Excitability of excitons and biexcitons in a ring cavity

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We discuss the excitable behavior of excitons and biexcitons in a nonlinear optical ring cavity. The nonlinearity is due to the process of the creation of biexcitons by photon-assisted conversion of excitons. In the bifurcation analysis a region where a saddle point is close to an equilibrium has been found. In this region the system shows excitability. It is shown that the mechanism of the excitable behavior of excitons and biexcitons in a ring cavity is different from that of two-level atoms in the same system. The possible applications of an excitable ring cavity are discussed.

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I. INTRODUCTION

Excitability is quite an old concept, which is particularly well known in biology [1–3] where it is used to explain a number of phenomena including neural communication by nerve cells via electrical signalling. A system is said to be excitable if a stimulus below some threshold value produces a negligible response while one above the threshold results in a substantial response which is essentially independent of the size of the stimulus. Excitability also occurs in chemistry [4], physics, and engineering [5–8]. Some general concepts of excitability in optics and associated models have been discussed in Ref. [9]. Excitability in optics is of great interest because of its prospects for applications in optoelectronics devices, primarily for optical switching, clock recovery, pulse reshaping, tuneable pulses, and for generating a coherent resonance output pulse in communication networks.

Reference [5] has proposed and discussed excitability in a ring cavity containing a homogeneously broadened two-level nonlinear medium. Excitability in this system occurs in the small parameter window close to a bistable operating region, and originates from the combined dynamical effects of nonlinear intracavity field saturation and temperature-dependent absorption in the medium on two different times scales. The origin of the excitability is similar to that in the FitzHugh-Nagumo model. More recently, excitability has been predicted in lasers with a saturable absorber [6], with delayed optical feedback [7] and with an integrated dispersive reflector [8]. In Ref. [6] it is shown that a laser with a saturable absorber displays excitability just below threshold. The analytical expression for the excitability threshold was obtained by considering the slow-fast nature of the system. Under the influence of optical noise the laser displays coherence resonance. Excitability in this system is due to an attractor close to a saddle point. This is the second type of mechanism leading to excitability that is found in literature.

In this paper, we have studied the excitability of excitons and biexcitons in a nonlinear optical ring cavity. The optical nonlinearity is considered to be due to the creation of biexcitons by the interaction of excitons and photons. The relaxation times of excitons and biexcitons are very short, being of the order of picoseconds, which means that mechanisms based on them are suitable for use in optoelectronic devices where ultrafast response is required. Biexcitons can be readily created in wide gap semiconductors such as CuCl, CuBr, and CdS where the electron-hole interaction is strong. But different mechanisms for their formation in bulk semiconductors have been proposed in the literature. The giant oscillator strength model which has been proposed by Hanamura, and Gogolin and Rashba [10,11] has been successfully applied to explain many biexciton-related optical processes in bulk semiconductors. More recently, Ivanov, Haug, and Keldysh have proposed a bipolariton model of biexcitons [12]. It has been shown [13–15] that both microscopic models can be used to form the basis of theoretical description of the phenomena of optical bistability, self pulsation, and chaos. Comparison with high-precision experiments supports the view [12,16] that the bipolariton model gives the better description of the microscopic processes, particularly in low-dimensional systems. Nevertheless, the giant oscillator model has had considerable success in bulk semiconductors and provides a basis for a model of excitability which is substantially more tractable than what is currently possible with the bipolariton theory.

The paper is structured as follow. In Sec. II we present the model equations for excitons, biexcitons, and photons in the ring cavity and the bifurcation analysis. Section III demonstrates excitable behavior in the system and the possible applications of excitability are discussed. The conclusions are given in Sec. IV.

II. DYNAMICS

A. Equations

For simplicity we use the three-level model which has been previously applied to a CuCl crystal, where there is convincing experimental evidence of the existence of biexcitons. In a CuCl crystal the biexciton bond energy is of the order of 40 meV and the exciton absorption band and the M band of biexciton recombination are well separated from each other. We study the simultaneous action of two independent optical pulses. The photons of the first pulse with energy $h\omega_1 = E_g - I_{ex}$ are in resonance with a transition in the exciton spectral range. The photons of the second pulse, which

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