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Effect of argon on the performance of a fast-axial flow CO_2 laser

S. Jelvani, H. Amiri, H. Pazokian, M. Montazerolghaem,
M. Mollabashi, S.A. Naeimi, D. Esmaeilpour

Abstract. **The performance characteristics of a fast-axial flow (FAF) cw CO_2 laser are described. The dependences of the output power, efficiency, and discharge voltage on the discharge current of a FAF cw CO_2 laser with optimised composition of the CO_2:N2: He = 1:4.4:7.6 gas mixture with a small amount of argon are studied experimentally at two pressures of 50 and 60 mbar in open and closed cycle regimes of the laser system.**

Keywords: *fast-axial flow CO_2 laser, argon, closed and open cycles.*

1. Introduction

High power fast-axial flow CO_2 lasers are being widely used in many industries, for various material processing applications such as cutting, welding, drilling, marking, surface hardening. The influence of various gaseous additives (Ar, Xe, CO, ...) to the $CO_2 - N_2 - He$ gas mixture on operation of CO_2 lasers has been reported by a number of researchers [1 – 4]. Bletzinger et al. [1] proposed that the addition of xenon causes a considerable reduction in the total discharge voltage and the electron temperature as well as the CO_2 laser can also operate without nitrogen. Meanwhile xenon is used in sealed-off low-power cw CO_2 lasers to improve both the output power and efficiency.

Chatterjee et al. [2] have reported the improved performance of a fast-axial flow cw CO_2 laser due to the addition of small quantities of argon to the gas mixture ($CO_2 - N_2 -$ He). They have studied the increase in the output power as a function of argon concentration and determined that a sharp power maximum occurs when the content of argon amounts to 2.6 % in the mixture. In the present paper, we study the influence of argon on the laser output power, efficiency and the discharge properties of a fast-axial-flow CO_2 laser under closed and open-cycle conditions. In the open-cycle operation regime, the laser gas mixture is constantly renewed to maintain lasing, but in the case of the closed cycle the fresh gas mixture is not injected into the system.

2. Experimental setup

Figure 1 shows the scheme of the experimental setup. The setup is similar to that described in paper [5]. We used in the experiments a discharge Pyrex channel with a diameter of 30 mm that consisted of two tubes symmetrically arranged. Each discharge tube has a common cathode and separate anodes, the distance between the anodes and cathodes being 41 cm. The four-pin anodes and cathodes are made of tungsten. The resonator is formed by a gold mirror with a 4-m radius of curvature and a ZnSe plane output coupler with a transmission of about 30 %, the distance between the mirrors being 226 cm. The gas mixtures composition and operating pressure are maintained with a precision needle valve and digital manometer.

The laser tube is evacuated using a vacuum pump with a flow rate of 25 $m^3 h^{-1}$. The gas circulation system in the laser is a turbo blower, which can produce a flow rate of 2500 $m^3 h^{-1}$. The variable frequency converter is used to

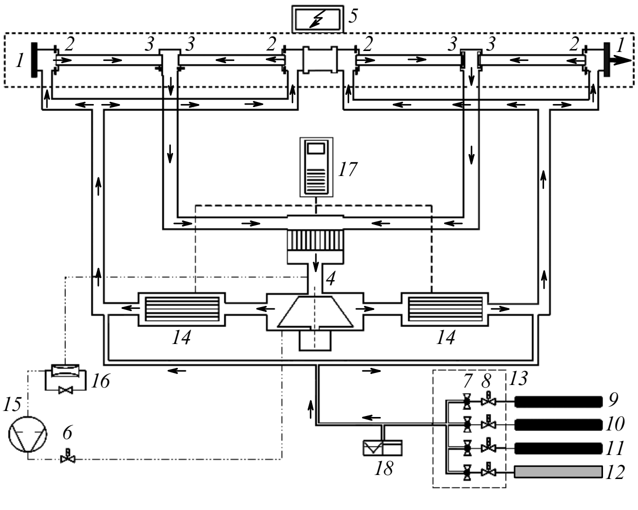

Figure 1. Scheme of the experimental setup:
(*1*) laser mirrors; (*2*) anodes; (*3*) cathodes; (*4*) turbo pump; (*5*) electrical power supply; (*6*) control valve; (*7*) bulb vacuum valves; (*8*) needle vacuum valves; (*9*) He gas vessel; (*10*) N_2 gas vessel; (*11*) CO_2 gas vessel; (*12*) Ar gas vessel; (*13*) mixture tank; (*14*) heat exchanger; (*15*) SOGEVAC vacuum pump; (*16*) metering orifice and bypass valve; (*17*) water chiller; (*18*) pressure gauge.

