DINAMICS OF CO_2 – LASER GENERATION IN A PASSIVE Q_SWITCHING MODE

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Passive Q-switching of a CO_2 laser using an intracavity nonlinear absorber has been studied experimentally and theoretically. We propose a model enabling one to describe both qualitatively and quantitatively the operational limits, PRF, amplitude distribution and pulse shape.

A Q-switched the CO_2 laser with a nonlinear absorber generates periodic pulse train with a variety of pulse shapes from smooth, nearly symmetrical pulses to highly asymmetric long-tailed pulses with a steep leading edge. The characteristic laser pulse duration varies from microseconds to tenths of milliseconds. It was shown earlier[1] that Q-switching is caused by the instability of the stationary generation regime, when absorption reaches a critical value. The importance of Q-switching studies in IR lasers is explained by their possible applications to lidar systems[2,3] and to pumping of FIR lasers[4]. The role of Q-switching in the production of high-repetition pulsed-periodic lasers with mean powers of 1 to 1.5 kW should be stressed as well. In spectroscopic and lidar applications, the preservation of pulse-to-pulse coherence is of crucial importance.

In the present paper, we describe experimental and theoretical studies of Q-switching in CO_2 lasers with an intracavity nonlinear absorber are described. The influence of active and passive media parameters on pulse shape is given special consideration.

It is well known that in order to describe the dynamics of CO_2 laser pulse generation one has to take into account the multilevel character of the active medium. For this reason, we have chosen the simplest version of the multilevel[5] model which is a simplification of the well known five-temperature model of the CO_2 laser[6]. The latter model provides a quite adequate description of the pulse shape during active modulation for different types of CO_2 lasers. To describe the passive medium we used a relevant multilevel model[7] as well.

It was shown earlier[8] that the combination of these two models appears to be sufficient to describe all experimentally observed Q-switching characteristics. It should be noted, that this compound model seems to be the simplest, since all attempts to simplify it, say by choosing a two-level approximation for the passive medium, have produced results in consistent with the experimental data.

The set of equations in which the multilevel structure of both media is taken into account takes the form

$$\begin{aligned}
\dot{q} &= S_1 q (P_1-P_2) + S_2 q (P_4-P_5) - \nu q + S_{SP} P_1 ;\\
\dot{P}_1 &= -S_2 q(P_1-P_2) - \gamma_1 P_1 + \alpha_1 n_e P_c^0 + \gamma_0 (P_n P_c - P_n P_n^0) ;\\
\dot{P}_2 &= S_1 q (P_1-P_2) - \gamma_2 (P_2-P_2^{st}) ;\\
\dot{P}_3 &= \alpha_2 n_e P_c^0 + \gamma_2 (P_2-P_2^{st}) - \gamma_3 (P_3-P_3^{st}) ;\\
\dot{P}_n &= \alpha_3 n_e P_n^0 - \gamma_0 (P_n P_c^0 - P_1 P_n^0)\\
\dot{P}_4 &= -S_2 q (P_4-P_5) - \gamma_r P_4 + \gamma_r' P_6 ;\\
\dot{P}_5 &= S_2 q (P_4-P_5) - \gamma_r P_5 + \gamma_r' P_7 ;\\
\dot{P}_6 &= \gamma_r P_4 - \gamma_r' P_6 - \gamma_{21} P_6 - P_6^{st} ;\\
\dot{P}_7 &= \gamma_r P_5 - \gamma_r' P_7 - \gamma_{22} (P_7 - P_7^{st}) .
\end{aligned} \qquad (1)$$

Here q is the cavity photon number density, S_{SP} is the sponteneous emission rate, $S_1 = cI_1\sigma_1/L$, $S_2 = cI_2\sigma_2/L$, I_1 and I_2 are the active and passive medium length respectively, L is the cavity length, σ_1 and σ_2 are the active and passive medium absorption cross-sections, c is the speed of light, α_1, α_2 and α_3 are the CO_2 and N_2 level excitations rates, n_e is the electron density, γ_0, γ_1, γ_2 and γ_3 are the active medium relaxation constants, P_1, P_2, P_3 and P_n are the 001, 100, 010 CO_2 and first excited N_2 level populations, the superscript *st* denotes the stationary value in the absence of a field, P_c^0 and P_n^0 are the CO_2 and N_2 lower level populations, P_4 and P_5 are the populations of rotational levels of a absorber directly interacting with the field, P_6 and P_7 are the remaining rotational level populations for the relevant vibrational transitions. We also have $P_1 + P_2 + P_3 + P_c^0 = P_{ctot}^0$, $P_n + P_n^0 = P_{ntot}^0$, where P_{ctot}^0 and P_{ntot}^0 are the CO_2 and N_2 densities. The possible departure from a Boltzmann distribution at the leading edge of a pulse was taken into account by allowing the cross-section σ_1 to vary with field intensity:

$\sigma_1^* = \sigma_1/(1 + \sigma_1\tau_r q)$, where τ_r is the CO_2 rotational relaxation time. This approach was suggested in Ref. 9.

