Evaluation of the efficiency of the mid-IR laser heterodyne spectrometer using hollow fibers

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Introduction

MIR heterodyne spectroscopy enables an unprecedented high-spectral resolution at 7 – 12 micron with resolving power > 10^6 and sensitivity close to the quantum limit[1]. Notable successes on Venus, Mars, Jupiter, Titan, and Earth have been accomplished by ground-based observations[2,3,4], meanwhile the space-born IR heterodyne spectrometer has never been done so far due to its volume, weight, and a precision of optical alignment. Rodin et al. (2015) proposed a compact, lightweight multichannel laser and heterodyne spectrometer for the ExoMars landing platform in near-IR by using a bundle of single fibers and directional couplers[5]. The solution for MIR, however, is still open issue.

The hollow optical fibers developed by Tohoku Univ. transmits electromagnetic wave with any wavelengths from X-ray to Terahertz-wave with low transmission losses (0.5 dB/m at 10 micron)[6].

Here we demonstrate the feasibility study of hollow optical fibers for MIR heterodyne spectroscopy for future solar system exploration missions.

Experimental Setup

An IR source from the target is combined with a laser local oscillator (LO) and is focused onto a MCT photodiode mixer. The resultant intermediate frequency in the radio region preserves the intensity and spectral information of the IR spectrum. A single 30cm-length hollow optical fiber is applied to lead the LO and the target to the beam splitter. Schematics of the experimental setup are shown in Figure 1.

