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Rapidly tunable pulsed CO_2 laser based on Acoustic-optic Modulator

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ABSTRACT

A rapidly tunable pulsed CO_2 laser intended for use in DIAL lidar system has been developed. For achievement of short tuning time, the system of laser based on two oppositely placed Acoustic-optic Modulators has been created. In this laser system, a fixed reflector and a rotating grating were used as rear mirrors of two oscillation paths to select wavelengths, and two AOMs were served as a switcher between two paths. Under the control of time sequence of two AOMs, two wavelengths emitted from different oscillation paths with time interval of 1 ms were obtained from the single output mirror of CO_2 laser, and the pulse duration was 220 ns and 280 ns for two paths, respectively.

1. Introduction

CO_2 lasers emitting in 9–12 μm wavelength range are useful in differential absorption lidar (DIAL) system for remote detecting of atmospheric pollutants, because this emitting band falls into an important atmospheric transmission window and contains absorption peaks of the pollutants [1–4].

Tunable CO_2 laser emitting two wavelengths alternately is used as radiation source for DIAL system. The measured beam with wavelength λ_1 lies in the absorption line of a measured pollutant, and the reference beam with wavelength λ_2 lies outside any absorption line for that pollutant. These two beams output alternatively from the same laser device and propagate in the same path to ensure they work under the same atmospheric conditions. The pollutant concentration is measured through comparing the difference in signal received from atmosphere. In order to obtain accurate measurements, these two beams should be emitted within atmospheric freezing time, so rapidly tunable pulsed CO_2 laser has attracted much attention [5]. Several techniques have been developed, and rotary tuning elements were commonly used.

Dvaid presented a high repetition frequency multiple wavelength CO_2 lidar system, which used a fixed grating and a galvanometer-controlled mirror to realize rapidly tuning output [6]. Utilizing a rotating six-sided scanning mirror and a fixed diffraction grating, Yanchen-Qu realized more than 40 rotational lines TEA CO_2 laser output, which the time interval for single-branch emission at two wavelengths was 10 ms [7]. Faxvog and Mocker used a six-sided grating as the tuning element, by continuously rotating the grating and exactly controlling the discharge time of the TEA CO_2 laser, the grating was rotated to the corresponding wavelength to realize full band output [8]. Yongqiang-Cheng developed a rapidly tunable TEA CO_2 laser based on a fast rotating grating driven by a direct drive AC servomotor, and through rapidly triggering, 85 tunable lines were obtained with the shortest tuning time of 20 ms [9]. All the systems above can realize multiple wavelength pulse CO_2 laser output with high accuracy, but the tuning time is prolonged. In this paper, we demonstrate a rapidly tunable pulsed CO_2 laser based on two Acoustic-optic Modulators (AOM). Two laser oscillation paths sharing the same gain medium were switched by these two AOMs, so as to realize double wavelengths alternatively output from the single laser system with short tuning time.

As the output performances are influenced by the AOMs, the characteristics of AOM including diffraction efficiency and frequency shift were investigated firstly. Then a fast tuning experimental device was built based on intracavity acousto-optic deflection, and the results show that it is possible to shorten the tuning time to 1 ms with fast tuning technology based on acousto-optic deflection.

2. Characteristics of Acoustic-optic Modulator

2.1. Diffraction efficiency of AOM

An AOM can diffract and shift the frequency of light by using ultrasound wave, which makes the acousto-optic material as a Bragg grating. When the incident angle is Bragg angle, the first order of diffraction reaches the maximum energy, and the diffraction efficiency is defined by the following equation:

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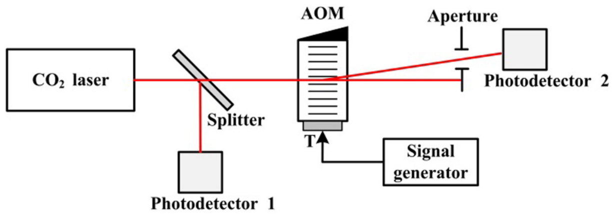

Fig. 1. Schematic diagram of AOM diffraction efficiency measurement.