S. Jelvani, M. Montazerolghaem, S.A. Naeimi, D. Esmaeilpour Laser & Optics Research School, Nuclear Science and Technology Research Institute, Tehran, Iran; e-mail: sjelvani@aeoi.org.ir;
M. Mollabashi Department of Physics, University of Science and Technology, Tehran, Iran;
H. Amiri, H. Pazokian Laser & Optics Research School, Nuclear Science and Technology Research Institute, Tehran, Iran; Department of Physics, University of Science and Technology, Tehran, Iran

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control the rotating speed of the turbo blower as well as the flow rate of the gas mixture. The cooling system includes three heat exchangers, one heat exchanger cools the hot gas exiting from the discharge tube, and two other heat exchangers remove the heat released during the operation of the turbo blower. The heat exchangers are cooled by running water from a water chiller, the water temperature being about 8 °C. The laser is excited by switching on the power supply that is capable of producing a peak voltage of 25 kV and a current of 2 A.

3. Experimental results

The $CO_2:N_2:He = 1:4.4:7.6$ gas mixture composition is optimal for our laser system [6]. The effect of the argon addition into the optimal gas mixture ($CO_2:N_2:He = 1:4.4:7.6$) is shown in Fig. 2 under open-cycle operation, where the output power is plotted as a function of discharge current for two gas pressures of 50 and 60 mbar [6]. In Fig. 2a, the maximum output power of about 575 W was obtained at a discharge current of 475 mA for a 50-mbar gas pressure in the $CO_2:N_2:He:Ar = 1:4.4:7.6:0.28$ mixture. One can see that the threshold discharge current increases when an optimal amount of argon is added. Figure 2b shows similar characteristics at a gas pressure of 60 mbar. The maximum output power in this case is about 350 W at a discharge current of 300 mA for the $CO_2:N_2:He:Ar = 1:4.4:7.6:0.14$ mixture. However, unlike the dependences in Fig. 2a, the position of the peak output power occurs near 300 mA for different Ar concentrations. Figure 2b also shows that the maximum output power is lower at high Ar concentrations. Based on the data from Figs 2a, b, we can conclude that the optimal amount of Ar is different for gas mixtures with pressures of 50 and 60 mbar.

The laser output power versus the discharge current in a closed-cycle system is shown in Fig. 3. It can be seen that the optimal amount of Ar is independent of the type of the cycle (open or closed) for two gas pressures under study (50 and 60 mbar). In addition, the position of the peak output power shifts toward a higher discharge current at the optimal Ar concentration. The dependence of the laser efficiency on the discharge current and the argon amount in open- and closed-cycle operation regimes for the gas pressure of 50 mbar is shown in Fig. 4. In the case of the open-cycle regime (Fig. 4a), the highest efficiency occurs without Ar, while the highest efficiency in the case of the closed-cycle regime is achieved at a gas pressure of 50 mbar when the gas mixture ratio is $CO_2:N_2:He:Ar = 1:4.4:7.6:0.28$ (see Fig. 4b). The obtained results show that addition of argon leads to such a distribution in the electron energy or electron temperature, which favours efficient excitation of the upper levels of CO_2 and N_2 molecules [2]. However, the addition of argon at a gas pressure of 60 mbar in the case of the closed cycle does not change the electron temperature any longer.

