High temperature superconducting MgB2 heterodyne receivers

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Program: FY22 R&TD Strategic Initiative
Strategic Focus Area: Long-Wavelength Detectors - Strategic Initiative Leader: Charles Lawrence

Objectives:

The primary objective of this effort is to raise the technology readiness level of MgB_2 HEB mixer from TRL 3 to TRL 5 while taking full advantage of 20K operation. This effort will significantly reduce the cooling requirement, adjust the receiver architecture to take advantage of the warmer 20K operational temperature and produce components that can be flow over with near state-of-the-art performance. 20K operation is enabling for HEB mixers to achieve enough IF bandwidth to fully resolve galaxies at several THz. The net result will be state-of-the-art heterodyne performance that can fit within a SMEX cost cap.

<u>Our objectives to this task in FY22 (Year 1) were</u>:

- Develop a 20K receiver test bench including a mechanical cryocooler, optics, quasi-optical mixer block, local oscillator, IF system, windows for Y-factor or gas cell measurements and coherent signal injection. This will allow all the relevant mixer parameters (e.g., system noise temperature, IF bandwidth, RF bandwidth, conversion efficiency) to be evaluated systematically.
- Design a quasioptical mixer block
- Develop quasi-optical antenna designs that are linear polarized and matched to a range of MgB_2 film sheet resistances.
- Fabricate MgB_2 mixer devices for life testing

Background:

The present state-of-the-art for MgB_2 is that films with higher critical temperature and critical current produce better mixers. The IF bandwidth increases rapidly with temperature while the noise increases more slowly until close to the critical temperature where mixing become ineffective. It is also known that MgB_2 films appear to degrade when exposed to humidity. Finally, there is good infrastructure to test at 4.2K (Liquid Helium) but not at the desired 20K operational temperature.

From a strategic perspective, the technology developed in this proposal will be the key technology for future space missions requiring heterodyne receivers that would follow in this time order:

1. SmallSat proof of concept 2. MIDEX-class survey mission 3. THz interferometer pathfinder 4. Swarm Imaging Interferometer

Approach and Results:

The primary activity for FY22 was the test bench construction. This borrowed the 20K chamber approach used in the development of Planck receivers allowing temperature control around 20K as well as equipment for analyzing all aspects of performance. Year 1 provides the necessary infrastructure to perform meaningful device evaluations and advance the TRL levels.

- A test bench has been developed (Fig. 1) using the configuration like that initially used to test Planck LNA based receivers (Fig. 1). All the components have been procured and the mechanical support infrastructure has been fabricated;
- A 6-pixel quasioptical mixer block has been designed and fabricated (Fig. 2);
- Quasiptical HEB mixers have been fabricated using a 10-nm thick HPCVD-grown MgB_2 film. The mixers were tested at 2.5 THz and 3.3 THz using far-IR gas laser and QCL as local oscillators (Fig. 3);
- A new MgB_2 film development effort has been going on using a sputtering technique. The advantage of this is the possibility to fabricate HEB devices on a large 4” Si wafer thus exploring a variety of designs in a single fabrication run (Fig. 4).

Significance/Benefits to JPL and NASA:

This task is to demonstrate a robust lab system for a SmallSat payload. By increasing TRL to 5, it will put JPL in much more competitive position for winning a SmallSat-class AO in the near-term. In addition, this technology enables a class of heterodyne array receivers which can be deployed on a large space telescope (e.g., MIDEX-class mission) at a significantly lower cost that the SOA receivers requiring cryocooling to 4K. Finally, we envision applications in swarm interferometry in space using a constellation of SmallSats as well as a large interferometer on the Moon. The MgB_2 HEB mixer and QC-VECSEL technologies are unique and give to JPL a competitive edge.

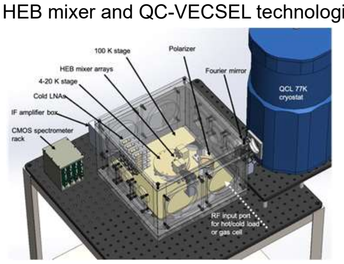

Figure 1. CAD drawing of the THz test bench based on the 2-stage Stirling cryocooler

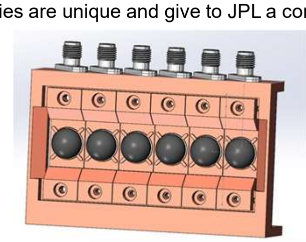

Figure 2. 6-pixel quasipotical HEB mixer using AR coated Si lenses at 2.7 THz and 4.7 THz

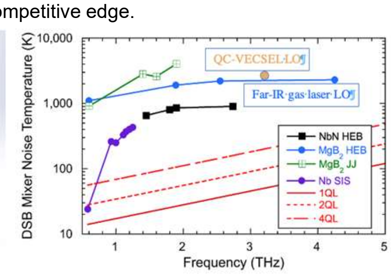

Figure 3. State-of-the-art of JPL THz mixers

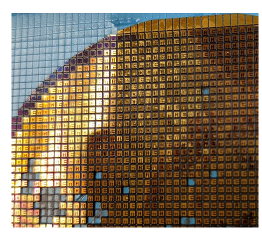

Figure 4. Fragment of a 4” Si wafer with many MgB_2 HEB devices.

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Publications:

[A] B. S. Karasik et al, “THz heterodyne receiver for astrophysics using MgB_2 HEB mixer,“ *presented at the SPIE AT+I Symp., Montréal, Québec, Canada, Jul. 17-22, 2022.*

[B] C. Curwen et al., “THz Heterodyne System Using Novel Mixer and Local Oscillator Devices,” *presented at the 47th IRMMW-THz 2022 Conf., Delft, The Netherlands, Aug. 28-Sep. 2, 2022.*

[C] C. A. Curwen et al., “Broadband THz heterodyne receivers using an MgB_2 superconducting hot electron-bolometer and laser local oscillator sources,” *JATIS, submitted*

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