High repetition rate TEA CO_2 laser with randomly coded wavelength selection

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High repetition rate transversely exited atmospheric pressure (TEA) CO_2 laser with randomly coded wavelength selection is suggested. The laser wavelength is tuned by a Fabry-Perot (F-P) etalon of low fineness, whose space interval is controlled by a piezoelectric transducer (PZT). A digital controlled programmable voltage source is introduced to vary the voltage applied on PZT so as to swiftly shift the laser output wavelength pulse by pulse. Detailed theoretical analysis is carried out by six-temperature mode rate equations.

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Besides rf discharged CO_2 lasers, which are generally operated in CW mode or pulse mode, transversely excited pulsed CO_2 lasers are among the most widely used CO_2 lasers in various industrial fields. Tunable exited atmospheric pressure (TEA) CO_2 laser is one example. In a tunable TEA CO_2 laser, grating is one of the most widely used optical elements. By changing the incident angle on the grating, the output laser wavelength can be selected. However, it generally takes some time to shift the oscillating wavelength since the revolving speed of the rotating stage on which the grating is mounted is limited to ensure stability and reliability. As a result, it is difficult to shift the transition wavelength pulse by pulse, especially under high repetition rate operation. Based on the previous experimental work on high repetition rate TEA CO_2 laser[1,2], a kind of tunable TEA CO_2 laser with a Fabry-Perot (F-P) etalon is suggested, in which the laser output wavelength can be selected randomly as well as shifted swiftly.

Figure 1 is a block diagram of the suggested tunable TEA CO_2 laser with randomly coded wavelength selection. The system consists of a TEA CO_2 laser, whose resonator is composed of a total reflective copper concave mirror and a F-P etalon of low fineness. A programmable voltage power supply is used to drive the piezoelectric transducer (PZT). The space interval of a specially designed F-P etalon can be linearly varied by the voltage applied on the PZT. The central control unit is applied as an interface connecting the laser system and the operator. A random data generator (RDG) and a wavelength bank are placed before a D/A converter. The RDG produces random numbers with each number corresponding to one wavelength stored in the wavelength bank. Once a random number is generated by RDG, a relevant wavelength is selected so that the D/A converter outputs a certain voltage to change the peak output voltage of the PZT power supply, thus the space interval of the F-P etalon can be varied accordingly. Consequently, the oscillating wavelength of the laser system is selected.

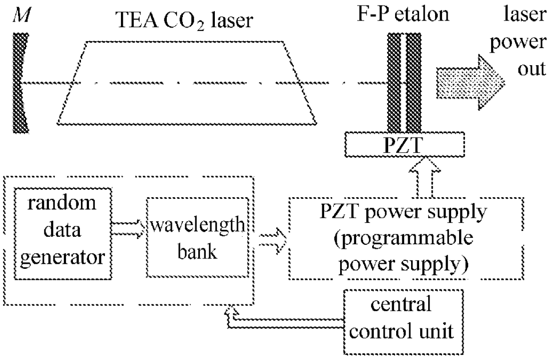

Fig. 1. Block diagram of a high repetition rate TEA CO_2 laser with randomly coded wavelength selection.

Figure 2 is a schematic diagram of the F-P etalon. The two plates are made of the same material. Surface 1 and surface 4 are antireflection (AR) coated. Surface 2 and surface 3 are partially silvered. The two plates are parallel to each other, forming an etalon. When a light beam travels vertically through the etalon from surface 1 to surface 4, the power reflectance $R(\nu)$ and the power transmission $T(\nu)$ are expressed as follows

$$R(\nu) = \frac{4 \cdot R_0 \cdot \sin^2 \varphi}{(1 - R_0)^2 + 4 \cdot R_0 \cdot \sin^2 \varphi}, \tag{1}$$

$$T(\nu) = 1 - R(\nu) = \frac{(1 - R_0)^2}{(1 - R_0)^2 + 4 \cdot R_0 \cdot \sin^2 \varphi}, \tag{2}$$

$$\varphi = \frac{2\pi\nu}{c} d. \tag{3}$$

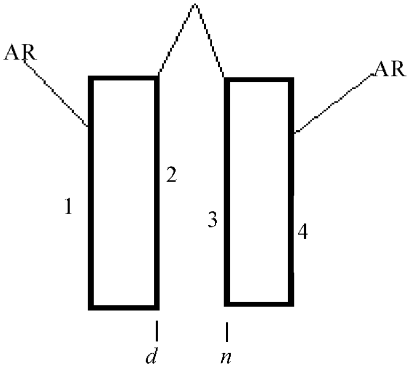

Fig. 2. Schematic diagram of a F-P etalon.

