NOTATION

\( p, v, T \), pressure, volume, and temperature; \( R \), universal gas constant; \( \text{N}_2O_4 \), molecular mass; \( C_v, C_p \), isochoric and isobaric specific heats; \( Z \), compressibility coefficient; \( C_{pe f} \), effective specific heat at constant pressure; \( Z_{ef} \), effective coefficient considering effects of dissociation and nonideality; \( K_{p10}, K_{p20} \), temperature dependent equilibrium constants for first and second reaction stages for an ideal gas mixture; \( \alpha_{10}, \alpha_{20} \), degree of dissociation of first and second reaction stages in ideal gas state.

LITERATURE CITED


CHARACTERISTICS OF A GAS-DISCHARGE CO-LASER IN GENERATION ON AN OVERTONE

1. STEADY-STATE REGIME

Yu. B. Konev, I. V. Kochetov, A. K. Kurnosov, V. G. Pevgov, and A. V. Dem'yanov

The work presents the parametric dependences of the energy and spectral characteristics of the gas-discharge CO-laser in steady-state regime in generation on the first overtone on the gas temperature, the pumping power, and the cavity Q-factor of the resonator. The article examines questions of the selection of the individual vibrational and rotational lines. Comparisons with experimental results are made.

At present there is considerable interest in lasers on vibrational overtone of the carbon monoxide molecule [1-4]; this is due to the potentially high effectiveness of such a laser close to the IR range and the possibility of using it for problems of laser chemistry, isotope separation, etc. We will also demonstrate that the investigation of this laser makes it possible to elaborate on the kinetics of CO molecules, especially at high vibrational levels. Knowledge of the theoretical parametric dependences obtained on the basis of numerical modeling makes it possible to predict the expected characteristics of such a laser, and it stimulates and facilitates its experimental investigation. The present work consists in the theoretical investigation of the characteristics of the gas-discharge CO-laser operating in steady-state regime of generation on the first overtone. We analyze the parametric dependences of the energy and spectral characteristics on the gas temperature, the pumping power, and the cavity Q-factor of the resonator. We also examine questions of the selection of individual vibrational and rotational lines.

Previously, we substantiated the possibility of obtaining generation on vibrational overtones of carbon monoxide molecules with pumping in a stationary and pulsed electric discharge [1]. An analysis of the population density of vibrational levels of CO molecules indicated that it is possible to effect partial inversion at the transitions \( J-1, v \rightarrow J \).
v=k not only for k=1 but also for k≥2, and at the first overtone the gain according to the calculation exceeded 0.1 m⁻¹ with parameters of the discharge and of the gaseous medium close to those obtained in the experimental work [5]. It also followed from the results of the calculations that the gain of the small laser signal at the first overtone is maximal at high vibrational transitions. In this the laser on a overtone differs markedly from a laser on the fundamental frequency where the gain of the small signal rapidly increases with increasing number of the vibrational level, after which the maximum is attained and a drop begins. This result is basically due to the different nature of the dependences of the Einstein coefficient vs the number of vibrational levels on the fundamental frequency and on overtones. The authors of [1] also investigated the maximum values of the gain on the fundamental frequency and on the first two overtones vs the gas temperature and the pumping power. These dependences are analogous for all three types of transition, but on each subsequent overtone the gain decreases by more than one order of magnitude.

The conclusions arrived at in [1] also began to receive experimental confirmation. At the same time as [1], [2] was also published where generation on the first overtone in a supersonic stream with previous pumping of the vibrational levels in an electric discharge was experimentally obtained. Later on, generation on an overtone was also obtained in a pulsed discharge [3]. We will show that the calculation of the generation spectrum on the first overtone in a pulsed electric discharge was carried out in [4] on the assumption that there is no generation on the fundamental transitions. In the mentioned experimental works the authors did not succeed in suppressing generation on the fundamental frequency, and it occurred together with generation on the first overtone. Such an operating regime is investigated in detail below.

To find the distribution function of the CO molecules according to vibrational levels and the generation spectrum on the vibrational and rotational transitions, here we carried out the numerical solution of a system of kinetic equations for the population densities of the levels by a method described in [6]. The kinetic equations have the form

\[
\frac{dn_v^n}{dt} = R_{eV} + R_{VV} + R_{VT} + R_A + g_2^{v-2} P_{v-2} - g_v^{v-2} P_v = 0, \tag{1}
\]

where \(R_{eV}, R_{VV}, R_{VT},\) and \(R_A\) are terms describing the change in the population densities of the vibrational levels due to excitation and deexcitation by electron shock, \(V\) of the exchange, \(VT\) of relaxation and spontaneous emission. Equations (1) take into account forced emission on the first overtone, \(I_v^{v-2}\) is the flux density of the radiation quanta at the transition \(v \rightarrow v-2; g_v^{v-2}\) is the gain on this same transition. The gain is calculated by the formula

\[
g_v^{v-2} = \frac{\lambda^2}{8 \pi} A_{v,v-2} J \left[ n_v \frac{B_v}{T} e^{-\frac{B_v (J-1) J}{T}} - n_{v-2} \frac{B_{v-2}}{T} e^{-\frac{B_{v-2} (J+1) J}{T}} \right] G(v), \tag{2}
\]

where \(\lambda\) is the wavelength of the corresponding transition; \(G(v)\), normalized profile of the line; \(J\), rotational quantum number of the lower level. The energy passing into the molecular vibrations was determined by the numerical solution of the Boltzmann equation for the energy distribution function of electrons [7]. The Einstein coefficients for the corresponding radiational transitions were taken in accordance with the analysis carried out in [8]. To find the distribution functions of the CO molecules according to vibrational levels where generation occurs on the transitions between them, the following condition was used:

\[
g_v^{v-2} = G, \tag{3}
\]

where \(G\) is the threshold gain determined by the losses in the resonator. To find the radiation intensity at these transitions, Eq. (1) was used. In the process of solution, the gain \(g_v^{v-2}\) was chosen maximal with respect to \(J\), the number of the rotational transition \(J-1 \rightarrow J\). In the kinetic equations, temperature figures as a parameter, and it is determined by the pumping power and the removal of heat. In our calculations we confined ourselves to the examination of conditions close to those obtained in [5].

Figure 1 shows the distribution functions of carbon monoxide molecules according to vibrational levels in the gain regime, in generation on the first overtone and on the fundamental frequency. The conditions of the calculation are as follows: density of the carbon monoxide molecules \(n_{CO}=8.5 \times 10^{16} \text{ cm}^{-3}\), of the helium molecules \(n_{He}=8.8 \times 10^{17} \text{ cm}^{-3}\), gas temperature \(T=100^\circ\text{K}\), density of the pumping power \(W=1.5 \text{ W/cm}^3\), reduced electric field intensity \(E/N=1.3 \times 10^{-16} \text{ W cm}^{-2}\).