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NUMERICAL ANALYSIS OF THE OPERATION OF A MOLECULAR AMPLIFIER
OF NANOSECOND PULSES

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The creation and investigation of molecular amplifiers of nanosecond and subnanosecond pulses of infrared radiation remains as before one of the leading and most promising directions of development of quantum electronics, although already a number of papers (e.g., [1]) have been devoted to the development of such systems and the calculation of their parameters.

The distinctive feature of the operation of a molecular amplifier of nanosecond pulses with coherence effects taken into account are analyzed in this paper on the basis of a semiclassical computational method.

The time scale of the amplified pulses is

\[ 10^{-9} \text{ sec} > \tau_u > 0.5 \cdot 10^{-9} \text{ sec} \]

\[ \left( \frac{1}{\tau_u} > \frac{1}{\tau_{19}}, \frac{1}{\tau_{20}}, \frac{1}{\tau_3}, \frac{1}{\tau_{42}} \right), \]

and only processes of intramodal and rotational relaxations remain significant.

The layout of the amplifier is given in Fig. 1. The difference between it and the schemes already known of multipass amplifiers consists of the fact that the mirrors in Fig. 1 are arranged such that the bypass loop of an axial ray of a beam through the amplifier does not lie in a single plane but is located in three-dimensional space. As has been shown

*The notation of the relaxation times is according to [1].
in [2, 3], in the first place such a mirror system is less critical to misalignments. Secondly, upon a circuit around a three-dimensional loop a rotation of the field is observed by an angle $\beta$, whose magnitude is determined by the arrangement of the reflectors, which determines the presence of helical symmetry in the radiation field resulting in an averaging of the transverse distribution of the intensity.

In the third place, upon a specific choice of the number of reflectors (an odd number) self-excitation of the amplifier is absent in such a closed system of mirrors.

In order to describe the kinetics of the active medium and the energy conversion in the amplifier, the system of equations is written in the following form:

$$\frac{\partial E}{\partial z} = -\gamma E + PN_{CO_2}, \quad (1a)$$

$$\frac{\partial P}{\partial t} = -\frac{P}{T_2} + i(\omega - \omega_0)P + \frac{\sigma \Delta N}{2 T_2} E, \quad (1b)$$

$$\frac{\partial N_{00}^{+1}}{\partial t} = A_{00}^{+1} - 2(E^*P + EP^*) - \frac{N_{10}^{+1} - z_1 N_{00}^{+1}}{\tau_{00}^{(10)}} \frac{1}{\tau_{00}^{(10)}}, \quad (1c)$$

$$\frac{\partial N_{10}^{+1}}{\partial t} = A_{10}^{+1} + 2(E^*P + EP^*) - \frac{N_{10}^{+1} - z_{11} N_{10}^{+1}}{\tau_{10}^{(10)}} \frac{1}{\tau_{10}^{(10)}}, \quad (1d)$$

Here $E = \tilde{E}(1/4 h \hbar)^{1/2}$, where $\tilde{E} = E_0 e^{i\phi}$ is the complex envelope of the electric field intensity, $k$ is the wave vector, $P = \tilde{P}/4 \left(\frac{k}{\hbar}\right)^{1/2}$, where $\tilde{P} = -(S + iC) l^0$ is the complex envelope of the polarization, $\sigma$ is the cross section of the induced emission, $\gamma$ is the coefficient of linear nonresonant losses (these losses were not taken into account in [4]), $\Delta N = N_{10}^{+1} - N_{00}^{+1}$ is the population inversion, and $A_{00}^{+1}$ and $A_{10}^{+1}$ are the noncoherent pumping terms, which describe the electron excitation and the relaxation processes in the CO$_2$--N$_2$--He mixture (these terms are described in detail in [4]).

The kinetic constants and excitation rates in the noncoherent pumping terms were calculated on the basis of the electron distribution function $f_{e}(\varepsilon)$, which was determined from Boltzmann's equation similarly to [5]. The use of the time-independent $f_{e}(\varepsilon)$ is justified here by the fact that the process of interaction of the input pulse with the active medium of the amplifier coincides (in the calculation) with the instant $\tau_m$ of the achievement of maximum inversion in the active medium under excitation conditions (the amplitude and duration of the discharge current and the discharge voltage) which are characteristic for experiments with molecular mixtures (e.g., see [6]). In our calculations $\tau_m$ was $(0.3-0.5) \cdot 10^{-6}$ sec, which according to the estimates of [7] is completely satisfactory for the establishment of an equilibrium distribution.

In comparison with [4], in which the variation of the level populations is described only under the action of rotational relaxation, we have introduced terms into Eqs. (1c) and (1d) which describe the variation of the populations under the action of intramodal $v-v$ relaxation; $\tau_{vv}^{00}$ and $\tau_{vv}^{10}$ are the times for establishment of a Boltzmann distribution in the populations of the vibrational levels of the corresponding mode of the CO$_2$ molecule.

*The basis for writing them this way follows from the equations given in [4].