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CO_2—N_2 CW Gasdynamic Laser Facility

A concise technical description of the design and working principles of a CO_2 (H_2O)—N_2 (Ar) CW gasdynamic laser facility is given. Primary results of experiments, carried out with the use of conventional optical resonators are discussed. The obtained power of radiation ($\lambda \simeq 10.6$ μm) transmitted out of the cavity amounted to $P_c = 35$ W, the corresponding power density per unit volume of resonator was $p_c = 2.29$ W/cm^3 whereas the output power per unit mass flow was equal to $g_c = 1.15$ kW/kg$\cdot$s^{-1}. The radiation beam divergence was about $\theta \simeq 22'$.

Furtheron, the facility in question is compared with other CW gasdynamic lasers and the possibilities of its optimization, aimed at increasing the output power and overall efficiency, are formulated.

Introduction

1. The history of gasdynamic lasers, and among them of the gasdynamic lasers of continuous action (CW-GDL) is not a long one. The majority of experimental and theoretical works on these lasers have been published during the last two years. The priority in putting forward the idea of supersonic expansion in a laser device belongs to Hurle and Hertzberg [1], whose paper may be regarded as the rudimentary outline of the concept of the gasdynamic laser.

Preliminary analysis of the problem of creating population inversion by supersonic expansion of mixtures of CO_2, N_2 and H_2O was given in [2, 3, 4]. A series of theoretical papers [5, 6, 7, 8, 9, 10, 11, 12] was published, analysing the influence of high velocity of an optically active medium moving perpendicularly to the axis of the optical resonator on the gasdynamic laser's power and efficiency. Bronfin *et al.* have published the first paper [13] about experiments on a carbon dioxide CW gasdynamic laser. Similar lasers were described thereafter in reports [14, 15], popular scientific magazines [16] and papers [17, 18, 19, 20]. It seems likely that up to now not much more than about twelve such devices have been built; the one having maximum output power has been designed at Avco-Everett Research Laboratory under supervision of Gerry [14].

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2. The CW gasdynamic lasers are powerful sources of quasimonochromatic infrared radiation (at $\lambda \simeq 10.6$ μm for carbon dioxide as the optically active medium). From that viewpoint two applications can be considered. The first: for technological operations requiring continuous radiation beams of high power. The second application – mentioned recently by Hertzberg (see [21]) – is for direct energy conversion. A gasdynamic laser can be regarded as a device for direct conversion of thermal and kinetic energy of mixtures of molecular gases into energy of quasi-monochromatic radiation beam and subsequent transmission of this energy to receivers otherwise inaccessible.

3. The above mentioned applications are promising enough to constitute a stimulus for further rapid progress in the GDL technology. The development of chemically driven CO_2 gasdynamic lasers is very probable, as well as of those in which CO produced by combustion would serve either directly as the optically active medium or – instead of nitrogen – as the pumping medium [22] for CO_2. The construction of gasdynamic lasers on combustion products of hydrocarbons [23] seems, also, only a matter of time. Also the development of electrically driven high – speed flow lasers of type proposed by Hill [24] seems very likely. Here use could be made of supersonic flow, characteristic of the GDL. In such a way high efficiency closed cycle gasdynamic lasers could be designed.

One should emphasize the fact that GDL technology did not come out as yet from the early stage where the construction of a device and making it work is an attainment important enough. At this stage a dominating tendency is towards increasing the output power by increasing dimensions and redesigning the device and by modifications of excitation and pumping techniques. Experimental investigations aimed at executing some specified physical programs have not been reported yet. However, as they will unavoidably appear, it would be possible to optimize – on the basis of model parameters – the excitation and pumping techniques, the composition of mixtures and their thermodynamic and gasdynamic parameters, as well as geometrical parameters and design of the nozzle system and optical cavities. Only then optimization of gasdynamic lasers of various types from the viewpoint of energy together with a simultaneous optimum choice (for certain technical purposes) of the output beam parameters (a degree of monochromacity and coherence, divergence and transverse energy distribution throughout a beam), would be possible.

Working principle of CO_2-N_2 CW Gasdynamic lasers

4. The supersonic expansion of working gases flowing in the direction transverse to the optical resonator axis is essential for the concept of gasdynamic laser. As a result of such expansion, the output power is increased, approximately in direct proportion to the velocity of the gases within the laser region [5, 6]. Population inversion is produced as a result of different degree of freezing of populations on different levels of CO_2 and N_2 molecules [2, 3, 4], its value being higher than that of conventional gas lasers. Also the rate of extraction of the excess energy from the resonance cavity is higher; correspondingly larger are also the output power and efficiency of the laser. In the gasdynamic lasers the excess energy is rapidly extracted by forced convection (characteristic time $\tau_{GDL} \simeq d_M/v$

[14]) whereas the conventional lasers manifest a relatively low rate of energy extraction by diffusion (characteristic time $\tau_{CL} \simeq (d_M/\lambda_t)^2(\bar{\lambda}_t/\bar{c}_t)$ [14]). The latter feature is most essential among the factors limiting the CW output power of the conventional lasers. By virtue of the three above mentioned factors a considerable rise of the CW output power density per unit volume of the optical cavity can be expected for a GDL, the theoretical value of the power density being about 10^3-10^6 times higher than with conventional lasers [14, 16].