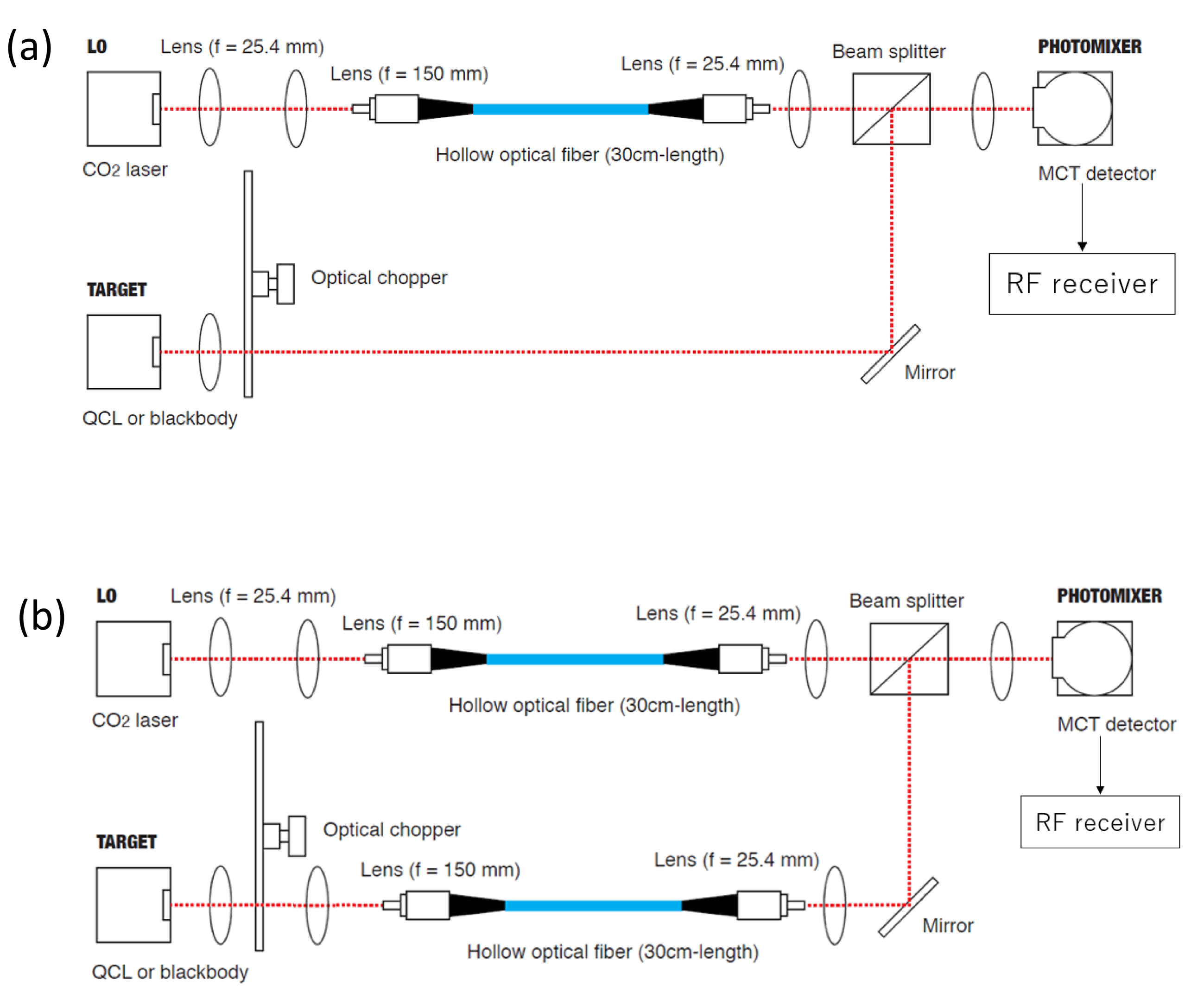

Fig.1 Optical configuration of the experimental setup. CO_2 gas laser as the LO. A room-temperature-type MCT generates an IF signal with a bandwidth of 250 MHz. A calibrated blackbody is applied for the hot load (400 degC). A room-temperature-type QCL is also applied for the target in order to assess the spectral feature. The backend spectrometer of 1.5 GHz resolved in 1Hz.
***(a)**Fiber is applied to lead the LO. (b)Fibers are applied to lead the LO and the target.*

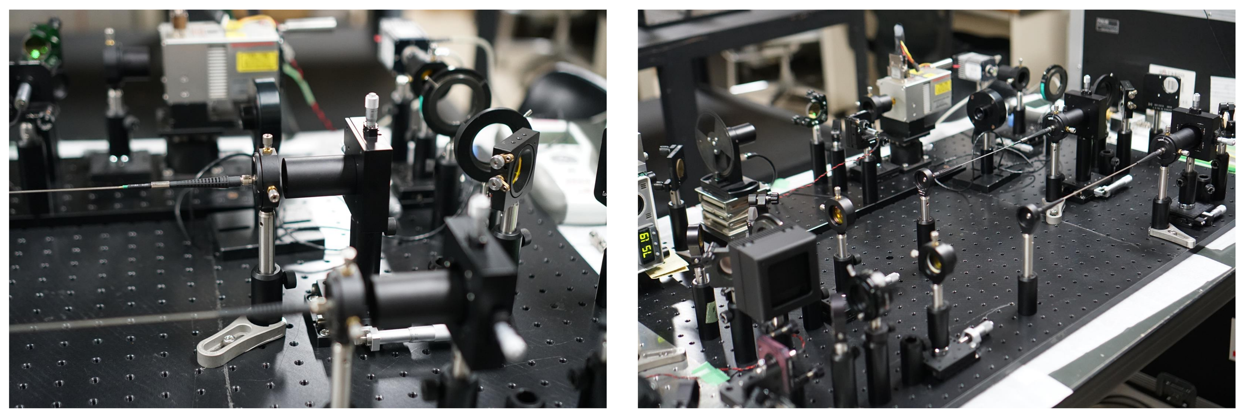

Fig.2 View of the optics and fiber of the experimental setup. The hollow optical fibers are set exchangeable with commercial SMA connectors.

Results

Transmittance

The transmittance of the hollow optical fiber including the commercial SMA connectors is typically measured in the system to be ~60% (up to 77% in the experimental setup) to a coherent light from CO_2 laser or QCL, and ~10% to broad and incoherent light from the reference blackbody. The measured output of a coherent light suggests an improvement comparing with conventional PIR fibers. Work on improving transmittance continues.

Setup (a) CO_2 laser + QCL

Figure 3 shows the spectral feature of the QCL emission line obtained at 0.5s interval by heterodyne measurement on the system shown in Fig.1 (a). Laboratory measurement with hollow optical fiber shows a quite well match with our previous setup without fiber[7].