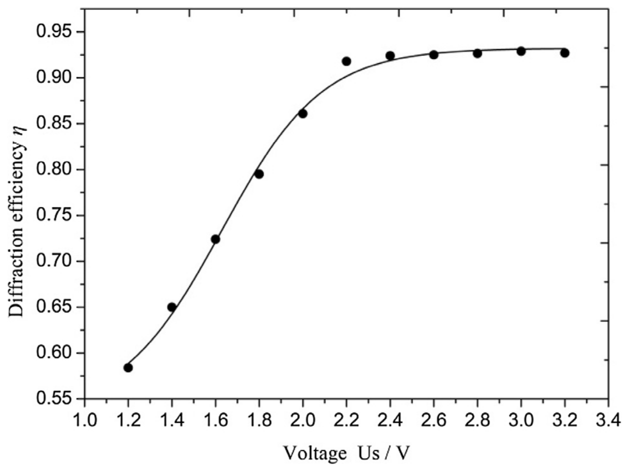

Fig. 2. Diffraction efficiency η as a function of voltage U_s.

$$\eta = \sin^2\left(\frac{\pi}{\sqrt{2}\lambda}\sqrt{M_2\left(\frac{L}{H}\right)P_s}\right)$$

where λ is the wavelength of incident light, M_2 is the acousto-optic figure of merit, H and L are the width and height of piezoelectric transducer, and P_s is the power of ultrasonic wave. For a given acousto-optic modulator and piezoelectric transducer, M_2, H and L are constant, so the diffraction efficiency η only varies with P_s. The transducer is fed by a high-frequency voltage U which carries amplitude modulation generated by a signal generator with voltage U_s, meaning that P_s is determined by U_s. So an experiment was made to study the variation between diffraction efficiency η and input voltage U_s.

Fig. 1 is the experimental setup. A beam emitted from a frequency stabilized CO_2 laser is separated into two parts by a beam splitter with reflectivity of 10%, the reflected part is registered by photodetector 1, and the refracted part with power P_i passes through an AOM and diffracts on an acoustic wave excited in the cell by a transducer (T). There is an aperture in the diffraction path, which passes the diffracted beam and rejects the non-diffracting beam when AOM is on. The diffracted beam with power P_d is registered by photodetector 2.

The diffraction efficiency can be calculated with equation $\eta = P_d/P_i$. The input power is defined by laser source, and under the same working conditions the change of input power P_i is very small, so the diffraction efficiency is just defined by the power of diffracted beam P_d. Since P_d changes with voltage U_s, the optimum optical diffraction efficiency can be obtained by properly choosing of U_s. Fig. 2 demonstrates the experiment results when input power P_i is about 3.8 W.

It is seen that under the small value of U_s, diffraction efficiency η increases quickly with U_s till U_s reaches 2.2 V. Then, when U_s is higher than 2.2 V, η increases rather slowly and becomes saturated with value higher than 0.9. The limitation of η is caused by dissipation problem of acousto-optic crystal. When signal voltage is higher than 3 V, the radio frequency power added on AOM is very high, which results in a fast temperature rise in acousto-optic crystal and makes heat dissipation very difficult. So the signal voltage U_s should be chosen in the range 2.2–3 V to obtain high diffraction efficiency as well as low thermal effect.

2.2. Frequency shift characteristics of AOM

There exists a frequency shift between diffracted light and incident light when light is diffracted by a sound wave. The diffracted light frequency f_d is equal to the sum or difference of incident light frequency f_i and acoustic frequency F. Sound waves occured when an RF drive signal was added on the transducer, and a 4.4° diffraction angle was obtained when the frequency of RF drive signal was 40.68MH, which is consistent with theoretical value. Fig. 3 demonstrates the frequency spectrum analysis of laser signal before and after frequency shift by using fast Fourier transform (FFT) algorithm. Fig. 3 (a) shows the FFT spectrum analysis in the case that the laser beam just single passes through a working AOM. The frequency shift is 40.6 MHz, which is close to the frequency of RF drive signal. While in the case that the laser beam go back and forth through a working AOM (see Fig. 3(b)), the frequency shift is doubled as compared with single pass, which means when the AOM is located inside the laser, the frequency shift accumulates due to laser oscillation. Commonly, direct discharge CO_2 laser has low gain line width (about one hundred MHz), meaning the frequency of laser would be removed from gain spectrum after light making many round trips in laser cavity, and the laser oscillation would stop. So frequency compensation should be considered. One way is to put two identical AOMs in laser system. They are installed in the

