Ultrabroadband 5 THz array receiver for extragalactic and galactic mapping

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Program: Strategic Initiative

Project Objective:

Recently, single-pixel heterodyne sensors aimed at the detection of [OI] line (4.7 THz) have been pursued. More instruments are planned for the near future (e.g., a 7-pixel array receiver for upGREAT instrument on SOFIA, DLR/Germany; a single-pixel receiver for GUSTO, SRON/Netherlands). However, none of them will be broadband enough to capture the entire spectral features, which will be encountered during a survey of the Galaxy. To address the need for faster imaging capability, we are producing a multi-pixel (16-pixel, at the end of the 3-year project) monolithic waveguide mixer block for 5-THz operation. The design is highly scalable and can be expanded into many tens of pixels in the future. This will far exceed the 7-pixels design of the recently deployed 4.7 THz channel on upGREAT instrument. In order to meet the demand for wider IF bandwidth, we are employing a Hot-Electron Bolometer (HEB) mixer based on high-T_C superconductor MgB_2 which has been developed at JPL. The previous JPL work has demonstrated the representative mixer operation with the noise temperature of 1,000-2,300 K in the frequency range of 0.6-4.3 THz and the noise bandwidth of $\Delta f_{IF} \approx 7$ GHz. The noise temperature is constant in the 5-15 K temperature. The current work advances this mixer even further by making mixer devices on Si membranes which can be embedded into waveguide mixer blocks. The goal in FY19 was to demonstrate the feasibility of the of such an approach. In order to do so, the membrane supported devices were designed and fabricated and the complete 5-THz array mixer block with 4 horn antennas was machined

FY19 Results:

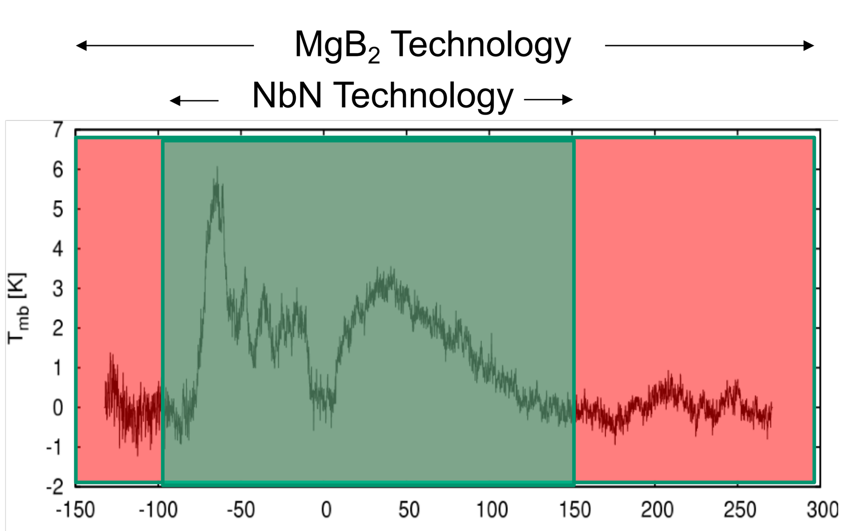


Figure 1. Measurements of [CII] line (1.9 THz) across the Galactic Center show a very large velocity spread between clouds ~ 400 km/s. In order to perform a similar survey for [OI] line an instantaneous bandwidth ~ 8 GHz or greater is required. It is not available using the SOA NbN HEB but it is available with novel MgB_2 HEB.

