«Atmospheric and Oceanic Optics», **14,** No. 11 (2001)

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Small signal gain characteristics and gas analysis of medium of power combustion driven CO_2-gas dynamic laser

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Received October 7, 2001

The effect of different oxidizer/fuel proportion on the operational characteristics of a combustion driven 17 kW gas dynamic laser was investigated. Small signal gain measurements showed that the highest value of gain was determined by condition in which the pressure (or temperature) in after burning chamber was highest one. It corresponds to complete consumption of oxidizer or stoichiometric proportion of oxidizer/fuel in the combustion reaction. Furthermore, gas analysis indicated that the small signal gain is not sensitively dependent on variations of combustion products composition.

Introduction

The output characteristics of combustion driven CO_2 gas dynamic lasers are critically determined by combustion conditions. In the case of complete combustion, the products of conventional fuels are usually CO_2 and water. Combustion incompleteness can reduce the active molecules (here CO_2) and produce undesired species, which may affect on the output power. Then, determination of the combustion products and comparison with output characteristics is a key for optimization of laser operation. Up to the knowledge of the authors there is no report addressing the influence of combustion regime on laser output characteristics of toluene combustion driven CO_2 GDL. In the present study the small signal gain and product gases, at the different operational conditions, are measured.

Experiment

The laser under investigation is a combustion driven 17 kW gas dynamic laser (Fig. 1) with toluene as fuel, high-pressure air as oxidizer and solid propellant used for ignition.

Fig. 1. Laser view.

The time of operation is 0.1 up to 5 s. It uses a nozzle array with expansion ratio of 65 and throat height of 0.3 mm.

The system of small signal gain measurement consists of a stabilized CO_2 probe laser, output line of which could be tuned over different rotational transitions, and detecting system comprising chopper, He–Ne laser, photodiode, and IR detector (Fig. 2). In order to minimize noise contribution, the detection procedure was carried out at the frequency of 450 Hz.

The gas mixtures of after burning combustion chamber were probed and analyzed by Gas Chromatography (GC) and FT–IR. Due to the technical problem, the gas samplings were made only in the after burning chamber, where the pressure and temperature is about 35–40 bars and 1200–1300°C, respectively.

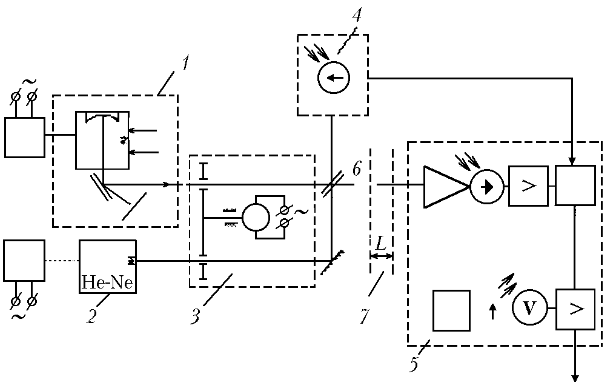


Fig. 2. Gain measurement apparatus diagram: probe CO_2 laser *1*, He-Ne laser *2*, chopper *3*, synchronizing detector *4*, measuring device *5*, beam splitter *6*, CO_2-GDL active medium *7*.

Results and Discussion

Figure 3 shows the time dependence of small signal gain in one test. The oscillations are due to uncompensated chopper contribution.

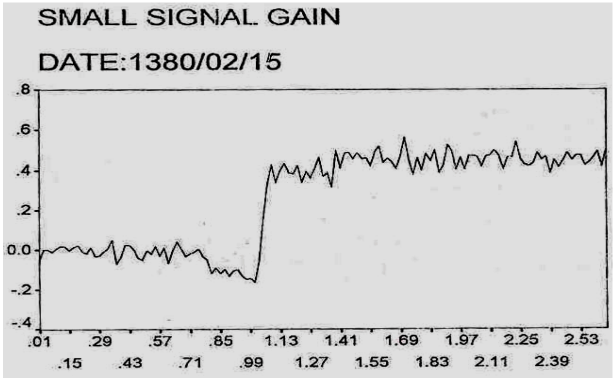


Fig. 3. Typical curve of small signal gain vs. time.

