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A. Ionin, M. Kelner, A. Lobanov, D. Okhrimenko, D. Sinitsin, et al.. HIGH PRESSURE N₂O LASER : DISCHARGE PROPERTIES, GAIN AND SPECTRA. Journal de Physique IV Proceedings, 1991, 01 (C7), pp.C7-729-C7-735. 10.1051/jp4:19917197 . jpa-00250877

HAL Id: jpa-00250877

<https://hal.science/jpa-00250877>

Submitted on 1 Jan 1991

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HIGH PRESSURE N₂O LASER: DISCHARGE PROPERTIES, GAIN AND SPECTRA

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Abstract. The influence of pressure, temperature, composition and components ratio of laser mixture on the discharge properties, gain and lasing parameters of pulsed electron beam controlled discharge N₂O laser with the output energy more than 100 J and efficiency about 10 % has been studied experimentally and theoretically. The excitation efficiency in EB CD and relaxation constant of N₂O laser levels have been estimated.

1. Introduction.

Among the electric-discharge IR lasers the N₂O lasers with $\lambda_{\text{las}} \approx 10.9 \mu\text{m}$ /1/ are inferior to CO and CO₂ lasers only as regards power and efficiency. The power of low-pressure CW N₂O lasers is, however, 4-6 times lower than the power of CO₂ laser, and the efficiency $\leq 3\%$. The energy of a TEA N₂O laser did not exceed, up to the beginning of our experiments, one Joule, and the efficiency $\leq 2\%$. The application of electron-beam-controlled discharge (EB CD) pumping method in /2/ did not make it possible to make a powerful and effective N₂O laser (0.6 J, 2 J/1.atm, 0.3 %). This paper reports the results of the experimental and theoretical studies of a powerful and efficient EB CD N₂O laser with energy and efficiency essentially exceeding the known values for electric discharge N₂O lasers.

2. Experimental setup.

The experiments on investigations of output power characteristics, discharge, gain and spectral properties of the active medium of high power pulsed EB CD N₂O laser were carried out at the two EB CD laser installations with active volumes $\sim 2 \text{ l}$ ($3.6 \times 4.2 \times 140 \text{ cm}^3$) and $\sim 10 \text{ l}$ ($10 \times 10 \times 100 \text{ cm}^3$) /3/. Electron beam current density (in both

installations) was in the range $10\text{--}20\text{ mA/cm}^2$, the discharge current pulse duration was $20\text{--}50\text{ }\mu\text{s}$. These laser devices were able to operate both independently and as "master oscillator - laser amplifier" system /4/.

3. Discharge properties and laser energy characteristics.

Fig.1 demonstrates the dependence of input energy on reduced

Fig.1. Specific input energy Q_{in}^{sp} vs reduced initial field E/p .

Mixture $N_2:N_2O:CO:CO_2:He=$
 $1:0:0:0:1$ (a),
 $20:3:0:0:27$ (b),
 $10:3:10:0:27$ (c),
 $0:3:20:0:27$ (d),
 $5:0:0:1:6$ (e).

initial field E/p in active medium (gas pressure = 0.25 atm.) of EBCD N_2O laser. The addition of a small amount of N_2O into the mixture of N_2 and He decreased, by more than an order of magnitude, the energy input into discharge (Fig.1, lines a and b). The decrease in the input energy is connected with the decrease of the electron concentration in EBCD due to dissociative attachment of electrons /5/:

The energy input in the EBCD was increased considerably when part of N_2 was substituted for CO (Fig.1, line c). The increase of input energy can be due to a process of associative detachment of electrons /5/ :

The largest energy input in the gas mixtures containing N_2O was realized when N_2 was fully substituted for CO (Fig.1, line d). When the value of parameter E/p was fixed, the energy input was lower than that known for typical gas mixtures of EBCD CO_2 lasers with 50 % concentration of He (Fig.1, line e).

The power and efficiency of EBCD N_2O laser depended essentially on the composition of the laser mixture. The influence of atomic (He, Ar, Xe) and molecular (N_2 , CO) gas concentrations on the output energy and efficiency of the EBCD N_2O laser was studied at the experimental conditions: the electron beam current density $\sim 20\text{ mA/cm}^2$, the EBCD discharge duration $\sim 20\text{ }\mu\text{s}$, the active volume $\sim 2\text{ l.}$ The laser cavity of 3.5 m length was created by two copper mirrors (one flat and one concave spherical with radius of curvature 10 m). The radiation was extracted by means of NaCl flat plate inserted into laser cavity and slightly disaligned from its optical axis.

