Antenna-Coupled 30 THz Hot Electron Bolometer Mixers

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Abstract— **We report on design and characterization of a superconducting Hot Electron Bolometer Mixer integrated with a logarithmic spiral antenna for mid-IR range observations. The antenna parameters have been adjusted to achieve the ultimate performance at 10 µm (30 THz) range where O_3, NH_3, CO_2, CH_4, N_2O, …. lines in the Earth's atmosphere, in planetary atmospheres and in the interstellar space can be observed.**
The HEB mixer is made of a thin NbN film deposited onto a GaAs substrate. To couple the radiation we rely on the quasi-optical approach: the device is glued to a semi-spherical germanium lens with diameter ~ 3 mm. A wet cryostat equipped with a germanium window and narrow band-pass filter is used to characterize the antenna and estimate the mixer performance.

I. Introduction

Mid-IR range observations play an important role in studying the Earth's atmosphere, planetary atmospheres and astrophysical objects [1]. Mid-IR heterodyne instruments, such as THIS [1-2], HIPWAC [3-4] and others, have demonstrated their unique capabilities in planetary astronomy, achieved primarily due to unprecedented spectral resolution reaching $\lambda/\delta\lambda \sim 10^7$. Ground-based observations of Mars, Venus and Titan with these instruments have resulted in precise measurement of temperature, wind velocities and concentration abundances of the atmospheric gases. Not only heterodyne detection provides much higher spectral resolution than other spectroscopic techniques, it also preserves frequency and phase information, that may be important in such applications as space communication and navigation. Development of mid-IR heterodyne instrumentation has a long history starting from 1960s [5]. In most of these studies, a mercury cadmium telluride (MCT) photo diode was used as the mixer operating in the 8-14 µm range, allowing for IF bandwidth of ~1 GHz.

Another possible candidate for mid-IR mixing is the HEB mixer whose conversion efficiency is nearly frequency independent until the plasma frequency of the metal is achieved. Successful operation of the HEB mixer has been demonstrated at wavelength of 10.6 µm [6-7] and 1.5 µm [8]. It was demonstrated that such a mixer can rely on the direct absorption of the incident radiation and the NbN bridge size would be determined by the diffraction limit at the chosen LO frequency [6]6-7]. As the efficiency of coupling incident radiation to the thin-film HEB mixer is limited, a special field amplification photonic device is needed to achieve acceptable performance of the heterodyne detection [8]. To decrease both signal losses and the LO power needed, we have proposed a wide-range spiral antenna centered at 10.6 µm and designed with help of HFSS [9].

II. Device Layout

The mixers are made of an ultrathin NbN film deposited on GaAs substrates. The NbN bridge sized to 0.25×0.75 µm^2 is imprinted into a planar logarithmic-spiral antenna. Two different antennas have been simulated. For the experiments, the HEB mixer is installed on the cold plate of a LHe cryostat. A germanium window and an extended semi-spherical germanium lens with a diameter of ~ 4 mm are used to focus the incident radiation on the antenna.

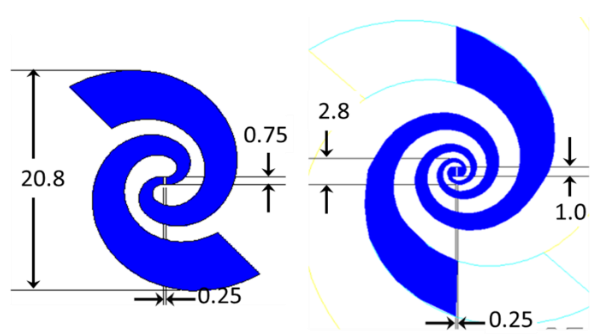

Fig. 1 Scetch of the central part of antenna type A (left) and antenna type B (right). Dimensions are shown in micrometers.

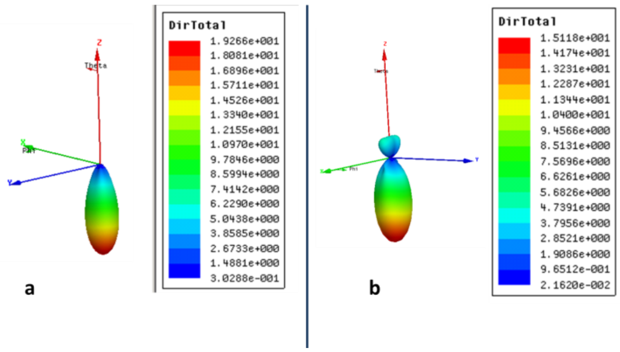

Fig. 2 Simulated directivity for antennas A and B.