5. The gasdynamic lasers constructed heretofore and described in the literature are – as may be easily checked – the molecular carbon dioxide – nitrogen ones. Two methods of pumping are being adopted:

a. Thermal excitation and mixture expansion (CO_2+N_2+additives) in a supersonic nozzle (e.g. [17, 18]). Here the population inversion is effected through a process of non-selective pumping evoked by the difference between relaxation times of CO_2 (00^01) and CO_2 (10^00) levels, and augmented by an additive (usually H_2O or He) which accelerates depopulation of the lower laser level CO_2 (10^00).

b. Thermal excitation of N_2 and selective pumping of cold CO_2 caused by near-resonance collision processes of the type: $CO_2\ (00^00)+N_2\ (v=1) \rightleftharpoons CO_2\ (00^01)+N_2\ (v=0)$. The processes take place during mixing of supersonic streams of the both, separately expanded, components.

The first method seems to be less effective than the other. However, the first method seems well suited for construction of laser devices of very large capacity, because of relative ease of producing very big quantities of working gas mixtures by combustion. A decrease of pumping efficiency caused by inevitable thermal populating of the lower energy levels of CO_2 molecules may also be partly compensated by the ease of producing working gas mixtures. The expansion of a mixture was employed in the biggest, till now, laser device of 60 kW output power [14]. Investigations of gasdynamic lasers by Basov *et al.* [2] have gone in the same direction, too.

With the second method of pumping of a laser it is theoretically possible to excite selectively only the upper laser level CO_2 (00^01), i.e. to obtain a very high initial value of population inversion, which is principal advantage of this method over the first one. In view of that, the gasdynamic laser facility described in this paper was designed, in principle, for investigations of the second method. It may also be adapted to employ the first method of pumping after slight modifications.

6. The gasdynamic laser facility presented in this paper can be divided into three principal units with separate physical processes being performed in each of them:

a. The unit where nitrogen is excited from the ground energy level to the vibrational levels $v \geqslant 1$, consisting of an arc heater with a plenum chamber (Fig. 1 and 2).

b. The unit where the mixing of excited nitrogen with carbon dioxide in the ground state takes place after expansion of the both components. Simultaneously pumping of CO_2, occurs as a result of collisions with vibrationally excited molecules N_2 $(v \geqslant 1)$. This unit cannot be separated *sensu strico* from the others, since the mixing and pumping processes take place downstream of the outlets of a system of supersonic nozzles for expansion of N_2 and CO_2 (Fig. 3). The expansion is performed inside a relatively long and slightly divergent channel which is followed directly by a laser region. A sufficient length of the mixing region was chosen to have both components mixed well enough and, as a result, the vibrational energy of N_2 ($v \geqslant 1$) molecules transferred to possibly large number of CO_2 ($00^0 0$) molecules.

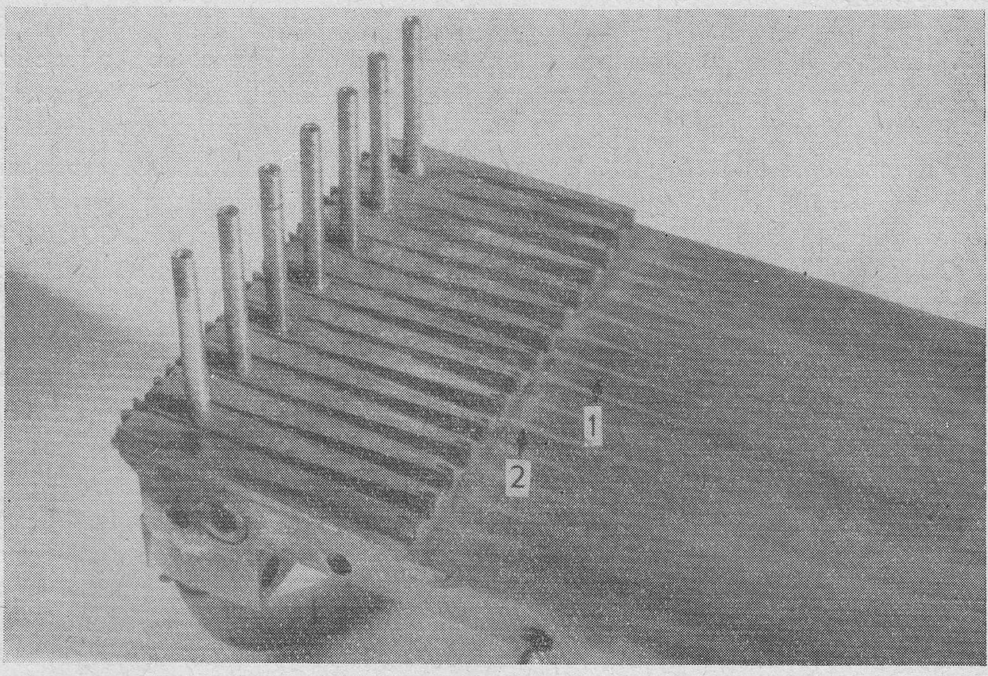

Fig. 3. Thermal traces of mixing process
1 — N_2—flow, *2* — CO_2—flow

c. The unit where laser action takes place. This unit – the laser region – is an extension of the mixing region furnished with mirrors of an optical resonator (Fig. 4 and 5). The generated radiation $\lambda \simeq 10.6$ μm is led out from this unit.

d. The facility is working in an open cycle. Since the used up gas mixture must be rejected into atmosphere, an additional device, of no importance from the viewpoint of radiation generation, is indispensable. It compresses the exhaust gases to the pressure above atmospheric and consists of a diffuser with an axially located wedge, the angle and length of the wedge being properly chosen to compress the gas up to the atmospheric pressure in a sequence of oblique shock waves. The diffuser may be in this facility additionally assisted by a set of auxiliary vacuum pumps.

