ISSN 1054-660X, Laser Physics, 2012, Vol. 22, No. 7, pp. 1173–1176.



# High Power Repetitive TEA $CO_2$ Pulsed Laser[1]

**Guilong Yang*, Dianjun Li, Jijiang Xie, Laiming Zhang, Fei Chen, Jin Guo, and Lihong Guo**

*State Key Laboratory of Laser Interaction with Matter, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun, 130033 China*

*e-mail: yanggl@ciomp.ac.cn

Received February 4, 2012; in final form, March 10, 2012; published online June 12, 2012

**Abstract**—A high power repetitive spark-pin UV-preionized TEA $CO_2$ laser system is presented. The discharge for generating laser pulses is controlled by a rotary spark switch and a high voltage pulsed trigger. Uniform glow discharge between two symmetrical Chang-electrodes is realized by using an auto-inversion circuit. A couple of high power axial-flow fans with the maximum wind speed of 80 m/s are used for gas exchange between the electrodes. At a repetitive operation, the maximum average output laser power of 10.4 kW 10.6 μm laser is obtained at 300 Hz, with an electro-optical conversion efficiency of 15.6%. At single pulsed operation, more pumping energy and higher gases pressures can be injected, and the maximum output laser energy of 53 J is achieved.

**DOI:** 10.1134/S1054660X12070158

## 1. INTRODUCTION

TEA $CO_2$ laser (transversely excited atmospheric $CO_2$ laser) has numerous applications, such as industrial process, medical treatment, scientific research and so on [1–6]. Especially, high power repetitive TEA $CO_2$ laser is in demand for the research on laser propulsion [7]. In recent years, the output power, energy, stability, beam quality and operating lifetime for TEA $CO_2$ laser are investigated extensively and improved obviously [8–12]. Whether continuous wave (CW) or pulsed discharge pumping TEA $CO_2$ laser, it should be operated in the condition of uniform glow discharge [13–16]. To enhance the output laser power or energy, higher energy storage system is needed, and higher gases pressures should be injected and maintained at non-arc discharge [17, 18]. As known to all, the generation of arc discharge is characterized by high current density, and the major measures for improving the TEA $CO_2$ laser performance will lead to the transition from glow discharge to arc discharge. To solve this problem, preionization technique is introduced, and it is one of the fundamental differences for kinds of TEA $CO_2$ laser system. By now, there is no report on high-repetition-rate (several hundred Hz) high pulse energy (tens joules) myriawatt single-stage TEA $CO_2$ laser oscillator by using a simple spark-pin UV-preionization. In this paper, a high power repetitive TEA $CO_2$ laser system is designed and constructed. The highest average output laser power of 10.4 kW 10.6 μm laser is obtained at the repetition rate of 300 Hz, and the maximum output laser energy of 53 J is obtained at single pulsed operation.

## 2. EXPERIMENTAL SETUP

As shown in Fig. 1, the TEA $CO_2$ laser system is mainly consisted of the optical resonator, energy storage and discharge chamber, rotary switch, gases circulation cooling system and computer control device.

A conventional plano-concave optical resonator is used for stable and reliable laser operation. The resonator with a length of 2.3 m is placed on a high stable light bridge formed by three indium steel bars, which can greatly reduce the influence of environmental temperature on the output laser characteristics. Concave mirror with a curvature radius of $R = 18$ m is coated with reflective gold film on the oxygen-free copper plate. The plane ZnSe output mirror is coated with semi-reflective film of the transitivity of $T = 70\%$.

The energy storage and discharge chamber is the core of the laser system. As shown in Fig. 2, it is consisted of the energy storage capacitor, the charge up circuit, the discharge circuit and the discharge electrodes. Injected energy is determined by the energy storage capacitor and the discharge voltage. Discharge circuit is a LC auto-inversion circuit, which includes spark preionization and main discharge electrodes. The entire process from pre-ionization to the main discharge is completed for once trigger discharge of the rotary switch. Delay time about 200–400 ns between pre-ionization and main discharge can be adjusted by the inductance $L_1$. Preionization electrode is composed of 80 pairs of spark-discharge-pin, and the main electrode is a couple of symmetric Chang-electrodes.

Rotary switch includes spark switch, gases circulation fan and high-voltage pulse trigger, and it controls the laser pulse discharge process. At the open moment of the switch, gigantic electrical power is needed to

[1] The article is published in the original.

