Atmospheric Traces Sensor Based on Visible Dual-Comb Spectroscopy Using Ti:sapphire Mode-locked Lasers

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***Summary*—We propose a sensor scheme for atmospheric compositions analysis based on visible dual-comb spectroscopy. These combs are originated from Ti:sapphire mode-locked resonators, and with the spectrums spread, they cover 600-1000 nm band, which corresponds to the wavelength of absorption spectra of some trace gases such as NO_3 and O_2. The beat note between two combs proved that the spectrum resolution of the sensor reaches 0.00012 nm and the acquisition time reaches 0.085 microseconds.**

Keywords—atmospheric; dual-comb; spectroscopy; mode-locked laser

I. INTRODUCTION

Sensing absorption spectroscopy is an important method to analyze and detect the chemical compositions of the atmosphere. There are some trace substances in the atmosphere whose absorption spectrums are located in visible region [1], such as the absorption band of O_2 (780 nm), NO_3 (620-660 nm), and the Chappuis band of O_3 (600 nm). Observing these traces can help understand chemical reactions in the atmosphere [2].

Conventional traces sensors are based on Fourier transform spectroscopy (FTS) [3]. This scheme restricts the detection sensitivity, the acquisition speed and the sensing range of the spectrum. Dual-comb sensors [4] break these limitations and can meet the requirement for real-time detection. However, current researches of dual-comb spectroscopy (DCS) mainly focus on near-infrared [5] or mid-infrared [6] band instead of ultraviolet or visible band. To detect the electronic transition absorption spectrum of the atmospheric traces in visible wavelength, here we show a sensors scheme based on DCS using Ti:sapphire mode-locked lasers. Our results show that it can cover 600-1000 nm range with 0.00012 nm spectrum resolution and 0.085 ns acquisition time.

II. METHODS/RESULTS

In the DCS sensor scheme, two identical Ti:sapphire mode-locked lasers are chosen as the laser source. The center wavelength of these lasers is near 800 nm, which is the border between red light and infrared light. The schematic of is shown in Fig.1. Each x-folded resonant cavity is composed of six mirrors and a 2 mm Brewster-cut Ti:Sapphire crystal. The repetition rates of two optical combs output by these oscillators are 99 MHz and 99.012 MHz respectively. The difference between two combs determines the acquisition time of the sensor [7]. When the Ti:sapphire laser pumped by a 532 nm laser with 6 W power enters mode-locked state, its output spectrum has a 140 nm bandwidth at full width at half maximum (FWHM) and goes deep into visible band.

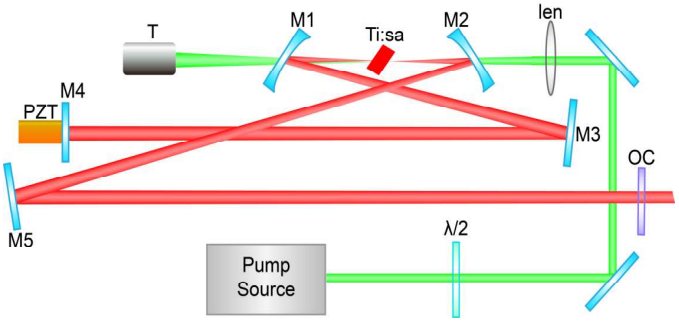

Fig. 1. Structure of a Ti:sapphire mode-locked laser source. Ti:sa: Ti:sapphire crystal. λ/2: half wave plate. M1, M2: concave chirped mirror pairs. M3, M5: plane chirped mirror pairs. M4: silver plane mirror. OC: output coupler mirror. T: optical trash collector. PZT: piezoelectric transducer.

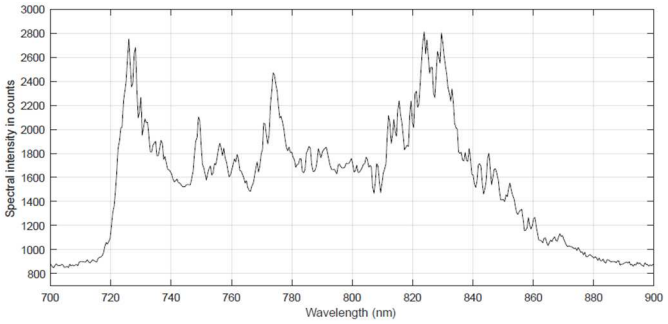

Fig. 2. Output spectra of the Ti: sapphire mode-locked laser.

