Numerical modeling of short pulse generation by laser diode pumped solid-state *Q*-switched lasers using a traveling wave model

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1. Introduction

In order to theoretically describe generation dynamics of *Q*-switched lasers, different laser models have been developed [1-3]. Two approximate approaches are most often used: considering the laser as a lengthy system within the intensity traveling wave model (TWM) and the laser as a dimensionless system within the point laser model (PLM). Because of its simplicity, the PLM is the most popular till now. To validate PLM, the technique of averaging the TWM equation over the resonator volume is often used (see [3,4] and references therein). It is obviously that for fiber lasers the TWM is more suited [2,5]. During recent years the TWM serves as a background for the generation dynamics studies of near and mid IR bulk lasers [3], thin disk lasers [6], etc. In this paper we applied this model for the numerical modeling of laser diode end-pumped solid-state neodymium minilasers.

2. Model

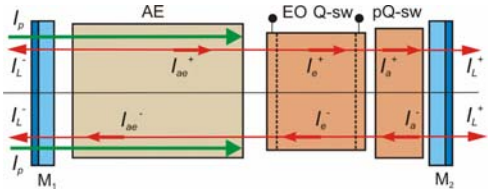


Fig. 1. The scheme of diode laser pumped (is the pump intensity) solid-state laser (*AE* is active element, $M_{1,2}$ are resonator mirrors) with combined active (EO *Q*-sw is electrooptical switch) and passive (p*Q*-sw is Cr:YAG saturable absorber) *Q*-switching.

The optical scheme of doubly actively and passively *Q*-switched laser is presented in Fig. 1. Modeling of the evolution of the optical field normalized intensities in the laser elements is based on the nondimensional transport equations

$$\hat{L}_i^{\pm}\bar{I}_i^{\pm} = F_i^{\pm}(z,t)\,,\quad \hat{L}_i^{\pm} = \frac{1}{\bar{v}_i^{\pm}}\frac{\partial}{\partial \bar{t}} \pm \frac{\partial}{\partial \bar{z}}$$

in positive (+) and negative (-) propagation directions, $\bar{v}_i^{\pm}$ are group velocities, $F_i^{\pm}(z,t)$ are known functions, depending on variables through the corresponding intensities, population densities, etc. For an AE this function has a form

$$F_{ae}^{\pm} = (\bar{\sigma}_{em}^{\pm}\bar{N}_3 - \bar{\sigma}_a^{\pm}\bar{N}_2)\bar{I}_{ae}^{\pm} - \bar{\alpha}_{ae}^{\pm}\bar{I}_{ae}^{\pm} + \bar{\varepsilon}^{\pm}\frac{\bar{N}_3}{\bar{\tau}_{32}}$$

The rate equations for population densities have a form

$$\frac{\partial \bar{N}_3(\bar{z},\bar{t})}{\partial \bar{t}} = \bar{W}_p(z,t)\bar{\sigma}_{14}(\bar{N}_1(z,t) - \bar{N}_4(z,t)) - \bar{\beta}_\lambda \sum_{\pm} \bar{I}^{\pm}(\bar{\sigma}_{em}^{\pm}\bar{N}_3 - \bar{\sigma}_a^{\pm}\bar{N}_2) - \frac{\bar{N}_3}{\bar{\tau}_{32}},$$

$$\frac{\partial \bar{N}_2(\bar{z},\bar{t})}{\partial \bar{t}} = \frac{\bar{N}_3}{\bar{\tau}_{32}} + \bar{\beta}_\lambda \sum_{\pm} \bar{I}^{\pm}(\bar{\sigma}_{em}^{\pm}\bar{N}_3 - \bar{\sigma}_a^{\pm}\bar{N}_2) - \frac{\bar{N}_2}{\bar{\tau}_{21}}$$

The set of equations for saturable absorber has the form $\hat{L}_a^{\pm}\bar{I}_a^{\pm} = F_a^{\pm}(z,t)$

$$F_a^{\pm} = -(\bar{I}_a^{+} + \bar{I}_a^{-})\left[\bar{\sigma}_g \sum_j f_j(\theta)\bar{N}_{a1}^{(j)} + \bar{\sigma}_e \sum_j f_j(\theta)\bar{N}_{a2}^{(j)}\right] - \bar{\alpha}_a\bar{I}_a^{\pm},$$

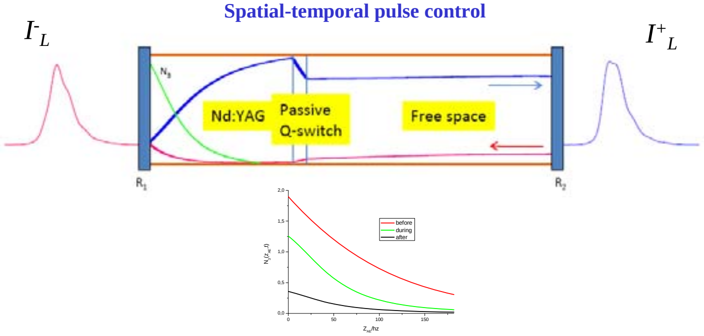
$$\frac{\partial \bar{N}_{a1}^{(j)}}{\partial \bar{t}} = -\beta\bar{\beta}_\lambda\bar{\sigma}_g(\bar{I}_a^{+} + \bar{I}_a^{-})f_j(\theta)\bar{N}_{a1}^{(j)} + \frac{\bar{N}_{a1}^{(j)}}{\bar{\tau}_{a21}}$$

$$f_j(\theta) = (\hat{\mathbf{j}}\hat{\mathbf{e}})^2$$

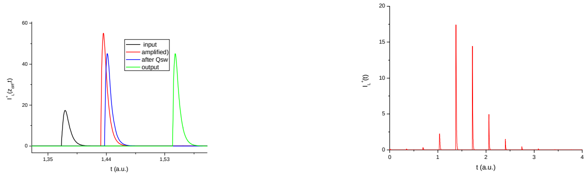
3. Results of numerical modeling

The full system of equations with corresponding initial and boundary conditions was numerically solved using algorithm developed in [5].

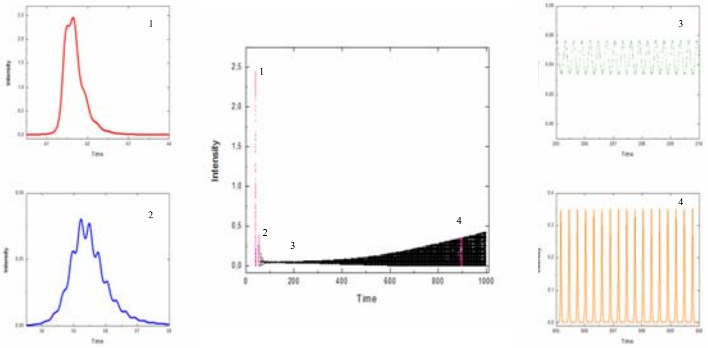
Spatial-temporal pulse control



Amplification of seed pulse



Different generation regimes at high pumping



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