimeter, heterodyne, detector, receiver, SIS

1. INTRODUCTION

Bolometers have been used in the past as heterodyne mixers primarily because of their high sensitivity and their ability to operate at very high frequencies. However, the very slow thermal response time limits the intermediate frequency (IF) to a range too low to be of practical value for most applications, and so bolometer mixers have not found widespread use. Recently however, a new type of bolometer mixer has been proposed which has a thermal response time as short as a few 10's of picoseconds; this leads to practical IF's of several GHz. It consists of a niobium (Nb) microbridge and relies on *electron diffusion* as a cooling mechanism. The microbridge is made short (~0.2.8 μm) to ensure that this rapid out-diffusion of the electrons dominates over electron-phonon interactions. It is also narrow (~0.14 μm) to provide an appropriate device resistance for matching to RF and IF circuits. The niobium film is very thin (~10 nm), which results in a very short mean free path (~1-10 nm) and an enhanced electron-electron interaction?. The dissipated submillimeter wave energy is therefore shared between all the electrons in a very short time, allowing the electron temperature to increase relative to the lattice. The resistance of the microbridge bolometer is a function of the electron temperature, which provides the mechanism used for heterodyne mixing.

It should be noted that superconducting hot-electron bolometers cooled by electron-*phonon interaction*[2-6] have achieved IF roll-off frequencies of: 100 MHz for Nb devices and recently up to 1.5 GHz for niobium nitride (NbN)[7], for operation at millimeter wave frequencies. However, low-noise heterodyne receiver performance in the submillimeter band has not yet been demonstrated with these devices.

In this conference paper we briefly describe the first heterodyne receiver measurements at submillimeter wave frequencies with a diffusion-cooled superconducting hot-electron bolometer mixer (a more extensive discussion is given elsewhere[8,9]).

2. MEASUREMENTS

The submicron-sized bolometer was fabricated from Nb on a fused quartz substrate with the dimensions indicated above, see, figure 1. The transition temperature of the thin film was measured to be ~ 5.3 K, which corresponds to a gap frequency of 410 GHz. The device was mounted into a two-tuner waveguide mixer block designed for operation around 547 GHz[10]. The mixer was cooled down to 2.2 K in a vacuum cryostat, that was equipped with focusing optics, a window to the 300 K environment, and Fluorogold filters to reduce the infrared heat load on the mixer block. The 533 GHz local oscillator (LO) power was supplied by a X2X3 multiplier that was pumped by a Gunn oscillator.

In the measurements of receiver noise temperature the LO was coupled into the receiver beam by a folded Fabry-Perot diplexer[11], and the output of the mixer was coupled to a cooled HEMT amplifier intermediate frequency (IF) system with a noise temperature of 6 K. The IF band was filtered down to 320 MHz around a center frequency of 1.4 GHz. The receiver sensitivity was determined in a Y-factor measurement where, 295 K and 77 K blackbody loads (Eccosorb absorber) were switched in to the receiver signal path, while the output IF power was measured. The best Y-factor measured in this way was 1.15 dB, which corresponds to a receiver noise temperature of 650 K double sideband (DSB). The measurements indicated a mixer conversion of -11.4 dB (DSB). Figure 2 shows an IV curve of the LO-pumped device under optimized conditions at a physical temperature of 2.2 K. It also shows the IF output power of the receiver.

For measurements of the bolometer IF roll-off, narrow-band components of the receiver were appropriately modified or replaced. The cooled HEMT amplifier was replaced by a more broadband (0.5-18 GHz) FET amplifier, and the resonant Fabry-Perot diplexer was replaced by a diplexer made from a thin Kapton membrane. The input signal to the receiver was thermal blackbody radiation from 77 K and 295 K absorber loads. To determine the dependence of the conversion on the IF, the output power was filtered to 1 MHz bandwidth and down converted to 10 MHz using a spectrum analyzer. The 10 MHz output from the analyzer was subsequently detected by a power meter. To accurately characterize the mixer response, careful calibration of the gain and noise of the IF system were required, the details of which have been previously discussed[9]. Figure 3 shows the normalized mixer conversion efficiency as a function of intermediate frequency, when the bolometer is DC biased in the optimum regime at the lower end of the resistive branch of the IV curve. A fitted curve with the theoretical frequency dependence $\left(1+\left(f_{IF}/f_{Roll-off}\right)^{2}\right)^{-1}$ is also shown[12], Where the roll-off frequency $f_{Roll-off}$ = 1.7 GHz. Other bias point at higher DC bias voltages gave roll-off frequencies of up to 1.9 GHz.

