

LASERS

PACS numbers: 42.55.Lt; 42.60.Da; 42.60.Jf
DOI: 10.1070/QE2004v034n04ABEH002671

High-quality beam generation in a 8-kW cw CO_2 laser

Yu.V. Afonin, A.P. Golyshev, A.I. Ivanchenko, A.N. Malov,
A.M. Orishich, V.A. Pechurin, V.F. Filev, V.B. Shulyat'ev

***Abstract*. The use of a self-filtering cavity in a laser makes it possible to obtain a high-quality high-power output beams. A maximum output power of 8.3 kW with an electrooptical efficiency of 11.3 % is obtained. Estimates show that a high-quality beam with power up to 20 kW can be generated in electric-discharge CO_2 lasers with a self-filtering cavity.**

Keywords: *CO_2 laser, optical cavity, beam quality*.

High-power CO_2 lasers are widely used for processing materials and in scientific research. 20-kW cw CO_2 lasers are being produced commercially at present. The quality of a laser beam, which determines together with the radiation power W the beam brightness $J \sim WK^2/\lambda^2$, where K is the beam quality parameter, is an important characteristic of the beam.

The requirements of high power and high quality of a beam are mutually contradictory. An increase in the active medium volume requires an increase in the aperture and Fresnel number N of the optical cavity. For $N > 1$, higher-order transverse modes are excited in a stable cavity, resulting in deterioration of the beam quality. The radiation power does not exceed 3 – 4 kW during lasing in the TEM_{00} mode ($K = 0.6 - 0.9$) [1 – 3]. For an 8 – 10-kW power, the beam quality parameter is ~ 0.25 [1, 2], while for 30-kW power, its value is ~ 0.1 [4], i.e., the beam divergence is an order of magnitude greater than the diffraction-limited divergence.

Over the last decade, cavities ensuring an increase in the radiation power to 5 – 6 kW, in which the high quality of the high-power CO_2 laser beam is preserved, have been proposed. These are various modifications of cavities with a semitransparent output mirror with a nonuniform reflection along the radius [5 – 7], and a stable – unstable cavity formed by totally reflecting mirrors [2, 8]. The maximum power of 6.2 kW was achieved in Ref. [6] using a cavity with nonuniformly reflecting mirrors. In this scheme, the Fresnel number is equal to 1.5 and the radiation power is limited by the small mode volume. The drawback of the schemes described in Refs [5 – 7] is that they use a technologically complicated nonuniform semitransparent mirror. Absorption of radiation in such a mirror may cause phase distortions of the beam (as was indeed observed in Ref. [6]). In a stable – unstable cavity that was used in a transverse-flow laser [8] and in commercial slab lasers with output powers up to 4.5 kW [2], lateral extraction of radiation was used. This scheme is in poor agreement with the active media having an axial symmetry. The output radiation is characterised by a rectangular cross section and a considerably non-Gaussian intensity distribution. Spatial filtration of the beam is performed to correct its spatial structure [2]. For beam powers of 10 – 20 kW, filtration may be practically inadmissible because of its complex technical realisation. Moreover, a significant part of radiation power is lost in the case of spatial filtration.

In this work, we obtained a 8-kW high-quality beam from a cw CO_2 laser, whose quality was close to that of the TEM_{00}-mode beam. A self-filtering resonator formed by highly reflecting mirrors with Fresnel number 6.5 was used in the laser.

A self-filtering resonator [9 – 11] (Fig. 1) is a confocal cavity formed by concave spherical mirrors of different curvatures with an intracavity spatial filter. The beam quality improves with increasing the geometrical magnification $M = f_1/f_2$ of the resonator because the relative size of the coupling aperture decreases and energy is redistributed in the far-field zone from side diffraction maxima to the central spot. The Fresnel number N_1 for the larger arm of the resonator is proportional to M; conversely, the feedback R' decreases with increasing M: $R' \approx 2/M^2$. A weak feedback for large values of M, when advantages of the self-filtering resonator (a high quality of the beam and a

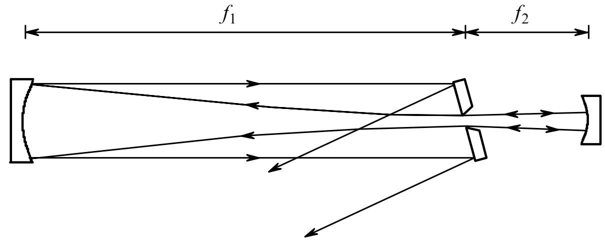

Figure 1. Optical scheme of a self-filtering resonator.

