1.9 THz balanced superconducting Hot Electron Bolometer mixers fully integrated on chip

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***Abstract*—We present the development of a balanced HEB mixer operating at 1.9 THz. The mixer is a waveguide-based and its complete RF circuit is integrated on a chip employing a planar 180° RF hybrid-ring coupler. Preliminary measurement results with a first fabricated batch of devices at 4.2 K shows well balanced pumping of the two separated micro-bridges of a mixer device, using a 1.9 THz VDI multiplier chain or a QCL LO.**

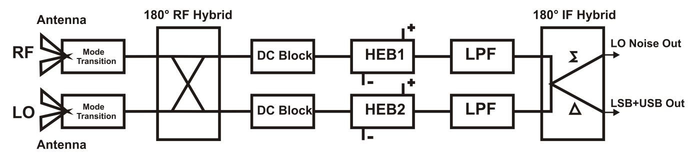

Fig. 1. HEB Balanced mixer schematic

I. Introduction

HOT -electron-Bolometer (HEB) mixers are currently the most sensitive heterodyne detectors above the 1THz. They are applied for example in the GREAT instrument on SOFIA flight observatory to observe the [CII] line at 1.9 THz in the interstellar medium (ISM)[1]. In order to achieve high resolution and time efficient observations focal plane arrays (FPAs) are used, where a balanced mixer configuration can be an appealing approach, see Fig.1. A balanced mixer removes the need for the existing diplexer or beam-splitter for combining the LO and sky signal, thereby allowing an efficient use of local oscillator power. Putting the complete RF circuit on chip avoids the development of waveguide circuitry with dimensions considerably smaller than the waveguide itself. While this is still possible with precision CNC mechanical fabrication at lower frequencies, THz waveguide circuitry is commonly defined and fabricated using some sort of photolithographic technique. There have been two groups that reported about the 1.3 [2] and 2.7 THz balanced HEB mixers [3] based on 90 ° waveguide hybrid couplers. First work uses the technique of putting metal over a photo-lithographically patterned thick SU-8 [4]. The latter case is based on waveguide structures etched in Silicon. Our group has already developed a balanced on chip mixer around 460 GHz [5], showing that the on chip approach can be successful. In this work, we present the development of 1.9 THz balanced HEB mixers where we are using a 180° ring RF-hybrid coupler. Using a standard through waveguide for the LO and RF input, the designed isolation between the LO and sky signal is at least -30 dB in the final mixer circuit. All the RF elements are defined directly by the E-beam lithography on a SOI substrate. This brings advantages of reducing the complexity in the fabrication and improving re-producibility which is especially important in the development of THz-FPAs.

II. Design

We used CST^{TM}studio suite to design and simulate the THz mixer circuit established in Au coplanar (CPW) and slot lines on a 3μm Silicon substrate. The complete design of a 1.9 THz balanced HEB and its RF performance are shown in the Fig.2a and Fig.2b, respectively. The circuit consists of a co-planar

