Size Dependence of HEB Mixer Performance

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***Abstract*— In this paper, we present the size dependence of the waveguide niobium titanium nitride (NbTiN) superconducting hot electron bolometer (HEB) mixers at 0.8 and 1.5 THz. The HEB mixers are cryogenically cooled by a 4-K close-cycled refrigerator, and are characterized by conventional Y factor method. We find that the noise performance of the HEB mixers is closely related with the NbTiN microbridge size. The smaller the microbridge size is, the less receiver noise temperature the HEB mixers have. The best uncorrected double-side band (DSB) receiver noise temperature is measured to be 500 and 1700 K at 0.8 and 1.5 THz respectively, for the smallest devices.**

I. INTRODUCTION

Superconducting hot electron bolometer (HEB) mixers have matured as the most sensitive heterodyne detectors at frequencies between 1.2 to 6 THz, which have excellent performance of double-sideband (DSB) receiver noise temperature approaching four times the quantum limit ($4h\nu/k$) and require the local oscillator (LO) power of only a few tens of nanowatt (nW) [1]. Therefore, they have been applied in various astronomical telescopes as sensitive detectors to observe faint signals from the astronomical target, such as ground based APEX telescope [2], space based Herschel satellite, and airborne SOFIA observatory [3, 4].

Currently the state-of-the-art phonon-cooled HEB mixers are fabricated from thin niobium nitride (NbN) film. However, the niobium titanium nitride (NbTiN) HEB mixer is an alternative option as well for the HEB mixers [5, 6], since the physical and chemical properties of the NbTiN and NbN films are quite similar to each other. Although some efforts have been made for the NbTiN HEB mixer [5, 6, 7], it is still in an infancy stage in comparison with the NbN mixer. In this paper, we investigate the dependence of the noise performance of the HEB mixers on the microbridge size at 0.8 and 1.5 THz.

Manuscript received 15 May 2009. L. J. thanks Japan Society for the Promotion of Science, for financial support. This work is supported by Grand-in-Aid from the Ministry of Education, Culture, Sports, Science, and Technologies (14204013 and 15071201) of Japan.

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II. HEB MIXER AND EXPERIMENTAL SETUP

The HEB device is fabricated from 12-nm thick NbTiN superconducting thin film, which is deposited on a Z-cut crystalline quartz substrate by the reactive sputtering of an NbTi (weight ratio of Nb:Ti = 4:1) alloy target in a mixture of Ar and N_2 gas at room temperature. The HEB element is accommodated into a waveguide mixer block which couples radio frequency (RF) and local oscillator (LO) signals into the NbTiN microbridge located in the center of the HEB chip.

The experimental setup for measuring the noise performance of the HEB mixers is illustrated in Figure 1. The HEB mixer chip is housed in the waveguide mixer block, which is mounted on the cold plate of a GM two-stage 4 K close-cycled refrigerator. The LO sources are provided by 0.8 and 1.5 THz multiplier chains respectively. The LO beam is collimated with a parabolic mirror, and is combined with the RF signal of blackbody radiation from a slab of Eccosorb at 295K (hot load) and 77 K (cold load) through Mylar beam splitter, then pass through another parabolic mirror, finally enter the 4 K cryostat. The cryostat has a 7.5 μm thick Kapton vacuum window at 295 K and one layer of Zitex G106 on the 4 K shield for blocking infrared radiation into the HEB mixer. The RF and LO signals are focused by a parabolic mirror thermally anchored to the 4 K cold plate of the cryostat to a diagonal horn for the HEB mixer.

The IF output of the HEB mixer is connected via a bias-tee to a cooled isolator and a 0.9-1.3 GHz FET low noise amplifier, which is followed by a room temperature amplifier chain. The latter consists of two amplifiers, a directional coupler with through output followed by a spectrum analyzer, and coupling

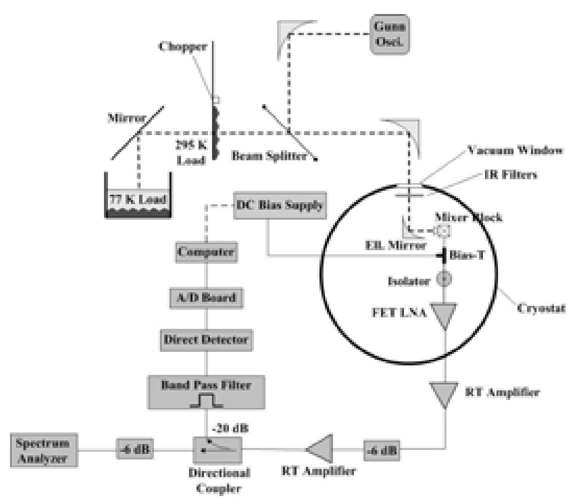

Fig. 1. Diagram of the experimental setup for measuring the noise temperature of superconducting NbTiN HEB mixers.

output filtered by a band pass filter, detected by a square law direct detector, and recorded by computer. The band pass filter has a bandwidth of 200 MHz at the center frequency of 1.1 GHz.