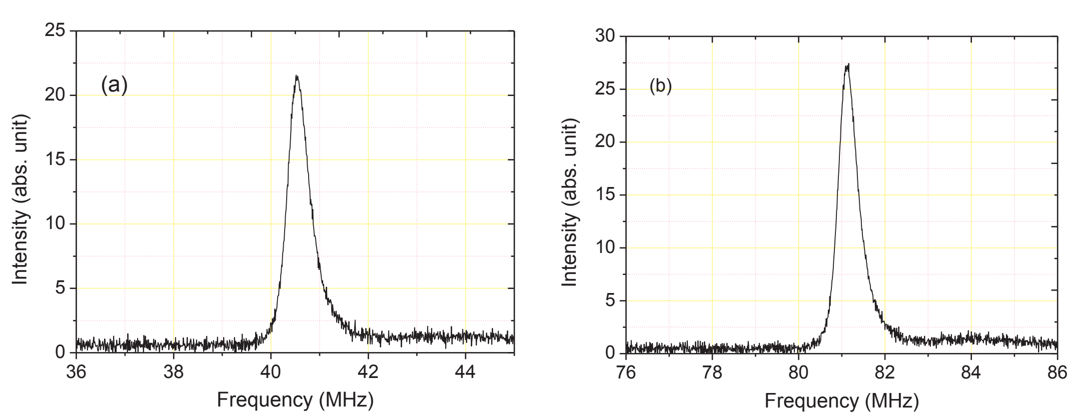

Fig. 3. Fast Fourier frequency spectrum analysis of laser signal before and after frequency shift. (a) Single pass and (b) a round trip.

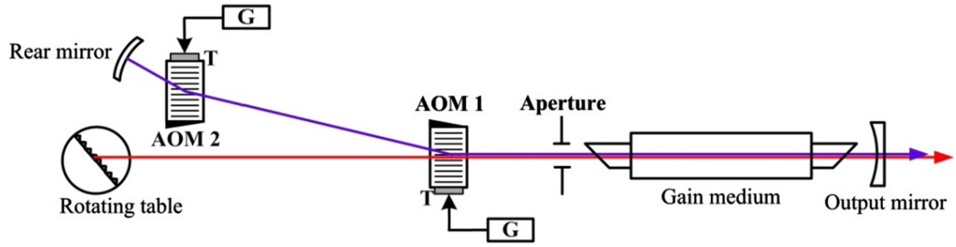

Fig. 4. Experimental device of rapidly tunable pulsed CO_2 laser.

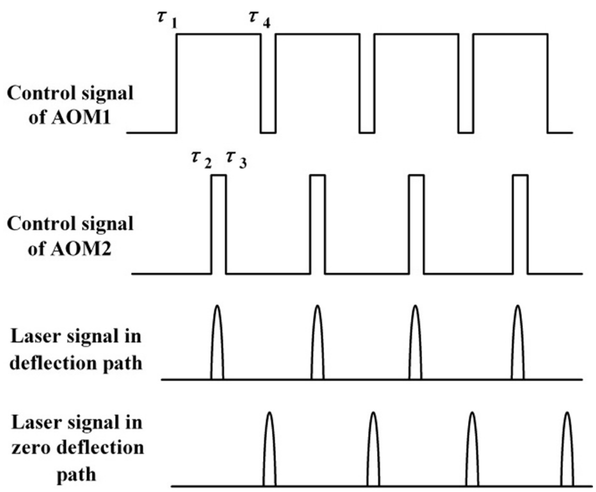

Fig. 5. Schematic diagram of sequential control for AOMs.

opposite direction, with one AOM's piezoelectric transducer on the top and the other AOM's transducer on the bottom. When the two AOMs are loaded with the same RF drive signal, frequency shift can be compensated in real time during a single oscillation.