Yu.V. Afonin, A.P. Golyshev, A.I. Ivanchenko, A.N. Malov, A.M. Orishich, V.B. Shulyat'ev Institute of Theoretical and Applied Mechanics, Siberian Branch, Russian Academy of Sciences, ul. Institutskaya 4/1, 630090 Novosibirsk, Russia;
e-mail: shulyat@itam.nsc.ru;
V.A. Pechurin, V.F. Filev Laser Engineering Design Bureau, Siberian Branch, Russian Academy of Sciences, ul. Institutskaya 4/18, 630090 Novosibirsk, Russia

Received 8 September 2003; revision received 22 January 2004
Kvantovaya Elektronika **34** (4) 307 – 309 (2004)
Translated by Ram Wadhwa

large mode volume) are manifested, requires a considerable increase in the active medium gain to ensure a high efficiency of energy transformation in the resonator. This peculiarity, which limits the range of application of such a resonator, is discussed in detail in Ref. [12].

Our theoretical and experimental investigations show that a quite large volume of the lowest mode, a high efficiency of energy transformation in the resonator, and a high quality of the output beam can be ensured simultaneously in a cw electric-discharge CO_2 gas flow laser with a self-filtering resonator. The field distribution in the resonator was calculated numerically with the help of the Fresnel – Kirchhoff diffraction integral using iterative technique [13, 14]. Calculations show that even for $M > 4 - 4.5$, less than 0.1 – 0.08 of the entire beam power lies outside the central spot in the far-field zone, and the intensity of the first side peak is less than 0.007 – 0.005 of the axial intensity. Thus, the output beam is nearly Gaussian in quality. The magnification $M = 4 - 5$ corresponds to $N_1 \approx 5.5 - 7$ and $R' = 0.12 - 0.08$.

The design of the laser used in our experiments is described in Ref. [11]. The active medium is excited by a self-sustained dc discharge in a transverse gas flow. The system consists of two discharge gaps, each having two tubular cathodes and a common flat anode. The separation between the anode and cathodes is 55 cm in each discharge gap, the length of the electrode system along the direction of propagation of radiation in the resonator is 110 cm, and the gas velocity in the discharge gap is 50 m s^{-1}. The pressure of the gas mixture in the discharge chamber is 24 Torr for partial pressures of the components in the proportion $CO_2 : N_2 : He = 10 : 50 : 40$.

In the larger arm of the resonator, the beam completes three transits along a Z-shaped trajectory in each discharge gap. The magnification of the resonator is 4.5, its length along the optical axis is 11.25 m, and the aperture of the mirrors is 50 mm. The maximum output power is 8.3 kW for an efficiency (ratio of the output power to the electric power supplied to the discharge) of 11.3 %. Water-cooled copper mirrors were used in the resonator. The radiation was extracted from the discharge chamber through a ZnSe window with an anti-reflection coating.

The intensity distribution in a focused beam was measured by the method of a rotating reflecting cylinder [15, 16]. Scanning of a beam by a cylindrical mirror is equivalent to scanning by a slit whose width in geometrical approximation is equal to $aR/(2L)$, where a is the aperture of the photodetector, L is the distance between the cylinder and the photodetector, and R is the radius of the cylinder. Estimates show that the spatial resolving power of the method for these values of the measuring system parameters is 30 – 50 μm. The radiation was focused with a ZnSe meniscus lens of focal length $F = 190.5$ mm, which is normally used in cutting experiments. The diameter of the laser beam after passing through a matching reflecting telescope decreased to 30 mm at the lens entrance. For a major part of the cross section, the measured intensity (Fig. 2) had a bell-shaped distribution characteristic of the TEM_{00} mode and a number of weakly manifested side maxima. The beam diameter at half the maximum intensity was equal to 125 μm, and the diameter of the central spot at the base was 330 μm.

The beam quality parameter estimated from the results of measurements was $K = 0.6 - 0.7$. No variation in the axial intensity, shape and diameter of the focal spot was observed upon varying the radiation power from 0.5 to 6 kW.

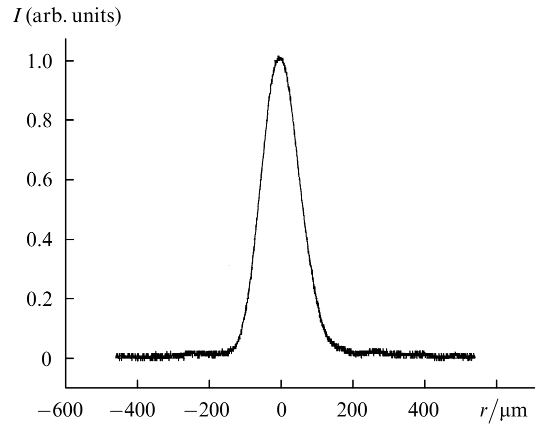

Figure 2. Intensity distribution at the waist of a focused beam.

