

LASERS

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Promising high-pressure DF–CO_2 laser for amplifying picosecond radiation pulses

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Abstract. **A scheme of the experiment is described and the results of measuring the small-signal gain in the active medium of a pulsed chemical DF–CO_2 laser at a medium pressure in the range from 1 to 2.5 atm are reported. The values obtained (above 5 m^{-1} at a pressure of 2.5 atm) make this laser a promising final amplifier of a multiterawatt laser system in the 10-μm wavelength region.**

Keywords: *DF–CO_2 laser, small-signal gain.*

In recent years, there has been much interest in the development and elaboration of superpower laser systems for generating 10-μm ultrashort (~1 ps) pulses of relativistic intensity [1–3]. Electric-discharge or electron-beam-controlled CO_2 lasers are generally used as final amplifiers in high-power laser systems generating such pulses [2, 3]. It was proposed [4] to use a pulsed chemical wide-aperture DF–CO_2 laser [5] (which can operate in a pressure range of 1–2.5 atm [6]) as a final amplifier, instead of wide-aperture electron-beam-controlled CO_2 laser. A distinctive feature of amplifiers of this type is a high spatial optical homogeneity of the active medium and a relatively large small-signal gain [7, 8]. Good specific characteristics of DF–CO_2 laser at elevated pressures were demonstrated in [6], and in [7, 8] the small-signal gain was measured only at a pressure of 1 atm. The purpose of this study was to measure the small-signal gain at higher (up to 2.5 atm) pressures of the medium. Specifically, the pressure range above 2–2.5 atm is most favourable for using a DF–CO_2 laser as an amplifier of picosecond pulses in multiterawatt laser systems [4].

The gain of DF–CO_2 laser was measured on an experimental setup, whose schematic diagram is shown in Fig. 1. Probing was performed by an electric-discharge TE CO_2 laser, for which the pulse energy and shape were monitored using a pyroelectric calorimeter C and a photodetector PD1. The measurements of the pulse energy and shape at the amplifier input showed that the radiation intensity at this point did not exceed 5 W cm^{-2}; i.e., even at the largest measured transmission single-pass gain (160), the radiation intensity at the amplifier output remained almost two orders of magnitude lower than the saturation intensity. The photodetector PD2 at the output of the DF–CO_2 laser recorded only the pulse shape. Both photodetectors were liquid-nitrogen-cooled CHT photodiodes with a response time of 100 ns. An attenuator A was installed before each photodiode. The reactor of DF–CO_2 laser was made of a Teflon tube 90 cm long, with an inner diameter of 66 mm. Two pulsed quartz xenon lamps with an external diameter of 23 mm and an interelectrode gap of 75 cm were placed in the reactor to initiate a reaction. The initiation energy was accumulated in two 3-μF capacitors charged to 35 kV (total energy is 3675 J). ZnSe windows with a clear aperture of 11 mm were arranged on metal flanges at the ends of the Teflon tube along its axis. They have antireflecting coating (for 10.6 μm), which, simultaneously, protected ZnSe from the chemical action of the active medium. Measurements were performed for three mixtures with different F_2 contents: $D_2:F_2:CO_2:He$ = 5:7:35:53, 5:10:35:50, and 5:15:35:45; they were prepared by rapid dynamic inflow. The oxygen content in all mixtures was at a level of 0.008 of the F_2 content. A $CO_2:N_2:He$ = 1:12:12 mixture at a pressure of 100 Torr was used in the TE CO_2 laser. The mixture with a high N_2 content was chosen to obtain a long pulse (with a duration exceeding 50 μs), having a gradually decaying 'tail'. The laser cavity consisted of a copper spherical mirror with a radius of curvature of 8 m and a flat dielectric mirror with a reflectance of 94%.

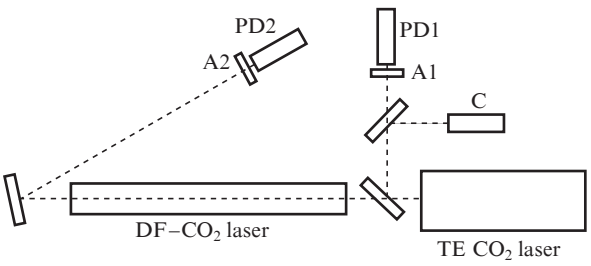

Figure 1. Experimental layout for measuring the small-signal gain.