The addition of CO in the laser mixture $N_2O:N_2:He$ or the total substitution of N_2 for CO increased not only the energy input into EBOD, but the output energy and efficiency of the N_2O laser. The laser

Fig.2. Specific output Q_{out}^{sp} and efficiency η vs specific input energy Q_{in}^{sp} .
 $N_2:N_2O:CO:CO_2:He =$
 20:3:0:0:27 (a,e),
 10:3:10:0:27 (b,f),
 0:3:20:0:27 (c,g),
 5:0:0:1:6 (d,h).
 Free-running mode.

energy ~ 8 J (specific output ~ 16 J/l·atm) and efficiency ~ 7 % were obtained in laser, acting on the gas mixture $N_2O:CO:He = 3:20:27$ (Fig.2, lines c and g). The efficiency was increased up to 9 % (6.5 J, 13 J/l·atm) by using four-component gas mixture $N_2O:CO:N_2:He = 3:10:10:27$ (50 % of N_2 was replaced by CO) characterized by less input energy (Fig.2, lines b and f). The efficiency was also increased up to 11 % by cooling of gas mixture down to 220 K.

For three-component gas mixture $N_2O:CO:He$ that contained 50 % of He (the total gas pressure $P = 0.25$ atm.) the dependence of laser output energy on the

N_2O to CO concentrations ratio was investigated.

The output energy maximum for the parameter $E/P \sim 10$ kV/cm·atm was obtained at the ratio $N_2O:CO$ nearly 5:33. The laser output energy without He in the gas mixture (mixture $N_2O:CO:He = 3:33:X$ with total pressure $P = 0.25$ atm) was not higher than 5 J. The optimum concentration of He in N_2O laser mixture $N_2O:CO:He$ was $X \sim 30$ %. The maximum specific output energy of EBOD N_2O laser with gas mixture $N_2O:CO:He = 5:33:16.5$ and $E/P = 10$ kV/cm·atm was 30 J/l·atm at the efficiency ~ 9 %.

The usage of Ar and Xe as the partial substitute of He in the laser mixture of EBOD CO_2 lasers was permitted to increase the pumping and the laser generation power with the same electron beam current density [6], because the ionization degree of Ar and Xe is more than that of He. The influence of Ar and Xe on the EBOD N_2O laser output characteristics was investigated on the laser gas mixture $N_2O:CO:(He+Ar+Xe)=5:33:16.5$. When part of He (up to 6 %, $[Xe]=0$) was replaced by Ar a low increase of output laser energy (up to 10 %) was obtained. The further diluting of He by Ar ($[Xe]=0$) led to the sharp decrease of the laser output energy. The addition of Xe to the laser gas mixture led to the decrease of laser output energy. The full

substitution of He for Ar or Xe led to 6-7 times reduction of EBCD N_2O laser output energy.

The comparison between energy characteristics of N_2O lasers acting on gas mixtures with carbon monoxide and without CO demonstrated that influence of carbon monoxide on laser energy and efficiency was due to the process (2). One can see from Fig.2 that there must be optimum proportion between N_2O and CO concentration in laser mixture. At the same pumping conditions laser energy and efficiency of EBCD N_2O laser was about 1.5 times lower than that of EBCD CO_2 laser acting on conventional laser mixture $CO_2:N_2:He=1:5:6$ (Fig.2, lines d and h). But it should be pointed out that under experimental conditions the output energy of CO_2 laser was 1.5-2 times lower than that of limit magnitude.

The EBCD N_2O laser generated on several lines P(19), P(20), P(24) within the spectral band with center wavelength $\sim 10.9 \mu$. At the same pumping conditions EBCD CO_2 laser acted on P(18) and P(20) lines (input energy 200 J/l.atm.). The laser acting was observed simultaneously on CO_2 and N_2O laser transitions when carbon dioxide was added to the laser gas mixture ($N_2O:CO_2:CO:N_2:He = 1.5:1.5:10:10:27$). The number of lines and laser wavelengths depended on input energy, temperature and composition of laser mixture.

Using the optimum laser gas mixture $N_2O:CO:He = 5:33:16.5$ and the laser installation with active volume 10 l we obtained the output laser energy ~ 80 J (P=0.25 atm., E/P=10 kV/cm.atm., specific laser output energy ~ 30 J/l.atm.). The maximum efficiency was $\sim 9\%$ with specific input energy ~ 200 J/l.atm. The further input energy increase led to the efficiency reduction. It may be connected with overheating of the gas mixture and with the de-excitation of the upper laser level by electron strike. When the laser gas mixture was cooled to the temperature $\sim -30^\circ C$ (the relative gas density $N = 0.3$ Amagat), the output laser energy grew up to 106 J (specific output energy 36 J/l.Amagat, efficiency 10%). This growth was determined by the decrease of the upper laser level relaxation rate and by the reduction of the N_2O molecules dissociation rate when cooling laser gas mixture in the EBCD /7/. The free-running laser action appeared on several transitions from P(15) to P(24) depending on laser gas temperature and specific input energy.

