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EXPERIMENTAL STUDIES ON A GAS DYNAMIC LASER WITH  
NARROW THROAT AND HIGH AREA-RATIO GRID NOZZLES

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# Experimental Studies on a Gas Dynamic Laser With Narrow Throat and High Area-Ratio Grid Nozzles

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(1) Manuscript received in June, 1981.

**Abstract** This paper describes a combustion-driven CO<sub>2</sub> gasdynamic laser with a throat height of 0.3mm and an area-ratio 30 grid nozzles, and presents some experimental results. The behavior of flow and the location of shock waves in the optical cavity were observed. The variation in small-signal gain  $G_0$  with CO<sub>2</sub> or H<sub>2</sub>O contents were measured and compared with the experimental data from similar equipment of nozzle throat height 0.8mm and area-ratio 17. Some advantages are obvious for the narrower throat height and higher area-ratio GDL, i.e. the  $G_0$  can be increased by a factor of 50% and the H<sub>2</sub>O contents may be increased from 1% to 5%.

## I. Introduction

Shortly after the first gasdynamic laser was reported by E. T. Gerry[1] the suggestion for the "second generation" gasdynamic laser technology was proposed by J. D. Anderson et al,[2] and smaller throat height, larger area-ratio, higher gas stagnant temperature and pressure, and higher moisture content were suggested. Calculation had shown that with these combinations,

higher gain coefficient and higher usable energy were achievable. Simulation test was later carried out by J. S. Vamos in sudden wave wind tunnel.[3] However, no similar results were published for combustion driven gasdynamic laser devices.

Based on the result of combustion driven  $\text{CO}_2$  gasdynamic laser with nozzle throat height 0.8mm and outlet area-ratio 17, the characteristics of arrayed gasdynamic laser with nozzle throat height 0.3mm, area-ratio 30, and flow rate 11/sec was studied. This paper describes the measurement of small signal gain and the comparison with similar data obtained on a throat height 0.8mm and area ratio 17 device.

## II. Experimental Set-Up

As shown in figure 1, the combustion chamber was a cylinder 140mm in inner radius and 400mm in length and the mixing section was 350mm in length, both were layered structure. The combustion agent was a mixture of CO and  $\text{H}_2$ , and air was the combustion-assisting agent.  $\text{CO}_2$  and  $\text{H}_2\text{O}$ , generated by combustion process, were mixed with  $\text{N}_2$  to reach certain pressure and temperature. Particle number inversion was achieved by virtue of difference in delay speed of  $\text{CO}_2$  energy levels through rapid expansion when particle stream passed by the supersonic nozzle.

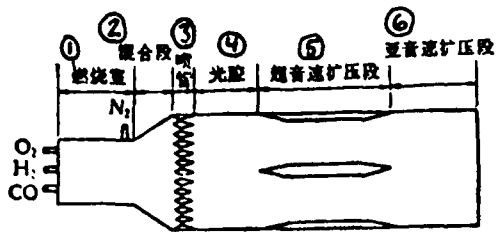


Figure 1: Illustration of combustion-driven gasdynamic laser

Key: 1 - combustion chamber; 2 - mixing section;  
 3 - nozzle; 4 - light cavity; 5 - supersonic expansion section; 6 - subsonic expansion section.

To better "freeze" the high energy  $\text{CO}_2$  and  $\text{N}_2$  particles, the nozzle throat height was chosen to be 0.3mm, the ratio of nozzle outlet to throat area was chosen to be 30, the ratio of specific heat of gas mixture was chosen to be 1.37. Design of nozzle wall was based on the analytic method, [4] and the structure was an arrayed combination with 32 blades mounted on the panel to form a nozzle cross section of 300mm wide and 30mm high. To prevent formation of sudden wave at the joint of nozzle and light chamber and deterioration of quality of laser beam, the top and bottom walls of the light chamber and nozzle panel were molded into a single body. Also, proper expansion was made to correct the effect of the boundary layers.

The light chamber was 170mm in length. Circular or rectangular mirrors could be mounted on the sides to form optical resonant chamber. The mirrors were coated with oxygen-free copper plated gold film.

The pressure expansion section was divided into the supersonic and subsonic sections. Movable flow-guiding plates

could be added to the center of supersonic section to adjust the cross-sectional area of the second throat. The subsonic section resumed the pressure to atmospheric pressure.

### III. Small Signal Gain

Small signal gain, a measure of CO<sub>2</sub> particle number inversion, is an important parameter when the performance of a laser device is concerned. Through the measurement of this parameter, the optimal working condition can be obtained and the design of the optical resonance chamber can be based. Magnification method was used in this study to measure this parameter.[5]

The principle of the magnification method was to penetrate a laser beam of equal wavelength through the excited media and observe the increase in its intensity and calculate the gain of the media. As shown in figure 2, let  $I_0$  and  $I$  be the intensities at the inlet and outlet, respectively, and the distance between  $H_1$  and  $H_2$  be  $L$ , the average gain along this distance is  $G_0 = 1/L \ln(I/I_0)$ .

