REMOTE METHANE GAS IMAGING SYSTEM USING INFRARED OPTICAL PARAMETRIC UP-CONVERSION DETECTION

Masaharu Imaki, Satoshi Hirota, Hironori Inaba, and Takao Kobayashi

Graduate School of Engineering, University of Fukui, 3-9-1 Bunkyo Fukui, 910-8507 JAPAN
imaki@optele.fuee.fukui-u.ac.jp

ABSTRACT

A remote methane detection system has been developed by using the single-frequency tunable optical parametric oscillator. The received infrared signal is converted by the optical parametric up-convertor into the near infrared signal. Using this system, high-resolution absorption line of methane gas was measured and the imaging of the methane gas is realized by raster scanning the infrared laser beam.

1. INTRODUCTION

The monitoring of methane gas plumes is required for the detection of natural gas leak and distribution of greenhouse gas. The natural gas leak is detected at the present time by using flame ionization detectors, hence remote sensing in connection to safety requirements is not realized in this method.

On the other hand, the laser remote sensing system provides real-time and nondestructive measurement and several techniques have been developed. In the long-path absorption laser radar (LPAL), topographic targets are used as the reflectors to measure column content of the leak gas with high sensitivity. This technique was realized by using a compact laser such as laser diode [1] and optical parametric generator (OPG) [2]-[4]. However, the measurement sensitivity and range is limited by the laser power and the system size is limited by the use of cooled infrared array detector.

In this paper, the methane gas imaging system based on the LPAL technique has been developed by using the single-frequency optical parametric oscillator (OPO). By using the raster scan method of the infrared beam, the efficient and compact system design is realized compared with the line scan method using the array detector [2]. Furthermore, the high sensitive detection can be achieved by using the optical parametric up-conversion technique for accurate measurement of gas plume distribution.

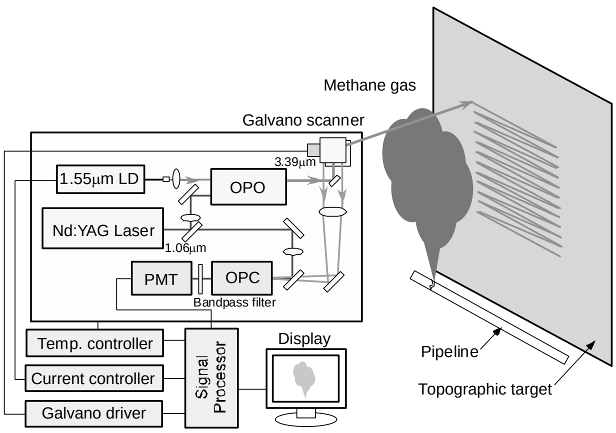


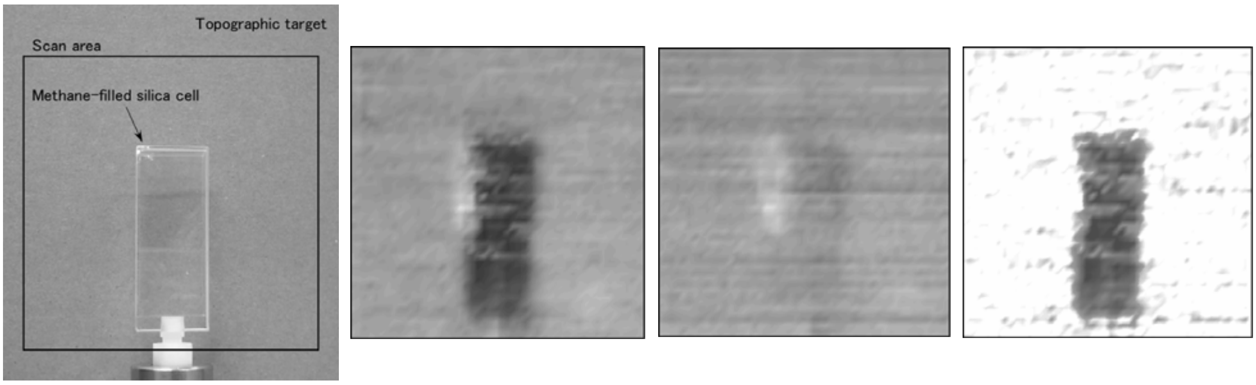
Fig. 1 Schematic of the remote methane gas imaging system.