3. Experiment on fast wavelength tuning

3.1. Experimental setup

To improve the tuning speed and shorten the pulse width of the tunable CO_2 laser, the experimental setup shown in Fig. 4 was used. There are two laser oscillation paths in the device: a deflection path and a zero deflection path. The deflection path is made up of a rear mirror, AOM2, AOM1, aperture, laser gain tube and output mirror, and the distance between two AOMs is about 500 mm, making laser transverse offset large enough to ensure these two AOMs have no shade on the optical path. While the zero deflection path is made up of a rotating grating, AOM1, aperture, laser gain tube and output mirror. Since these two paths share the same gain area and output mirror, they can finally output laser pulse from the shared path. When no RF drive signal is added on AOM1, laser oscillates in zero deflection path, and tunable radiation output is achieved with a 100 line/mm grating as cavity reflector. Oppositely, when RF drive signal is loaded on AOM1, laser oscillates in deflection path, in which AOM2 is placed oppositely with AOM1.The frequency shift is compensated during a single oscillation under the condition that the AOMs are driven with the same signal. After many oscillations, the strongest gain line 10p (20) is achieved in deflection path. In TEA lasers and RF excited high gain lasers, the rear mirror can be replaced with a rotating grating, realizing two arbitrary

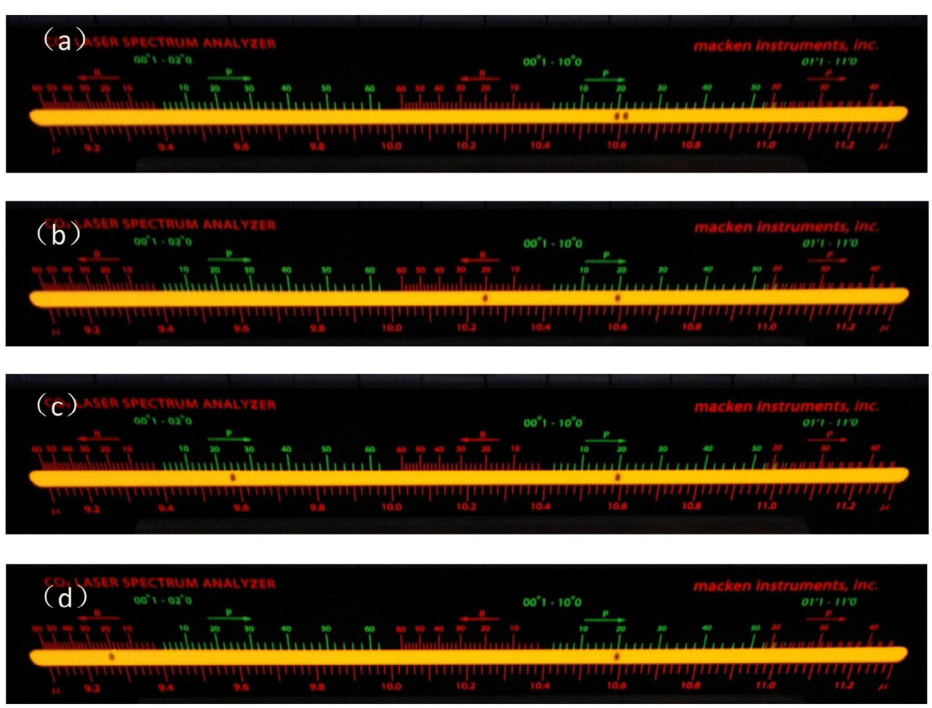

Fig. 6. Double lines of CO_2 laser: (a) 10P (20) and 10P (22) lines, (b) 10P (20) and 10R (20) lines, (c) 10P (20) and 9P (24) lines, (d)10P (20) and 9R (20) lines.