A schematic arrangement of the GDL facility operating in accordance with the above listed working principle is presented in Fig. 1. Fig. 2 shows a simplified layout of the laser proper together with the arc heater, plenum chamber, nozzle system and diffuser. For photographs of the laser and its main units see Figs. 3 to 7.

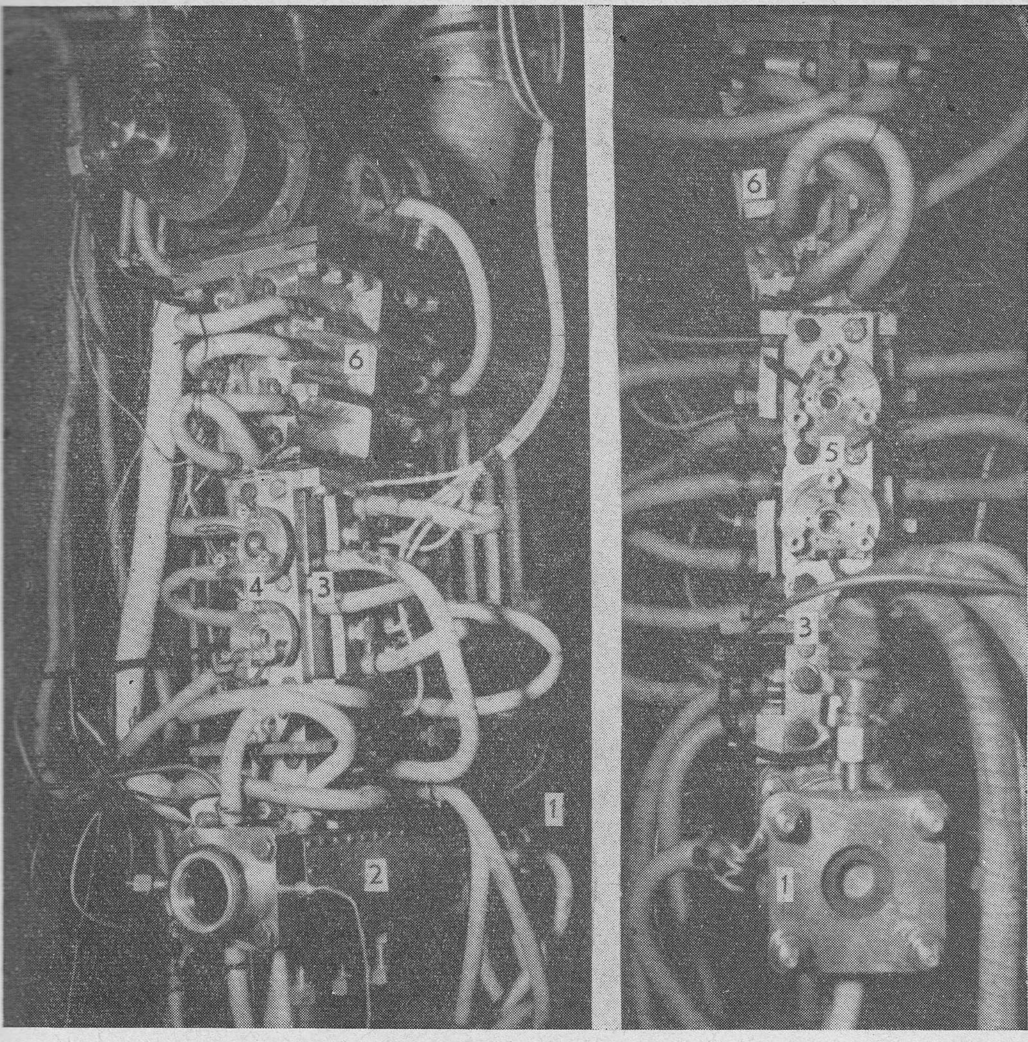

Fig. 4. $CO_2 - N_2$ gasdynamic CW laser

1 — plasma heater, *2* — plenum chamber, *3* — GDL channel, *4* — transmitting mirrors, *5* — non-transmitting mirrors, *6* — diffuser