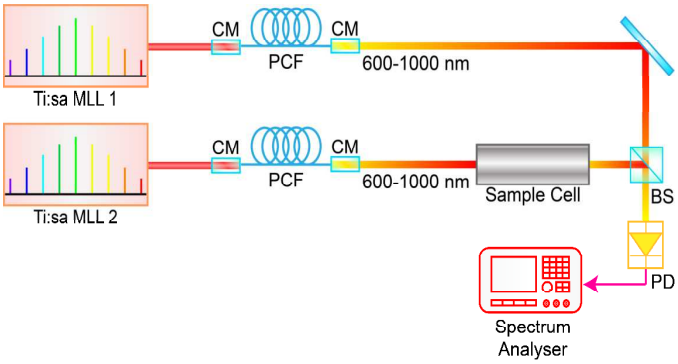

Fig. 3. Scheme of the trace gases sensor based on visible DCS. Each optical comb covers 600-1000 nm range after a spectrum broaden process via a photonic crystal fiber. Ti:sa MLL: Ti:sapphire mode-locked laser. CM: collimator. PCF: photonic crystal fiber. BS: beam splitter. PD: photodiode.

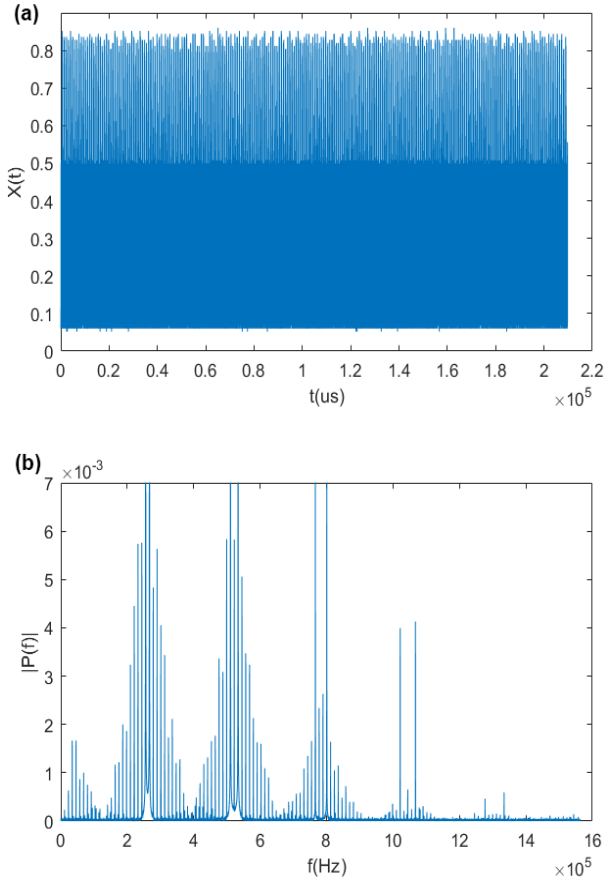

Fig. 4. Beat note signal acquired by PD. (a) Waveform of beat note in time domain. (b) Single-sided amplitude spectrum of beat note signal.

The whole sensor adopts asymmetrical DCS structure that is illustrated in Fig.3. To meet the wavelength requirements for broaden the spectrum to 600-1000 nm. Then one laser beam regarded as the probe light passes through the sample cell, and NO_3, O_2, and holmium doped glass (637.9 nm) [8], a 30 cm length of photonic crystal fiber (PCF) is used for each comb to beats with another laser beam treated as a reference light source. The beat note is received by a photodiode (PD), causing that the detected spectrum information is transferred from the optical frequency to the radio frequency. By analyzing the spectrum of electrical signals, we can restore the actual absorption spectrum of the atmospheric trace.

Figure 4 shows the waveform in time domain and the single-sided amplitude spectrum of the beat note signal acquired by PD without any gas sample. In terms of the spectrum, we can know that the spectrum resolution of the sensor is 0.00012 nm, which is more than two order higher than the traditional FTS sensors. And the acquisition time reaches 0.085 microseconds.

III. Conclusions

We show a sensor scheme for atmospheric traces detection based on DCS with higher spectrum resolution and time resolution. The sensor is able to distinguish the trace gases whose absorption spectrums are at the 600-1000 nm range. Such performances make it possible to monitor real-time chemical reactions in gas cells or observe open-path night atmospheric chemical compositions.

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