The TE CO_2 laser with a nonselective cavity generates mainly at the P20 transition of the 10-μm CO_2 band, which is quite acceptable for measuring the DF–CO_2 laser gain. The system for laser triggering made it possible to vary controllably the initiation instant for the chemical laser medium with respect to the probe pulse. Figure 2a shows a typical oscillogram of the signal from the photodetector PD2 with a 42-μs delay of the initiating pulse with respect to the probe pulse.

The signal from PD2 was recorded with two oscilloscope channels of different sensitivities, which made it possible to

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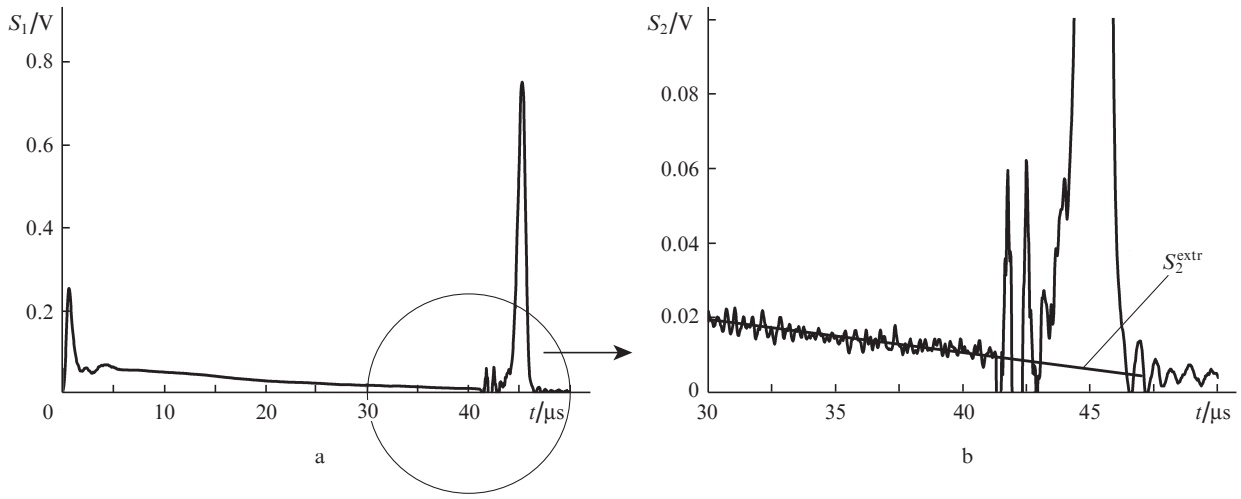

Figure 2. Typical signal at the output of DF–CO_2 amplifier (photodetector PD2), recorded with sensitivities of (a) 100 and (b) 10 mV per division.

obtain a signal at the amplifier input by reliable extrapolation of the gradually decaying probe-pulse 'tail' to the time interval of inversion existence (straight line in Fig. 2b). Thus, using an oscillogram and its extrapolation, one can obtain a temporal inversion profile in one 'shot':

$$k(t) = \frac{1}{L}\ln\left[\frac{S_1(t)}{S_2^{\text{extr}}(t)}\right],$$

where $L = 0.75$ m.

The results of small-signal gain measurements in the inversion maximum are shown in Fig. 3. It can be seen that the data for the mixtures with a fluorine content of 10% and 15% are indistinguishable within the measurement error. The small-signal gain for these mixtures changes with an increase in the mixture pressure from 6 m^{-1} at 1 atm to 5.1 m^{-1} at 2.5 atm. For the mixture with a fluorine content of 7% the small-signal gain is much smaller and does not exceed 4.3 m^{-1} at 2.5 atm. This can be due to the lower rate of chemical reaction. The optimal (for a large energy extraction ratio) $F_2:D_2$ ratio is known to be close to 3:1 [9]. In our experiments this ratio changed from 3:1 to 1.4:1. For DF–CO_2 amplifiers with a large aperture (100 mm or more) and a pressure of the active medium of about 2.5 atm, the high F_2 content in the mixture may lead to inhomogeneous initiation throughout the volume of the medium because of the strong absorption of initiating radiation by molecular fluorine. Just for this reason we measured the gain in the mixtures with a reduced F_2 content.

