Compact waveguide CO_2 laser excited by a RF power supply

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Received April 12, 2004

The design and performance of radio frequency (RF) excited partial Z-fold waveguide CO_2 laser with two channels are exposed. The length of the partial Z-fold channel is 3×460 mm and that of the single channel is 460 mm. The electrodes for the two channels are common and excited by a same RF source. According to our analysis, this kind of structure can greatly improve the laser offset frequency stability. In the experiments, we studied the variation of laser output power with gas pressure for two different channels. The maximum laser output power is about 23 W for the partial Z-fold channel and about 6 W for the single channel.

OCIS codes: 140.3470, 140.4130.

CO_2 waveguide laser has been found widespread applications as a compact infrared source in portable systems. At present, high-power CO_2 laser is used widely in industry, military, and metrology[1−4]. Up to now, most of CO_2 coherent laser radars utilize two lasers with different wavelengths. But this may suffer from possibly unacceptable penalties of increased size, weight, complexity, and cost[5]. However, a single radio frequency (RF) source may be used to excite two laser channels. On the basis of the requirement shown above and the previous study, we designed a new partial Z-fold waveguide CO_2 laser with two channels excited by the same RF power supply. The partial Z-fold channel is used as transmitter laser and a single channel is used as local oscillator laser. By using two different channels, most of the RF power is transmitted to the partial Z-fold channel. Because of the structure of common electrodes and the close distance between the two channels, the voltages on the two channels are nearly equal. When the RF input power is varied, the variations of gas refractive index and cavity length of the two channels are nearly in the same direction. So the relative frequency stability of the laser from the two channels is less disturbed by the variation of RF power and circumstance influences. It can be predicted that the relative frequency stability between two lasers excited by the same RF generator is much better than that for both independent and separate lasers[6−8]. Furthermore, this kind of structure has the advantages of low cost, easy manufacturing, and small size. At present, laser output has been obtained from the two channels simultaneously.

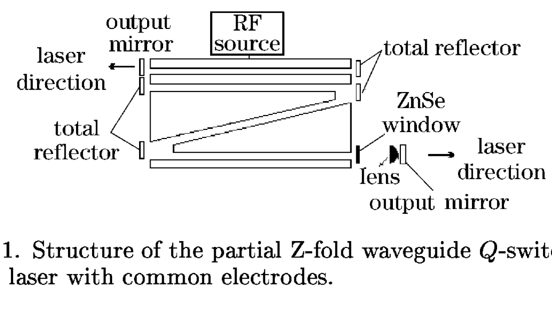

Fig. 1. Structure of the partial Z-fold waveguide Q-switching CO_2 laser with common electrodes.

The laser is designed around a metal ceramic sandwich waveguide, which has a 2.25×2.25 mm^2 cross-section, as illustrated in Fig. 1. The laser structure has two channels, a partial Z-fold channel and a single channel. The two channels are excited by a same RF source and placed within a water-cooled stainless vacuum housing, incorporating a RF feed through to enable the power to be transmitted into the waveguide. The distance between the two channels is 20 mm. The partial Z-fold channel is 3×460 mm in length and the single channel is 460 mm. A case I waveguide resonator with a flat total reflector and a flat output mirror is used for the single channel. For reducing coupling losses for the EH_{11} mode and to easily insert a modulator crystal and other optical elements into the resonator, we designed an equivalent Case III waveguide resonator for partial Z-fold channel. Two total reflector laser mirrors are placed 5 mm away from the ends of the two waveguides, the other two total reflectors are at the elbow parts of the Z-fold. A flat ZnSe window is placed 5 mm away from the front of the partial Z-fold waveguide. A ZnSe lens and an output mirror, which are placed close to each other, are equivalent to concave mirrors as Case III waveguide resonator for partial Z-fold channel. The four total reflectors, ZnSe window, and flat output mirror are attached to the vacuum housing with mounts sealed by "O" rings, which permit angular adjustments along the two orthogonal axes. The laser output directions from the two channels are opposite.