The ordinary differential equations modeling the processes in question are obviously stiff. That is why the numerical calculations were carried out using the implicit multistep Gir method implemented by the program 'STIFF'[10]. This program is convenient for dealing with Cauchy problems for a stiff set of ordinary differential equations. The MicroVAX-II was used for computations.

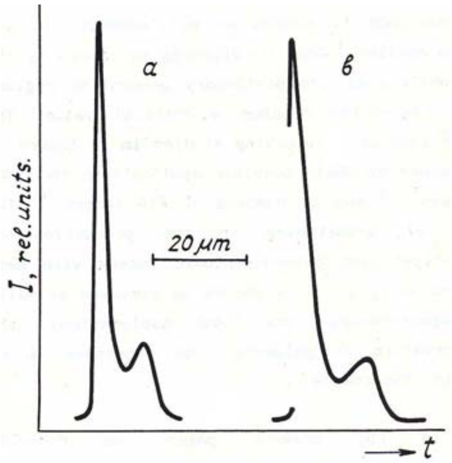

Fig. 1. Pulse shapes: a) computed according to the model of Eqs (1). The constants are taken from Refs. 5–7 *for* SF_6 *pressure* 210 *mTorr,* CO_2:N_2:He = 1:2:8 *with their total pressure* 15 *Torr and discharge current* 15 *mA; b) the experimental results for the same conditions.*

The experiments were performed on a low-pressure diffusion-cooled CO_2 laser with longitudinal glow-discharge. One or two absorbing cells were placed within the cavity. The nonlinear absorbers used were SF_6, HCOOH, CF_2Cl_2 and hot CO_2, either pure or mixed with buffer gases (N_2, He, H_2). The vacuum setup permits one to maintain different compositions in the laser and the absorption cells. A typical operating pressure range for the active medium was 5–25 torr, and for the passive medium, 10 mtorr – 5 torr. By changing absorbing cells and active elements, we could vary the absorber and discharge length. The maximum dischange length was 2.6 m, and the maximum absorption cell length was 2 m. The laser cavity was formed by a total reflector and a grating with 100 lines/mm. The effective field transversive cross-section, i.e. the medium saturation degree can be varied by usage of different curvature mirrors. ZnSe Brewster windows were used. The grating reflection coefficient, that is, the cavity Q, could be varied by changing the grating orientation. An SPM-2 monochromator was used to identify the lasing lines. The mean power was measured with a power meter, and dynamical characteristics by a Ge-Au photoresistor. The region over which absorption Q-switching took place, the pulse repetition rate, and pulse shapes, were determined experimentally as functions the active and passive medium parameters.

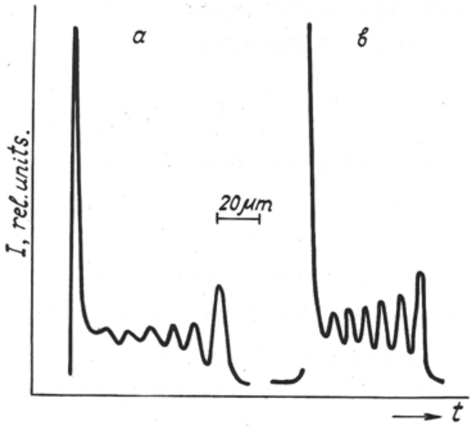

Fig. 2. Pulse shapes: a) the computed shape for SF_6 *pressure* 130 *mTorr; b) the experimental behavior. The remaining conditions are the same as in Fig. 1.*

Figures 1 and 2 represent the theoretical and experimental results. Typical pulse shapes calculated on the basis of Eqs. (1) are shown in Figs. 1*a* and 2*a*. The relaxation constants used were from Refs. 5–7. Typical experimentally recorded pulse shapes are plotted in Figs. 1*b* and 2*b*.

Thus, one can say that the theoretical, model adopted results in quantitative as well as in qualitative agreement characteristics in a CO_2 laser with a nonlinear absorber. These include the conditions required for Q-switching, pulse rate, amplitude, shape and duration as the active and passive medium parameters are varied.

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