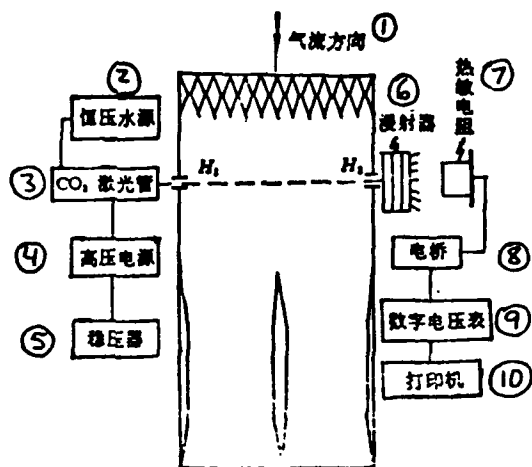


Figure 2: Illustration of measurement of gain

Key: 1 - direction of gas flow; 2 - constant-pressure water supply; 3 - CO<sub>2</sub> laser tube; 4 - high voltage power supply; 5 - voltage stabilizer; 6 - scattering device; 7 - heat-sensitive resistor; 8 - electrical bridge; 9 - digital voltmeter; 10 - printer

The experimental result (measured at 26mm downstream of nozzle outlet) is summarized below.

#### 1. Variation of $G_0$ with CO<sub>2</sub> content

If the moisture content is kept constant (around 2.5%) and the CO<sub>2</sub> mole fraction varied, the best condition was achieved when CO<sub>2</sub> content was around 13 to 14%. In this range, the average gain  $G_0$  was 0.85/meter (see figure 3) and the maximum  $G_0$  was 0.96.

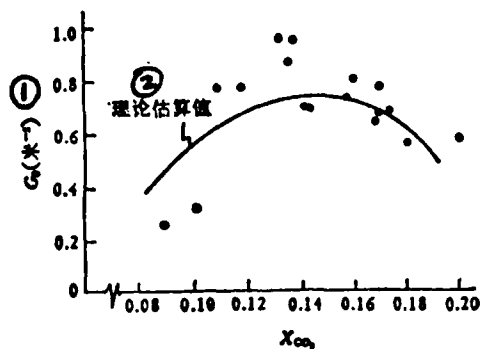


Figure 3. Variation of  $G_0$  with  $CO_2$  mole fraction

$A^* = 0.3mm$        $A/A^* = 30$   
 $X_{H_2O} = 0.025$        $P_0 = 50atm$

Key: 1 -  $m^{-1}$ ; 2 - theoretical value

From the two sets of data mentioned above, the small signal gain for narrow throat, large area-ratio gasdynamic laser was increased by about 50%.

On the similar device with nozzle throat height 0.8mm and area-ratio 17, the best  $G_0$  was also obtained around  $CO_2$  molar fraction of 13%. However, the average gain was 0.58/meter (see figure 4) and the maximum gain was 0.69.

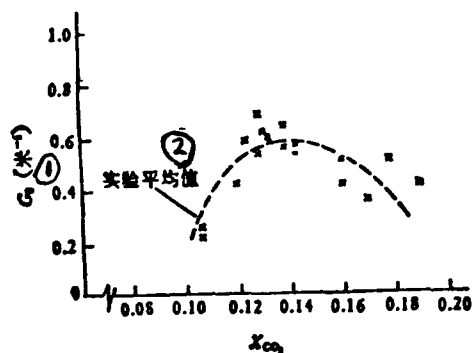


Figure 4: Variation of  $G_0$  with  $CO_2$  mole fraction

$A^* = 0.8mm$        $A/A^* = 17$   
 $X_{H_2O} = 0.008$        $P_0 = 22atm$

Key: 1 -  $m^{-1}$ ; 2 - experimental average value

## 2. Variation of $G_0$ with $H_2O$ content

Maintaining  $CO_2$  content to be within 12 to 14% and adjusting  $H_2$  input to change the  $H_2O$  percentage after combustion, the variation of small signal gain  $G_0$  with  $H_2O$  molar fraction was measured and shown in figure 5. When  $H_2O$  content was 2.5%, the average  $G_0$  was 0.85(1/meter); when  $H_2O$  content was 5.6%, the average  $G_0$  was 0.51(1/meter). For gas laser with nozzle throat height 0.8mm, the best condition was achieved when moisture content was around 0.8%. When moisture content exceeded 5.5%,  $G_0$  would approach 0 (figure 6). This explains why gasdynamic laser with narrower throat and larger area-ratio could allow more moisture content.