III. Measurement Results

We measure the DSB receiver noise temperature of the HEB mixers with different sizes at 0.8 and 1.5 THz. The receiver noise temperature is found to be inversely proportional to the NbTiN microbridge size, as shown in Table 1. The lowest receiver noise temperature is measured to be as low as 500 and 1700 K at 0.8 and 1.5 THz respectively. Figure 2 shows the IF output power as a function of bias voltage at optimum LO pumping level for the 1.5 THz HEB mixer with the smallest microbridge (1.5 μm × 0.3 μm).

The size dependence of the receiver noise temperature of the HEB mixers can be explained by the cooling mechanism of the hot electrons existed in the HEB mixers. Our NbTiN HEB device is based on a 12 nm NbTiN film which is thicker than that used by other groups (a few nm) for the phonon-cooled mixers. Since the phonon-cooling is less effective for a thicker film [5, 6, 7], this is a disadvantage. In contrast to conventional fabrication process of the phonon-cooled HEB mixers, we employ an *in situ* process in HEB fabrication, which ensures good transparency between the NbTiN film and Ti/Au contact pads, and reduces the contact resistance. The RF loss is minimized due to the clean interface of the contact layer. Meantime, the out-diffusion of the hot electrons is shunted to the contact pads, which contributes to the mixer cooling in addition to electron-phonon interaction [8]. Therefore, it makes the two types of cooling mechanism, i.e., the diffusion-cooling and phonon-cooling processes work simultaneously in our HEB devices. Since the diffusion-cooling efficiency increases with the decrease of the microbridge length of the HEB mixer, the receiver noise temperature of the HEB mixers is reduced while gradually narrowing the microbridge.

TABLE 1 Dependence of Noise Teperature on Microbridge Size

Frequency (THz)	**Size (width×length)**	**Noise Temperature (K)**
0.8	3.5 μm × 0.4 μm	950
	2.5 μm × 0.4 μm	870
	2 μm × 0.2 μm	500
1.5	3 μm × 0.4 μm	3000
	1.5 μm × 0.3 μm	1700

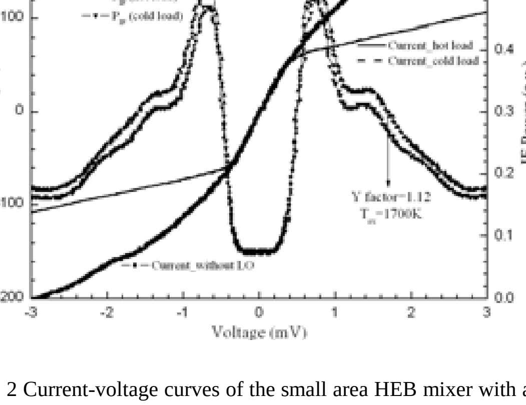

Fig. 2 Current-voltage curves of the small area HEB mixer with and without LO at 1.5 THz, and receiver IF output powers P_{IF} (hot) and P_{IF} (cold) corresponding to the hot (295 K) and cold (77 K) loads respectively as a function of the bias voltage at the optimum LO pumping level. The maximum Y-factor (P_{IF} (hot) / P_{IF} (cold)) is 1.12, which corresponds to the receiver noise temperature of 1700 K.

IV. Conclusion

We characterized waveguide NbTiN superconducting HEB mixers at 0.8 and 1.5 THz respectively, cryogenically cooled by a 4-K close-cycled refrigerator. The lowest DSB receiver noise temperature of the HEB mixers is measured to be 500 and 1700 K, respectively, at 0.8 and 1.5 THz. In our NbTiN mixers, the diffusion-cooling mechanism would contribute in addition to the phonon-cooling, and hence, the receiver noise temperature of the HEB mixers is found to sensitively depend on the superconducting NbTiN microbridge size; the smaller area devices provide better noise performance. This is the reason why we obtain good noise performance in spite of the use of a relatively (12 nm) NbTiN film.

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