3. SUMMARY

An ultra-fast, hot-electron bolometer mixer has been operated at 530 GHz, which is well above the gap frequency of the superconductor. Since the bolometer mixer relies on heating of electrons, it is expected to work well up to several THz, where competing Schottky and SIS mixers are difficult or impossible to operate. The noise temperature,

conversion efficiency, and 1 .O power are compai able to competitive SIS mixers at 500 GI Iz. The measured IF roll-off is the highest achieved foi a sensitive bolometer mixer. This heterodyne sensor should find practical applications al very high submillimeter Wave frequencies.

4. ACKNOWLEDGMENTS

This research was performed by the. Center for Space Microelectionics Technology, Jet Propulsion 1 .aboratory, California Institute of Technology and by Yale University and was jointly sponsored by the National Aeronautics and Space Administration, Office of Space Access and Technology, the National Science Foundation, and **the** Netherlands Organization for Scientific Research. Funding for P. J. Burke was provided by a NASA Graduate Student 1 'ellowship as well as a Connecticut 1 ligh Technology 1 'ellowship.

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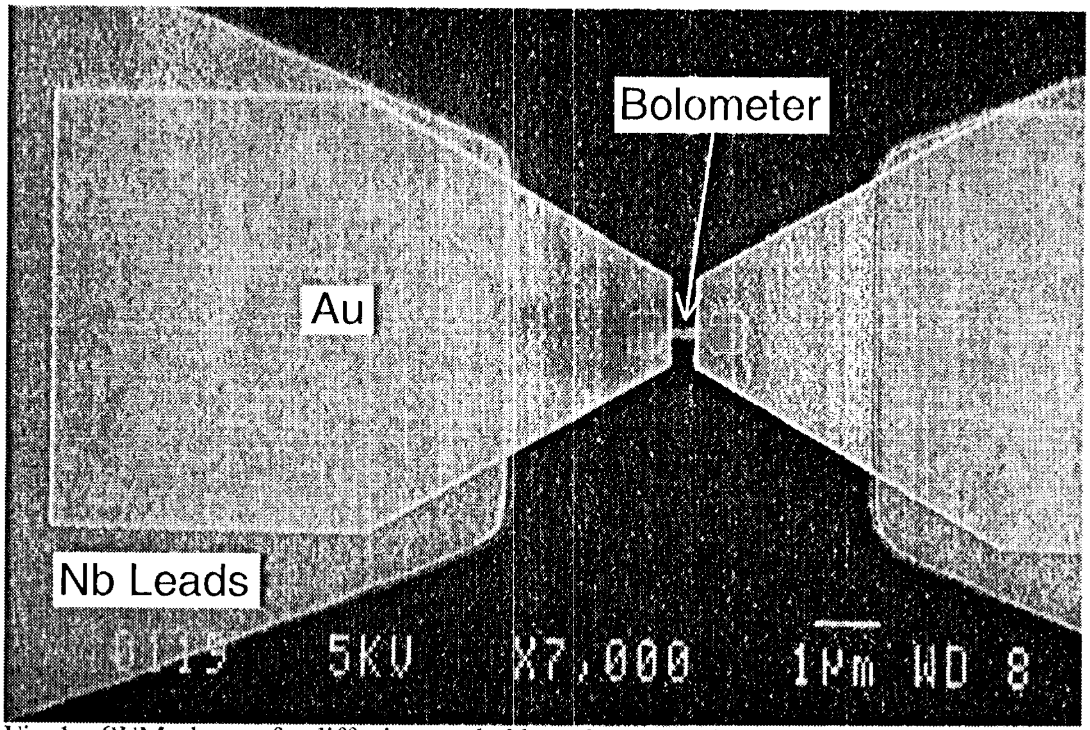


Fig.1: SEM photo of a diffusion cooled hot-electron bolometer. The bolometer used in the measurements was 0.28 μm long, 0.14 μm wide, and 10 nm thick.

