Development of Membrane Based Quasi-optical HEB Mixers at 1.4 THz

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Abstract— **In this paper we present our recent design of quasi-optical membrane based superconducting hot electron bolometer (HEB) mixers at 1.4 THz. The HEB device is coupled to a double slot antenna on a thin membrane. The THz radiation is focused onto the antenna by a parabolic off-axis mirror and a back-short is placed behind the membrane to increase the gain of the antenna.**
The whole structure including the HEB, the antenna, the back-short and the off-axis mirror was designed with the aid of the full wave electromagnetic solver CST Microwave Studio. In order to evaluate the impact of the double slot antenna dimensions we carried out two quite different designs, for the same HEB. The input impedance and the radiation pattern have been simulated. Heterodyne and FTS measurements are being performed to evaluate the impact of the two antenna designs on the mixer performance.

I. INTRODUCTION

Superconducting HEB mixers are the most sensitive mixers at terahertz frequencies. Different technical layouts and coupling structures for HEBs have been developed and tested. In this paper, we describe the development of a membrane based quasi-optical HEB mixer at 1.4 THz. Observations with a 1.4 THz heterodyne receiver enable us to detect the transitions of CO, H_2D^+ or N^+. Such observations can improve our understanding of cores of high and low mass star formation and of the warm ionized medium in the galactic ring, respectively.

We propose a new quasi-optical configuration where a mirror rather than a lens focuses the incoming radiation onto a double slot antenna (DSA). The antenna and the HEB are on a 1.4 µm thick membrane and a back-short at $\lambda_0/4$ enhances the coupling efficiency. This configuration is expected to have several advantages: At high frequencies the device manufacturing is easier than in the case of a device using thick substrate. The use of a mirror has smaller losses than the use of a lens, which has dielectric losses.

In order to investigate the importance of the antenna dimensions and the IF filters, we carried out two quite different double-slot antenna designs, which allows us to perform a direct comparison.

II. MIXER DESIGN

Both antennas were designed for 1.4 THz and use a 1.4 µm thick stress-less layer of Si_3N_4/SiO_2 as a membrane. When the thickness of the dielectric supporting the slot antenna is less than 0.04 λ_d (with λ_d the wavelength into the dielectric), the antenna is acting as if suspended in free-space [1]. Therefore for a double slot antenna on membrane the slot length needs to be around 0.75 λ_0 [2] which is approximately 2.5 times larger than in the case of an antenna on a thick silicon substrate.

For our first membrane based antenna we simply applied the scaling factor of 2.5 on the standard design of a double slot antenna on thick silicon substrate and the back-short is placed at a distance of $\lambda_0/4$ behind the antenna. Then, we optimized the parameters of the antenna (width (W), length (L) and separation (S) of slots) with CST to refine the results and to obtain the desired resonance frequency with an impedance close to 75 Ω which equals the impedance of the HEB. The back-short is also optimised by adjusting its size in order to increase the gain of the antenna. The beam pattern is not symmetric and seems to be deformed by the geometry of the intermediate frequency (IF) output Fig. 2.

In order to compare and to evaluate if there are critical parameters in the conception, which could influence the performances of the mixer, we have tried a different approach for the membrane based antenna design. The slot length L is kept around 0.75 λ_0 as in design 1, but the W/L ratio is chosen between 0.02 and 0.07 to get an antenna impedance between 50 and 100 Ω [3]. In design 2 the width W is 8 µm, compared to 22 µm in design 1. The separation S is set to around 0.17 λ_0 as in general case (in design 1: S = 2.5 x 0.17 λ_0). Moreover, special care has been taken to keep the symmetry of the beam pattern by extending part of the ground plane on the opposite side of the IF output. The designed membrane based DSA and the simulated beam patterns are shown in Fig. 1 and Fig. 2. It can be seen that for the second approach the slots are much thinner and closer to each other than for the first one. It is interesting to note that design 1 has a simulated radio frequency (RF) bandwidth at -15 dB of 330 GHz whereas design 2 is more selective with a RF bandwidth of 160 GHz. The symmetry of the beam pattern is restored for design 2, which is due to the ground plate extension opposite the IF circuit.

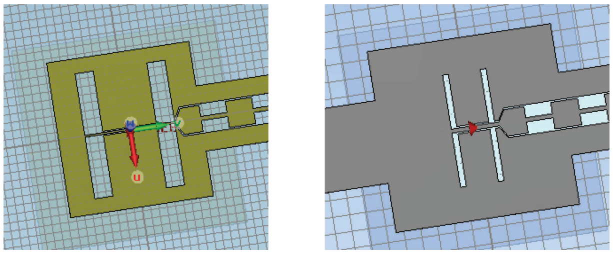

Fig. 1 On the left, design 1. On the right, design 2 where the slots are thinner and less spaced than in the first case. Both pictures have the same scale.

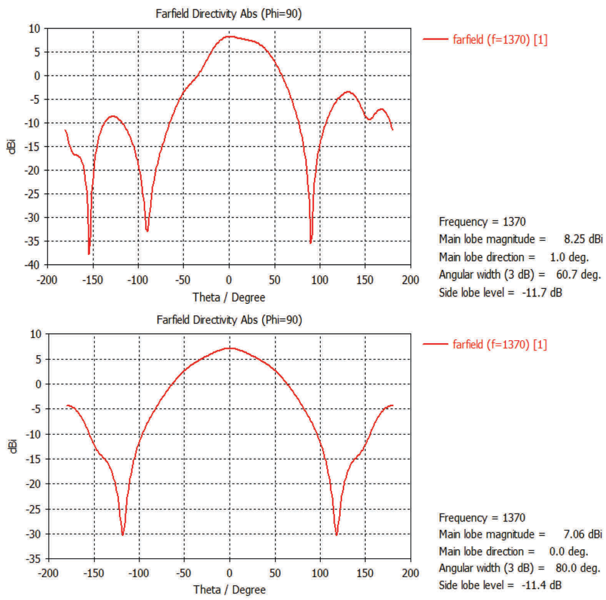

Fig. 2 On top, the beam pattern of design 1, it is deformed by the geometry of the IF output. Below, the beam pattern of design 2, the symmetry is restored.

III. Experiments

The membrane based HEB devices and the two antennas have been fabricated according to the process developed at LERMA/LPN [4], the NbN superconducting microbridge is 0.2 µm long, 2 µm wide and 3.5 nm thick with a normal resistance between 75 and 90 Ω. The HEB device is mounted into a mixer block in the focal plane of the off-axis parabolic mirror (Fig. 3). Heterodyne measurements around 1.4 THz are underway with a VDI multiplier chain as local oscillator. FTS measurements will be performed to compare the RF bandwidth of both antenna designs. We'll present and analyse the measurement results in our poster.

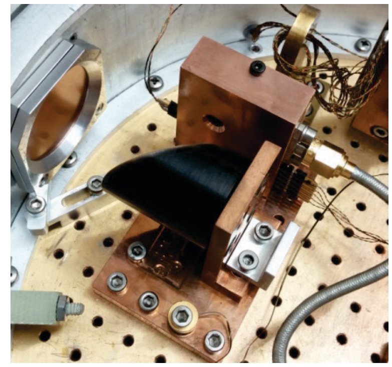

Fig. 3 Photograph of our membrane based HEB mixer block with the off-axis mirror inside the cryostat.

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