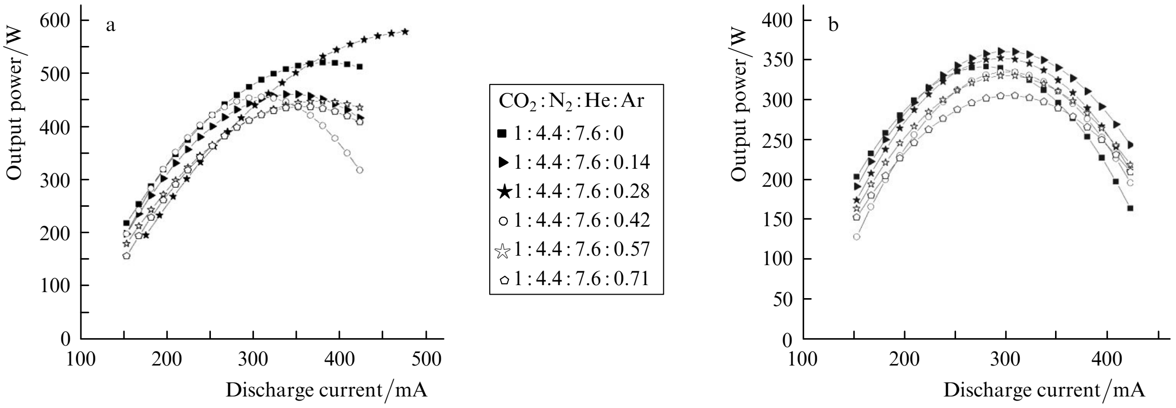

Figure 2. Dependences of the laser output power on the discharge current for various gas mixtures of $CO_2 - N_2 - He - Ar$ in the open-cycle regime at a gas pressure of 50 (a) and 60 mbar (b).

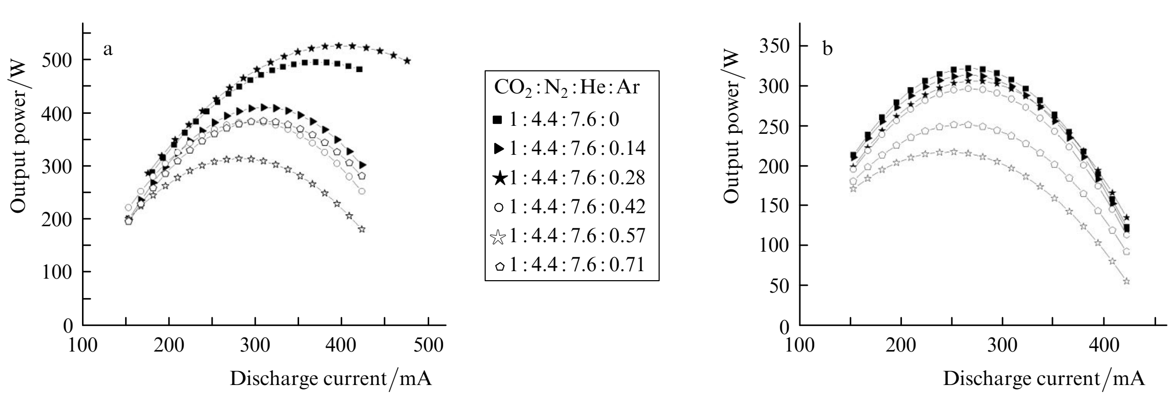

Figure 3. Dependences of the laser output power on the discharge current for various gas mixtures of $CO_2 - N_2 - He - Ar$ in the closed-cycle regime at a gas pressure of 50 (a) and 60 mbar (b).