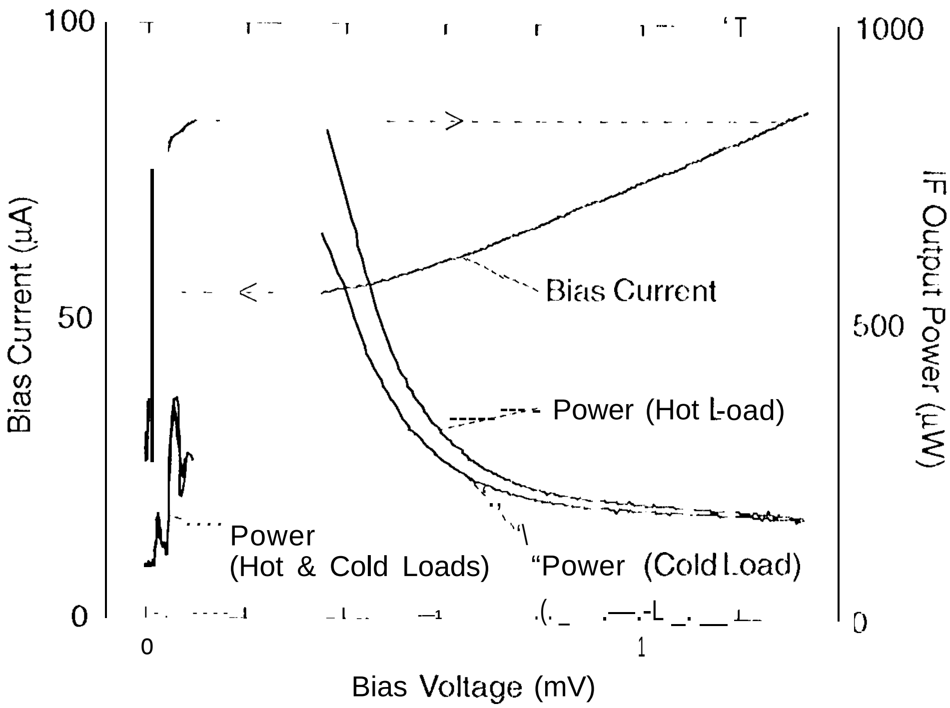
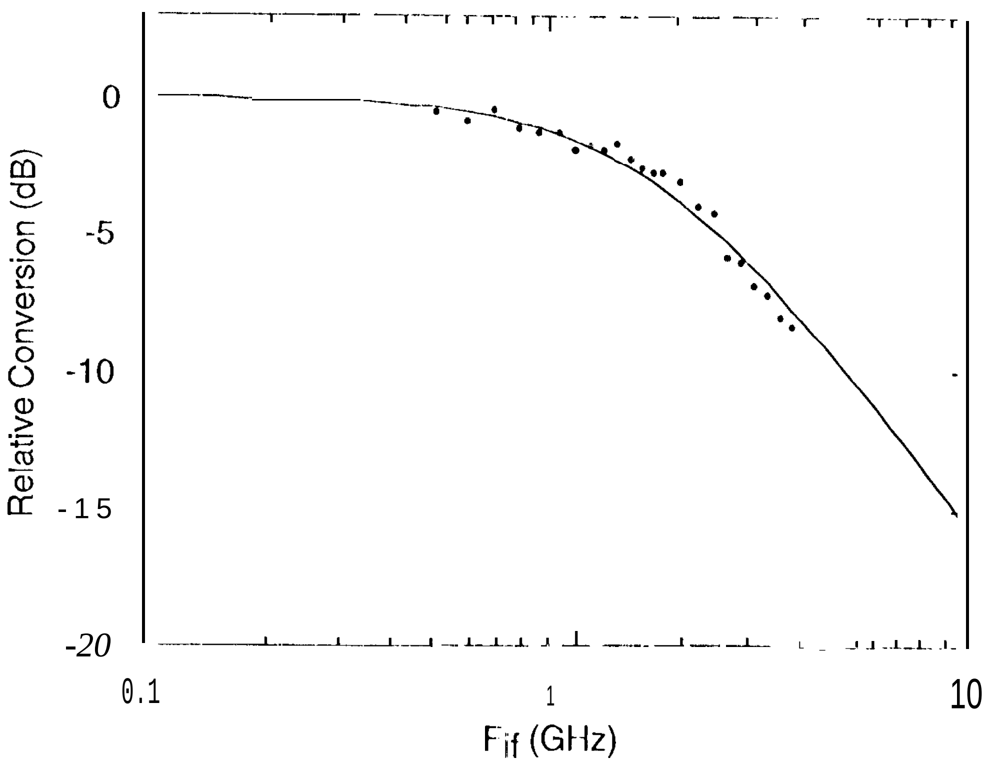


Fig.2: Local oscillator pumped IV curve of the bolometer and IF receiver output power at the intermediate frequency



1 ˈig.3: Measured (normalized) conversion versus frequency and a fitted single-po]c roll-off Curve.