EPJ Web of Conferences **119**, 17011 (2016) DOI: 10.1051/epjconf/201611917011
ILRC 27

CHARACTERISTICS OF THE OPG SYSTEM USIG QUASIPHASE-MATCHED NONLINEAR CRYSTALS FOR 1.6 μm CO2 DIAL

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ABSTRACT

We have developed a direct detection 1.6 μm differential absorption lidar (DIAL) technique to perform range-resolved measurements of vertical CO2 concentration profiles in the atmosphere. Our 1.6 μm DIAL system consists of the optical parametric generator (OPG) and amplifier (OPA) transmitter that excited by the LD pumped Nd:YAG laser with high repetition rate (500 Hz). The OPG system consists of a quasi-phase-matched (QPM) crystal and does not need a cavity. The output power of the OPA system is 6 mJ, the full width at half maximum (FWHM) of the spectrum is about 280 MHz and spectrum purity is 91.0 +- 0.2 ~ 0.5%. CO2 concentration error from fluctuation of the spectrum purity is 0.3% at 6 km altitude and 0.4 % at 10 km altitude.

1. INTRODUCTION

In recent years, there have been significant advances in a QPM nonlinear optical frequency conversion [1, 2]. The QPM condition is produced to use periodically poled ferroelectric crystals. Optical parametric oscillator (OPO), amplifier (OPA), and generator (OPG) devices are widely recognized as versatile coherent tunable spectroscopic sources. Many applications of PPLN-parametric radiation sources, such as laser remote sensing and molecular spectroscopy, require broadly tunable and narrow linewidth operation in the infrared region [3, 4].

We developed an optical parametric oscillator (OPO) laser system for 1.6 μm CO2 DIAL [5]. In order to improve the measurement accuracy of CO2 profiles, development of high power and wavelength stabilized laser system has been conducted. We have developed a new high-power 1.6 μm laser transmitter based on a parametric master oscillator-power amplifier (MOPA) system pumped by a LD-pumped Q-switched Nd:YAG laser which has the injection seed laser locked to the iodine absorption line. The master oscillator is the OPG system and the amplifier is the OPA system [6]. Since the OPO system has a cavity mirror, running the system without mode hopping requires complex control of cavity length. By contrast, the OPG system has no cavity mirror, so there is no need to control cavity length. In this paper, we describe characteristics of the OPG system for the 1.6 μm CO2-DIAL.

2. CHARACTERISTICS OF THE OPG SYSTEM

2.1 Experimental setup

The OPO system requires either active control of the cavity length or slight misalignment of the cavity. On the other hand, the OPG system does not need a cavity and instead rely on sufficient conversion efficiency to be obtained with a single pass through the crystal. Figure 1 shows a schematic diagram of the LD pumped Q-switched Nd:YAG pumped OPG/OPA system.

The OPG consisted of a QPM crystal (35×3×3 mm3) with a domain period of 30.9 μm with the duty ratio close to the ideal value of 0.5. The end facets were coated with an anti-reflection material to prevent feedback effects induced by residual reflection. The pump source was a Nd:YAG laser, that was injection seeded by the iodine locked cw Nd:YAG laser. The pulse energy of the pumping laser is 100 mJ and repetition rate is 500 Hz. This pump laser is used less than 40 mJ for each QPM crystal to avoid damaging during high-energy pumping. Each QPM crystal was mounted on a copper holder, and the temperature was maintained at 36 °C using a Peltier module. The holder's temperature was stabilized to within 0.01 °C when the copper holder was covered with a plastic case. Single-frequency oscillation of the QPM-OPG was achieved by injection seeding, as described in the following. Two injection seeder were DFB lasers having maximum power of 40mW with a 1MHz oscillation spectrum Their oscillation wavelength was coarse tuned by temperature and fine tuned by adjusting injection currents. The partial power of the on-line wavelength was split in the wavelength control unit. The DFB laser was locked to the on-line wavelength (1572.992 nm) by referencing the fiber coupled multipath gas cell (path length 800 mm) containing pure CO2 at a pressure of 700 Torr by monitoring the feedback signal of a wavelength-controlled unit. Stabilization was estimated to within 4.0 MHz rms of the line center of the CO2 absorption spectra. The DFB laser as an injection seeder of the off-line wavelength is operated by the free run mode with the stability of 0.5 pm/hour. Both on-line and off-line DFB lasers were connected to an optical fiber switch. Although the previous switching speed was 250 Hz. The OPG/OPA output power is 6 mJ and the full width at half maximum (FWHM) of the pulse width was about 20 ns.