In this new structure, parallel resonant inductors are placed along the electrodes, and their value can be adjusted until a resonance at the RF oscillating frequency is realized. These inductors provide a negative admittance[9,10] which compensates for the variation in the phase angle of the transmission line. The parallel inductors not only reduce the voltage variation but also serve as part of the impedance matching network by transforming the laser impedance to a pure resistance. The waveguide laser utilizes a parallel resonant distributed-inductance (PRDI) technique to uniformly distribute voltage along the electrodes and hence to uniformly excite the gain medium. With this method[11] a large number of equal-value parallel inductors are uniformly placed from the center of the laser channels to approximate a distributed inductance. In order to efficiently couple the RF power into the active medium, a LC matching circuit is used between the generator and the laser head[12,13].

There are normally two kinds of folding geometries, the general Z-fold waveguide[14] and the partial Z-fold waveguide. The figures are shown schematically in Fig. 2. In the case of the general Z-fold waveguide shown in Fig. 2(a), the coupling is provided by an external mirror placed at the interception of the two waveguide optic axes. For the partial Z-fold waveguide shown in Fig. 2(b), the top, bottom, and outside waveguide walls are extended past the end of the inside wall to, or nearly to, the reflector. In partial Z-fold waveguide, the light exiting the first waveguide experiences three walled or partial waveguide over a path length d_1, followed by free space propagation over a short path length d_2 to a planar reflector. The light experiences an identical path, but in reverse, before entering the second waveguide.

According to the experimental results reported by Paul[15], this kind of structure can improve the laser output power for about 40%. The coupling loss is only (1.2±0.1)%, less than that of the general folding geometry. In addition, the tolerance to misalignment is far greater with the partial waveguide fold reflector than with the general geometry. In the experiments, a fold angle of $2\theta = 4.5°$ was used with $d_1 = 35$ mm, $d_2 = 5$ mm, mirror Fresnel numbers $N = a^2/\lambda d_2 = 3.4$, where a is the waveguide half-width and λ is the wavelength. The spacing between the waveguide inner wells at the end face is $s = 0.5$ mm.

According to laser theory, the frequency excursion of laser is influenced by the variations of cavity length and refractive index of gain media,

$$\Delta\nu = -\nu_0\left(\frac{\Delta n}{n_0} + \frac{\Delta L}{L}\right), \tag{1}$$

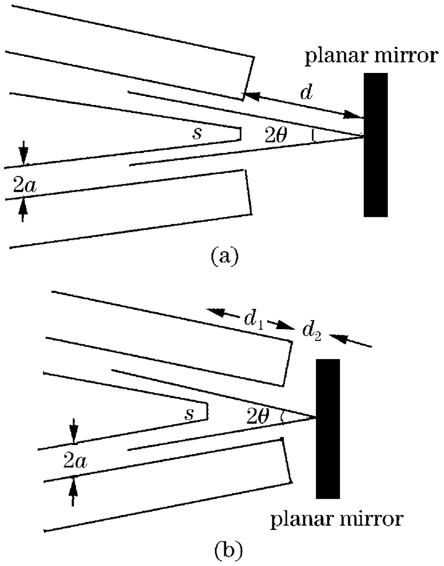

Fig. 2. Sketch of elbow in Z-fold waveguide laser. (a): General Z-fold waveguide laser; (b): partial Z-fold waveguide laser. $2\theta = 4.5°$; $2a = 2.25$ mm.