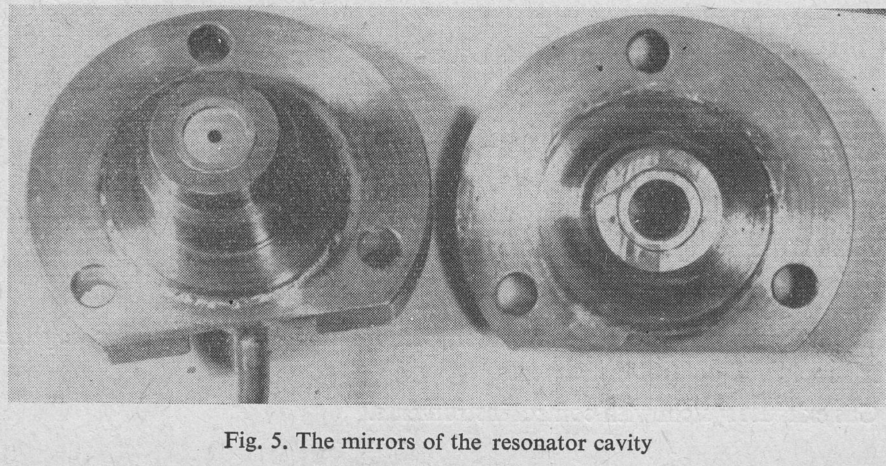

Fig. 5. The mirrors of the resonator cavity

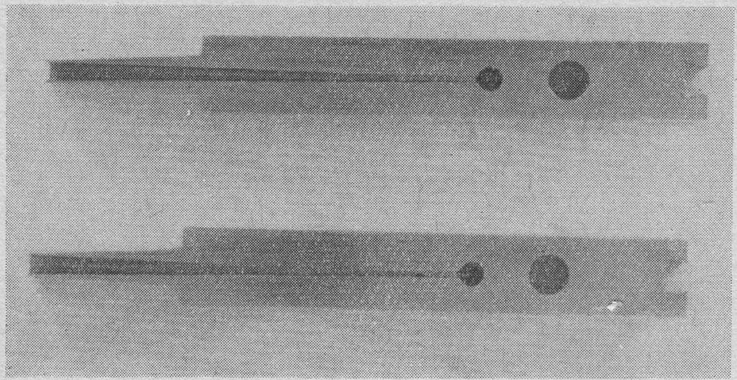

Fig. 6. Separate nozzles

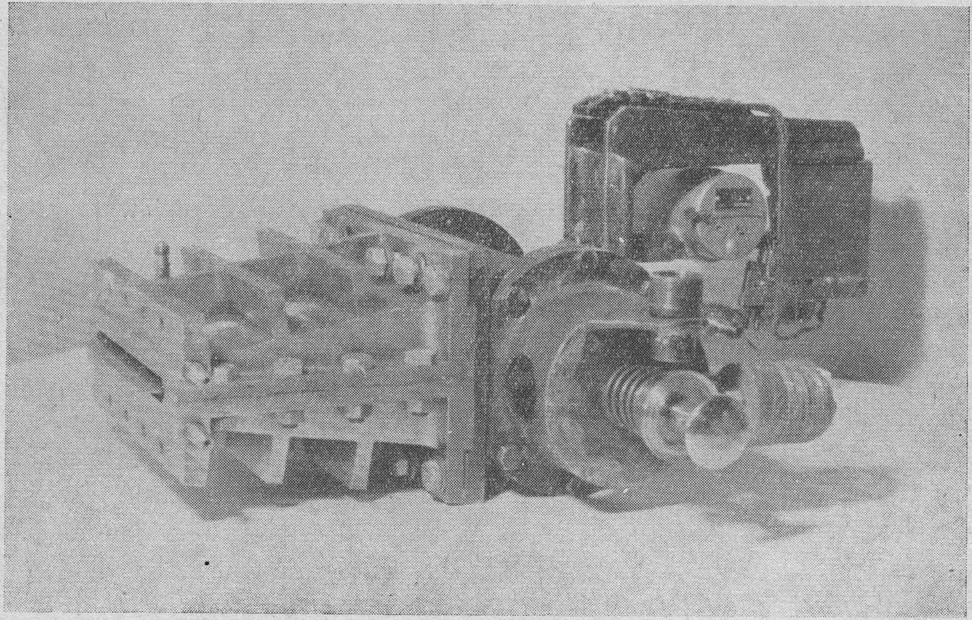

Fig. 7. Diffuser

Brief description of CO_2-N_2 mixing gasdynamic laser facility

7. As is evident from the schematic diagram (Fig. 1) the facility under consideration can be divided into three separate parts, namely:

a. Gas supply system, together with control instruments.

b. The laser proper with the arc heater, plenum chamber and diffuser, together with a power supply and control instruments.

c. Gas exhaust system with control instruments.

The GDL facility is described beneath basing on that division. Electric power supply circuit and a system of programmed control of the facility are omitted, because they have been described thoroughly in [17].

8. The gas supply system consists of four independent subsystems: argon supply, nitrogen supply, carbon dioxide and water vapour supply and a reserve subsystem for delivering additives in order to investigate their influence on laser action.

Argon supply. Argon is stored in a three-cylinder collector of 18 m^3 (n.t.p.) capacity. It is delivered to the arc heater, serving there as a neutral protection of the cathode. Owing to this protection, the rate of wear of the thorium added tungsten cathode tip is reduced.

Nitrogen supply. Nitrogen is delivered from a 60 m^3 capacity collector to the arc heater (between its first and second anode) and to the plenum chamber.

