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# Mathematical modelling of gain-switched RF-excited $CO_2$ waveguide laser*

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The detailed mathematical models for the evolution of light pulses in RF-excited $CO_2$ waveguide lasers are derived. Explicit expressions for the pulse characteristics in RF-excited $CO_2$ waveguide lasers are obtained. The effects of losses and unsaturated gain on output power are calculated.

**Keywords:** mathematical modelling, gain-switched, RF excited, $CO_2$ waveguide lasers
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## 1. Introduction

Due to their interesting physical and chemical parameters, $CO_2$ lasers have become widely utilized in scientific and industrial applications. However, many of the processes for determining the dynamic transitions between vibrational energy levels of molecules of the gas mixture $CO_2$–$N_2$–He are still not fully understood.[1,2] For instance, there are many factors that may cause a decrease in the output power, such as nonsystematical electrical discharge and dissociation of $CO_2$ to CO molecules.[3] The degree of dissociation could reach 80%–90% according to experimental data, particularly in sealed systems.[4] Letalick *et al* made a theoretical analysis for the kinetic processes of a Q-switched $CO_2$ laser.[5] They considered mainly the processes of rotational relaxation but neglected some processes such as dissociation of $CO_2$, electron collision excitation and energy-transfer of some vibrational levels.[6]

In addition to the dissociation phenomena, many reactions in the gas mixture could produce different molecular gases such as $NO_2$, $O_2$, $N_2O$, NO, $CO_2^+$, $CO_2^-$, ..., etc.

In previous studies of the output power $CO_2$ lasers, there are several models describing the dynamic emission of $CO_2$ laser: i.e. four-, five- and six-temperature models.[7−9] The purpose of the present work is to develop new analytic models for the laser output including a time-dependent pump rate and spontaneous relaxation.

These solutions are reduced to the simplest possible mathematical forms and then applied to specific laser systems.

## 2. Theoretical analysis

There are various ways to approach the problem of light propagation in $CO_2$ laser systems, and the details depend on the type of approximations that can be made. In the majority of practical applications the coherence time is short compared with any other time of interest and the behaviour is governed by familiar rate equations.[10] Thus the coupled pair of rate equations governing the frequency-dependent population densities of the upper and lower laser states in a medium with inhomogeneous broadening is[11]

$$\begin{aligned}&\frac{\partial n_2(y,z,t)}{\partial t}\\&=s_2(y,z,t)\\&\quad-n_2(y,z,t)\left(A_2+\frac{2B_0}{\pi\Delta\upsilon_{\rm h}}\int_{-\infty}^{\infty}\frac{I(y_l,z,t)}{1+(y-y_l)^2}{\rm d}y_l\right)\\&\quad+n_1(y,z,t)\frac{2B_0}{\pi\Delta\upsilon_{\rm h}}\int_{-\infty}^{\infty}\frac{I(y_l,z,t)}{1+(y-y_l)^2}{\rm d}y_l,\qquad(1)\end{aligned}$$

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