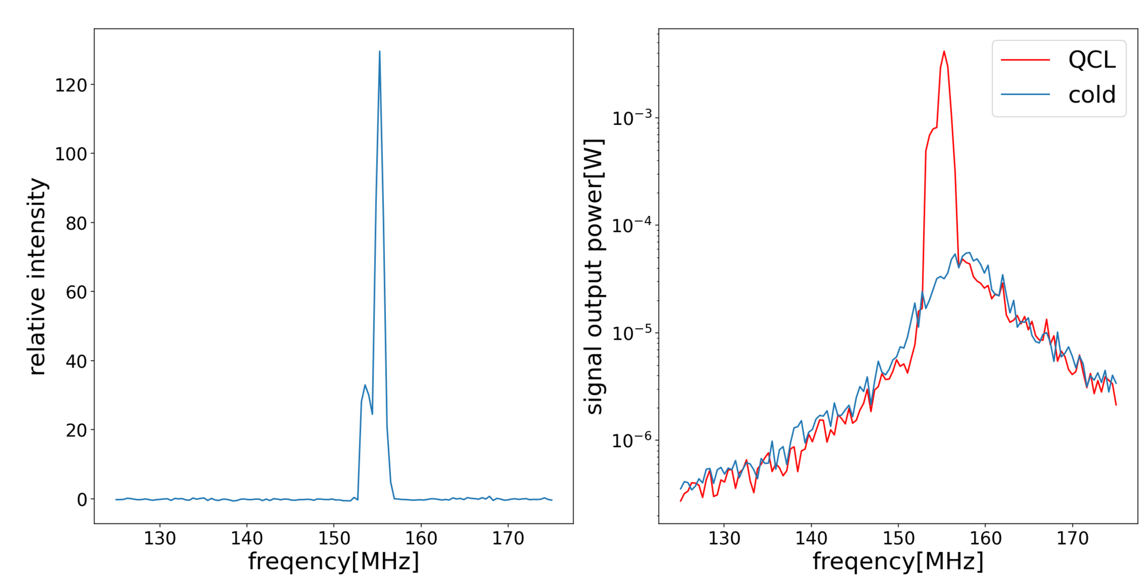

Fig.3 An example of the emission spectrum of the QCL obtained by heterodyne measurement with a CO_2 laserbased heterodyne system shown in Fig.1 (a) at 10.3 micron at 0.5s interval (left). The obtained spectra by the spectrometer with QCL (red) and with ambient room temperature load (blue) (right).

Setup (a) CO_2 laser + blackbody

The typical system noise temperature achieved less than 3000 K at 10.3 micron, as shown in Figure 4. This is only ~100% above the quantum limit. The difference between spectra with and without fiber on the LO light path is not significant.

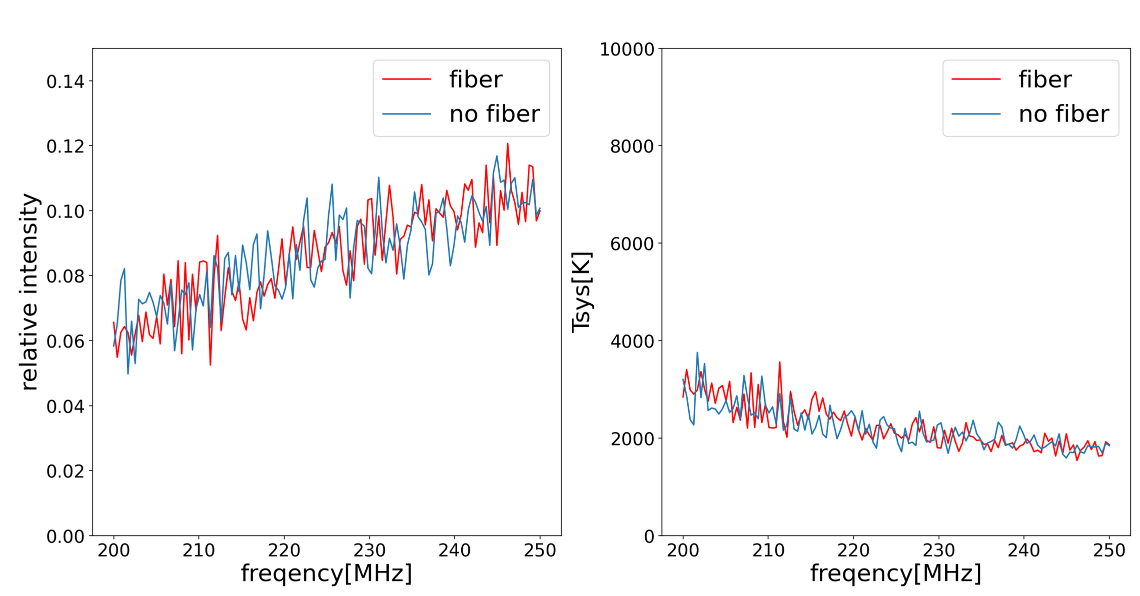

Fig.4 The spectra of the reference blackbody obtained by a CO_2 laserbased heterodyne system shown in Fig.1 (a) with hollow optical fiber (red) and without fiber (blue) (left).
System noise temperature at 10.3 micron with the heterodyne system with hollow optical fiber (red) and without fiber (blue) (right).