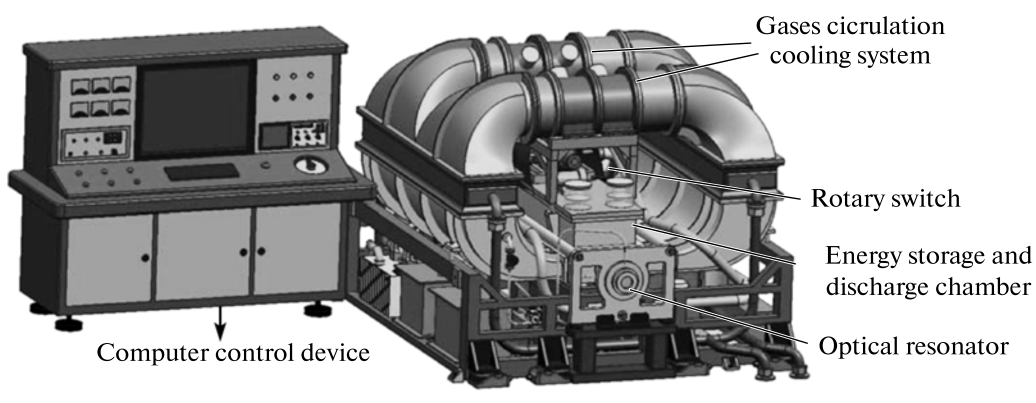


**Fig. 1.** Schematic of the setup for high power repetitive TEA $CO_2$ laser system.

conduct, and it should be cut off quickly and completely. To prevent the arc discharge, gases should be exchanged and cooled rapidly. Furthermore, the choice of electrode material is very important, which is the key issue that the spark switch works normally.

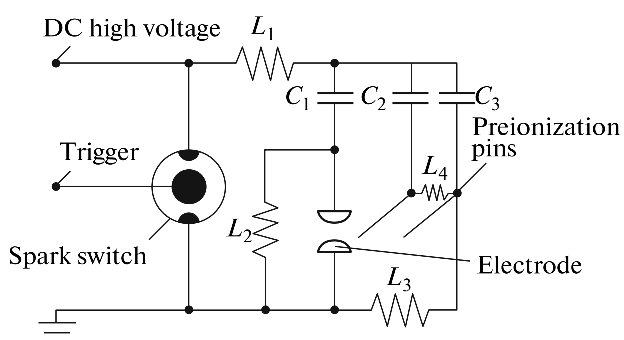


**Fig. 2.** Schematic of energy storage and discharge circuit.

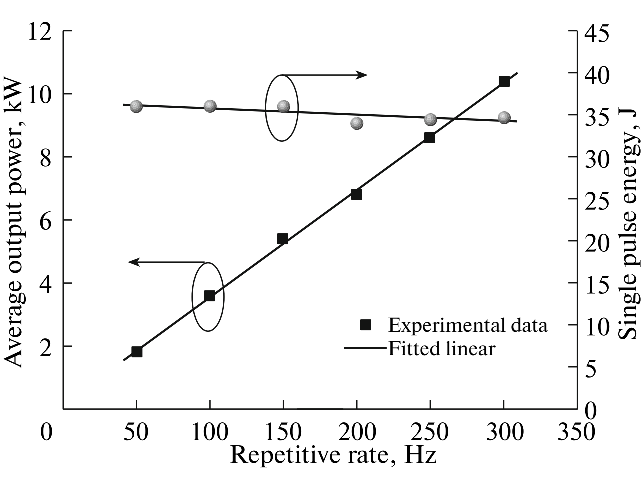


**Fig. 3.** Average output power and single pulse energy of TEA $CO_2$ laser versus repetitive rate.

Gases circulation cooling system is an auxiliary part, which is used to take away the waste heat and cool the gases after discharge. Two high-power axial-flow fans with the maximum wind speed of 80 m/s are used, giving 3–5 times of the cleaning factor. The flowing channel is very important for the uniform and stable flowing gases are required when they enters into the discharge zone. 0therwise, the uneven distribution of gases density will directly lead to the generation of arc discharge. After testing, the non-uniformity of the wind speed is less than 10% throughout the discharge region, and the temperature increase for gases is lower than 2°C at repetitive operation.

Computer control system is used to monitor the working state of laser subsystems in real-time, and display the temperature, gases pressure, voltage waveform and other parameters simultaneously. Moreover, all work-related parameters can be controlled and adjusted, such as the laser frequency, charging voltage, cycle gases velocity, pressure switches and so on.

