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Optical Breadboard Integration of a 3.5-THz Quantum-Cascade Laser Local-Oscillator for the LOCUS Atmospheric Sounder

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INTRODUCTION

An “elegant breadboard” system has been developed, which demonstrates the integration of terahertz-frequency (THz) sources, optics and compact cryocooler technology for the LOCUS satellite (Linking Observations of Climate, the Upper Atmosphere and Space Weather) [1]. This proposed satellite instrument has the aim of providing the first global mapping of key molecular species within the mesosphere and lower thermosphere (MLT) from low-earth orbit (LEO), using compact radiometers operating in the 0.8–4.7-THz band and a set of infrared detectors. The LOCUS THz radiometers will incorporate planar-Schottky-diode (SD) mixers, driven using waveguide-integrated local-oscillators (LOs). The LOs will be based on SD multipliers operating at 0.8 and 1.1 THz, and THz quantum-cascade lasers (QCLs) operating at 3.5 and 4.7-THz. A key technological challenge, addressed by the LOCUS elegant breadboard, is the integration of these components into a compact and robust satellite payload, including space-qualified cryocooler technology, and suitable fore-optics. In this paper, we discuss recent progress in QCL integration within the 3.5-THz channel.

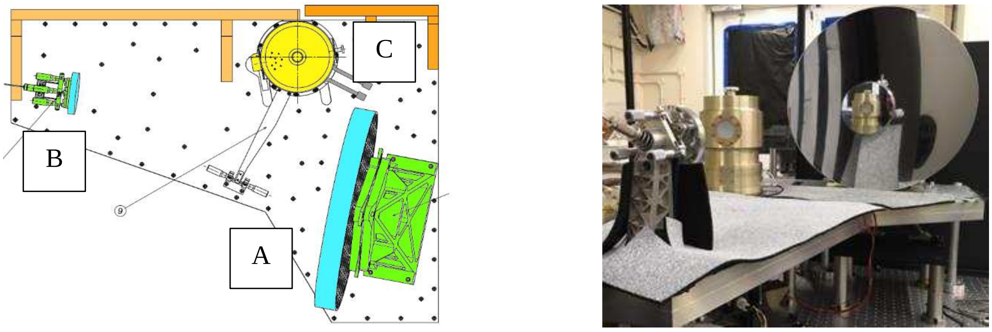

Fig. 1 (Left) Top-down CAD illustration of LOCUS breadboard: A, B = telescope optics, C = cryocooler. (Right) Photograph of fully-constructed system.

SYSTEM ARCHITECTURE

Figure 1 shows a CAD illustration and photograph of the LOCUS elegant breadboard system, which is constructed on a custom-machined aluminium supporting plate. A Cassegrain telescope configuration (A,B) is used for the fore-optics to yield a compact instrument envelope (< 1 m^3). A 480-mm-diameter diamondturned concave primary mirror, and 100-mm convex secondary were designed to yield 2-km atmospheric-layer resolution from an 800-km altitude, and onto a 25-mm focal plane diameter.

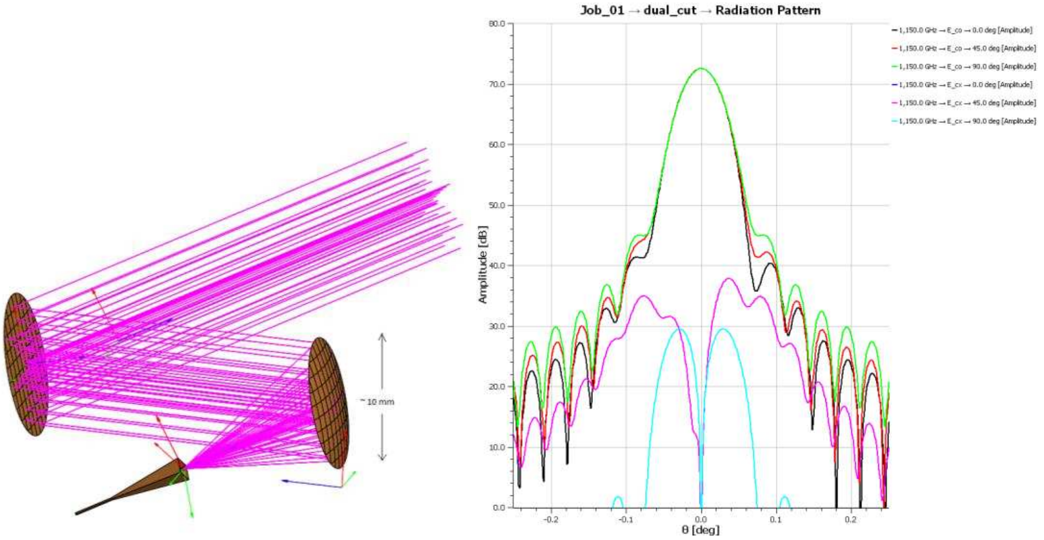

Fig. 2 (Left) Periscope arrangement of the horn receiver for an interim flight-usage of the breadboard. (Right): Low side-lobe performance of the overall beam with the periscope solution.