2. METHANE IMAGING SYSTEM

The arrangement of the methane imaging system is shown in Fig. 1. The Nd:YAG laser at 1.06 μm wavelength was used as the pump source for the OPO and the laser diode at 1.55μm was used for injection seeding of the OPO for single-frequency oscillation. The OPO was realized by using a periodically poled MgO:$LiNbO_3$ (PPMgLN) as the nonlinear optical material with improved resistance to photorefractive damage in contrast to its undoped counterpart. At 30.5 μm domain interval, the phase matched signal output at 1.55 μm and the idler output at 3.39 μm are generated. Methane has strong absorption lines in the idler wavelength region at 3.39 μm [5], and the high sensitive detection can be realized. Furthermore, the single - frequency OPO provides the high resolution spectroscopic analysis. Molecular concentration is derived from the differential signal of the detector output at the absorption wavelength λ_{on} and the off-absorption wavelength λ_{off}, and the frequency modulation of the idler wavelength was realized by the current modulation of the 1.55 μm laser diode.

The scattered infrared beam from topographic targets is converted by the optical parametric up-convertor (OPC) into the near - infrared wavelength at 810 nm and detected by the photo - multiplier tube (PMT). The optical parametric up-conversion technique is advantageous because the infrared signal is converted with high efficiency and detected by the PMT with higher quantum efficiency and smaller Johnson noise characteristics than the infrared detectors. Therefore, the infrared up - conversion technique provides high sensitive detection of the infrared signal.

The OPO output beam is scanned by two galvano mirrors with 15 mm diameter. The angle of raster scanning can be controlled within +/- 30 degree. This scanning method utilized a single un-cooled detector which has higher sensitivity and low cost features as compared with the cooled array infrared detector.



(a) Picture of the target (b) λ_{on} signal image (c) λ_{off} signal image (d) Differential image

Fig. 2 Imaging results of methane-filled silica cell. (a) is the target picture, (b) and (c) are λ_{on} and λ_{off} signal images, respectively. (d) is the differential image.

3. EXPERIMENTAL RESULTS

The OPO idler output beam at 3.39 μm was used for the methane concentration measurement. The output pulse energy of the idler wavelength was 5 μJ at 45 μJ pump laser energy. The idler linewidth is estimated to be 380 MHz from pump linewidth of 280MHz and signal linewidth of 100MHz. In this experiment, the received signal was detected by the InAs photodiode with 0.25 mm diameter.

The absorption spectra of the methane at P7 branch line were measured by tuning the current of 1.55μm laser diode and the results are in good agreement with the HITRAN absorption spectra.

Figure 2 shows preliminary examples of the gas imaging using methane-filled silica cell at the range of ~1 m. This image was acquired by raster scanning the infrared beam with 50 x 50 pixels resolution. Figure 2 (a) is the picture of the topographic target and methane-filled silica cell. Figure 2 (b) and (c) correspond the images measured with single wavelength at λ_{on} (3391.6 nm) signal and λ_{off} (3391.0 nm) signal, respectively. In this imaging method, methane absorption was observed in λ_{on} signal imaging. The differential image can be derived by subtracting λ_{off} signal from λ_{on} signal and the clear imaging of methane is realized.

4. SUMMARY

The methane gas imaging system has been developed using the single frequency OPO. Using this system, the measurement of high resolution absorption line of methane has been realized and methane imaging was realized by raster scanning the OPO beam using the photodiode. The experiments using the optical parametric up-conversion technique is in progress and the higher detection sensitivity can be realized than the InAs photodiode detector. Long-range measurement will be achieved with compact system arrangement.

The OPO and OPC can be incorporated into a high-repetition-frequency and compact fiber laser to increase the frame rate and detection sensitivity. By optimizing the system performance, the imaging system will be used for detecting the methane leak of the pipeline.

Furthermore, this system is useful for the measurement of other gases such as CO_2 and other greenhouse gases using the broadly tunable OPO device in the infrared region.

ACKNOWLEDGEMENT

This research was supported by Grants-in-Aid for Scientific Research of number 16360201 of Japan Society for the Promotion of Science (JSPS).

REFERENCES

[1] T. Iseki, “A portable remote methane detector using an InGaAsP DFB laser”, Environmental Geology, vol.44, p.1064-1069 (2004).

[2] T. J. Kulp *et al.*, “The application of quasi - phase - matched parametric light sources to practical infrared chemical sensing systems”, Appl. Phys. B, 75, pp. 317-327 (2002).

[3] A. Minato *et al.*, “Laser long-path absorption lidar technique for measuring methane using gas correlation method”, Jpn. J. Appl. Phys., 37, pp.3610-3613 (1998).

[4] M. Imaki *et al.*, “Compact long - path absorption laser radar system for measuring greenhouse molecular concentration”, Proceedings of CLEO / PR2003, THP-10-4, p581, Taipei, Taiwan (2003.12).

[5] L.S.Rothman *et al.*, “The HITRAN molecular spectroscopic database and HAWKS (HITRAN atmospheric workstation): 1996 edition”, J. Quant. Spectrosc. Radiat. Transfer, 60, pp. 665-710 (1998).