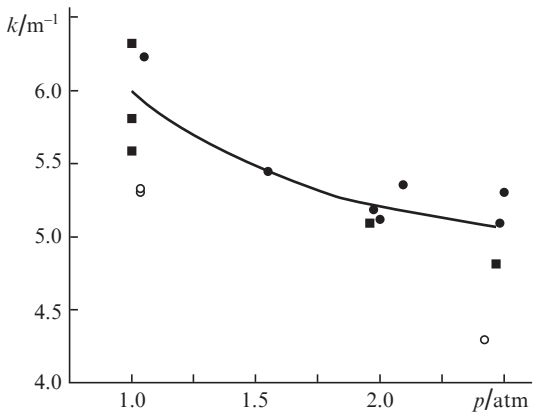

Figure 3. Results of small-signal gain measurements for mixtures with F_2 contents of (○) 7%, (●) 10%, and (■) 15%. The solid line is the result of averaging data for the mixtures containing 10% and 15% of F_2.

Two more characteristics of the inversion profile $k(t)$ were determined in each experiment: the FWHM of the profile ($t_{1/2}$) and the delay of the inversion maximum with respect to the initiation beginning. The dependences of these characteristics on the mixture pressure and composition are shown in Fig. 4. The results obtained are quite reasonable: the higher the mixture pressure and the higher the F_2 content in it, the higher the reaction rate and, correspondingly, the shorter the inversion delay and lifetime.

The modern picosecond 10-μm laser systems [2, 3] use CO_2 lasers with non-self-sustained discharge and a gain of 2–2.5 m^{-1} as final amplifiers. Note that much larger small-signal gains (up to 5.5 m^{-1} [10]) were obtained in discharge CO_2 lasers, but at much smaller apertures. Thus, our results showed that the DF–CO_2 laser is promising as a final amplifier in picosecond 10-μm laser systems.

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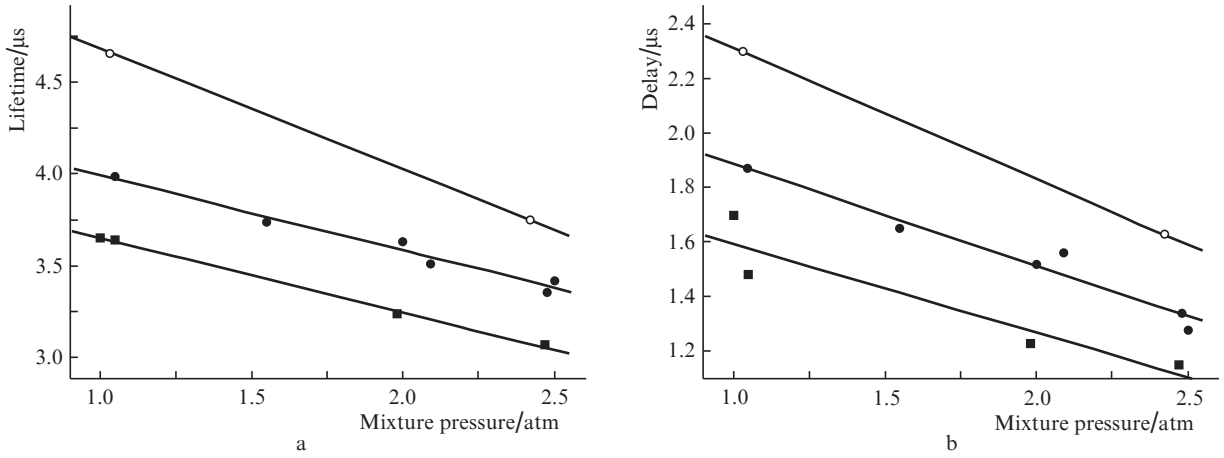

Figure 4. (a) Inversion lifetime $t_{1/2}$ and (b) the delay of inversion peak with respect to the initiation onset for mixtures with F_2 contents of (○) 7%, (●) 10%, and (■) 15%.

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