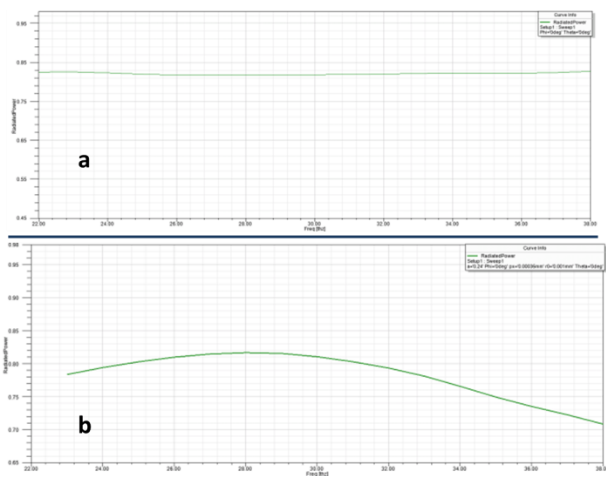

Fig. 3 Simulated efficiency the antennas vs. frequency.

The cryostat is equipped with a germanium optical interference filter which is ~ 0.5 mm thick. Center wavelength of the filter is either 10.4 µm or 10.6 µm, the half-power-bandwidth - ~200 nm.

A. *Antenna design and simulation*

Central parts of the two antennas (Type A and Type B) are shown in Fig. 1.

Fig. 2 represents simulated directivity and Fig. 4 shows efficiency as a function of frequency for both antennas.

B. *Fabrication of the antenna-coupled HEB mixer*

The mixers are made of ultrathin NbN film deposited on GaAs substrates (which possess good transparency in the desired range) by reactive magnetron sputtering. For the film deposition, we used two different sputtering systems: Leybold Heraeus and AJA Orion. Processing parameters were adjusted to achieve better characteristics of the NbN film. As GaAs substrates cannot be heated to high temperatures, a compromise between achievement of high critical temperature for NbN film and the possible heating is needed. Table I summarize NbN film deposition parameters and measured characteristics of the NbN film. Fig. 4 SEM image of the antenna type A. depicts a SEM micrograph of a device of Type A.

TABLE II
NBN FILM PROCESSING PARAMETERS FOR DIFFERENT SPUTTERING SYSTEMS

Parameter	**Sputtering system**	
	Leybold Heraeus	**AJA Orion**
Target – substrate distance, cm	7	16
Target diameter, ”	4	2
Residual pressure, mbar	$2.1\cdot10^{-6}$	$4\cdot10^{-7}$
Deposition temperature, °C	200	200
Deposition rate, A/s	11	1.3
Film thickness, nm	4.4	5.3
R_s , Ohm/□	450-580	490-500
T_c , K	7.8	7.5
ΔT_c , K	0.36	0.45
$k=R_{300}/R_{20}$	0.8	0.83

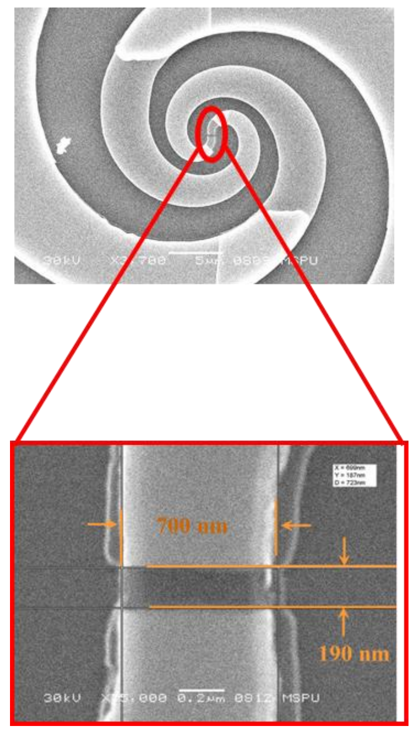

Fig. 4 SEM image of the antenna type A.

III. EXPERIMENTAL PLANS

To estimate performance of the fabricated devices, the following measurements are needed:

- Antenna directivity and input bandwidth measurement,
- HEB mixer sensitivity and noise performance measurement.

IV. CONCLUSIONS

In conclusion, we have simulated and fabricated antenna-coupled HEB mixers for mid-IR range. It has been predicted that such mixers would demonstrate a quantum-limited sensitivity combined with a sufficiently wide IF bandwidth. With use of a planar antenna, one can decrease the LO power required to a readily available amount of power provided by a compact state-of-the-art source such as quantum-cascade-laser.

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