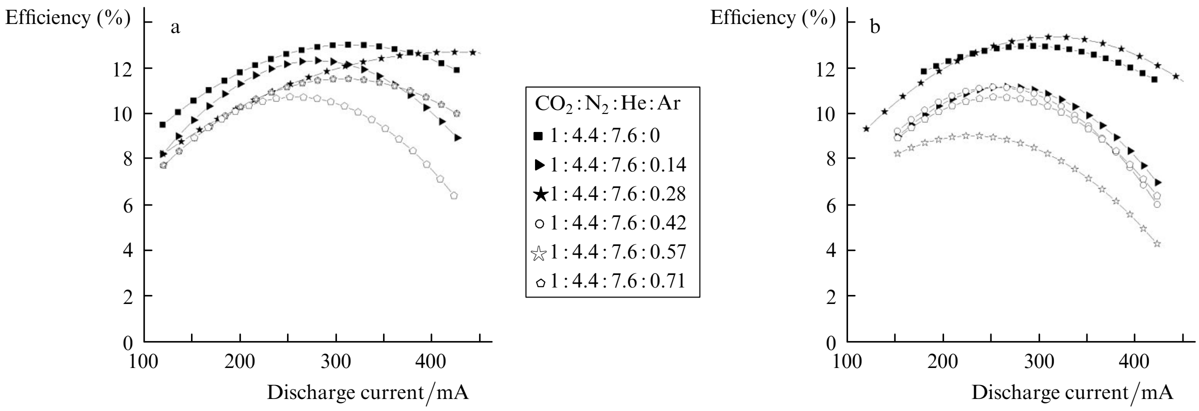

Figure 4. Dependences of the laser efficiency on the discharge current for various gas mixtures of $CO_2 - N_2 - He - Ar$ at a gas pressure of 50 mbar in the open- (a) and closed-cycle (b) regimes.

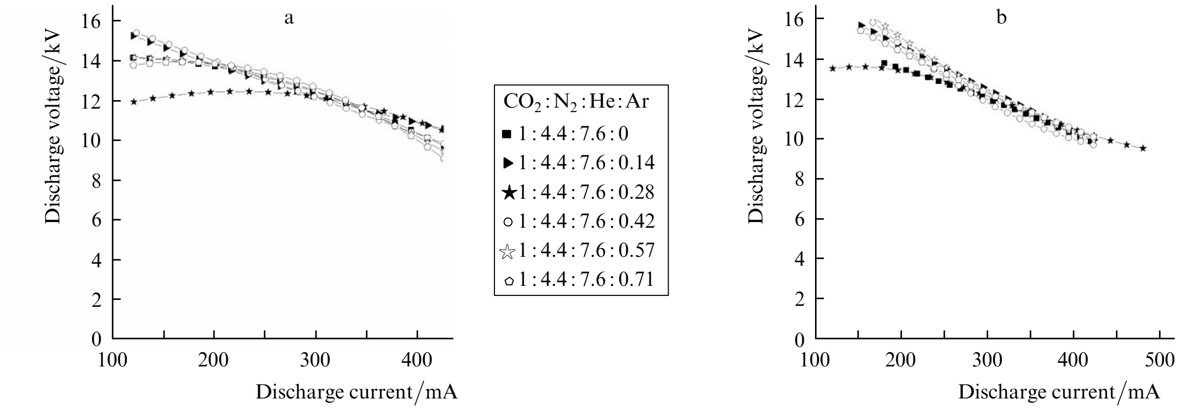

Figure 5. Dependences of the discharge voltage on the discharge current for various gas mixtures of $CO_2 - N_2 - He - Ar$ at a gas pressure of 50 mbar in the open- (a) and closed-cycle (b) regimes

We also measured the discharge voltage vs. the discharge current for several concentrations of argon in the gas mixture at a gas pressure of 50 mbar for open and closed cycles. The threshold discharge current was affected by adding some argon to the gas mixture of the CO_2 laser (Fig. 5). The discharge stability strongly depends on the gas composition. Figure 5 illustrates the effect of Ar on the discharge stability under open- and closed-cycle conditions. One can see from Fig. 5a that the gas mixture containing argon ($CO_2:N_2:He:Ar=1:4.4:7.6:0.28$) is essential for a stable open-cycle operation at a gas pressure of 50 mbar. On the contrary, in the case of the closed-cycle regime, the addition of argon does not produce any effect on the discharge stability.

4. Conclusions

In this work we have studied the effect of argon addition to the $CO_2 - N_2 - He$ gas mixture in a fast-axial flow cw CO_2 laser at two gas pressures of 50 and 60 mbar under open- and closed-cycle operation regimes.

The main valuable results are as follows:

(i) For a gas mixture at a pressure of 50 mbar, the output power and efficiency in two operation regimes are improved by adding argon (whose concentration was 0.28 of the CO_2 concentration) to the gas mixture.

(ii) In both open- and closed-cycle systems, at a gas pressure of 50 mbar, the threshold discharge current increases when adding an optimal amount of argon.

(iii) The optimal amount of argon is different for different gas pressures.

(iv) The optimal amount of argon is independent of the laser operation regime.

(v) The position of the maximum laser output power shifts toward a higher discharge current at the optimal Ar concentration.

(vi) A stable discharge is maintained under open-cycle operation for the $CO_2:N_2:He:Ar=1:4.4:7.6:0.28$ gas mixture of at a gas pressure of 50 mbar.

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