Setup (b) CO_2 laser + QCL

Figure 5 shows the spectral feature of the QCL emission line obtained on the system shown in Fig.1 (b). The spectral feature of the QCL emission shows a quite well match with our previous setup without fiber.

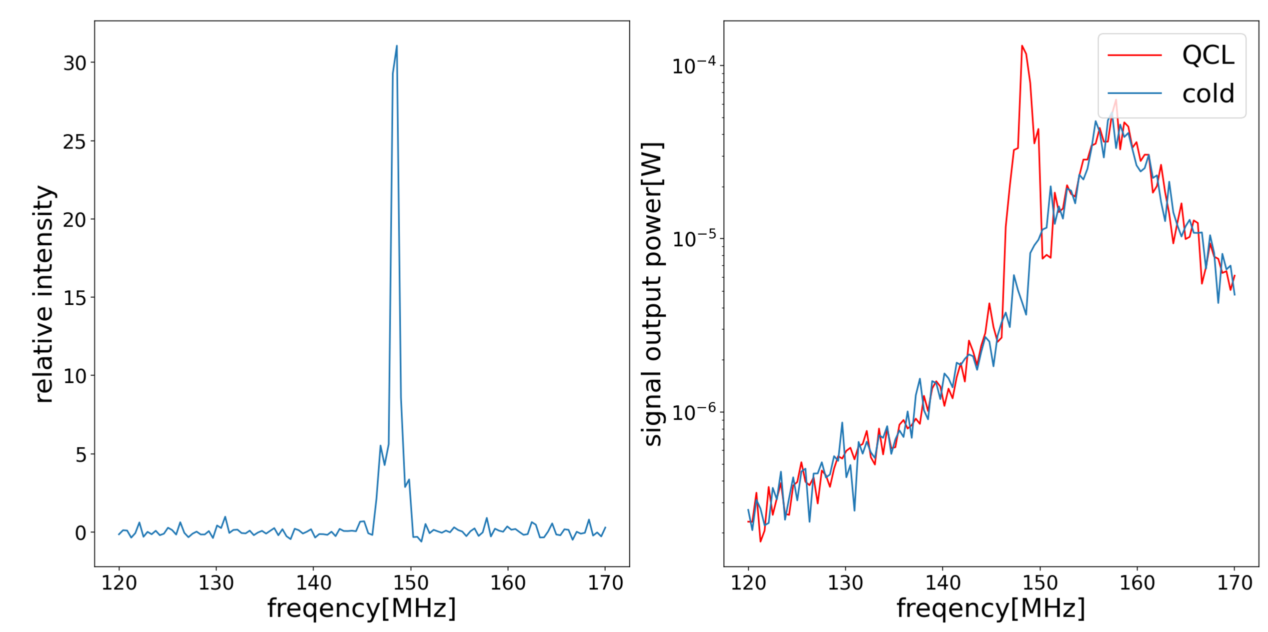

Fig.5 An example of the emission spectrum of the QCL obtained by heterodyne measurement with a CO_2 laserbased heterodyne system shown in Fig.1 (b) at 10.3 micron at 0.5s interval (left). The obtained spectra by the spectrometer with QCL (red) and with ambient room temperature load (blue) (right).

Setup (b) CO_2 laser + blackbody

The typical system noise temperature was larger than 20000K at 10.3 micron. Larger system noise temperature is due to larger loss of the fiber to broad and incoherent light from the reference blackbody. Transmittance to broad and incoherent light can be improved by optimizing incident angle of the beam.

Conclusions

We demonstrate a new design hollow optical fiber suitable for use on an IR heterodyne spectroscopy in mid-infrared wavelength region. The spectral feature of the laser emission line and the system noise temperature obtained by heterodyne detection with hollow optical fiber are confirmed by a laboratory measurement.

1. **We confirmed applicability of hollow optical fiber for heterodyne spectroscopy.**
2. **The hollow optical fiber allows heterodyne detection with a sufficient efficiency when the fiber leads coherent light.**
3. **The present study permits simplified fabrication, provides even more weight reduction.**

Work on improving transmittance continues.
Further investigation is required for use on the extended light source with the large F-value telescope from quasi-infinity distance.
The hollow fiber coupler under development.

References

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