Saturation behavior of active medium is illustrated in Fig. 4. The saturation intensity, knowing the beam cross section of probe CO_2 laser being approximately 0.1 cm^2, is estimated to be 80 W/cm^2. The dependence of small signal gain on fuel and air flow rates are shown in Figs. 5 and 6. The best result was obtained at flow rates proportion of fuel/air: 2.5/116 (mol).

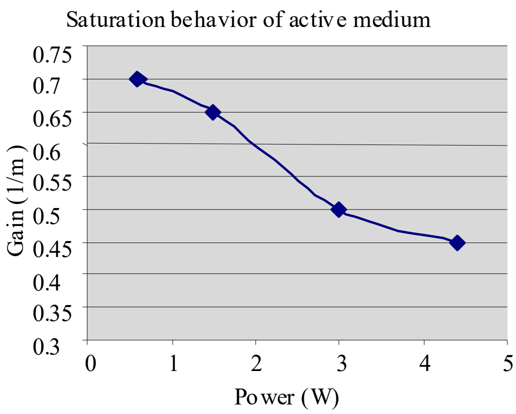


Fig. 4. Gain vs. laser probe power.

This molar proportion of fuel/air, within the accuracy of the measured parameters, corresponds to the complete combustion of toluene in the reaction:

$$C_7H_8 + 9O_2 \rightarrow 7CO_2 + 4H_2O.$$

In this case maximum heat is released, giving the highest pressure and temperature in the after burning combustion chamber.

At this point small signal gain was 0.9 m^{-1} and average after burning pressure and temperature were measured to be 38 bars and 1550 K, respectively.

This behavior is similar to what has been reported in Ref. 1, in which the dependence of output power on airflow rate was determined.

IR spectroscopy revealed CO_2 and CO as the main constituents of gas sample. GC analysis, in addition, measured the absolute concentrations of O_2, CO_2, CO, and H_2 as the main combustion products apart from stable Ar and N_2 components. The H_2O concentration, due to the liquidation of the vapor in the analyzing cell, could not be revealed.

The compositions of product mixtures are shown in Table 1. In the last column the corresponding small signal gain is given.

Based on this analysis it seems that the gain is dominantly determined by total pressure and gas temperature of after burning chamber and, in less degree, is influenced by the mixture composition variations and it's departure from the optimum N_2/CO_2 ratio. Since the frozen population of the upper laser level is determined by Boltzman distribution

$$N(001) \sim N_0 \exp\{-E(001)/KT\},$$

i.e. the population inversion is exponentially dependent on inverse of combustion temperature while; it depends linearly on concentration (N_0 or partial pressure) this behavior, without considering the complicated model, could be qualitatively expected. Anderson[2] has discussed, using the experimental data and theoretical models, the dependence of small signal gain on molar percentages of active medium constituents, reservoir temperature and pressure but for the first generation lasers in which the combustion was not the source of active species.

