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SEMICONDUCTORS AND DIELECTRICS

Dynamics of a Nonlinear Ring Cavity: Excitability and Coherent Resonance

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Abstract—The phenomena of excitability and coherent resonance in a nonlinear ring cavity in the presence of excitons and biexcitons are considered. A bifurcation analysis of the dynamics of the nonlinear ring cavity indicates that both self-pulsation and excitability can exist in the system. It is demonstrated that coherent resonance can be observed in an excitable exciton–biexciton system in the ring cavity. The optimum conditions for the manifestation of these phenomena are investigated, and their possible applications are discussed.

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1. INTRODUCTION

The phenomena of excitability and coherent resonance are associated with new, rapidly developing trends in optics. Originally, these phenomena received much attention in biology [1–3] and chemistry [4]. In terms of biology, the phenomenon of excitability can be illustrated by neuron behavior: pulses with amplitudes below a threshold value excite local nonpropagating responses, whereas pulses with amplitudes above a threshold value give rise to an intense response of the system. Recently, it was predicted that excitability can occur in optical systems. Under specific conditions, the phenomenon of excitability can manifest itself in a nonlinear ring cavity [5, 6], lasers with a saturable absorber [7], and semiconductor lasers with a delayed optical feedback [8]. In the case of lasers with dispersive reflectors, this phenomenon has been investigated theoretically and experimentally [9, 10].

The phenomenon of excitability exhibited by optical systems based on semiconductors has attracted particular research attention, because it holds considerable promise for practical applications in optoelectronic devices. Investigation of this phenomenon is based on the analysis of two possible mechanisms [11]. The so-called first-order excitability occurs when a singularity of the saddle type in the corresponding phase space is located in the vicinity of the stable point, whereas the second-order excitability arises from the stability loss associated with the Andronov–Hopf bifurcations.

The inclusion of noise effects in the analysis of nonlinear systems is of special interest. The influence of noise on oscillatory, excitable, and bistable systems can bring about various effects [12]. However, in this paper, we will restrict our consideration to the specific case of coherent resonance in an excitable ring cavity. Coherent resonance arises when there exists a nearly periodic response of the system to noise and this response can be associated with a nearly periodic trajectory in the phase space of the perturbed system. This behavior can be explained in terms of the different time dependences of the activation and return times (the activation time is the time it takes for the given system to be excited from the state corresponding to the stable point, and the return time is the time it takes for the given system to return from the excited state to the stable state). The FitzHugh–Nagumo model [3] is a simplified version of the Hodgkin–Huxley model, which, however, makes it possible to perform analytical treatment. In the framework of the FitzHugh–Nagumo model, it has been demonstrated that coherent oscillations are strongly enhanced at specific amplitudes of external noise. Dubbeldam et al. [7] theoretically demonstrated that coherent resonance can occur in lasers with saturable absorbers. Buldú et al. [13] carried out a theoretical investigation of this phenomenon within the Lang–Kobayashi model for lasers with an optical feedback. Recently, Marino et al. [14] experimentally observed coherent resonance in a diode feedback laser and showed that the noise affects the laser intensity.

The possibility of observing the excitability phenomenon in a system of excitons and biexcitons in a nonlinear ring cavity was predicted in our previous study [6]. In the present paper, we generalize the results obtained in [6] and, for the first time, demonstrate theoretically that coherent resonance can be observed in this system. We derive the equations describing the model system and discuss possible bifurcations in the dynamic behavior of the system. It is shown that coher-