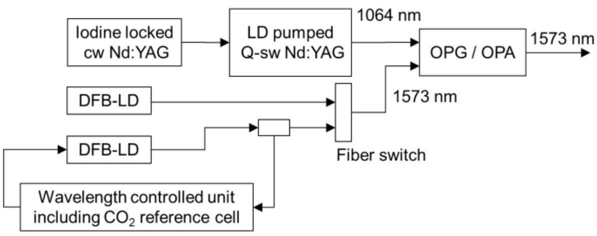

Fig. 1 Schematic diagram of the 1.6 µm transmitter for CO2-DIAL.

2.2 Line narrowing

The threshold power of the injection seeder radiation for successive injection seeding was about 1.0 mW. As the power of the injection seeder radiation was increased, the linewidth of OPA output narrowed and the peak power increased. The seeded OPA radiation was easily tuned by changing the wavelength of the injection seeder radiation, and was mode-hop free in the range of the parametric radiation spectrum of the unseeded OPA. The seeded OPA signal can be continuously tuned within about 10 nm by changing the crystal temperature using the wavelength of the injection seeder radiation. Fig. 2 shows the etalon fringe pattern (FSR = 2.0 GHz) and OPA spectra with seeded and unseeded. The linewidth of the OPA radiation was reduced to ~280 MHz or less by injection seeding. The spectral width of unseeded OPA is about 1.4 nm. Fig. 3 shows OPA spectra with on-line seeded and off-line seeded. Spectral purities of on-line seeded and off-line seeded were 91.0 % respectively. In a long term measurement, shown in Fig. 4, fluctuations of spectral purity were 0.47 % of on-line and 0.23 % of off-line. We calculate the CO2 concentration error given by this purity fluctuations. Fig. 5 shows CO2 distribution error as functions of purity error at 3 km altitude and 6 km altitude. Purity of on-line and off-line are respectively 91.0%. Influence on CO2 concentration error of offline purity fluctuation is less than the online purity fluctuation. This is due to the difference in the Influence on the absorption cross-section by prity fluctuation. Fig. 6 shows CO2 density error as a function of altitude with on-line purity 91.0±0.5% and off-line purity 91.0±0.2%. From this result, CO2 concentration error is 0.3% at 6 km altitude and 0.4 % at 10 km altitude.

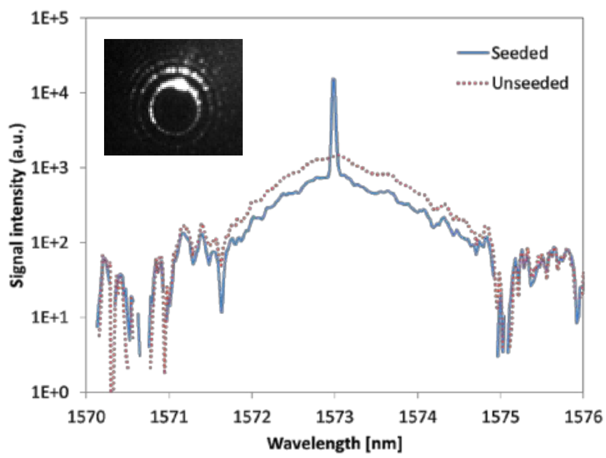

Fig. 2 Etalon fringe pattern and signal spectra of injection-seeded and unseeded. (FSR = 2.0 GHz)

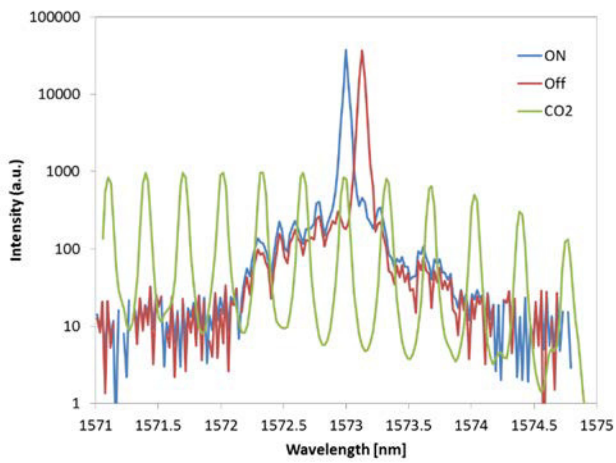

Fig. 3 Spectra of the OPA radiation measured by means of an optical spectrum analyzer: narrow-band online and offline radiation during seeded operation and calculated CO2 absorption lines.