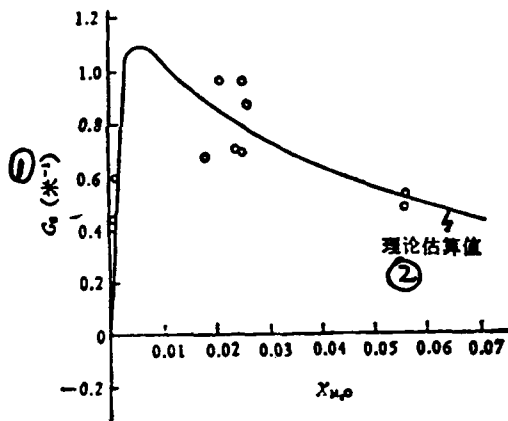


Figure 5: Variation of  $G_0$  with  $H_2O$  mole fraction

$h^* = 0.3\text{mm}$   $A/A^* = 30$   
 $X_{CO_2} = 0.13$   $P_0 = 50\text{atm}$

Key: 1 -  $m^{-1}$ ; 2 - theoretical value

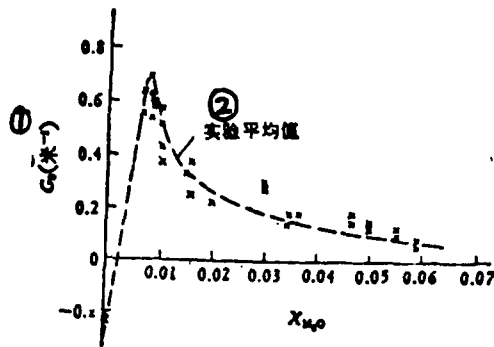


Figure 6: Variation of  $G_0$  with  $H_2O$  mole fraction

$A^* = 0.8\text{mm}$   $A/A^* = 17$   
 $X_{CO_2} = 0.13$   $P_0 = 22\text{atm}$

Key: 1 -  $m^{-1}$ ; 2 - experimental average value

### 3. Variation of $G_0$ with stagnant temperature $T_0$

If the working medium in the combustion  $CO_2$  gasdynamic laser were not pre-heated, the elevation in temperature was mainly achieved by increasing the input of  $CO$  or  $H_2$ , thus increasing the  $CO_2$  or  $H_2O$  after combustion. When the moisture content was fixed, the temperature was directly determined by the amount of  $CO_2$ . Therefore, the relationship between  $G_0$  and  $T_0$  is the same as that between  $G_0$  and  $CO_2$  (see figure 7). When  $T_0$  was 1500 to 1600K, small signal gain  $G_0$  reached its maximum. When  $T_0$  exceeded 1600K,  $G_0$  would start decreasing because  $CO_2$  content would be driven from the optimal working range, energy exchange between  $N_2$  and  $CO_2$  would be affected, and rate of agglomeration of low energy  $CO_2$  molecules would increase.

Based on the experimental conditions specified in figures 3, 5, and 7, the variation of  $G_0$  with respect to  $CO_2$ ,  $H_2O$  and  $T_0$  was calculated with normal procedures and was basically consistent with the experimental result.[6]

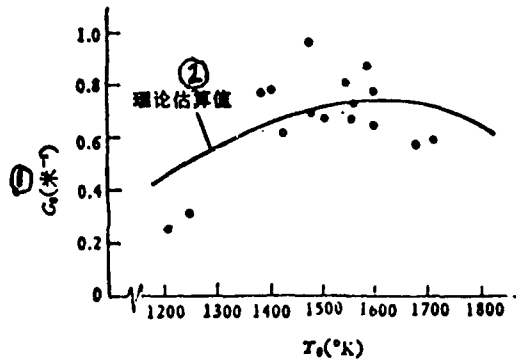


Figure 7: Variation of  $G_0$  with stagnant temperature  $T_0$

$A^* = 0.3 \text{ mm}$   $A/A^* = 30$   
 $X_{H_2O} = 0.025$   $P_0 = 50 \text{ atm}$

Key: 1 -  $m^{-1}$ ; 2 - theoretical value

#### IV. Conclusions

1. The small signal gain was increased by 50% on gasdynamic laser with nozzle throat height 0.3mm and area-ratio 30 than the similar device with nozzle throat height 0.8mm and area-ratio 17.

2. With the decrease in nozzle throat height, increase in area-ratio, and increase in stagnant temperature and pressure, moisture content in the working gas could be increased from 1% to 5%, thus providing a possibility for using combustion gas with higher hydrogen content. (While high-hydrogen gas generates higher temperature, the moisture content after combustion was also higher.)

3. For gasdynamic laser devices with narrower throat, the effect of nozzle manufacturing on the optical chamber flow field was significant and high accuracy is required. Also, effective cooling procedure should be taken to prevent deformation of nozzle as a result of heat during experiment and deterioration of optical beam quality.

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