1.9 THz Waveguide HEB Mixers for the upGREAT Low Frequency Array

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Abstract— **We report on the development of waveguide HEB mixers for the upGREAT low frequency array (LFA). upGREAT is the focal plane array extension of the German Receiver for Astronomy at THz frequencies (GREAT) in operation on SOFIA. Its LFA will have 14 pixels for the 1.9–2.5 THz band divided in two 7 pixel hexagonal sub arrays. The mean corrected noise temperature of 12 of the 14 mixers characterized so far, averaged over a 1 – 2 GHz IF bandwidth, is 700 K (+/- 100 K). In order to meet the LO power requirement of the receiver we reduced the NbN HEB device volume to 3.5 nm thickness x 200 nm length x 3250 nm width (120 Ohm normal state impedance), by a re-optimization of the critical NbN device layer and an adjustment of the RF circuit. We will present the measured performance of the mixers with a focus on uniformity.**

I. Introduction

GREAT is the THz heterodyne high-resolution spectroscopy instrument (R > 1E7) on SOFIA and has been in operation since 2011 [1]. The single pixel receivers cover frequency bands at 1.4 THz, 1.9 THz, 2.5 THz and 4.7 THz [2], [3]. The receiver is operated as PI instrument by a consortium of German institutes [4]. At these frequencies the underlying technology for mixers and local oscillators is challenging, and as a consequence up to now has prohibited the use of heterodyne THz focal plane arrays (FPAs) with more than a few pixels. The upGREAT focal plane array will ultimately provide 14 pixels covering 1.9 – 2.5 THz (LFA) and 7 pixels at 4.7 THz (HFA) in order to significantly improve the instrument's observing efficiency. The LFA is on schedule for commissioning flights in May 2015.

The LFA receiver will be tested at the MPIfR in Bonn with the hot electron bolometer (HEB) waveguide mixers discussed in this contribution. The receiver testing will be presented in a second contribution to this conference [5].

For the upGREAT LFA mixer series production we have greatly profited from our experience made in the past, which culminated in the first 4.7 THz waveguide circuit HEB mixer that was operated with GREAT H channel commission in May 2014 [6]. However, mixers for Focal Plane Arrays (FPAs) have the additional constraint that they have to be reasonably uniform in performance, which is a challenge for the total chain of mixer production, from fabrication of devices and waveguide blocks towards the assembly and test procedures. Especially for THz frequencies the available local oscillator power per FPA mixer is limited, and sets an upper limit to the size of the microbridge.

We will report in this contribution about the successful development of 14 very similar mixers around 1.9 THz for use in the upGREAT focal plane array receiver.

II. Mixer description

The upGREAT LFA mixers have a layout that is very similar to that of the mixer described in [6], using a metal machined waveguide structure in a backshort-type CuTe block and a feedhorn assembly which clamps on top of the HEB mixer chip that is contacted by beam leads.

A. Device Development

Different from our previously reported HEB devices the LFA devices were optimized for lower local-oscillator power requirement by reducing the volume of the HEB microbridge. To achieve this the layer thickness of the NbN HEB device layer was reduced from about 5.5 nm to 3.5 nm (extrapolated from the sputtering duration and profilometer measurements of 40 nm thick films). In addition the bridge length was shorted from 300 nm to 200 nm and the device's normal resistance was increased from 80 Ohm to 120 Ohm, resulting to a nominal microbridge width of 3250 nm.

A careful optimization of the NbN layer resulted in a average Tc, after device fabrication, of 9K which is only about 0.5 K lower than the Tc of the thicker devices used in [6].

The uniformity of the device fabrication remains excellent despite the shortening of the bridge length by 50%, as is shown in Fig. 1, where the DC IV curves, and the resistance versus temperature measurements of the 14 devices are shown.