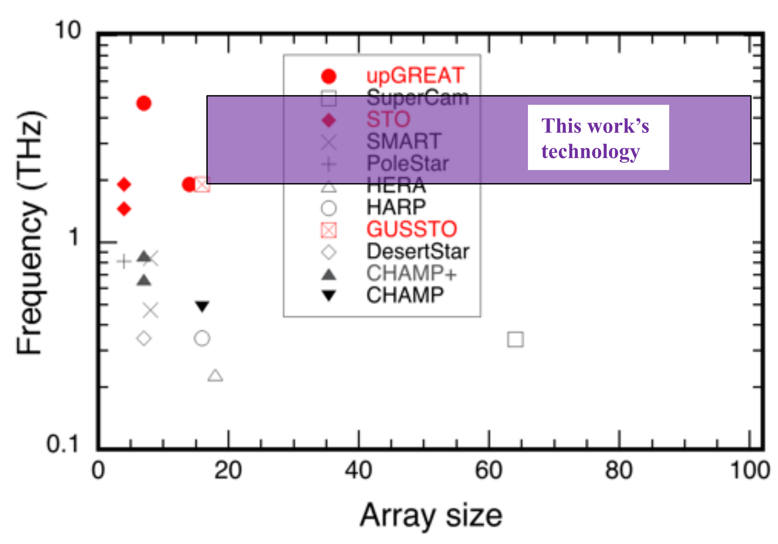


Figure 2. A multi-pixel array receiver can be implemented using monolithic array technology pursued in this work resulting in **less volume**, **less mass**, and less complicated fore-optics.

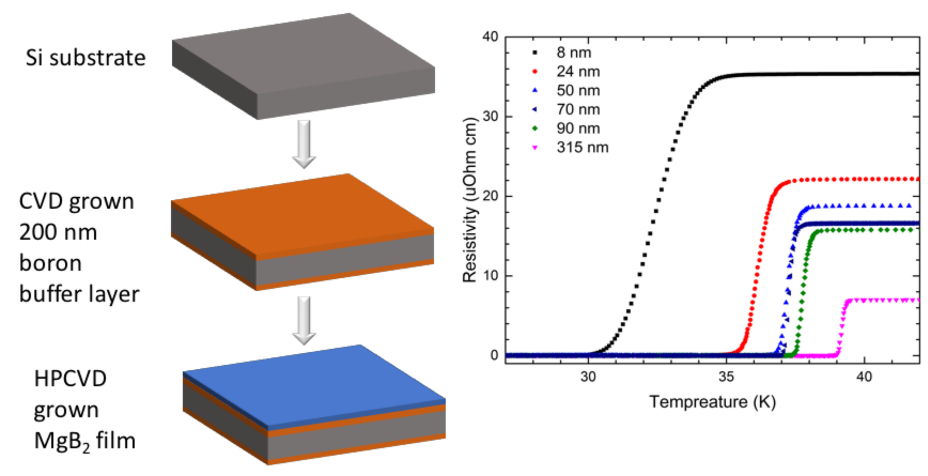


Figure 3. Fabrication process and superconducting transitions for MgB_2 films grown on Si membrane.