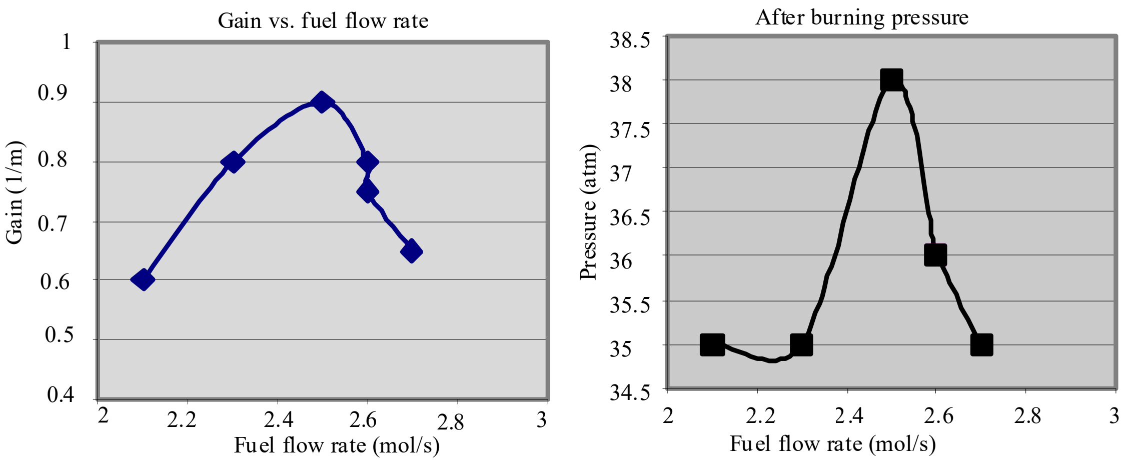
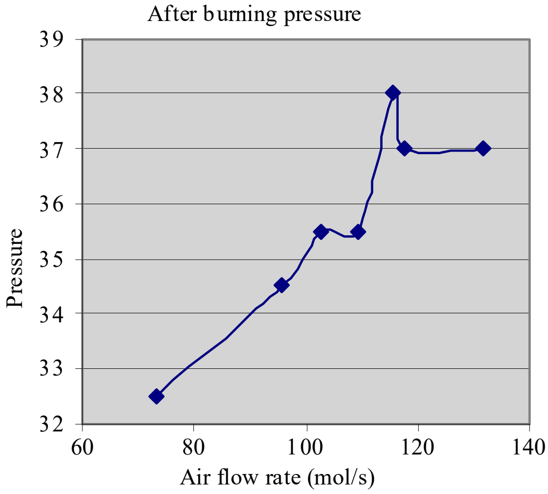


Fig. 5. Gain and pressure behavior against fuel flow rate with constant airflow rate of 116 mol/s.



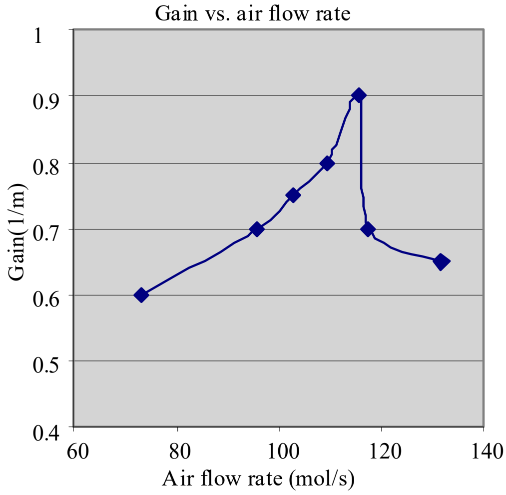


Fig. 6. Gain and pressure behavior against air flow rate with constant fuel flow rate of 2.5 mol/s.

Table 1. Typical data obtained for gas compositions (GC analysis) and gain in different experimental conditions

Test No.	H_2 Molar Percent	O_2 Molar Percent	N_2 Molar Percent	CO_2 Molar Percent	CO Molar Percent	Ar Molar Percent	Small signal gain g_0 (1/m)
No. 1	0.6	2.8	73	16	1	0.8	0.7
No. 2	0.3	2.0	73	17	0.5	0.9	0.7
No. 3	0.1	2.3	82	14	T	1.0	0.5
No. 4	T	T	80	13	3.5	1.1	0.5

T:Trace < 0.1 percent.

The different data given in Ref. 2 shows that the small signal gain is critically dependent on reservoir pressure and temperature, as is the case in our work.

Acknowledgment

The authors thank the Physics Group of the Imam Hussein University for financing this project.

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2. John D. Anderson, *Gas Dynamic Lasers: An Introduction* (Academic Press, New York, 1970), p. 78.