CO_2 supply. Carbon dioxide is stored in a ten cylinder collector; its nominal delivery to the laser equals 22 m^3p.h. The gas is heated twice, the first heating applied directly at the collector exit (by a 1.8 kW heater) to avoid freezing of the pressure regulator. It may be heated additionally, up to the temperature of 650°K in a 10 kW preheater before entering the nozzle system. This heating was designed to avoid possible flow discontinuities during expansion, which could be due to the thermal properties of CO_2. As they did not arise, use was made of the preheater only if water vapour was to be added to the expanding carbon dioxide. Otherwise preheater served as a low-temperature ($T_{CO_2}=300-500$°K) plenum chamber, where CO_2 was stored under the pressure of $p_{CO_2}\simeq 11$ ata.

Water vapour supply. Vapour of pure H_2O used as an additive accelerating the relaxation of the lower laser level CO_2 (10^00) can be mixed with carbon dioxide inside the CO_2-preheater. The water is delivered either directly from a pressure-vessel or from a vaporizer. In the first case not more than 10–20 volume percent of water vapour may be introduced into the mixture of CO_2+H_2O, the limit being determined by the heat capacity of the preheater. If larger amounts of H_2O were demanded during experiments one should use an additional vaporizer.

It is possible to supply the laser with other gases in order to investigate the influence of such additives as e. g. carbon monoxide, hydrogen or helium on the laser action.

The gases used for experiments were all of commercial quality, with low degree of chemical and mechanical purity. To protect the laser region against uncontrolled quantities of water vapour and mechanical impurities it was necessary to furnish the gas delivery system with high pressure vessels containing drying agent removing both the water and most of the mechanical impurities from the gas.

9. Expansion channel, together with the arc heater, plenum chamber and diffuser. The system consisting of the expansion channel, arc heater, plenum chamber and diffuser (Fig. 2 and 4) forms a central part of the GDL facility. Nitrogen is heated in the arc heater and plenum chamber. In the expansion channel expansion of gases occurs with freezing of population $N_2(v)$ in the state determined approximately by equilibrium parameters in the plenum chamber, mixing of CO_2 and N_2 with a transfer of vibrational energy quanta and the laser action within the segment embraced by resonator mirrors. The diffuser at the channel outlet is used for compressing the gas to the atmospheric pressure.

In order to secure a high population of the first vibrational levels of nitrogen, a possibly high temperature of the gas is needed. This temperature is, however, limited by dissociation of N_2 (its influence being significant only over 6000°K) and technological requirements, namely thermal resistance of the wall coating materials in the plenum chamber. These requirements restrict the static temperature there to the limit of about 3000°K. Actually the limit 2500°K was assumed to assure a sufficient durability of coating materials.

The measured input power of the arc heater, working at about 10 atm pressure, was equal to about $P_p = 25 - 60$ kW (total), its efficiency equal to $\eta_p = 40 - 60\%$. This power is to be dissipated inside an arc column of possibly high resistance in order to minimize the surface current density on the electrodes and to increase the durability of the electrodes. This requirement was fulfilled by using a two-anode arc heater with the whirl-stabilized arc. The water-cooled copper cathode has a shape of a cone with thorium added tungsten tip. The anodes are water-cooled copper nozzles positioned along the cathode axis. The bodies of the electrodes are made of brass and isolated by epoxy rings. The cathode has an argon shield to protect against rapid wear. Argon is fed to the chamber between the cathode and the first anode with an initial whirl. The chamber between the anodes is supplied with nitrogen which enters also with a strong whirl. Since nitrogen is heated mainly inside the second anode, it is desirable to lower the first anode current as much as possible. This is executed by a limiting resistor and a switch (which is used for disconnecting the anode from the power supply after reaching nominal working parameters). The Ward-Leonard system serves as electric power supply, connected through a stabilizing resistor. The arc heater is ignited by a pulse short-circuiting through the cathode and the first anode, an arc being shifted to the second anode as a result of increasing the nitrogen flow.

The plenum chamber serves as a reservoir for equalizing the pressure and temperature of the ($N_2 + Ar$) mixture before expansion. It is located coaxially with the arc heater, at the outlet of the second anode. The whirling hot gas entering the chamber is mixed with a cold nitrogen pressed inside through a swirler. A ceramic wall protection (from either MgO or ZrO_2) is adopted, whereas the steel body of the chamber is water-cooled. Nominal gas parameters within the plenum, for continuous operation, are: temperature $T_{0N_2} = 1200 - 2500$°K, pressure $p_{0N_2} = 8 - 12$ ata.

Nitrogen enters the nozzle system of the expansion channel through a ceramic coated slit in the side wall of the plenum. The nozzle system has a form of segmented slab (Fig. 2, 3 and 6) made of heat-resisting alloy, where N_2- and CO_2-expansion nozzles are alternately placed, carbon dioxide (with or without water vapour) being fed from the preheater (which serves thus as a plenum for CO_2). Each of 15 identical N_2-nozzles has a length of $L_{N_2} = 75$ mm, a throat cross-section area of $A_{N_2} = 1.96$ mm^2 and expansion angle of $\alpha_{N_2} \simeq 9°$. A total volume flow of nitrogen is $Q_{N_2} = 40 - 55$ m^3 p.h. Corresponding values for CO_2-nozzles are: $L_{CO_2} = 57$ mm, $A_{CO_2} = 0.41$ mm^2 and $\alpha_{CO_2} \simeq 3°$, a total volume flow being equal to: $Q_{CO_2} = 15 - 25$ m^3 p.h. After leaving the nozzles, parallel streams of the both gases flow along the slightly divergent channel, the mixing taking place within boundary regions of the neighbouring streams (Fig. 3). The population inversion $N_{CO_2}(00^01)/N_{CO_2}(10^00)$ is obtained as a result of the vibrational energy transfer between N_2 (v) and CO_2 (0) states (see [18]). This process occurs before the gas mixture enters the resonator region.