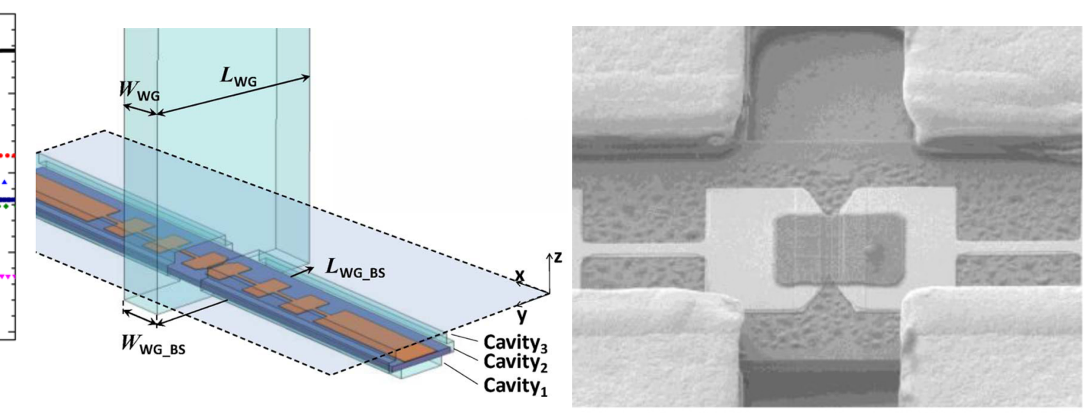
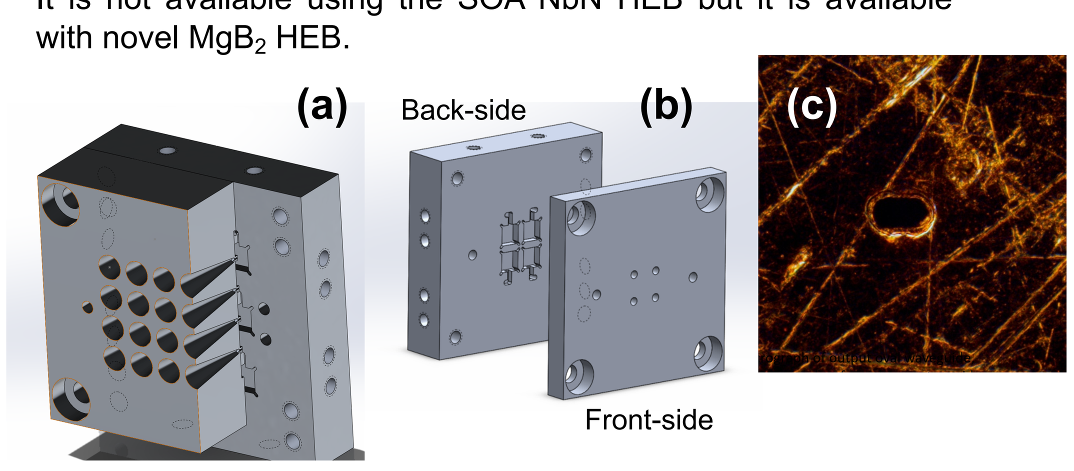
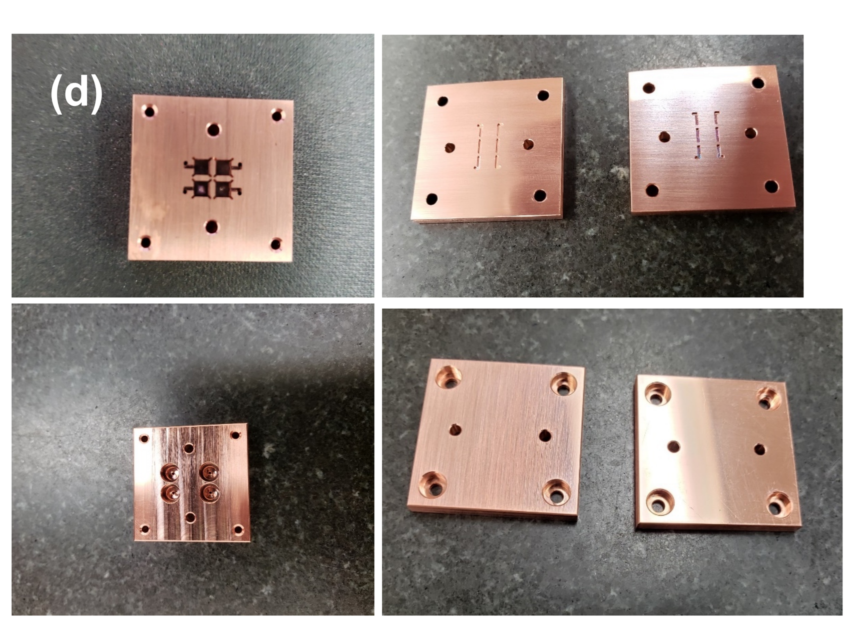


Figure 4. Design of the HEB mixer chip embedded into a waveguide block (left) and a single-pixel 2.7 THz NbN HEB mixer chip (right). Similar devices have been also achieved at 1.9 THz for the 16-pixel array block.