4. Gain and spectra.

The theoretical small signal gain (SSG) calculations for laser mixture $N_2O : CO : He$ excited in EBCD have been made on the base of

vibrational temperature model /8,9/. The corrected values of V-V and V-T rate constants /10/ and Einstein's coefficient /11/ have been taken for the $(0,0^{\circ},1-1,0^{\circ},0)$ transition of N_2O molecule. As there is not a selfconfirming set of electron strike excitation crosssections for vibrational N_2O molecule levels, that needs to SSG calculations, experimental values of electric field E/P and current I in EBCD and adapting parameter δ (EBCD energy part coming to CO and N_2O excitation) have been used.

Fig.3. SSG peak value α_{peak} vs specific input energy in EBCD Q_{in}^{sp} . $N_2O : CO : He = 1:6:3$, $P = .25 \text{ Amagat}$, $P(20)$ line, $T = 293K(1)$, $260K(2)$.

The SSG peak value dependence on specific energy input in EBCD presented at the fig.3. If $Q_{in}^{sp} > 300 \text{ J/l} \cdot \text{Amagat}$ one can see saturation of SSG at the temperature $T = 293 \text{ K}$ (line 1) called by laser mixture heating in EBCD. The initial laser gas cooling up to $T = 260 \text{ K}$ increased the SSG peak value to $1.15 \cdot 10^{-2} \text{ cm}^{-1}$ (line 2). The comparison of experimental and calculated SSG values permitted to define dependence δ vs E/P , that may be approximated by expression $\delta = 0.675 + 0.093 \cdot \lg(E/P - 3)$ within E/P range from 3 to 8 $\text{kV/cm} \cdot \text{atm}$.

The experimental (a) and calculated (b) SSG time histories for the different laser mixture pressures at fixed specific input energy are presented on fig.4. With the increase of laser gas pressure the duration of these dependencies back fronts were shorter, that will entail relaxation time reduction of upper N_2O molecule laser level $(0,0^{\circ},1)$.

Fig.4. Experimental (a) and theoretical (b) SSG time history for the different laser gas pressures P . Mixture $N_2O:CO:He=1:6:3$, $Q_{in}^{sp} = 150 \text{ J/l} \cdot \text{atm}$, $T = 293 \text{ K}$. $P = .07 \text{ atm}$ (1), $.125 \text{ atm}$ (2), $.25 \text{ atm}$ (3), and $.4 \text{ atm}$ (4).

Experimental relaxation constant was estimated about $4 \cdot 10^2 \text{ torr}^{-1} \text{ s}^{-1}$. The maximum values of calculated SSG (fig.4 b) are some higher than that measured in experiments (fig.4 a) and the rate of experimental lines lowering from time more than $\sim 20 \mu\text{s}$ is stronger than the calculated one. It may be called by existence of electric field inhomogeneities and thermal gas away flying in EBOD, that are not taken into calculations.

The spectral SSG peak value distribution through vibrational-rotational lines of N_2O molecules P- and R- branches, getting in our experiments, presented at the fig.5. High values of SSG

Fig.5. SSG peak values spectral distribution. Mixture $\text{N}_2\text{O}:\text{CO}:\text{He}=1:6:3$, $P=.4 \text{ atm}$, $Q_{in}^{sp}=150 \text{ J/l} \cdot \text{atm}$, $T=293\text{K}$. Selective laser mode.

Fig.6. Specific output spectral distribution. Mixture $\text{N}_2\text{O}:\text{CO}:\text{He}=1:6:3$, $P=.4 \text{ atm}$, $Q_{in}^{sp}=150 \text{ J/l} \cdot \text{atm}$, $T=293\text{K}$. Selective laser mode.

in EBOD N_2O laser and strong exceeding of pumping energy over threshold one ($\alpha_{th} \sim 10^{-3} \text{ cm}^{-1}$) permitted us to expend lasing vibrational-rotational lines row to P(2)-P(46) and R(47)-R(2). The maximum specific output was $\sim 16 \text{ J/l} \cdot \text{atm}$ on P-branch (line P(18)) and $\sim 12 \text{ J/l} \cdot \text{atm}$ on R-branch (line R(20)) (fig.6).

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