The expansion channel is embraced by four flat walls, the narrower, side walls having three pairs of openings furnished with quartz windows. The first pair uncovers nozzle outlets, the second and third one are spaced down the channel. Every pair of windows may be replaced by optical resonàtor mirrors. The streams of a cold nitrogen are used to protect mirror surfaces against impurities carried by the gas and the temperature rise within boundary layers. Also a movable probe for taking gas samples in order to examine the CO_2 content across the channel may be mounted in any of the pairs of openings. The upper and lower walls of the channel are water-cooled.

For the experiments two identical optical resonators were fit up to the openings at the distances $L_{R_1}=62$ mm and $L_{R_2}=135$ mm from the nozzle system outlet. Their circular mirrors ($d_M=9$ mm) were made of gold coated steel, the transmitting mirrors – flat with concentric holes of diameter $d_T=2$ mm, the totally reflecting ones – spherical with radii of curvature equal to about $r_M=1700$ mm. The holes were not covered and let the air into the channel, but, as has been proved experimentally, it did not affect the laser action. The active volume of each resonator was equal to $V_R=9.6$ cm^3. Pressure inside the first optical cavity (Fig. 1) amounted to $p_m=12$ - 20 *Tr*.

The diffuser has the form of an expanding channel with flat walls (Fig. 2 and 7), and a wedge-shaped slab inside movable upstream and downstream direction of the channel. The slab is made of heat-resisting alloy, its expansion angle being equal to 15°. The gas leaving the channel is compressed in a sequence of oblique shock waves building up between the wedge and the walls of the diffuser. The GDL facility is started with the wedge located downstream and the exhaust gas being sucked out by a 2-stage system of vacuum pumps. After that the wedge is moved upstream, causing gradual increase of the compression. A valve connecting the diffuser with atmosphere is opened after the pressure in the diffuser exceeds 1 atm. Then the main vacuum pump can be switched off (the first stage pump is already stopped automatically due to the first slight increase of the pressure).

10. Exhaust system. The described GDL facility has been designed to operate without sucking gases out. For that purpose the movable slab inside the compressing diffuser ought to be properly placed. However, low pressure inside the channel is needed before starting the laser. It is also necessary to extract the gases in case of inefficient operation of the diffuser. These requirements have been fulfilled by constructing an exhaust system composed of a two stage pump assembly of high delivery, able to remove up to 170 m^3 of gas per hour. As the first stage a centrifugal compressor (former aircraft engine supercharger) was adapted. It was driven by an 40 kW electric motor at 2980 r.p.m. Revolutions of the motor were matched to those of the compressor with the use of a suitable system of gearboxes and a centrifugal friction clutch. The suction pumps have been equipped with a common pressure oil lubricating system. The second stage suction pump is a liquid ring one, the working liquid being silicone oil. The oil is fed from a tank through a cooler by a small centrifugal pump; from the pump it flows gravitationally back to the tank. The working temperature of the oil is about 340°K (its ignition temperature being 520°K). For removing oil mist at the exhaust a tank with a system of screens is used. The pump is driven by a 55 kW electric motor at 735 r.p.m.

The main – second stage – pump allows to decrease the pressure in a closed chamber down to 20 Tr, while the whole assembly gives the minimum pressure of about 10 Tr (the compression ratio of the first-stage equal to 2). Its delivery is e.g. for $p=30$ Tr, $Q=50$ m^3 p.h., for $p=60$ Tr, $Q=150$ m^3 p.h.

The exhaust of the laser is cooled by a cooler placed between the diffuser and the pumps, down to the temperature of about 310 - 330°K, depending on the delivery.

11. Starting or stopping the GDL facility requires a series of timed operations, performed in a proper succession. For instance the arc heater ought to be switched on only after valves of the gas supply system are opened, gas delivery has to be exactly established, adding water to the gas must not take place too early etc. The individual units of the facility ought to be protected against damage in case of exceeding the permissible working regimes. To meet these requirement a simple programmed control system has been designed, its program covering the control of : gas and additives supply, electric power supply, shifting of the diffuser wedge and running the pump assembly. Also a number of protective circuits is controlled. Starting and stopping of the facility were each divided into two stages. Besides, manual control of the facility was possible between these stages, allowing to make corrections of the individual parameters or a shut-down. The protecting circuits have been designed to prevent damages to individual units of the facility by incorrect manual control. Also any erroneous ordering the improper stage of the starting or stopping has been excluded. Full set of measuring and control instruments has been mounted to control all the important parameters during operation. Types of instruments and points of measurement have been indicated in the schematic diagram (Fig. 1).