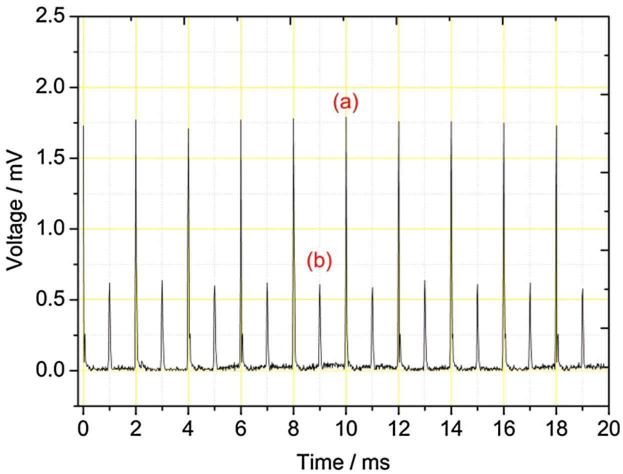

Fig. 7. Waveform of rapidly tunable double wavelength CO_2 laser.

spectral lines of tunable laser output in one laser system.

Since these two laser oscillation paths share the same gain area, in order to achieve Q switched pulse output, there must allow some time for particle number accumulation in upper level. So the driving sequence of AOM1 and AOM2 should be precisely controlled, which is shown in Fig. 5.

The sequential logic of AOMs is set as: deflection path (one order diffraction) works at high level while zero deflection path (zero order diffraction) works at low level. The working processes of fast tunable laser in a single sequential control period are: (a) at time τ_1, AOM1 is on while AOM2 is off, the Q factor of the optical resonator is low, so lasing cannot begin and upper level population accumulates till time τ_2; (b) at time τ_2, both of the AOMs are turned on, so the Q factor quickly changes from low to high, with a giant laser pulse emitted from the deflection path; (c) at time τ_3, AOM1 is on while AOM2 is off, resulting in a low Q factor in laser cavity, so upper level population accumulates till time τ_4; (d) at time τ_4, both AOM1 and AOM2 are turned off, causing a rapid increase in Q factor, so the accumulated population in upper level instantaneously exports from the zero deflection path in the form of a giant pulse. By adjusting duty cycle and delay time of these two AOMs, the accumulation time of the particle number in upper level can be appropriately changed, so as to optimize the laser power of double wavelength laser.

3.2. Experiment results and discussion

The Discharge current was adjustable from 8 to 16 mA, with the maximum continuous laser power of 22 W before placing AOMs in laser system. While the maximum power dropped to 9.5 W after inserting AOM1. Under the control of TTL trigger signal, AOM1 and AOM2 coordinated to achieve double wavelength fast tuning CO_2 laser output. In our experiment, the optimum output was attained when the repetition frequency of modulation signal was 500 Hz, which accords with the upper level life of CO_2 laser (about 1 ms). At this repetition frequency, the strongest gain line 10p (20) with wavelength of 10.59 µm in deflection path reached the maximum output power, which was 0.86 W. While in zero deflection path, laser wavelength was tuned with a rotating grating, and 10p (20) laser line had the highest power, with average power of 1.24 W. The spectrum lines were measured with a CO_2 laser spectrum analyzer and the results are shown in Fig. 6, which indicates that this laser device can realize full band 9.3–10.6 µm output of CO_2 laser.

The switching time between two laser lines in two oscillation paths was measured with an HgCdTe photodetector, and the results are shown in Fig. 7.

The double wavelength laser pulses were measured when the modulation frequency of AOM was 500 Hz. The pulses are divided into two groups, in which group (a) represents pulses from zero deflection path and group (b) represents pulses from deflection path. Two oscillation paths alternatively emit nearly stable laser pulses. The measured voltage amplitude of group (a) and group (b) is about 1.7 mV and 0.65 mV, respectively. The switching time between two lines is about 1 ms, which meets the requirement of DIAL system. Fig. 8 shows the detailed waveform of laser pulse chosen from each group. The pulse duration is about 220 ns for deflection path and 280 ns for zero deflection path. The deflection path is equivalent to double Q switched path, thus having a narrower laser pulse duration.

