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Modeling passively Q-switched solid state lasers with multimode

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ABSTRACT

Q-switching is considered as a favorable technology to generate short duration and high peak power pulses, which is widely used in industry. We derive a new model to simulate passively Q-switched solid state lasers in a three-dimensional (3D) space. In our model, several Gaussian modes are considered. Compared with single-mode models, 3D multimode models are much more capable of reflecting laser behaviors. In our modeling, the single-mode system is extended to a multimode system, which calculates photon numbers for different modes separately. In order to realize the numerical simulation of our multimode model, we apply a finite volume discretization respectively to the gain medium and saturable absorber, then the discretized multimode passively Q-switched laser system is obtained. The numerical results and applications of our model are shown at the end of the paper. The modeling and simulation of passively Q-switched solid state lasers can help to optimize laser designs.

1. Introduction

To generate short duration and high peak power pulses, Q-switching is an effective technology. Several methods have been developed to achieve this technology, which are generally classified into two groups: active and passive Q-switching.

In the cavity of a passively Q-switched laser, there is a gain medium and a saturable absorber (See Fig. 1). The gain medium is pumped while the absorber prevents the feedback of the generated photons into the gain medium, then a relatively large gain medium population inversion comes into being. When the absorber becomes saturable, the energy stored in the gain medium is released in the form of a high energy pulse. A series of Q-switched pulses are generated as this process repeats (See Fig. 2) [1,2].

Passively Q-switched laser has attracted a great deal of attention [3–8]. However, most existing work focus on single-mode models, which are inadequate for describing lasers in reality.

The objective of this paper is to model the passively Q-switched laser in a 3D space with several Gaussian modes. 3D multimode models are much more capable of reflecting laser behaviors than single-mode models. Compared with [3,4], this paper formulates the discretized multimode system in a much better way, adds applications of the model, supplies more numerical simulations and illustrative figures.

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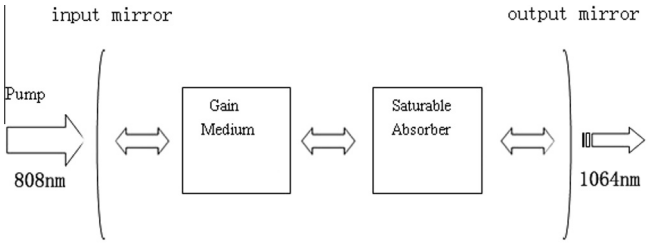

Fig. 1. An example of passively Q-switched laser. $Nd:YVO_4$ works as the gain medium and $Cr^{4+}:YAG$ works as the saturable absorber. The typical laser absorption wavelength of $Nd:YVO_4$ is 808 nm and emission wavelength is 1064 nm, which is highly absorbed by $Cr^{4+}:YAG$.

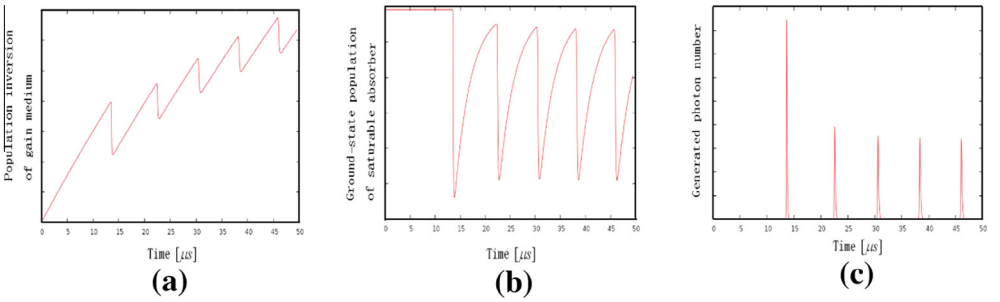

Fig. 2. Process of passive Q-switching. (a) Population inversion of the gain medium. (b) Ground-state population of the saturable absorber. (c) Q-switched pulses.

The rest of the paper is organized as follows: Firstly, we construct the passively Q-switched laser with only TEM_{00} mode. Secondly, the single-mode system is extended to a multimode system. Thirdly, by using a finite volume discretization, we deduce the discretized multimode system for numerical simulation. At the end of the paper, we present numerical results and applications of our model.

2. Model

In the modeling, we suppose that $\Omega = S_{2D} \times [0, L]$ is the 3D domain of a resonator (also called cavity) with length L (See Fig. 3); Ω_g is the 3D domain of the gain medium with length l_g; Ω_Q is the 3D domain of the saturable absorber with length l_Q.

Gaussian modes are solutions to the paraxial form of Helmholtz equation. Therefore paraxial ray approximation is the basis of Gaussian modes.

The physical assumptions of our model are:

- The gain medium is of four energy levels (See Fig. 4).
- The saturable absorber is of four energy levels. Both transitions of ions from level 1 to 3 and 2 to 4 cause absorption of photons generated by the gain medium (See Fig. 5).

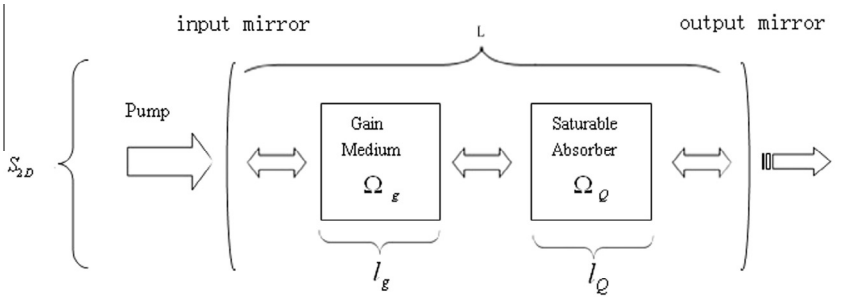

Fig. 3. Passively Q-switched laser resonator sketch.