To ensure a stable laser operation and prevent electromagnetic interference, the system is designed taking into account of measures for damping and electromagnetic shield. At normal operation, tests show that shake amplitude accelerations at the $X$, $Y$, and $Z$ directions are smaller than $1 \times 10^{-2}$ m/s$^2$, and the amplitude is smaller than $1 \times 10^{-7}$ m. Adding shielding measures, not only the hazards for human and electronic equipments are avoided by high frequency discharge, but also the testing laser characteristics are ensured to be accuracy.

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

TEA $CO_2$ laser pulse discharge is controlled by the rotary switch and high-voltage pulse trigger. Uniform glow discharge between the main electrodes is realized

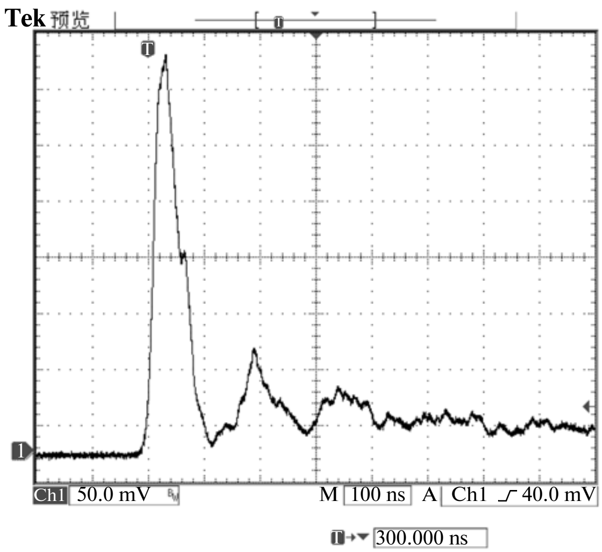


**Fig. 4.** Pulsed laser waveform.

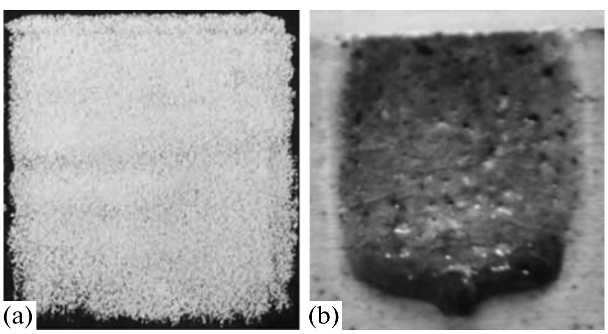


**Fig. 5.** Near field laser spot (a) single pulse recorded on thermosensitive paper (b) repetitive pulses exposuring on firebrick.

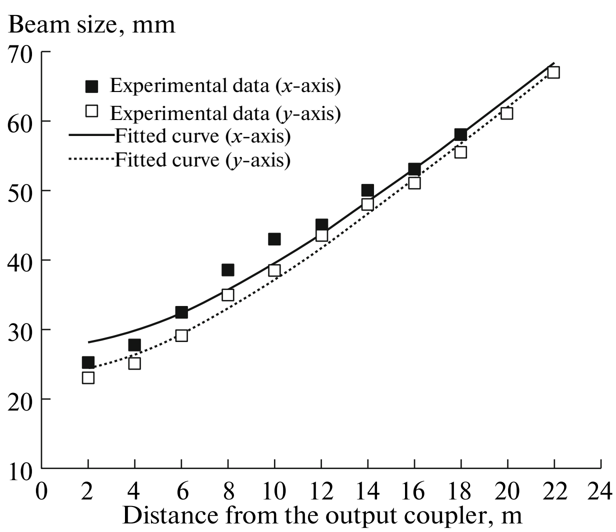


**Fig. 6.** Laser beam size measurement and beam quality test.

by the LC auto-inversion circuit. Injected the gases pressure of $5 \times 10^4$ Pa with a ratio of $CO_2 : N_2 : He = 1 : 1 : 6$, stable glow discharge can be operated below 300 Hz, and the average output power of $CO_2$ laser is increased linearly with the repetitive rate, as shown in Fig. 3. At 300 Hz and a discharge voltage of 38 kV, the maximum average output power of 10.4 kW 10.6 μm laser is obtained, with an electro-optical conversion efficiency of 15.6%. It was found that single pulse energy is almost kept at 34 J varying the repetition rate from 50 to 300 Hz, indicating that the electro-optical conversion efficiency is almost same at any repetition rate. For single pulsed or lower repetition rate operation, normal glow discharge can be realized at a higher discharge voltage and higher gases pressure. At the discharge voltage of 48 kV and the gases pressure of $7.0 \times 10^4$ Pa, the maximum laser energy of 53 J is achieved at single pulsed operation.