Primary results of experimental investigation

12. Two principal parameters of the laser have been measured during the experiments: the output power of radiation and the divergence of the radiation beam. The radiation power was measured with the use of a thermal gradient radiometer [25], the measurements being checked by means of a resistance calorimeter of power range 0 - 34 W. The divergence of the radiation beam was determined from thermal traces left by the beam in screens. Furthermore, a series of experiments of qualitative character was made in order to determine the direction of the laser modifications leading to higher output powers and energy transformation efficiencies. The following results have been obtained:

a. The maximum measured output power from the first resonator cavity (Fig. 1) was equal to $P_c^{(1)}=22$ W. The corresponding output power density per unit volume of the cavity was equal to $p_c^{(1)}=2.29$ W/cm^3, whereas the specific power per unit of mass flow of the working mixture was $g_c^{(1)}=0.724$ kW/kg$\cdot$s^{-1}. Simultaneous measurements of the output power from the second cavity yielded $P_c^{(2)}=13$ W, with the corresponding $p_c^{(2)}=1.35$ W/cm^3 and $g_c^{(2)}=0.426$ kW/kg$\cdot$s^{-1}. Thus, the total output power was equal to $P_c=35$ W with specific power $g_c=1.15$ kW/kg$\cdot$s^{-1}.

b. It is obvious that there is no influence of the second resonator on the working parameters within the first one. On the other hand, the output power of the second resonator cavity was approximately $P_c^{(1)}$ while the first one was completely misadjusted.

c. The beam divergence from each of the resonators was equal to $\Theta \cong 22'$.

d. The duration of continuous operation of the laser, limited by the capacity of the gas supply collectors, was about 1 hour. During the experiments thermal misadjustment of the resonators has been observed, leading to a drop in output power. Permanent corrections of the mirrors adjustment were made during the run, indispensable for maintaining maximum output power level.

e. Argon was added to nitrogen for arc heater cathode protection. This, however, affected the relaxation processes of nitrogen as well as of carbon dioxide [26] so that, strictly speaking, the considered gasdynamic laser ought to be recognized as a CO_2-N_2-Ar one.

f. The above given experimental results refer to the following working conditions and gasdynamic parameters of the GDL facility: the arc heater input power $P_p=49$ kW; its efficiency $\eta_p=56\%$; gas delivery: $Q_{N_2}=52$ m³ p.h (n.t.p), $Q_{CO_2}=19$ m³ p.h, $Q_{Ar}=9$ m³ p.h; static temperatures: $T_{0N_2}=T_{0Ar}=1700$°K, $T_{0\,CO_2}=300$°K; static pressures in the plenum chambers: $P_{0\,CO_2}=11$ ata, $p_{0\,N_2}+p_{0\,Ar}\cong 9.2$ ata; static pressures in the laser regions: $p_m^{(1)}= =13$ Tr, $p_m^{(2)}=15$ Tr, Mach number $Ma\cong 4.3$.

g. The laser action was observed already at starting parameters of the facility, i.e. with the arc heater power supply as low as $P_p=25$ kW, nitrogen delivery $Q_{N_2}=38$ m³ p.h and the following gas parameters within plenum chambers: $T_{N_2}=T_{Ar}=1200$°K, $p_{N_2}+p_{Ar}=6$ ata, $p_{CO_2}=11$ ata, $T_{CO_2}\simeq 300$°K. The total output beam power was equal to $P_c=16$ W (with corresponding value of specific power $g_c\simeq 0.58$ kW/kg·s^{-1}), outputs from the first and second cavity being equal, respectively, to $P_c^{(1)}=8.5$ W ($p_c^{(1)}=0.89$ W/cm³) and $P_c^{(2)}=7.5$ W ($p_c^{(2)}=0.782$ W/cm³).

h. The quantum efficiency of the laser region determined as a ratio of the power transmitted outside to the virtual radiation power stored in the isothermal nitrogen plenum chamber (in form of vibrational excited states $N_2(v)$) has also been calculated. It amounted to $\eta_c^{(k)}\cong 1.7\%$.

i. The generated radiation was partly absorbed by imperfect mirrors. The absorbed power has been evaluated by measuring the rate of the mirrors temperature increase; it amounted to about $P_a\geqslant 87$ W (with $P_a^{(1)}\geqslant 55$ W and $P_a^{(2)}\geqslant 32$ W).

The quantum efficiency value, if corrected for the above given values of absorbed power (as it was been made e.g. in [13]), was equal to $\eta_k^{(c+a)}\simeq 2.41\%$.

j. The influence of water vapour on the laser action has been evaluated only qualitatively. It was established that by adding about 3.5 percent of H_2O (with CO_2 considered as 100%) the laser action was entirely extinguished. However, unknown quantities of water carried by low quality commercial gases used in the experiments did not allow for making any quantitative evaluations of the water influence. It is planned to redesign the gas and water vapour supply systems in order to enable such an evaluation.

13. The gasdynamic laser facility presented in this paper can be compared, with regard to its dimensions and basic working conditions, with the CO_2-N_2 CW gasdynamic lasers described in [13, 14, 15, 21]. Such a comparison has been made in Table 1. For experiments reported in [13] two sets of data are presented in Table 1, namely: for the transmitting mirror with central hole of 0.8 mm diameter and (data in brackets) for the mirror with 7 holes of 0.8 mm diameter each; for this mirror maximum value of the output power was reached.