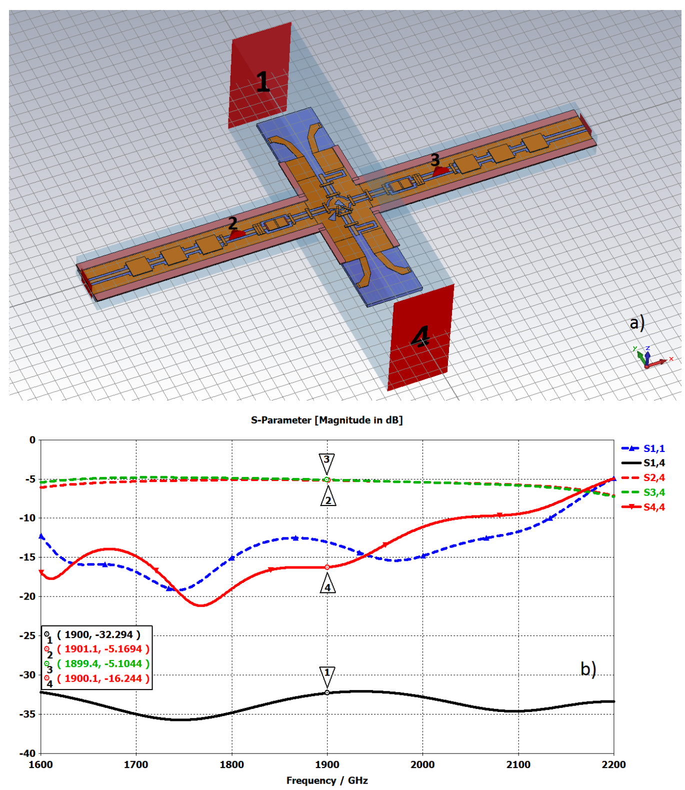

Fig. 2. a) Complete design of a 1.9 THz balanced HEB mixer on a 3 μm silicon b) S-parameter results of the simulated circuit in 'a' showing isolation (S1,4) between port 4 and port 1(opposite to the port 4), reflections at the port 4 (S4,4) and 1 (S1,1), and transmission from port 4 to the two HEBs (discrete ports 2 and 3)

ring hybrid coupler to equally distribute the LO and sky signals with 180° and zero phase differences to the two HEB bridges. Two slotline E-plane planar antennas are implemented to couple the signal and LO from the waveguide channels (50×100 μm^2) to the chip. Two NbN HEB microbridges which are integrated oppositely in gaps of the CPW transmission lines show the impedance of about 120 Ohm at 20 K for a dimension of 3 μm width, 200 nm length and about 4.5 nm thickness. Two blocking capacitors prevent on chip coupling between the two HEBs at the IF and at DC. S-parameter results show at 1.9 THz the amplitude imbalance between two signals is almost zero and reflection at waveguide ports is less than -10 dB over a Band from 1.6 to slightly above 2 THz with an isolation better than -35 dB the whole band.The phase imbalance is about ±2 degrees.

III. Fabrication and DC-Characterization

All mixer circuit elements on one chip are defined and written by the E-beam lithography. A detailed description of the Cologne HEB fabrication is given in [6]. The measured critical temperature (Tc) of about 4.5 nm sputtered NbN film on the SOI wafer is about 10.5 K. An important characteristic in the balance mixer circuit is that the two HEBs on one chip show very similar DC - responses.

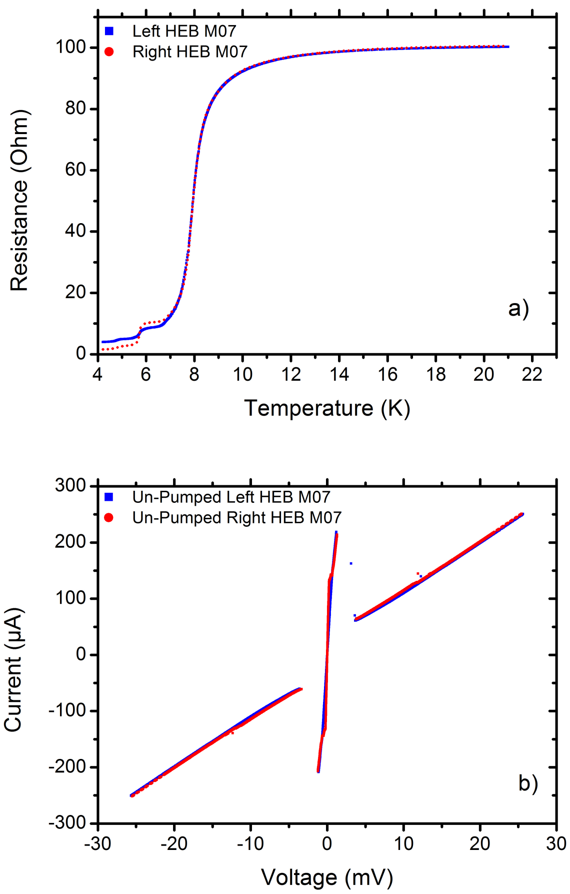

Fig. 3. a)and b) Measured R-T and I-V of the device M07 in liquid Helium before separation and SOI back side etching

The R versus T measurement in liquid Helium of the final micro-fabricated device before SOI back side etching and device separation, shows a Tc of about 8 K Fig.3a. The Ic of the same device is around 220 μA Fig.3b. This device is selected from the sector M and row number seven of the lithography fabrication mask. RN (HEB impedance at 20 K) is about 100 Ohm which is lower than 120 Ohm design value. However, the tolerance analysis in CST shows that we can accept such an impedance difference of the HEB bridges.