Under various conditions, the laser output remains almost the same waveform. As shown in Fig. 4, the laser waveform is consisted of a peak pulse with full wave at half maximum (FWHM) of 100 ns and a tail pulse with a magnitude of microsecond range. Near-field laser spot is shown in Fig. 5. Figure 5a is the spot on thermosensitive paper with single pulse energy of 38 J, and Fig. 5b is repetitive pulses of 8 kW laser exposuring on firebrick for 4 s, which are $50 \times 60$ mm$^2$ rectangular spots.

To measure the output laser beam quality, the laser beam sizes at different places from the output coupler at the $X$ and $Y$ directions are shown in Fig. 6. Calculated with the fitted results, the beam waist is estimated to be $W_{0x} = 27.6$ mm and $W_{0y} = 23.8$ mm, respectively. The divergence angles are $\Theta_x = 2.83$ mrad and $\Theta_y = 2.85$ mrad, and the beam quality factors are $M_x^2 = 26.4$ and $M_y^2 = 22.9$.

## 4. CONCLUSIONS

High power repetitive TEA $CO_2$ laser is developed in this paper. The highest average output laser power of 10.4 kW 10.6 μm laser is obtained at the repetition rate of 300 Hz, and the maximum output energy of 53 J is obtained at single pulsed operation. From the point of views of laser performance and operational stability, it reaches the pre-design goals. After further improvement and enhancement, the laser system can be applied in engineering.

## REFERENCES

1. V. Z. Gofman, V. V. Dembovetsky, V. G. Niziev, and M. N. Tarasov, Proceeding of SPIE **4165**, 197 (2000).
2. L. N. Myrabo, AIP Conf. Proceeding **664**, 49 (2003).
3. V. Hasson, Proceeding of SPIE **5120**, 717 (2003).
4. M. J. Torkamany, M. Kavian, and M. Zand, Laser Phys. Lett. **3**, 480 (2006).

5. Y. Qu, Z. H. Kang, T. J. Wang, Y. Jiang, Y. M. Andreev, and J. Y. Gao, Laser Phys. Lett. **4**, 238 (2007).

6. A. A. Ionin, J. Guo, L. M. Chang, J. J. Xie, Y. M. Andreev, I. O. Kinyaevsky, Y. M. Klimachev, A. Y. Kozlov, A. A. Kotkov, G. V. Lanskii, A. N. Morozov, V. V. Zuev, A. Y. Gerasimov, and S. M. Grigoryants, Laser Phys. Lett. **8**, 723 (2011).

7. W. L. Bohn and W. O. Schall, AIP Conf. Proceeding **664**, 79 (2003).

8. R. Tan, C. Y. Wan, J. L. Qi, S. M. Liu, J. W. Zhou, W. J. Xie, and J. Wu, Opt. Laser Technol. **31**, 393 (1999).

9. C. Y. Wan, S. M. Liu, R. Q. Tan, J. Wu, J. W. Zhou, Y. Lv, Y. N. Yu, and H. Yang, Opt. Laser Technol. **36**, 647 (2004).

10. Y. N. Yu, C. Y. Wan, Y. Lv, R. Q. Tan, J. W. Zhou, S. M. Liu, and C. Zhao, Opt. Laser Technol. **37**, 560 (2005).

11. D. L. Zuo, H. Lu, and Z. H. Cheng, Proceeding of SPIE **5777**, 442 (2005).

12. M. Zand and S. A. Naeimi, J. Russ. Laser Res. **31**, 98 (2010).

13. S. Marcus, Appl. Phys. Lett. **21**, 18 (1972).

14. H. Seguin and J. Tulip, Appl. Phys. Lett. **21**, 414 (1972).

15. R. L. Schriever, Appl. Phys. Lett. **20**, 354 (1972).

16. O. P. Judd, Appl. Phys. Lett. **22**, 95 (1973).

17. J. D. Daugherty, IEEE J. Quantum Electron **QE-8**, 594 (1972).

18. J. S. Levine and A. Javan, Appl. Phys. Lett. **22**, 55 (1973).