Numerical model for investigation of dynamics of short-cavity two-color fiber laser for THz generation

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Abstract— Numerical model of two-color short-cavity fiber laser with nonlinear crystal inside the cavity for terahertz generation is proposed. THz field generation is due to down-frequency conversion. Proposed model is based on the transport-type equations, spatial discretization along the cavity axis, and calculation of temporal variations both electric field amplitude and active media inversion at these points.

Keywords— terahertz generation, difference frequency, fiber laser, numerical modeling, wave equation, nonlinear optics, optical fiber

I. INTRODUCTION

The most challenging part of THz technologies is the realization of efficient THz sources. CW THz sources that are compact and tunable throughout the frequency range from 100 GHz to 10 THz with tens of microwatt power levels still remain a technological challenge. A simple configuration of THz sources even is desired for easy maintenance of the devices. Moreover, the stability of THz radiation is a requirement for reliable measurements. For the purpose of realization such CW THz source the optical to THz converter seems a rather solid choice. Such converter can include two laser sources which emit wavelengths with frequency difference in the desired THz region. With consideration for desires of low cost and high effective THz source the main candidates in this case are compact two-color fiber lasers or diode lasers [1]. For example, two-color fiber laser with Nd3+- and Yb3+-doped gain mediums [2] can be utilized for obtaining difference frequency ~10 THz.

Here we propose a numerical model of two-color fiber laser with nonlinear frequency converter inside the resonator for the purpose of THz generation.

II. NUMERICAL MODEL

The equation system for pulse envelope is as follows:

\[
\begin{align*}
\frac{\partial F_s(z,t)}{\partial t} + \frac{\partial}{\partial z} \left[ -i \sigma \omega_0 F_s(z,t) F_s^*(z,t) \right] & = \frac{1}{2} \left( \frac{\partial^2}{\partial z^2} + \frac{i}{\lambda D} \frac{\partial}{\partial z} - \frac{\lambda D}{i} \frac{\partial^2}{\partial t^2} \right) \delta \left( \omega_s - \omega_0 \right) \left( F_s(z,t) F_s^*(z,t) \right) \quad (1a) \\
\frac{\partial B_s(z,t)}{\partial t} + \frac{\partial}{\partial z} \left[ i \sigma \omega_0 B_s(z,t) F_s^*(z,t) \right] & = \frac{1}{2} \left( \frac{\partial^2}{\partial z^2} + \frac{i}{\lambda D} \frac{\partial}{\partial z} - \frac{\lambda D}{i} \frac{\partial^2}{\partial t^2} \right) \delta \left( \omega_s - \omega_0 \right) \left( B_s(z,t) F_s^*(z,t) \right) \quad (1b) \\
F_s(z,t) & = X_s(z) F_s^*(z,t) F_s(z,t) \quad (1c) \\
B_s(z,t) & = X_s(z) B_s(z,t) B_s^*(z,t) \quad (1d)
\end{align*}
\]

The indexes \( s, l, r \) are referred to shorter wavelength, longer wavelength and difference frequency respectively. \( F, B \) — slowly varying amplitudes of forward and backward wave. \( \nu_0 \) - group velocity, \( l \) is the losses, \( \delta \), takes the value -1 for shorter wavelength and +1 for longer wavelength. \( \chi \) - nonlinear susceptibility which is nonzero only on a crystal length.

\[
\begin{align*}
\Delta \rho_s^{(1)} & = \rho_a^{(s)} - \rho_{bb}^{(s)} \quad (2a) \\
\Delta \rho_s^{(2-2)} & = \rho_a^{(2-2)} - \rho_{bb}^{(2-2)} \quad (2b)
\end{align*}
\]

Here \( \rho_a^{(s)}, \rho_{bb}^{(2-2)} \) are expansion elements of density matrix terms [3]:

\[
\rho_{a}^{(s)}(z,t) = \rho_{a}^{(s)}(t) + \rho_{a}^{(s)}(t) e^{2 \sigma c} + \rho_{a}^{(s)}(t) e^{-2 \sigma c}.
\]

The system is solved using Courant-Isaacson-Rees method. Using grid points along \( z \)-coordinate, we have initial value problem if we start with arbitrary smooth distribution of field along \( z \)-axis at \( t=0 \). In lasers we should expect that the final state does not depend strongly from initial conditions. The solution on the next time step is given by

\[
\begin{align*}
F_s(t + \Delta t) & = (1 - \sigma) F_s(t) + c \Delta z F_s(z,t) \quad (3a) \\
B_s(t + \Delta t) & = (1 - \sigma) B_s(t) + c \Delta z B_s(z,t) \quad (3b)
\end{align*}
\]

where \( \sigma = \nu_0 \Delta t / \lambda D \times 1 \).

Temporal dependence of terahertz radiation is represented in Fig. 1.

Fig.1(a,b) Terahertz radiation temporal dependence

REFERENCES