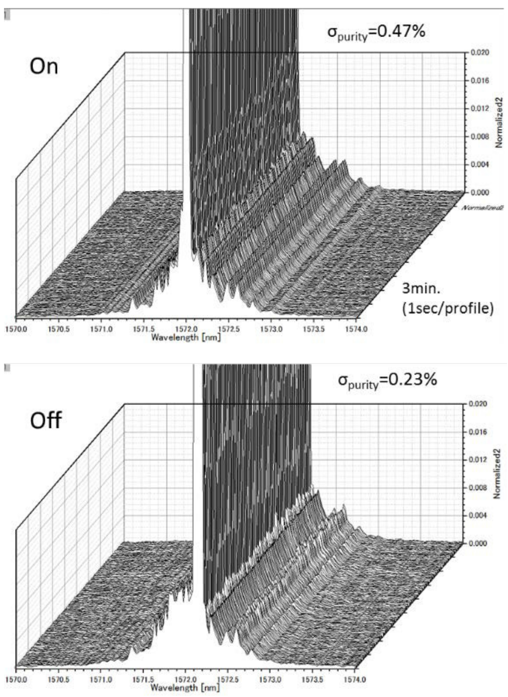

Fig. 4 Long term spectra measurements (3 min.) of on-line and off-line.

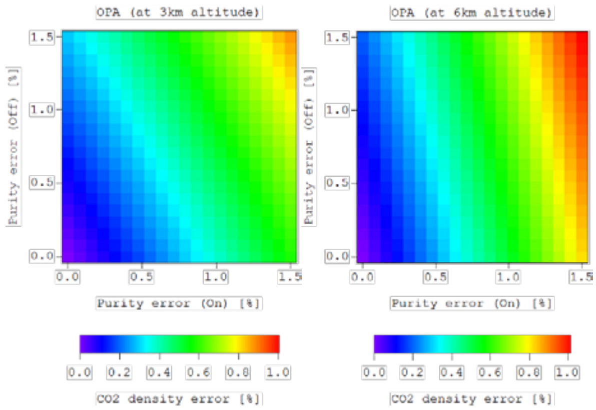

Fig. 5 CO2 density error as functions of purity error at 3 km altitude and 6 km altitude. Purity of on-line and off-line are respectively 91.0%.

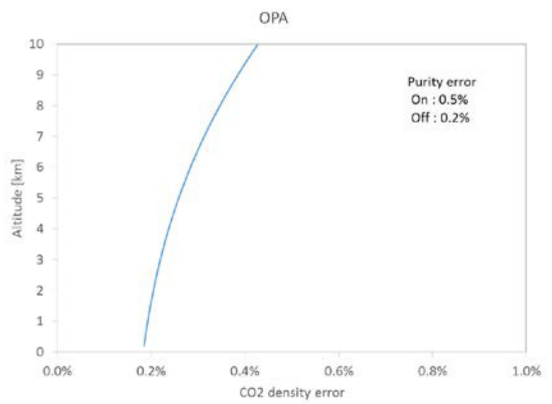

Fig. 6 CO2 density error as a function of altitude with on-line purity 91.0±0.5% and off-line purity 91.0±0.2%.

3. CONCLUSION

Injection seeding using DFB-lasers was performed with a OPG / OPA system for the 1.6 μm CO2 DIAL. The linewidth of the OPA radiation was reduced to ~280 MHz or less by injection seeding. The OPG radiation was easily tuned by changing the wavelength of the injection seeder radiation, and was modehop free. The mode-hop free performance of the OPG radiation made CO2 DIAL easy to perform. The output power of the OPA system is 6 mJ and the full width at half maximum (FWHM) of the spectrum is about 280 MHz. The spectrum purity of the OPA system is 91.0 % and fluctuations of spectral purity were 0.47 % of on-line and 0.23 % of off-line. +- 0.2 ~ 0.5%. CO2 concentration error from

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ACKNOWLEDGEMENT

This work was financially supported by the System Development Program for Advanced Measurement and Analysis of the Japan Science and Technology Agency.

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