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In the Eqs. (1)−(3), ν is the light frequency, R_0 and d are the power reflectivity of surface 2 and surface 3, and the space interval of the etalon respectively. For a fixed R_0, the power transmission and the power reflectivity can be changed periodically by varying the space interval of the etalon. Also, by varying the space interval, the wavelength with the largest net gain can suppress the oscillation of other wavelengths and generates laser output.

In the wavelength bank, there are a certain number of wavelength-voltage pairs. Each voltage corresponds to an output laser wavelength. Under each voltage, there will be only one strong line in the spectra of the laser output wavelengths. The number of the wavelength-voltage pairs is determined by the wavelength-selective characteristics of the active laser resonator. If the wavelength tunability of the resonator is good enough, there will be a large number of voltage-wavelength pairs in this bank. However, for a high power TEA CO_2 laser with a low fineness F-P etalon as one end of the resonator, the number of voltage-wavelength pairs in the bank is quite limited.

In the following, a repetition rate TEA CO_2 laser coupled by a low fineness F-P etalon that can be operated within four wavelengths of $9R20$, $9P20$, $10R20$ and $10P20$ will be discussed by numerical simulation. The laser is assumed of resonator length 2.4 m, active length 1.0 m, effective gain cross-section 2.5×2.5 cm^2 and curvature of the total reflective mirror $R = 20$ m. The laser gas mixture is composed of CO_2 9.8 kPa, N_2 9.8 kPa, He 39.3 kPa and CO 2.4 kPa at room temperature 300 K. The F-P etalon is made of ZnSe material, with a single surface reflectivity of $R_0 = 17\%$.

In order to analyze the output characteristics of the laser, six-temperature mode rate equations on tunable TEA CO_2 lasers are required. In Ref. [3], a set of rate equations describing the kinetic process of non-tunable TEA CO_2 lasers is given. Based on these rate equations, another group of rate equations that can be applied to tunable TEA CO_2 lasers is derived[4]. In these equations, every vibration-rotational line of the CO_2 molecule is assumed to be composed of several longitudinal mode frequencies; every excited vibration-rotational line can generate laser output depending on its net gain; and also there is only homogeneous broadening in each vibration-rotational line, which is rational in the case of TEA CO_2 lasers.

All data such as spectra frequencies, broadening widths and lifetimes, which are related to the rate equations on tunable TEA CO_2 lasers, can be found in Ref. [5].

Set the initial conditions as those stated in Ref. [6]. Assuming the pumping electron density as

$$N_e(t) = 3.0 \times 10^{19} \times \exp\left(\frac{-t}{0.5 \times 10^{-6}}\right) \times \left[1 - \exp\left(\frac{-t}{1.0 \times 10^{-6}}\right)\right]. \quad (4)$$

By solving the rate equations suggested, the laser output characteristics of the suggested TEA CO_2 laser can be calculated out numerically.

Ignoring the fine longitudinal mode structures of the vibration-rotational lines, Fig. 3 shows the calculated output wavelengths as the space intervals are varied from 0.5 to 50 μm with a 0.5-μm step. From Fig. 3, it can be seen that as the space intervals are varied, the output wavelengths vary nearly periodically. It is easy to find some space intervals at which the output wavelengths are mainly $10P20$, $10R20$, $9P20$ or $9R20$. Table 1 is a list of 48 intervals at which the laser output energies are larger than 1.7 J.

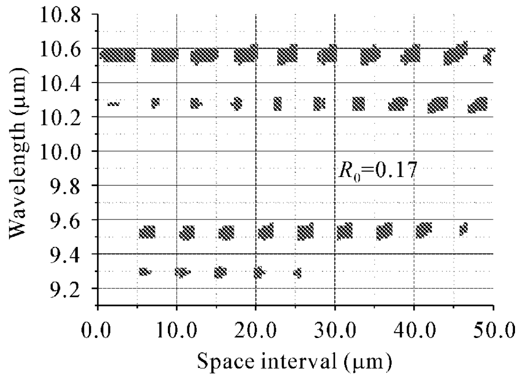
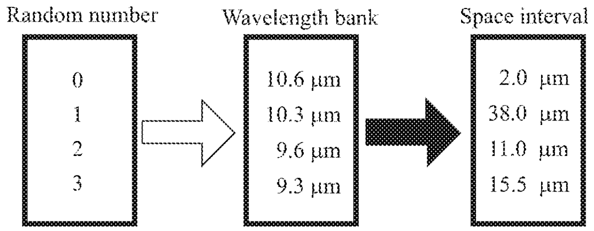


Fig. 3. Laser output spectra versus space intervals.