Figure 2 shows additional detail of the optical system design. Practical measures included within the design scheme include limiting the mirror aperture angle to 60° for compatibility with the available interferometers for system testing, limiting the bi-conical nature of the secondary mirror to avoid manufacturing complications during polishing, and introducing sufficient tilt into the optical path to allow placement of the cryostat for room-temperature tests. Although the outer cryostat enclosure would not be present within a final flight-model, the optical focal-plane in the test system lies within a compact, space-qualified Sterling-cycle cryocooler.

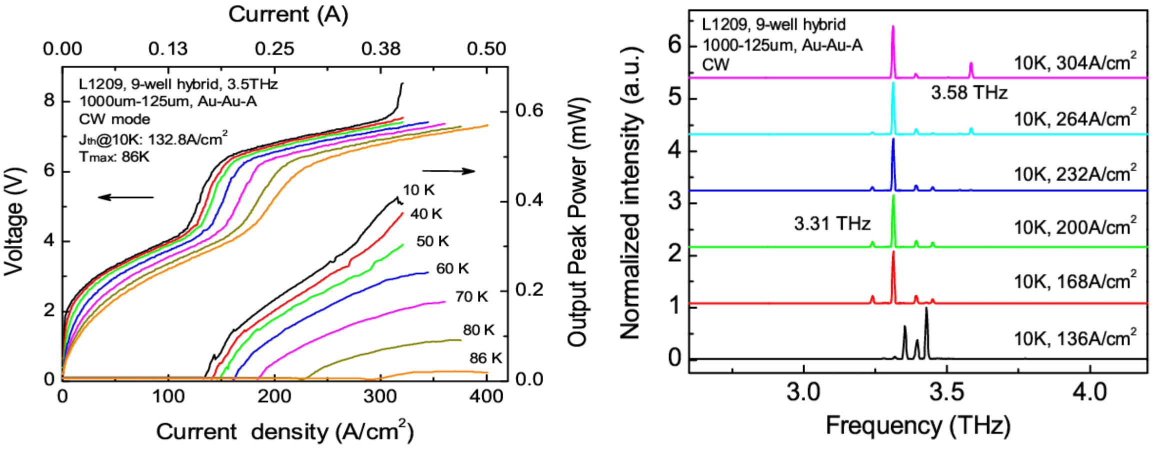

Fig. 3 (Left) THz output power and device voltage as a function of drive current-density for unmounted ~3.5-THz QCL. (Right) Measured emission spectrum, using Fourier-Transform Infrared (FTIR) spectrometer.

Within a flight-ready system, the mixer and LO for all channels will be mounted within the cooler. In the present configuration, however, the 3.5-THz LO source under-test has been mounted individually, and used as an emitter to test the optical system integration. For the LO, a ~3.5-THz QCL, based on the active region in [2] has been processed into a double-metal ridge waveguide with 75-µm width, and the substrate reduced through mechanical and chemical etching to a thickness of 90 µm. The device was cleaved to a length of 980-µm and diced into a 110-µm-wide chip. The performance characteristics for a reference device with similar characteristics are shown in Fig. 3. The reference device was mounted in a continuous-flow helium cryostat and driven in continuous-wave mode using a dc power supply. The emitted power was monitored using a pyroelectric detector, which was calibrated against a photoacoustic THz power meter. A peak operating temperature of 86 K and a maximum collected output power (at 10 K) of ~0.4 mW were recorded. The emission spectrum was recorded using a Fourier-Transform Infrared (FTIR) spectrometer and a helium-cooled bolometric detector. A principal emission peak at 3.31-THz was found to dominate the spectrum, with ~15 dB side-mode suppression.

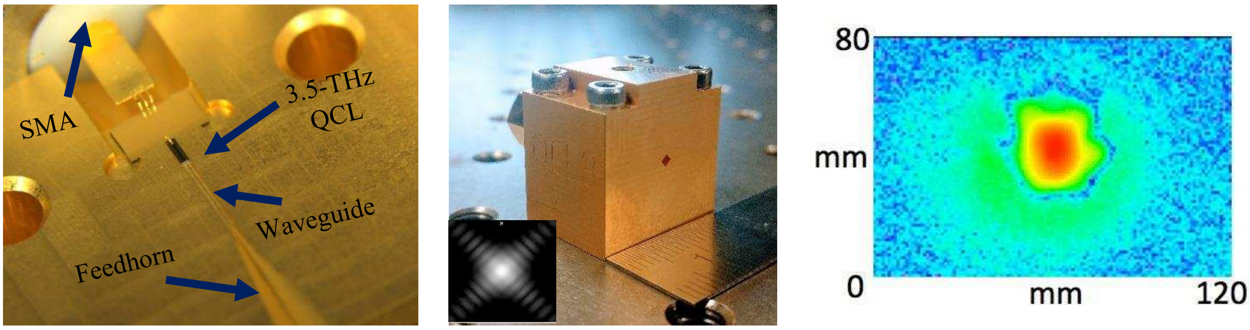

Fig. 4 (Left) 3.5-THz QCL mounted within a 150-µm-wide waveguide channel. (Centre) Complete assembled QCL/waveguide enclosure, with diagonal feedhorn aperture visible. Inset: Simulated far-field beam pattern. (Right) Far-field THz emission profile measured for the block-integrated QCL structure