One can see from Fig. 1 that the nature of filling of an active medium by radiation in a self-filtering resonator is similar to that in an unstable telescopic resonator. The efficiency of a self-filtering resonator (11.3 %) is close to the efficiency 10 % – 12 % typical of transverse cw CO_2-lasers with a self-sustained dc discharge and an unstable telescopic resonator [17, 18]. It should be noted that in lasers with a single-mode (TEM_{00}) stable resonator, the electrooptical efficiency is lower (8 % – 9 %) [3].

To our knowledge, the maximum power for cw CO_2 lasers with a high beam quality attainable at present is 8 kW. The obtained power can be increased by increasing the pressure of the gas mixture and the energy contribution per unit volume. Excitation of the active medium by an ac or rf discharge may lead to pump power densities that are 2 – 4 times higher than the characteristic value 5 – 7 W cm^{-3} for a self-sustained dc discharge [3, 4]. Thus a value of 15 – 25 kW can be taken as the upper limit of the power attainable for the above-mentioned values of the resonator parameters.

Experiments on cutting metal plates of thicknesses 0.5 – 30 mm at radiation powers of 0.5 – 6 kW showed that the cutting speed and the main parameters of cutting (absence of burr, straightness of edges and their roughness, width of the cut) were almost the same for lasers with self-filtering and stable resonators (the results of our experiments are being prepared for publication).

It can be concluded from a comparison of the above results with those obtained by using other resonator schemes that a self-filtering resonator is optimal for 5 – 20-kW CO_2 lasers with a high quality of radiation.

References

1. *Technical data of Trumpf lasers*. http//www.us.trumph.com
2. *Technical data of Rofin-Sinar lasers*. http//www.rofin.com/home-e.htm.
3. Yasui K., Kuzumoto M., Ogawa S., Tanaka M., Yagi S. *IEEE J. Quantum Electron.*, **25**, 836 (1989).
4. Habich U., Hertzler C., Wollermann-Windgase R. *Proc. SPIE Int. Soc. Opt. Eng.*, **2702**, 374 (1996).
5. Takeneka Y., Kuzumoto M., Yasui K. *IEEE J. Quantum Electron.*, **28**, 1855 (1992).
6. Takenaka Y., Nishimae J., Tanaka M. *Opt. Lett.*, **22**, 37 (1997).

7. Generalov N.A., Solov'yov N.G., Yakimov M.Y., Zimakov V.P. *Proc. SPIE Int. Soc. Opt. Eng.*, **3267**, 144 (1998).
8. Galushkin M.G., Golubev V.S., Korotchenko A.V., Zabelin A.M. *Proc. SPIE Int. Soc. Opt. Eng.*, **3092**, 134 (1996).
9. Gobbi P.G., Reali G.C. *Opt. Commun.*, **52**, 195 (1984).
10. Ivanchenko A.I., Krasheninnikov V.V., Ponomarenko A.G., Shulat'ev V.B. *Kvantovaya Elektron.*, **16**, 305 (1989) [*Sov. J. Quantum Electron.*, **19**, 203 (1989)].
11. Ivanchenko A.I., Krasheninnikov V.V., Smirnov A.L., Shulat'ev V.B. *Kvantovaya Elektron.*, **21**, 643 (1994) [*Quantum Electron.*, **24**, 591 (1994)].
12. Siegman A. *Opt. Commun.*, **88**, 295 (1992).
13. Anan'ev Yu.A. *Opticheskie rezonatory i problema raskhodimosti lazernogo izlucheniya* (Optical Resonators and Divergence of Laser Radiation) (Moscow: Nauka, 1979).
14. Anan'ev Yu.A., Anikichev S.G., Solov'ev V.D. *Opt. Spektr.*, **73**, 173 (1992).
15. Ivanchenko A.I., Shepelenko A.A. Author's certificate USSR No. 646774 (1977).
16. Lim G.C., Steen W.M. *J. Phys. E: Sci. Instr.*, **17**, 999 (1984).
17. Cheng Z., He X., Li Z. *Appl. Opt.*, **24**, 4260 (1985).
18. Takahashi T., Kakizaki K., Sasaki N., Sakuma J. *Proc. SPIE Int. Soc. Opt. Eng.*, **610**, 50 (1986).