B. RF

The finalized devices have a 2 µm Si membrane substrate and make use of a standard single side waveguide probe connected to a CPW transmission line. The RF planar circuit is similar to the one published in [3] The HEB is defined along the length of the CPW line, which is terminated by a RF blocking filter. This design is flexible if the dimensions of the HEB have to be adapted, last minute, to the actual HEB NbN layer parameters. It allows for HEBs of a width up to 10 µm, with a good match to the waveguide. The matching is easily tuned by adapting the CPW line length between the bridge and the blocking filter. This is especially important because the thinner HEB device layers have a 1.5 – 2x higher sheet resistance Rs. As all the layers of the RF planar circuit are completely e-beam written a simple position shift is straightforward to implement into a new fabrication run.

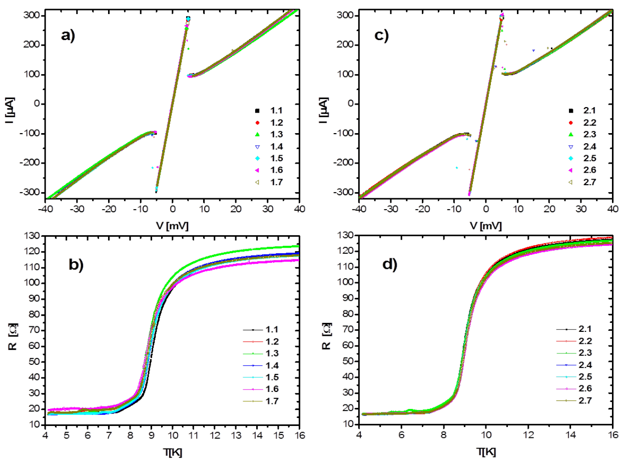

Fig. 1 Measured DC IV (panes a. and c.) and RF (panes b. and d.) characteristics of the HEB devices selected for the upGREAT LFA mixers.

We use a higher resistance HEB of 120 Ohm to keep the lateral dimensions, and thus the volume of the device in check. A higher volume increases the HEBs LO power consumption, and this is not desirable especially for FPA mixers.

The waveguide mixer blocks are made in the in our in-house workshop, by an optimized sequence of stamping and milling, within the tolerances that are determined by 3D EM simulation in CST Microwave Studio.

The waveguide spline profile horns are fabricated by electroforming and are obtained commercially from RPG [7].

C. *Assembly*

Similar to the mixers reported in [8] we make extensive use of beamleads to contact the device, to register the device onto the waveguide block and to form a contact layer between the mixer block and the horn. In Fig. 2 a photograph is shown of a device mounted on the waveguide mixer block. Micrometer precise, reproducible assembly of 14 mixers, within the tolerances obtained from EM –simulation, is only possible because we use a hexapod nano manipulator, enhanced by in house developed tools and procedures to prevent mechanical or ESD damage.

III. Measurements

We have currently measured the noise temperature and the IF bandwidth of 12 mixers. From our experience with the RF tested mixers the implied risk for bad mixers is low. All measurements are done at a local oscillator (LO) frequency of 1.89 THz using a solid-state multiplier chain from VDI. LO and calibration signal from a standard hot (300K) /cold (77K) load are combined by a wire-grid beam-splitter. The measurement set-up outside the liquid helium dewar that contains the HEB mixer and a CITLF4 0.5-5 GHz SiGe LNA [9] is non-evacuated.

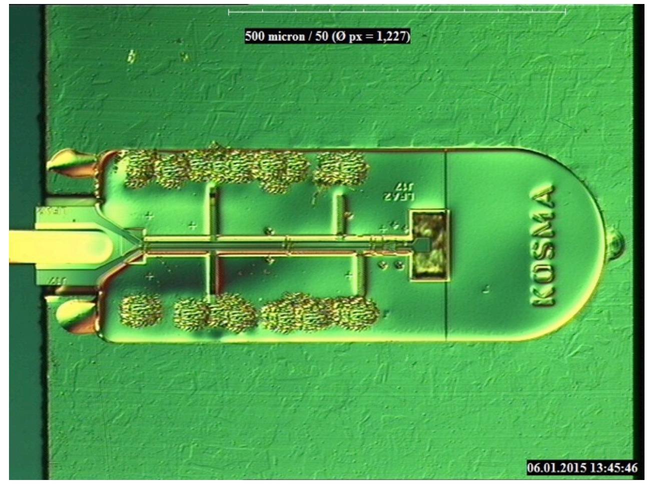

Fig. 2 Microscope photograph of a LFA HEB device mounted the its waveguide block. The use of difference interference contrast shows subtle height differences and explains the false colour of the gold layers.