Data obtained for the above described GDL facility are also divided into two sets; values within brackets have been obtained with the both resonator cavities regarded as one source of radiation.

14. The basic planned modification of the above described laser is foreseen in the optical resonator design; namely a resonator appropriate for gasdynamic lasers is to be applied, embracing relatively long segment of the laser channel in the direction of gas flow. This conclusion, coming from the observation of effective operation of the two conventional type cavities spaced in the flow direction ($P_c^{(1)} : P_c^{(2)} = 2.75 : 1$), has been confirmed by the theory presented in [11, 12]. It is worth mentioning that a resonator of construction similar to that described in [12] has been used by Gerry [14] in the GDL of power $P_c = 60$ kW and specific power $g_c = 4.3$ kW/kg·s^{-1} which are the highest ones obtained heretofore. As has been indicated before, the specific power per unit of mass flow is a proper parameter for comparing different gasdynamic lasers. Its value for the facility described in [14] is about 4 - 5 times greater than maximum values of the specific power presented in Table 1. Moreover, the analysis of published data leads to the conclusion that each of the CW gasdynamic lasers built heretofore (there are at least nine of them, based mainly on non selective pumping during expansion of the mixture) has, less output than the one reported in [14].

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Gazodynamiczny laser CO_2—N_2 o działaniu ciągłym

Streszczenie

Podaje się zwięzły opis techniczny stoiska i zasad działania gazodynamicznego lasera $CO_2(H_2O)-N_2(Ar)$ o działaniu ciągłym. Dyskutuje się rezultaty wstępnych eksperymentów przeprowadzonych przy użyciu w laserze gazodynamicznym konwencjonalnych wnęk rezonansowych. Transmitowana na zewnątrz kanału moc promieniowania $\lambda=10{,}6$ µm wynosiła $P_c=35$ W, co odpowiadało gęstości mocy produkowanej z jednostki objętości czynnej rezonatora optycznego $p_c=2{,}29$ W/cm^3. Modelowy parametr lasera gazodynamicznego określający ilość mocy produkowanej z jednostki wydatku masowego mieszaniny roboczej miał wartość $g_c=1{,}15$ kW/kg$\cdot$s^{-1}. Rozbieżność wiązki wynosiła ok. $\theta\cong 22'$.

W zakończeniu przeprowadzono porównanie omówionego urządzenia z innymi laserami gazodynamicznymi CO_2 o działaniu ciągłym formułując w oparciu o wyniki eksperymentu i wyniki porównania podstawowe wymagania, które muszą być spełnione dla podwyższenia mocy wyjściowej i sprawności technicznej GDL.

Gasdynamischer CO_2-N_2 Laser mit Dauerleistung

Zusammenfassung

Es wird eine kurzgefaßte technische Beschreibung des Prüfstandes und der Wirkungsweise eines gasdynamischen $CO_2(H_2O)-N_2(Ar)$ Laser mit Dauerleistung angegeben.

Die Resultate der ersten Experimente, die an einem gasdynamischen Laser unter Anwendung der konventionellen offenen Resonatoren durchgeführt worden sind, werden diskutiert. Die außerhalb des Kanals transmittierte Strahlungsleistung $\lambda=10{,}6$ μm betrug $P_c=35$ W, was einer vom wirksamen Einheitsvolumen des optischen Resonators erzeugten Leistungdichte $p_c=2{,}29$ W/cm^3 entsprach. Der Modellparameter des gasdynamischen Lasers, welcher die von einer Massenstromeinheit des Arbeitsmediums erzeugte Leistungsgröße bestimmt, hatte einen Wert von $g_c=1{,}15$ kW/kg·s^{-1}. Öffnungswinkel des Strahlungsbündels betrug ca. $\theta\cong 22'$.

Abschliessend wurde ein Vergleich der betreffenden Anlage mit anderen gasdynamischen Dauerleistungs-CO_2-Lasern durchgeführt.

In Anlehnung an die experimentellen Resultate sowie die Ergebnisse des obenerwähnten Vergleiches wurden die Anforderungen formuliert, die zur Erhöhung der Austrittsleistung und der technischen Wirksamkeit des gasdynamischen Lasers zu erfüllen sind.

Газодинамический лазер CO_2—N_2 непрерывного действия

Резюме

Дается краткое техническое описание стенда и принципов действия газодинамического лазера $CO_2(H_2O)$—$N_2(Ar)$ непрерывного действия. Обсуждаются результаты предварительных экспериментов, проведенных с употреблением конвенциональных резонансных ниш в газодинамическом лазере. Передаваемая наружу канала мощность излучения $\lambda=10{,}6$ μм равна $P_c=35$ вт, что отвечает плотности мощности, производимой из единицы активного объема оптического резонатора $p_c=2{,}29$ вт/см^3. Модельный параметр газодинамического лазера, определяющий количество мощности производимой из единицы массового расхода рабочей смеси, достигал значения $g_c=1{,}15$ квт/кг·сек$^{-1}$. Расходимость пучка достигала ок. $\theta\cong 22'$.

В заключении сравнивается обсуждаемое устройство с другими газодинамическими лазерами непрерывного действия, определяя на основе результатов экспериментов и проведенного сравнения основные требования, соблюдение которых необходимо для повышения исходной мощности и технической надежности газодинамического лазера.