Table 1. A List of 48 Intervals

Wavelength (μm)	Space Interval (μm)
10.6	1.5, 2.0,2.5,3.0,7.5,8.0,12.5,13.0, 18.0,18.5,23.5,28.5,29.0,34.0,35.0, 39.0,39.5,44.5,45.5,49.5,50.0
10.3	22.5,27.5,28.0,33.0,38.0,38.5,43.0,43.5,48.5
9.6	6.0,6.5,11.0,11.5,12.0,16.0,16.5,21.0, 21.5,26.0,27.0,30.5,31.0,31.5,35.5,36.5,41.0
9.3	15.5

As illustrated in Fig. 1, there is a RDG in this laser system, which can be set to generate numbers 0, 1, 2 and 3 randomly. In the wavelength bank, number 0 corresponds to a wavelength of 10.6 μm, and number 1 to 10.3 μm, number 2 to 9.6 μm, number 3 to 9.3 μm, respectively. Then the laser can be operated in the following form:



For example, the RDG gives twenty random numbers in the following time order: 1, 3, 2, 0, 1, 0, 2, 2, 2, 0, 1, 1, 1, 3, 1, 3, 3, 2, 3, 0. From the equations provided above, the detailed laser output spectra at each space interval (shown in Fig. 4), the laser output wavelengths changing with time (shown in Fig. 5), and the laser output pulse energy versus time (shown in Fig. 6) can be obtained,

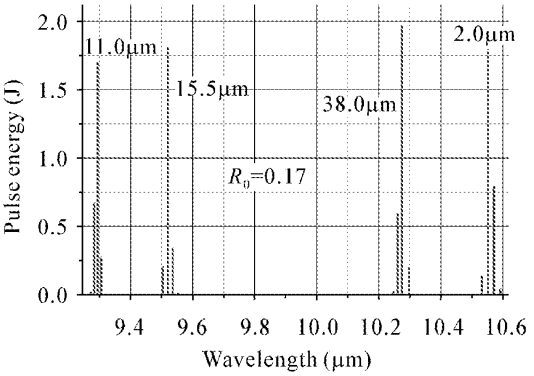


Fig. 4. Detailed output spectra at each space interval.

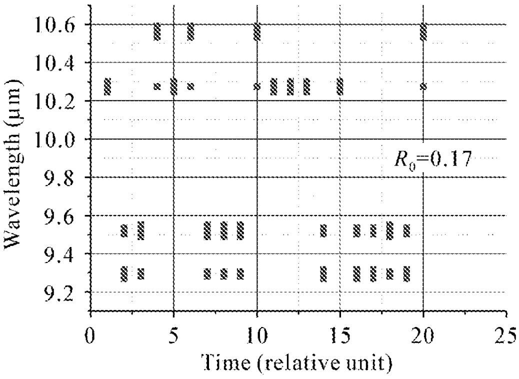


Fig. 5. Laser output spectra versus time.

respectively. It can be seen in Fig. 6 that the laser output pulse energy does not change so much though the output wavelengths change randomly among the four laser transition bands.

From the analysis above, It is obvious that the suggested tunable TEA CO_2 laser can be operated in a way that its output laser wavelength can be randomly coded among the four transition lines 10.6, 10.3, 9.6 and 9.3 μm. Theoretical calculation shows that though the output wavelength changes randomly, the output laser energy of each pulse almost remains the same. Since the laser can be operated in high repetition rate mode and the space interval of the F-P etalon can be varied swiftly by changing the voltage applied on the PZT, it is workable that the laser output wavelength can be coded pulse by pulse. It may be useful in some fields of application. Therefore, it is valuable to build such a kind of laser, though there might be some practical difficulties to overcome during the build-up.

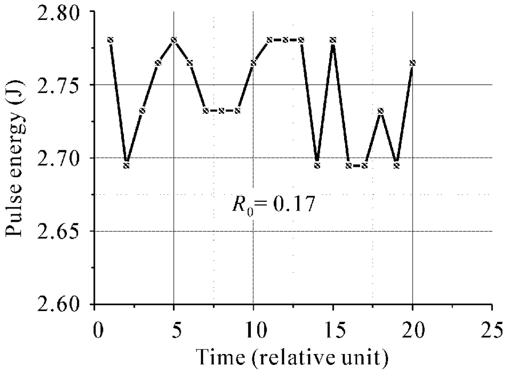


Fig. 6. Laser output pulse energy versus time.

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