An Investigation of the DC and IF Performance of Silicon-membrane HEB Mixer Elements

Andrey Trifonov[1,*],C.Edward-Tong[1], Yury Lobanov[2,3], Natalia Kaurova[2], Raymond Blundell[1], Gregory Gol'tsman[2]
[1]*Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA*
[2]*Moscow State Pedagogical University, Moscow, Russia*
[3]*Moscow Institute of Physics and Technology, Dolgoprudny, Russia*
*Contact: avtrifonov@cfa.harvard.edu

Abstract — **We report on our initial development towards a 2x2 multi-pixel HEB waveguide mixer for operation at 1.4 THz. We have successfully fabricated devices comprising an NbN bridge integrated with antenna test structure using a silicon membrane as the supporting substrate. DC measurements of the test chips demonstrate critical current from 0.1 - 1mA depending on the size of device, with T_c of around 10 K and $\Delta T_c \sim 0.8$ K.**

I. Introduction

During the last decade the Hot Electron Bolometer (HEB) mixer was established as the device of choice for heterodyne receivers operating at frequencies above 1 THz [1]. As the HEB mixer technology matures, further improvement in mixer/instrument performance can be made via the exploration of new superconducting and substrate materials, the implementation of multi-pixel receivers, or both [2,3].

We are developing the technology required to implement a multi-pixel (2x2 matrix) HEB receiver, based on an NbN film deposited on a silicon membrane. In this paper, we describe the fabrication process and show preliminary results made on mixer test chips.

II. Silicon Membrane

The silicon membrane is an attractive substrate for THz HEB devices, in part because it makes use of well-established technology. Furthermore, while Si has a relatively high permittivity ($\varepsilon_r \sim 11.8$), the thickness of the supporting membrane can be made sufficiently thin (a few microns thick) for THz waveguide applications.

Waveguide HEB mixers typically incorporate crystalline quartz as the substrate material because of its low loss and low permittivity. However, an MgO buffer layer is needed to achieve an acoustic match between an NbN film and a crystalline quartz substrate The use of silicon, compared to quartz, as substrate material offers a number of advantages. Firstly, the lack of an additional (buffer) layer simplifies the fabrication process. The fact that the thin membrane supporting the NbN bridge and associated planar antenna is part of a larger , robust structure significantly improves chip handling, during the mixer chip installation process. Finally, membrane-based devices also facilitate the extension to multi pixel receiver array as all elements of the array can be fabricated on the same wafer.

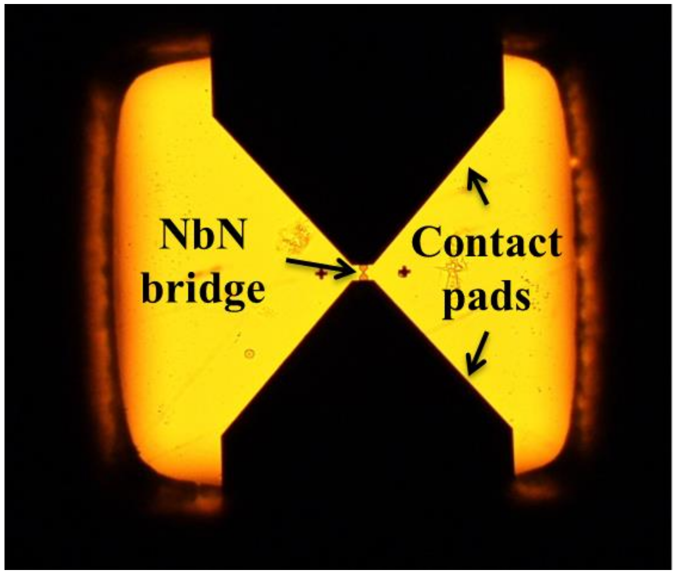

Fig. 1 Photo of a single NbN bridge on a silicon membrane. The clear membrane is visualized as the bright yellow square.

III. Fabrication

Test chips were fabricated to enable characterization of DC and IF performance. Using an SOI wafer as a substrate material, NbN and thin Au films are deposited by DC reactive magnetron sputtering in an *in situ* process [4]. This is followed by patterning of the superconducting NbN bridge using electron beam lithography and, several additional photo-lithographic and lift-off processes to define the planar antenna and contact pads. Finally, the silicon below the NbN bridge and antenna structure is etched from the back-side of the wafer, using the deep reactive ion etching process. The test mixer chips fabricated thus far measure 6 mm x 6 mm x 0.3 mm thick, with membrane thickness of 6 µm. A single element of the 2x2 matrix is shown in figure 1.

