Nonlinear propagation of light in semiconductors in the presence of two-photon excitation of biexcitons

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The steady- and nonsteady-state passage of light through a ring resonator in the presence of two-photon excitation of biexcitons from the ground state of the crystal is studied. The values of the parameters for which complicated nonlinear temporal formations are possible in the system are found. The possibility of observing the predicted effects experimentally is discussed.
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In the last few years a great deal of attention has been devoted to cooperative processes in the excitonic region of the spectrum. In Refs. 1 and 2, a theory of optical bistability and dynamic chaos in the excitonic region of the spectrum is constructed in the ring-resonator geometry on the basis of the Keldysh equations. In Ref. 3 it is predicted that the observation and breakdown of dynamic optical chaos are possible in a system of coherent excitons and photons exposed to an external periodic force. Reference 4 is devoted to the study of steady- and nonsteady-state optical bistability (OB), multistability, optical switchings, and self-pulsations in a system of coherent excitons and biexcitons in semiconductors, taking account of the exciton-photon interaction and optical conversion of excitons into biexcitons. In Ref. 5 a theory of OB and autooscillations in condensed media with the participation of excitons and biexcitons is constructed. A CuCl crystal, for which convincing experimental proofs of the existence of a biexciton are available, is chosen as the model. It is shown that both regular and stochastic self-pulsations with formation of complicated limit cycles and strange attractors in phase space are possible depending on the parameters of the system.

Biexcitons, predicted by Moskalenko[6] and Lampert,[7] are widely used to interpret new absorption and luminescence bands in semiconductors. Biexcitonics has essentially become an independent field of condensed-state physics. The most convincing experimental proofs of the existence of biexcitons are based on observations of two-phonon excitation of biexcitons from the ground state of the crystal (CuCl, CuBr, and others).[8–11] Moreover, Hanamura[12] was the first to show that the process of two-photon excitation of biexcitons from the ground state of the crystal is characterized by a gigantic oscillator strength. As a result, the method of two-photon excitation of biexcitons is now widely used for the experimental investigation of biexciton states. Here the absorption band has a narrow δ-function-like shape. The direct creation of biexcitons on account of the giant two-photon absorption of light in CuCl crystal was first observed by Gale and Mysyrowicz.[13–15]

The present work is devoted to the study of the steady- and nonsteady-state passage of light through a ring resonator in the presence of two-photon excitation of biexcitons from the ground state of the crystal. The values found for the parameters for which complex nonlinear temporal formations are possible in the system are found. The possibility of observing the predicted effects experimentally is discussed.

Let us consider the phenomenon of optical self-organization in the simplest model of a ring resonator. The photons of the propagating pulse excite biexcitons from the ground state of the crystal as a result of the two-photon absorption process.

The Hamiltonian of the problem consists of a sum of Hamiltonians of free biexcitons and the field and the Hamiltonian describing the interaction of the field with a system of coherent biexcitons. In the model adopted the interaction Hamiltonian has the form

$$H_{\text{int}}=-\hbar\mu(E^{-}E^{-}b+b^{+}E^{+}E^{+}), \qquad (1)$$

where b^{+} is the biexciton creation operatore and μ is a constant characterizing two-photon excitation of biexcitons from the ground state of the crystal,[12] and $E^{+}(E^{-})$ are the positive (negative)-frequency component of the electric field of the electromagnetic wave.

The equation of motion for the amplitude of the biexciton wave b has the form

$$i\frac{\partial b}{\partial t}=\omega_{\text{biex}}b-i\gamma_{m}b-\mu E^{+}E^{+}, \qquad (2)$$

where $\hbar\omega_{\text{biex}}$ is the biexciton formation energy and γ_m is the biexciton decay constant, which determines the rate at which quasiparticles leave the coherent mode into incoherent modes and was introduced into the equation of motion phenomenologically.