Step motor driven, Q-switched CO_2 laser theoretical modeling

T.J. Fernandes, N.A.S. Rodrigues*

***Instituto Tecnológico de Aetonáutica – CTA – São José dos Campos - SP**
Instituto de Estudos Avançados – CTA – São José dos Campos - SP
e-mail

Abstract

This paper presents a theoretical model, based on rate equations, which describes the kinetics of a CO2 laser, aiming to support the development of a step motor driven Q-switched CO2 laser, which has been developed at IEAv[1]. A simple 3 level model that describes the pulse modulation by modulating the resonator switching time[2] and a more complex, 6 level model, developed to describe a pulsed TEA CO2 laser, can be found in the literature. In the model described in this work it is taken into account both the complexity of the inter and intra-molecule energy exchange processes (from Ref. 3) and the pulse modulation due to a swinging mirror in the resonator.

Introduction

The CO_2 laser, operating in the Q-switching regime, is very attractive for material processing due to its characteristics of high peak and average power and relatively high repetition rate. It is being assessed the use of a step motor to drive a swinging mirror as the resonator switch, in a commercial CO_2 laser, with the intent of controlling the switching time and the pulse repetition rate independently[1]. It is necessary a theoretical model to help to interpret the experimental results of this laser. Although there are several theoretical models in the literature which allows to describe, both qualitative and quantitatively, the CO2 laser operation, it is not available, as far as we know, a model which allows to evaluate the effects of the switching time and the repetition rate. To do so, it was combined two models, found in the literature: the first of them cares about the inter and intra-molecular energy exchange and the second one evaluate the effects of switching time on laser power nodulation. This paper presents the detail of such a theoretical model.

The model

Fig. 1 shows the 6 level model used to described the kinetics of a CO2 laser. The pumping of the active medium is provided both by collision between CO2 molecules and electrons and by resonant energy transfer from excited N2 molecules (wich, are also excited by impact with electrons). The laser transition occurs between levels 1 and 2, and the level 3 is na intermediate one that limitates the overall relaxation rate of the CO2 molecule.

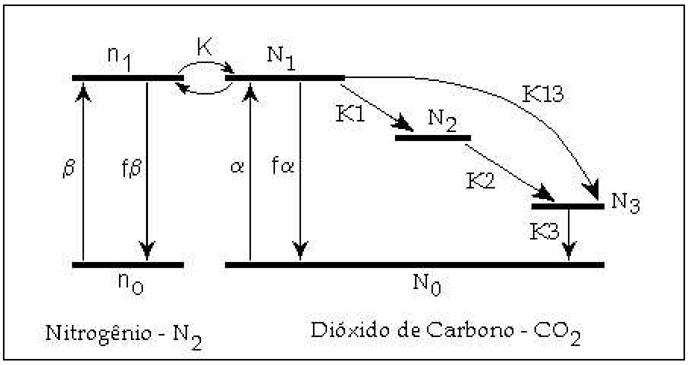

Figure 1: Level energy and kinetics diagram for laser action in CO_2.

The rate equations are written as

$$
\begin{aligned}
\frac{dN_0}{dt} &= -\alpha\left(N_0 - f.N_1\right) + K_{13}.N_3 \\
\frac{dN_1}{dt} &= \alpha\left(N_0 - f.N_1\right) + K\left(n_1.N_0 - N_1.n_0\right) - K_{13}.N_1 - Sq\left(N_1 - N_2\right) \\
\frac{dN_2}{dt} &= Sq\left(N_1 - N_2\right) - K_2.N_2 \\
\frac{dN_3}{dt} &= K_2.N_2 - K_3.N_3 + K_{13}.N_1 \\
\frac{dn_1}{dt} &= \beta\left(n_0 - f.n_1\right) - K\left(n_1.N_0 - N_1.n_0\right) \\
\frac{dq}{dt} &= Sq\left(N_1 - N_2\right) - \omega(x).q + D.N_1
\end{aligned} \tag{l}
$$

where:

K= 5,4.10^{-13} $cm^3.s^{-1}$, is the resonante transfer rate between the vibrationally excited N_2 level and the upper laser level;

K_{13} = 85.y + 110.x+365.w s^{-1}, is the decaying rate from level 1 to 3;

K_2 = 1,4.10^5.(w'+0,46.x'+0,056.y') s^{-1}, is the decaying rate from level 2 to 3;