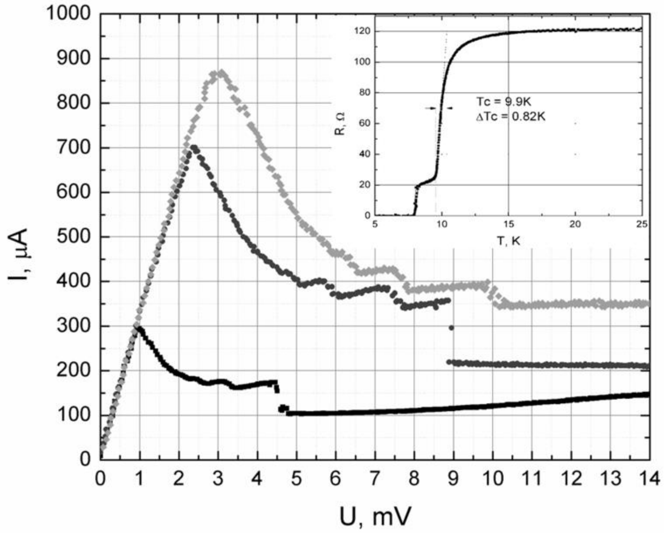

Fig. 2 Typical current – voltage characteristics of three of our HEB test devices. Referring to the insert, the main superconducting transition region corresponds to a T_c of 9.9K, and a transition width (ΔT_c) of 0.82K.

IV. Preliminary Results

We have successfully produced a set of test mixer chips using silicon membrane technology. A representative DC I-V curve for these mixers is given in Fig. 2. DC tests, made on a number of chips demonstrate critical current from 300 μA for smaller devices (2μm x 0.22μm) to 870 μA for the largest devices (5μm x 5μm). For all devices tested thus far, the main superconducting transition region lies in the range 9.5-10 K. This means that the deep reactive ion etching of the silicone substrate, which follows fabrication of the HEB mixer, has not adversely affected the superconductive qualities of the NbN film. Investigation of the IF quality of these HEB receivers is under way.

Acknowledgment

The research is partly supported by the Ministry of Education and Science of the Russian Federation, contract # 14.B25.31.0007.

References

[1] P. Putz, C.E. Honingh, K. Joacobs, M. Justen, M. Schultz, and J. Stutzki, "Terahertz hot electron bolometer waveguide mixers for GREAT," *Astron. & Astrophys.*, vol. 542, L2 , May 2012. doi: 10.1051/0004-6361/201218916.

[2] C. Risacher, Rolf Güsten, Jürgen Stutzki, Heinz-Wilhelm Hübers, Patrick Pütz, Andreas Bell, Denis Büchel, Ivan Camara, Rafael Castenholz, Mose Choi, Urs Graf, Stefan Heyminck, Christine Honingh, Karl Jacobs, Matthias Justen, Bernd Klein, Thomas Klein, Christian Leinz, Nicolas Reyes, Heiko Richter, Oliver Ricken, Alexei Semenov, Achim Wunsch, "The upGREAT heterodyne array receivers for far Infrared astronomy" IRMMW-THz 2014, 14-19 Sept. 2014, doi:10.1109/IRMMW-THz.2014.6956152.

[3] G. Gay, R. Lefèvre, Y. Delorme, F. Dauplay , A. Féret, T. Vacelet, L. Pelay, W. Miao, M. Ba-Trung, J.-M. Krieg, L. Pagani, "Membrane based quasi-optical superconducting HEB mixers at Terahertz frequencies" PROCEEDINGS- SPIE THE INTERNATIONAL SOCIETY FOR OPTICAL ENGINEERING; 8452; 8452 13, 2012.

[4] I.V. Tretyakov, M.I. Finkel, S.A. Ryabchun, A.I. Kardakova, S.V. Seliverstov, D.V. Petrenko, G.N.Goltsman, "Hot-Electron Bolometer Mixers With In Situ Contacts" *Radiophysics and Quantum Electronics*, vol. 56, nos. 8-9, Jan. 2014