4. Conclusions

A rapidly tunable pulsed CO_2 laser based on two oppositely placed Acoustic-optic Modulators and a rotating grating has been developed. The characteristics of AOM were investigated first for better utilizing AOMs in this laser system, which shows that there exists a signal voltage range (2.2–3 V) to obtain high diffraction efficiency η as well as low thermal effect. The investigation also shows that there is a frequency shift if just one AOM is placed in deflection oscillation path, and this frequency shift can be removed by putting two identical AOMs oppositely in deflection path. Then, by using grating selection method and combining with sequential control of two AOMs, double wavelengths with time interval of 1 ms and pulse duration less than 300 ns were obtained from the single laser device.

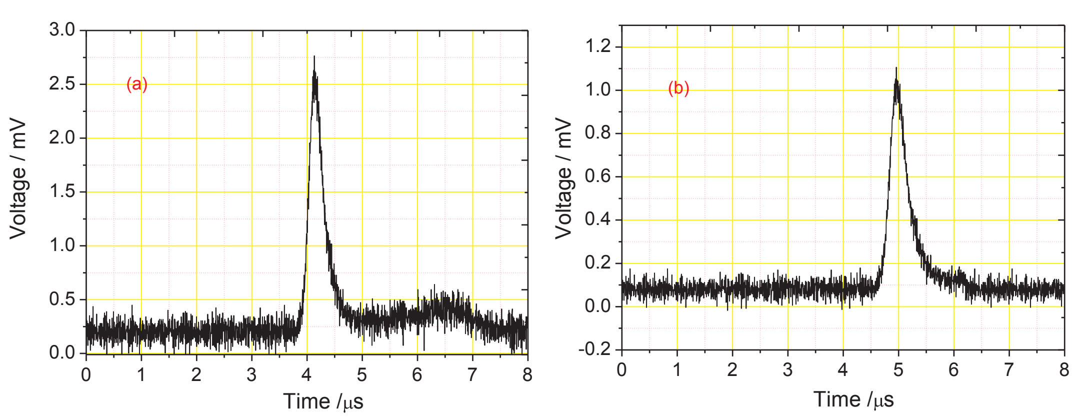

Fig. 8. Laser pulse waveform: (a) deflection path, (b) zero deflection path.

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Conflict of interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work in this paper.

References

[1] A.I. Karapuzikov, I.V. Ptashnik, I.V. Sherstov, et al., Modeling of helicopter-borne tunable TEA CO_2 DIAL system employment for detection of methane and ammonia leakages, Infrared Phys. Technol. 41 (2000) 87–96.
[2] S. Veerabuthiran, A.K. Razdan, M.K. Jindal, et al., TEA CO_2 laser based differential absorption lidar for the measurement of atmospheric gases, Nat. Laser Symp. (2016).
[3] H. Kariminezhad, P. Parvin, F. Borna, et al., SF_6 leak detection of high-voltage installations using TEA-CO_2, laser-based DIAL, Opt. Lasers Eng. 48 (4) (2010) 491–499.
[4] I. Karapuzikov, A.N. Malov, I.V. Sherstov, Tunable TEA CO_2 laser for long-range DIAL lidar, Infrared Phys. Technol. 41 (2) (2000) 77–85.
[5] S.N. Bagayev, G.N. Grachev, V.F. Zakharyash, et al., Rapidly tunable 2.5 kW CO_2 laser operating in single-frequency and two-wavelength modes for pollution monitoring, lidar and scientific applications, Filtrat. Indust. Anal. (2000).
[6] B. David, S.L. Emeyr, S.W. Goto, High pulse repetition frequency, multiple wavelength, pulsed CO_2 radar system for atmospheric transmission and target reflectance measurements, Appl. Opt. 31 (21) (1992) 4224–4232.
[7] Y.C. Qu, X.Y. Hu, F.M. Liu, et al., Rapidly tuning miniature TEA CO_2, laser–rotating mirror and grating mechanism, Infrared Phys. Technol. 41 (3) (2000) 143–147.
[8] F.R. Fxavog, H.W. Moeker, Rapidly tunable CO_2 TEA laser, Appl. Opt. 21 (22) (1982) 3986–3987.
[9] Y.Q. Cheng, R.Q. Tan, Y.J. Zheng, et al., Rapidly tunable experiment of grating line selectable TEA CO_2 laser, Infrared Laser Eng. 36 (5) (2007) 635–638.