The noise temperature is measured using the LO power sweep method [10], to prevent that direct detection of the calibration load power by the HEB influences the heterodyne calibration. In this measurement the IF output power is measured in a 1-2 GHz IF bandwidth. The IF bandwidth of the HEB mixer is measured using a 1.5 GHz wide DFTS spectrometer and room temperature IF processing that maps the successive parts of the IF band onto this spectrometer band.

The measured noise temperatures, corrected for the full beam splitter transmission of the test set-up, and the IF bandwidth measured at the same bias conditions are summarized in Table 1. For a better comparison of mixer uniformity we corrected for the wire-grid beam-splitter coupling. Also added in Table 1 is the relative LO power consumption per sub-array, This power is measured by replacing the beam splitter by a plane mirror, and then attenuating the LO power with a additional rotatable wire grid until the optimum pump level is observed in the HEB IV-curve. The incident LO power is calculated from the rotation angle of the grid, and is normalized that of the mixer with highest LO power consumption in each sub-array.

IV. Conclusions

We conclude that the delivered mixers achieve sufficient uniformity in noise temperature. All noise temperatures are similar to the present single pixel NbTiN microbridge L2 mixer operated in GREAT with the additional benefit of an increased IF noise bandwidth from 2.3 GHz to > 3.5 GHz due to the NbN material. The IF bandwidth varies more than we would have expected based the uniform DC device characteristics. This needs to be studied further. The relative LO power consumption is the less uniform parameter of the mixer. Receiver tests will have to show what the most effective approach for LO power balancing of the mixers is.

TABLE I
MEASURED MIXER DATA

Mixer Nr	Measured Performance Results		
	Trec [K]	**-3dB IF Noise Bandwidth [GHz]**	**Relative LO power consumption**
1.1	676	3.3	1.0
1.2	706	tbd	0.8
1.3	687	3.6	0.6
1.4	712	3.5	0.7
1.5	690	3.9	0.8
1.6	690	3.7	0.8
1.7	670	4.0	0.6
2.1	580	3.5	1.0
2.2	690	3.7	0.7
2.3	775	3.6	0.8
2.4	771	3.4	0.9
2.5	780	4.0	0.9
2.6	tbd	tbd	tbd
2.7	tbd	tbd	tbd

We have shown that it with a reasonable investment of resources it is possible to fabricate and test a sufficient number of waveguide mixers to fill a moderate size THz focal plane array to acquire at least a 10 times higher observing efficiency.

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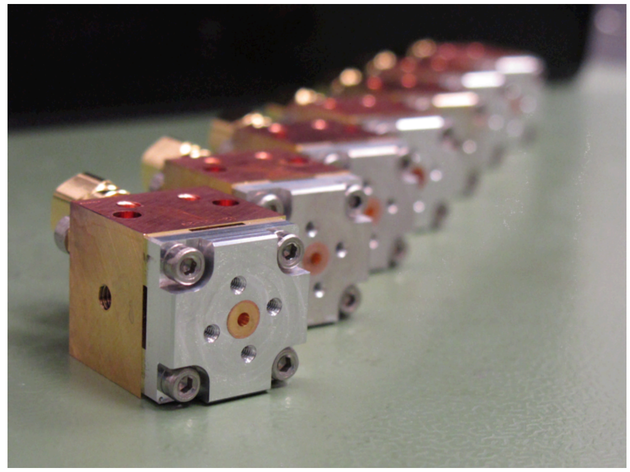

Fig. 3 Photograph of 7 of 14 flight mixers prior to delivery. Side length of the opto-mechanical interface with feedhorn is 16.5 mm.

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