A separate QCL was subsequently solder-mounted within a precision micro-machined 130-µm-wide × 75-µm-deep channel within an oxygen-free copper enclosure (Fig. 4:left), and ribbon-bonded to an integrated SMA connector. A second, symmetrical copper section was attached above the QCL to form a rectangular waveguide enclosure around the device. In contrast to our previous work [3], a single QCL ridge has been used, and a diagonal feedhorn (Fig. 4:centre) has been integrated into the waveguide structure to improve free-space coupling. The QCL waveguide block was mounted within the cryocooler and driven in continuous-wave (cw) operation using a dc current source. The cryocooler was found to provide sufficient heat-lift at the optimal QCL bias (3 W) and maintained a stable temperature of 60 K. The THz output power was measured using a photoacoustic power meter as > 8 mW, and the beamwidth was found to be 5–8°, using a raster-scanned Golay detector positioned in the far-field of the feedhorn antenna.

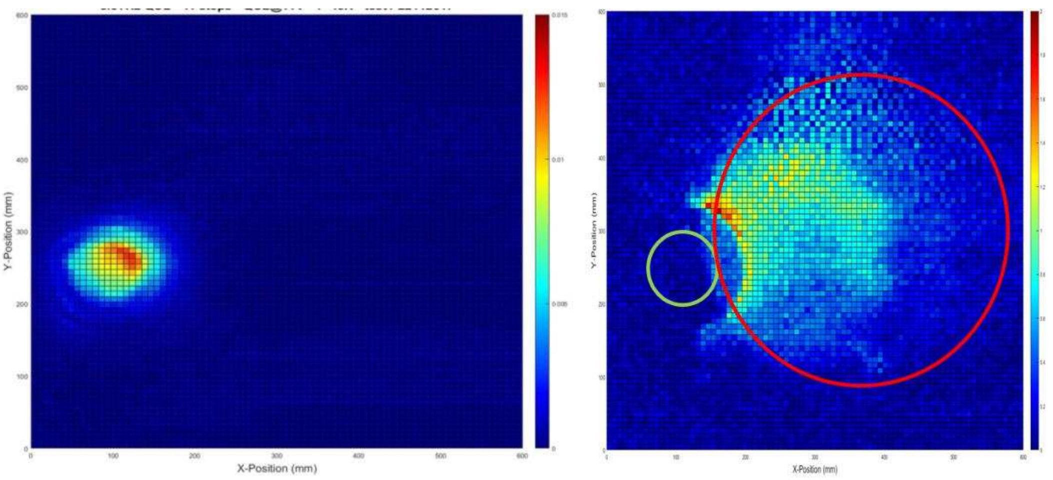

Fig. 5 (Left) Scan across breadboard optics, with secondary mirror removed. (Right) Measured near-field profile from Cassegrain optics showing location of primary and secondary mirrors (large and small circles, respectively).

The telescope optics were positioned and aligned on the breadboard, and the THz beam was measured, using the same technique, in the near-field of the primary mirror. Absorbing media were placed adjacent to the beam-path to eliminate stray reflections. Fig. 5:left shows the THz beam profile with the secondary mirror removed (ie., propagation of the beam from the QCL to the detector), indicating an approximately symmetrical emission profile. Fig. 5:right shows the profile obtained with both mirrors installed. Successful propagation of the ~3.5-THz signal has been obtained along the complete optical path. Subsequent alignment optimisation is expected to eliminate the slight field-truncation caused by the positioning of the secondary mirror, and beam-spill-over from the QCL source.

CONCLUSIONS

In conclusion, we have integrated a 3.5-THz QCL local-oscillator, waveguide and feedhorn within a space-qualified cooler, and installed these within an “elegant breadboard” system containing a demonstration of the fore-optics for the LOCUS atmospheric sounder. The QCL emission profile has been optimised through the use of a waveguide-integration scheme and a diagonal feedhorn, resulting in an approximately symmetrical emission with 5–8° beam-width. We have demonstrated successful propagation of radiation through a custom-machined Cassegrain optical system, although additional alignment steps will be required to optimise performance. This is a key step in raising the technology-readiness level of core system components for the proposed LOCUS satellite instrument.

REFERENCES

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