Development of compact mid-infrared heterodyne spectroscopy by hollow optical waveguide

Kosuke Takami[1], *Hiromu Nakagawa[1], Yasuhiro Hirahara[2], Takashi Katagiri[3], Oleg Benderov[4], Yasumasa Kasaba[1], Alexander Rodin[4], Isao Murata[1], Shin Tamura[3]

1. Graduate School of Science, Tohoku University, 2. Graduate School of Environmental Studies, Nagoya University, 3. Department of Electrical Communications Engineering, Tohoku University, 4. Moscow Institute of Physics and Technology

We have developed the mid-infrared (MIR) heterodyne spectrometer which can achieve the highest spectral resolution of ~3.0×10^7 which enables us to obtain temperature, wind velocity, and abundance of trace gas in planetary atmosphere (e.g. Sonnabend et al., 2012; Sornig et al., 2013; Stangier et al., 2015). We are operating this instrument installed to Tohoku university 60 cm telescope on Mt. Haleakala. This instrument is relatively large size and requests severe control for the alignment of superposition between two beams from source and one local oscillator with many mirrors and lenses. On the other hand, Rodin et al. (2015) proposed M-DLS which was planed to install the channel of near-infrared heterodyne spectroscopy developed for ESA ExoMars lander mission for atmospheric measurement. It achieved compact size and enabled us to control optical alignment easy and flexibly by optical grass fibers. Furthermore, it can switch multiple local oscillators quickly to observe at the multiple wavelengths by fiber coupler. For the utilization to our MIR heterodyne spectrometer, we are starting to evaluate the Ag-coated hollow optical fibers with higher transmission than the polycrystalline fibers in the wavelength 4-18 μm (Katagiri et al., 2017).

MIR heterodyne spectrometer requires the single-mode transmission for the mixture of two beams and enough low loss rate of 0.5 dB/m for the weak source light. The hollow optical fibers was confirmed to achieved single-mode transmission with the core diameter of 1.0 mm by quantum cascade laser of 7 μm with incident F-number of ~70 and that the loss rate was less than 0.5 dB/m with the fiber core diameter of 0.7 mm by CO_2 laser.

Optical grass fibers can be coupled by the fused fiber coupler which two fibers are twisted, heated, stretched, and fused to exchange the energy between cores by evanescent light. Although the hollow optical fibers cannot be used this coupler method because of no core material, we developed the Ag-coated rectangular hollow waveguide coupler which can mix MIR beams by mode couple. It can be utilized to the mixing part of the heterodyne spectrometer, which enables us to simplify the optical design of the current MIR heterodyne spectrometer and to observe with multiple local oscillators. We simulated two gauss beam was coupled with the rectangular hollow waveguide coupler by length of 15 cm.

We will evaluate the quality for heterodyne signal of source light and laser transmitted by the hollow optical fibers and will develop to the rectangular hollow waveguide coupler for beam mixture. We plan to show the plot of new compact MIR heterodyne spectrometer.

Keywords: Mid-infrared heterodyne spectrometer, Hollow fiber, Rectangular hollow waveguide coupler