where n_0 is the average value of refractive index, Δn represents the variation of the refractive index, L_0 is the initial cavity length, ΔL represents the variation of the cavity length, and ν_0 is the oscillation frequency corresponding to the cavity length L_0 and an intracavity refractive index n_0. From Eq. (1) we can see that two factors contribute to the frequency stability, i.e., the cavity length and the refractive index. The laser we designed is a Z-fold laser, in which

$$L_Z \approx 3L_S \quad \text{and} \quad \Delta L_Z \approx 3\Delta L_S, \tag{2}$$

where L_Z is the cavity length of the partial Z-fold channel and L_S is the cavity length of the single channel. The instantaneous oscillation frequencies of the partial Z-fold laser and single laser are respectively given by

$$\Delta\nu_Z = -\nu_0\left(\frac{\Delta n}{n_0} + \frac{\Delta L_Z}{L_Z}\right), \tag{3}$$

$$\Delta\nu_S = -\nu_0\left(\frac{\Delta n}{n_0} + \frac{\Delta L_S}{L_S}\right). \tag{4}$$

The variation of offset frequency from two channels can be expressed by

$$\Delta\nu_C = \Delta\nu_Z - \Delta\nu_S. \tag{5}$$

Substituting Eqs. (3) and (4) into Eq. (5), one can get

$$\Delta\nu_C = -\nu_0\left(\frac{\Delta L_Z}{L_Z} + \frac{\Delta L_S}{L_S}\right). \tag{6}$$

With the substitutions

$$L_Z \approx 3L_S \quad \text{and} \quad \Delta L_Z \approx 3\Delta L_S, \tag{7}$$

one can write the variation of offset frequency from two channels as

$$\Delta\nu_C \to 0. \tag{8}$$

According to the analytical result, the laser we designed can improve the offset frequency stability by compensating the variables of the cavity length imposed by circumstance temperature, voltage of RF input, random vibration, and so on.

Under the condition of 300-W RF input power and the volume ratio of unoptimized gas mixture of $CO_2 : N_2 : He = 1 : 1 : 3$, the two channels can uniformly discharge simultaneously and the laser output can be achieved from the two channels. Ten parallel inductors are placed across the electrodes to form a resonant transmission line at 80 MHz. RF power at 80 MHz is delivered to the top electrodes via a 50-Ω cable and LC impedance matching network. The output power of the laser was measured for different gas pressures and the results are shown in Fig. 3. The laser power was measured with a LP-3C power meter, and the RF power under near perfect impedance matching condition was measured with a cross RF power meter. Figure 3 shows that the peak laser output power of the Z-fold channel is 21 W at a gas pressure of 8 kPa and that of the single channel is 5.5 W at a gas pressure of 7 kPa, both with EH_{11} output mode. The addition of 5% xenon to working gas mixtures can increase the peak

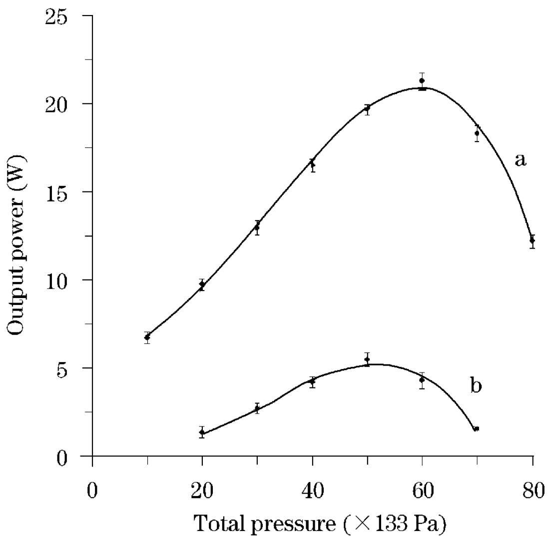

Fig. 3. Variation of laser output power with gas pressures for the partial Z-fold channel (a) and the single channel (b).

output power, up to 23 W for the partial Z-fold channel and about 6 W for the single one.

In conclusion, we present a partial Z-fold waveguide CO_2 laser with two channels. The partial Z-fold channel and the single channel are excited by a same RF source. The main advantages of the laser are compact structure, small size, high offset frequency stability, easy manufacturing, and lower cost.

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