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Ground based mid-IR heterodyne spectrometer concept for planetary atmospheres observations

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Abstract

We present a heterodyne spectrometer concept based on distributed feedback (DFB) quantum cascade lasers (QCL) operated in midle infrared region (MIR). The instrument is assumed to be mount on the Russian infrared observatories. The core features of the concept are compact design, utilizing a novel mid-IR fiber optical components and dynamic local oscillator frequency locking using reference molecule absorption line. The instrument characteristics are similar to modern heterodyne devices THIS (Cologne University, Germany) and MILAHI (Tohoku University, Japan) in terms of fundamental parameters, including spectral resolution, spectral coverage in a single observation.

1. Introduction

During last decades geology and internal structure of planets, their satellites and small bodies attract increasingly more attention. But planetary atmospheres remain most efficient sources of knowledge about planets and their evolution. The key advantage of high spectral resolution in the analysis of the outgoing radiation spectra of planets is concerned with the capability to retrieve detailed information about composition, structure, and photochemical kinetics of their atmospheres[1],[2]. Ultra-high spectral resolution ($\lambda/\Delta\lambda \sim 10^8$) provided by a heterodyne detection of the infrared radiation, allows for Doppler wind measurements at different altitudes[3]. The most valuable problems to be solved are vertical temperature and wind profiles on Mars and Venus, integral and vertical concentration measurements of minor constituents on Mars and Venus, wind and temperature on Titan. This provides information for heat balance and global atmospheric dynamics recovery, which is essential for comparison with 3D general circulation models.

To date direct wind measurements on planetary scale are only possible by means of ground-based telescopic observations with ultra-high resolution heterodyne spectrometers in the infrared and microwave spectral ranges. Such instruments are unique, being developed by only a few groups worldwide and upgraded slowly relative to the progress in infrared photonic technology. The development of heterodyne infrared spectroscopy for planetary astronomy based on modern technology would provide continuous air flow monitoring by means of modest meter-class telescopes. Such monitoring would provide data for numerical models verification and assimilation, required to step forward from climate models to prognostic ones.

2. Middle IR fiber devices development

MIR fiber application is still very limited due to absence of commercially available MIR fiber based devices, e.g. couplers. However, in past few years significant progress in developing of chalcogenide and fluoride fiber based devices were firstly presented[4]. Our group created theoretical model for chalcogenide fused fiber couplers and experimental setup for its fabrication and characterization. Optimal geometrical parameters for achieving required coupling ratio were studied with computer simulation. A custom workstation with NiCr electric heater to reach temperature of 100 – 350°C in heated region was developed.

3. MIR heterodyne spectrometer

The principal sketch of the MIR heterodyne spectrometer is presented on the Fig. 1. Incoming signal from a planet is received by IR telescope and then passes to the spectrometer's input aperture. After that this signal is being mixed with MIR QCL radiation via a free-space Pellicle beam splitter or

MIR fiber coupler and detected with a photo-detector (PD). In present work we used 7.8μ, 5.6μ and 10μ QCLs as local oscilators (LO) and TEC-cooled mercury-cadmium telluride (MCT) photodiodes with a bandwidth up to 1 GHz. Due to PDs nonlinear response with the respect to the electrical field, incoming signal is being down-converted form IR-frequency range to the radio-frequency range, so it is possible to retrieve its spectrum using high-frequency spectrum analyzer. In order to achieve extremely high level of LO frequency stability (~MHz) without long term temperature drifts we utilized frequency locking technique using QCL wavelength modulation and reference gas cell to record reference gas absorption line simultaneously with heterodyne measurements. In addition we used two black bodies for intensity calibration purposes and Fabry-Perot etalon for QCL frequency scale calibration.

For the purpose of miniaturisation, mass reduction and optical alignment simplification MIR fiber couplers are supposed to be used in the optical scheme of the instrument instead of the beam splitters. Single mode chalcogenide fiber of IHPS RAS was used for fiber coupler fabrication technique. First results were demonstrated for 3 um range[5].

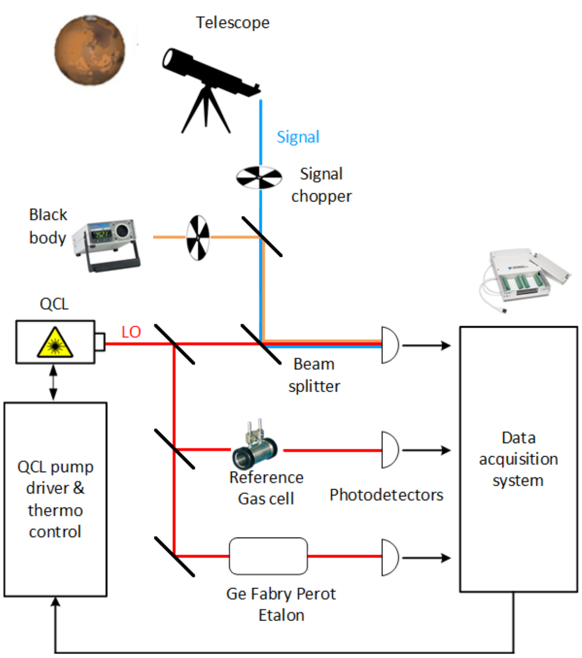

Figure 1: Scheme of mid-IR heterodyne spectrometer concept. Free-space beam splitter are planned to be replaced with mid-IR fiber couplers.

4. Summary and Conclusions

At present moment we created laboratory setup including all necessary elements of MIR heterodyne spectrometer that have been mentioned above. We have studied different components of noises of our system and found optimal value of LO power. The measured signal to noise ratio (SNR) with MCT PD was about 10 times greater than LO's shot noise (theoretical limit of heterodyne technique SNR) and limited by QCL relative intensity noise (RIN). However, applying additional filtering it is possible to reduce this value better than 5 shot noise level, which is typical to TEC cooled MCT PD[6]. Also we demonstrate heterodyne signal measurements using laboratory black body with temperature of 400 ºC.

Acknowledgements

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References

[1] Sornig, Manuela, et al.: Investigations of Dynamics and Temperatures in the Venusian Upper Atmosphere by Infrared Heterodyne Spectroscopy, 2011.

[2] Wirtz, Daniel, Guido Sonnabend, and Rudolf T. Schieder.: THIS: a tuneable heterodyne infrared spectrometer, Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, T. 58, № 11, pp. 2457-2463, 2002.

[3] Kostiuk T. et al.: Titan's stratospheric zonal wind, temperature, and ethane abundance a year prior to Huygens insertion, Geophysical research letters, T. 32, № 22, 2005.

[4] G. Stevens and T. Woodbridge: Mid-IR fused fiber coupler, Proc. of SPIE Vol. 9730 973007-7, 2016

[5] Dianov et al.: Singlemode optical fiber based on AsS gss, Rus. Nonorgan. Mater., vol 39, №6, pp. 741-745.

[6] Weidmann, Damien, et al.: Hollow waveguide photomixing for quantum cascade laser heterodyne spectro-radiometry, Optics express, T. 19, № 10, pp. 9074-9085, 2011.