Mechanism of Dispersive-Wave Soliton Interaction in Fiber Lasers

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On the basis of numerical simulation, we have found that long-distance soliton wings can be formed by dispersive waves which are emitted by solitons due to various lumped elements in passive mode-locked fiber lasers. We have analyzed peculiarities of the soliton interaction through such wings in lasers with lumped saturable absorbers. Different sets of bound steady states of a two-soliton molecule are demonstrated. Among them there are sets with and without an alternation of parity of neighboring quantum steady-states. It is shown that the investigated interaction can result in mechanisms of both attraction and repulsion of loosely bound solitons. The relation between the spectral sidebands and the dispersive-wave wings of a soliton is found.

The equation describing the evolution of a field in the fiber laser has the following form [1,2]:

$$\frac{\partial E}{\partial \zeta} = \left(D_r + iD_i\right)\frac{\partial^2 E}{\partial \tau^2} + \left(\frac{a}{1 + b\int I d\tau} + iq|E|^2 - \sigma_0 - \frac{(1-\eta)\sigma_{nl}}{1+pI}\right)E, \qquad (1)$$

where E, ζ, τ are the dimensionless field amplitude, coordinate, and time, respectively; D_r, D_i are the gain-loss and group velocity dispersions; a is the pump power, b is the gain saturation parameter, $I = |E|^2$; q is the Kerr nonlinearity. σ_0 is the linear losses, σ_{nl} is the total unsaturated nonlinear losses, p is its saturation parameter, $(1-\eta)$ is the fraction of the distributed nonlinear losses.

The evolution of a field in the lumped saturable absorber with the nonlinear losses is described by the equation [2]

$$\frac{\partial E}{\partial \zeta} = -\frac{\eta \sigma_{nl}}{1+pI}E, \qquad (2)$$

Varying the parameter η from 1 to 0 changes the fraction of the lumped nonlinear losses from 1 to 0, but the total nonlinear losses remain unchanged. It leads to drastically changes in soliton wings (see Fig. 1(a)). Numerical simulations have been performed for typical parameters of an Er-doped fiber laser with the anomalous dispersion of group velocity [3].

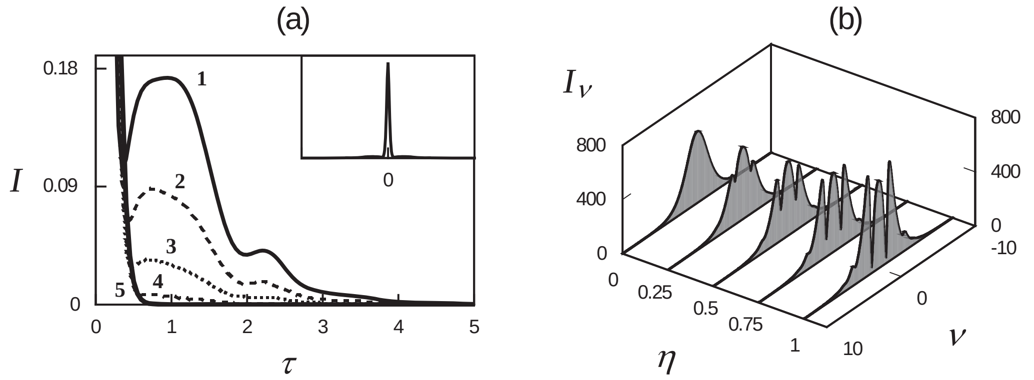

Fig. 1. (a) Soliton wing intensity I with varying lumped fractions of the saturable absorber: (1) $\eta = 1$, (2) $\eta = 0.75$, (3) $\eta = 0.5$, (4) $\eta = 0.25$, and (5) $\eta = 0$. (b) Soliton spectrum I_ν with varying lumped fractions of the saturable absorber.

We have found the main mechanism of formation of powerful long-distance soliton wings in a laser. These wings result in a strong interaction between solitons leading to formation of a soliton molecule with a large set of energy levels and stable steady states. The powerful soliton wings due to the dispersive waves result also in sidebands in the soliton spectrum (see Fig. 1(b)).

References

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