IV. RF Measurement

The mixer device is mounted in a machined CuTe alloy E-plane split waveguide block.The signal and LO are coupled by two waveguide horns. Two intermediate microstrip IF boards and two SMA connectors are used to extract the generated IF signals, and supply the DC bias at the output ports. In order to pump the mixer, 1.9 THz multiplier LO chain from VDI or an in-house developed QCL LO [7] is applied. In Fig.4a pumped IVs of two HEBs for the device M04 are shown. The relative power imbalance between the two HEBs is estimated by the Isothermal approach to be about 10% at a maximum, based on the single mixer results of the LFA development [8]. This should be acceptable for the balanced mixer performance. Unfortunately, due to technical difficulties, we could not apply

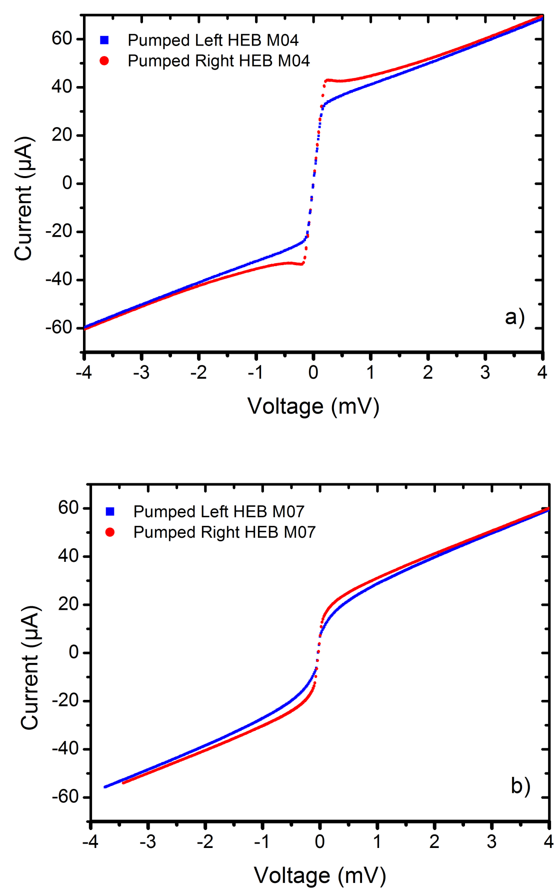

Fig. 4. a) Pumped IV curve of the device M04 in dewar with the VDI multiplier chain,b) Pumped IV curve of the device M07 in dewar with the QCL LO

RF signal from both ports.This prohibited any real balanced mixer measurement. To check if the circuit itself works also from the side that we were not able to apply RF, a new device (M07), with a flipped direction was built in. In this way, the other side of the chip is pointing towards the horn that is able to supply RF-signal. The measured pumped IV-curves for this configuration are shown in Fig.4b. To get a preliminary idea about the sensitivity, we performed a noise temperature measurement from the one accessible port, using a 24 μm thick Mylar beam-splitter in vertical polarization. The measured noise temperature, over a 1-2 GHz IF bandwidth is approximately 7000 K. This is the noise temperature of one of the mixers with two HEBs. Each HEB mixer receives only half of the input power unavoidably due to the coupling via the ring coupler. Therefore, a proper estimate for the noise temperature of a single mixer would be around 3500 K.

V. Summary

We have designed, fabricated and characterized the 1.9 THz balanced HEB mixer on one chip using a 180° planar ring hybrid. The initial RF measurement shows possible pumping of two HEB bridges with about 10% power imbalance. Further on, balance heterodyne measurement to obtain IF noise temperature is not executed due to technical difficulties. Single mixer heterodyne measurement shows a noise temperature of about 3500 K.

Acknowledgment

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