K_3 = 410^3.y + 40.x + 200.w s^{-1}, is the decaying rate from level 3 to the CO_2 molecule ground state;

$\alpha = n_e.\delta_1$, is the pumping rate for the CO_2 molecule;

$\beta = n_e.\delta_2$, is the pumping rate for the N_2 molecule;

n_e is the electron population (considered time independent in this work);

q is the photon population;

p = 10 torr, is the total gas pressure pressure;

w = 0,1p ; x = 0,1p ; y = 0,8p onde w, x and y are the partial pressure of CO_2, N_2, and He in room temperature;

$\sigma = 10^{-19}$ cm^2, is the stimulated emission cross section;

D = 10^{-10} s^{-1}, is the spontaneous emission rate;

E_m = 2 ev, is the average electgron energy in the discharge;

δ_1 = 6.10^{-9} $cm^3.s^{-1}$, is the effective upper laser excitation rate per unit of electron population;

δ_2 = 2.10^{-8} $cm^3.s^{-1}$, is the effective N_2 molecule excitation rate per unit of electron population;

l = 3,2 m, is the gain region length;

L = 5 m, is the resonator length;

S = $\frac{c.l.\sigma}{L}$ $cm^3.s^{-1}$, is the stimulated emission rate;

$\omega(x) = \frac{-c.\ln\left[R_2.R(x)\right]}{2.L}$ s^{-1}, is the resonator decayaing rate (inverse of the resonator lifetime);

R_1 = 0,5.R(x) is the modulated coupling mirror reflectivity;

R_2 = 1 is the total reflector reflectivity.

The formulas and parameters above were taken from Ref. [3].

The mirror misalignment was simulated by considering an angle dependent reflectivity in the coupling mirror. This dependence was calculated by doing the convolution between two circles with radius equal to the resonator optics; the first circle stands for the steady total reflector and the second circle represents the projection of the spinning coupling mirror over the first mirror.

The equations above are solved by using the 4th order Runge–Kutta method, implemented in the Mathcad versão 2001 software.

Preliminary results

Fig.2 shows a typical result from the modeling, considering a commercial CW CO_2 laser of 200 W, with 3,2 m long active medium, 5 m long resonator and a switching time of 60 µs. This model will be used to analyse experimental results that will be obtained with these characteristics.

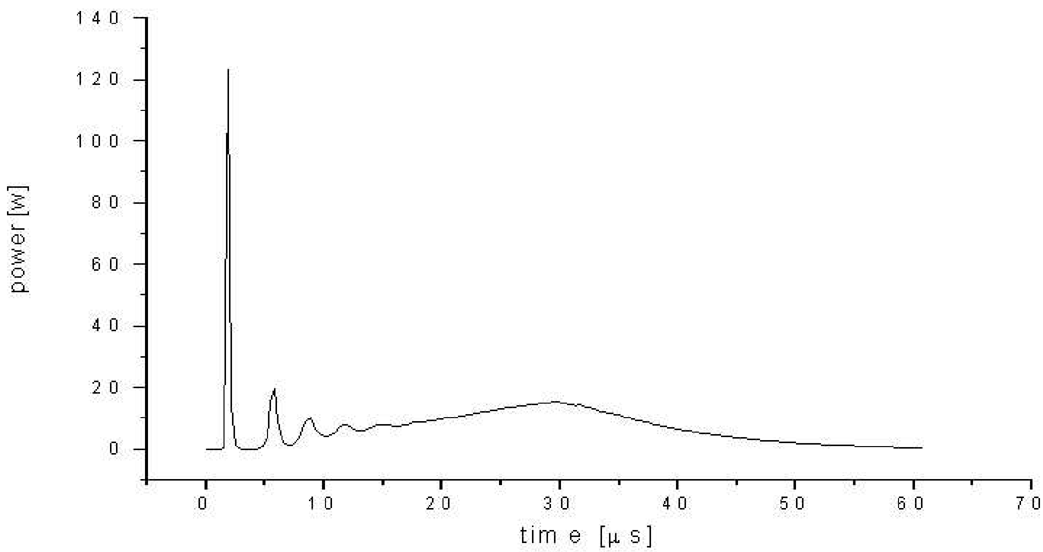

Figure 2 – Simulation of a CW CO_2 laser of 200 W, with 3,2 m long active medium, 5 m long resonator and a switching time of 60 µs.

Acknowledgements

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