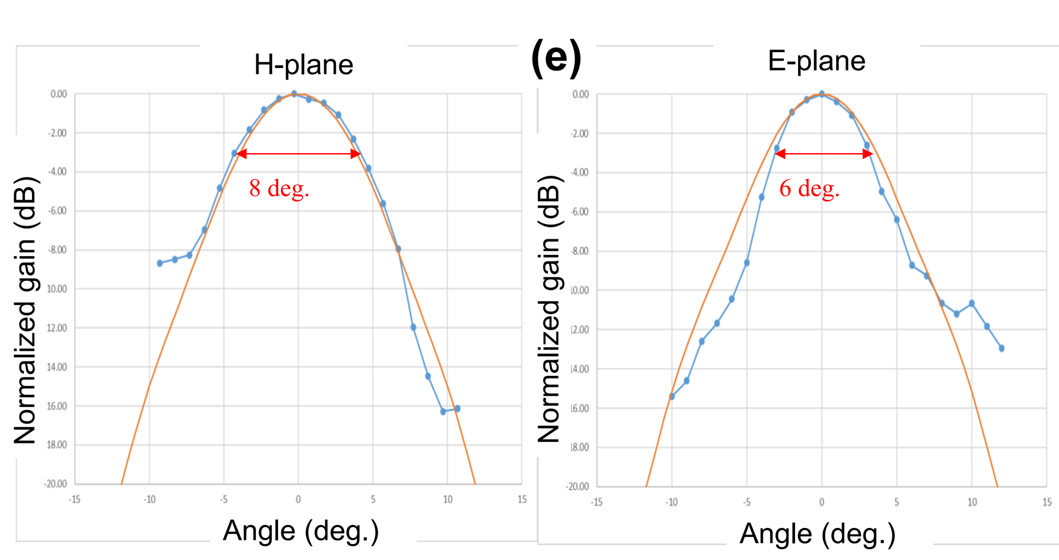


Figure 5. Summary of the micromachining effort. (a) CAD drawing of the 16-pixel waveguide mixer block; (b) CAD drawing of the front and back sides of the 4-pixel mixer block; (c) Optical micrograph of output oval waveguide, measuring 37 μm × 20 μm, taken from the back side of the horn; (d) Actual 4-pixel 5-THz mixer block machined from Cu; (e) Beam pattern data for a 5-THz horn-antenna.

- During FY19, a substantial amount of work has been carried toward achieving for the first time a mechanically machined monolithic waveguide mixer block.
- First waveguide mixer devices have been fabricated on SOI substrates and patterned for the use in 1.9 THz waveguides. The 1.9 THz 16-pixel mixer block has been previously developed as a part of the instrument efforts for STO-2 and SHASTA. Our plan is to demonstrate the novel MgB_2/Si mixers using these validated mixer blocks as a preliminary step towards the ultimate 5 THz array.
- Using the new Makino CNC tool at 169-121 prototype mechanical shop, it was possible to machine *in- situ* (with a micro-endmill completing the circular-to-rectangular transition) a 16-pixel 5 THz waveguide mixer horn-antenna front-end (Fig. 5(a,c)) and the complete 4-pixel block (Fig. 5(b,d). The small size of the array face allows one to use a flood illumination from a single LO source (QCL) for the entire array.
- A beam pattern has been measured for one of the 5-THz horn-antennas using a molecular gas laser emitting at 4.25 THz (Fig. 5e). The beam quality is good and thus the machining approach for achieving such high-frequency waveguide circuits is validated.
- The achieved blocks will be suitable also for the low-T_C NbN HEBs. Several frequency channels (up to 2.7 THz) will be used on ASTHROS balloon instrument. In view of the interchangeability of NbN and MgB_2 mixer chips, MgB_2 HEB can be fast-tracked into the field validation on existing platforms.

Benefits to NASA and JPL (or significance of results):

The obtained results demonstrate the good progress made in FY19 towards achieving the 5-THz heterodyne array based on the novel MgB_2 HEB mixer devices. First mixer devices on SOI wafer have been achieved and characterized. A complete 5-THz 4-pixel mixer block has been machined. The FY20 work will produce the 16-pixel 5-THz mixer array suitable for testing. The goal for future instruments is to have in excess of 100 pixels for a heterodyne array. Our prototype integrated monolithic mixer block has 16 pixels, with no practical limit to the number of elements. MgB_2 HEB mixer has the large IF bandwidth meeting the science requirements for detection of [OI]@4.7 THz line. The emerging THz QC VECSEL is an extremely powerful LO source capable of pumping the entire array without any special beam multiplexing technique. All these pieces together should result in a new THz heterodyne array technology for future instruments.

Publications & Presentations:

- B. Karasik, D. Cunnane, J. Kawamura, N. Acharya, W. Withanage, X. Xi, "THz Heterodyne Sensors Based on MgB_2," *presented at the Applied Superconductivity Conference 2018 (ASC2018), Seattle, Oct.28-Nov.2, 2018.*
- B. Karasik, D. Cunnane, J. Kawamura, D. Hayton, N. Acharya, W. Withanage, X. Xi,"Far- and Mid-IR Heterodyne Detectors Based on MgB_2," *presented at the 44th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz 2019), Paris, France, Sep. 1-6, 2019.*

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