

Development of mid-IR heterodyne spectrometer with hollow optical fiber for solar system exploration

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The mid-IR laser heterodyne spectroscopy provides high spectral resolution $> 10^6$, which is much greater than other direct spectroscopic measurements. This technique combines an IR source signal from the observing target and an IR laser (a quantum cascade laser (QCL) and/or a CO₂ gas laser) as the local oscillator (LO). We have developed the mid-infrared laser heterodyne spectrometer MILAHI (Mid Infrared LAser Heterodyne Instrument) mounted on our dedicated Tohoku 60 cm telescope (T60) at the summit of Mt. Haleakala, Hawaii. This instrument has successfully operated for the measurements of Venusian and Martian atmosphere (Nakagawa et al., 2016; Takami et al., 2020).

In the current system, two beams are combined at a ZnSe beam splitter and then focused onto a HgCdTe photomixer. In this scheme, a precise optical alignment is highly required to combine two beams. Since the wavelength of a single feedback (FB) QCL is restricted within the range of several cm⁻¹, switching LOs is needed for wider wavelength coverage. A CO₂ gas laser covers some parts of the wavelength ranges of 9-12 μm and four QCLs provide the wavelength ranges of 7.43-7.44 μm , 7.71-7.73 μm , 9.54-9.59 μm , 10.28-10.33 μm are installed in MILAHI as LOs. However, smooth switching mechanism of those LOs enhances the complexity of this system. We tried to simplify those optics with mid-IR transmissive hollow fibers.

There is few optical fiber which has a high transmittance at the wavelengths longer than 2 μm . Recently mid-IR (5-20 μm) transmissive hollow fibers has been developed by Tohoku University (e.g., Matsuura et al., 1995). The fibers are made of glass tubing whose inner diameter are 1 mm. Inner surface is covered by a conductive Ag layer covered by a dielectric AgI layer. With this fiber, we have tested the transmittance, heterodyne capability, and coupling/division of light.

(1) Transmittance of 0.5dB/m at 10.6 μm was reported in previous studies (e.g. Matsuura et al., 1995). At the moment, we have achieved about 70% transmittance with a 300 mm hollow fiber at 10.3 μm from our laboratory measurements. Since the transmittance strongly depends on the incident angle of the light, better transmittance might be possible by improving the alignment.

(2) We also confirmed the applicability of hollow fibers to mid-IR heterodyne system. The heterodyne spectroscopy with hollow optical fiber resolved the spectral feature of the narrow laser emission line. Achieved system noise temperature was less than 3,000 K, which was only twice the quantum limit and almost the same as that in the system without hollow fibers.

(3) We have developed the technology of the fiber coupler and divider, which enables coupling or splitting lights by combining fibers directly for the hollow fibers (Tamura et al., 2017). Now, we are testing the efficiency of the heterodyne signal using the fiber coupler. When it is succeeded, the fiber coupler can provide downsizing, weight saving, and high stabilization of the instrument. Those are essential progresses for this instrument optimizing to space-born missions.

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