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All optical AND and OR gate with excitable cavity soliton

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Cavity solitons (CSs) have an important role as information bits in all optical information processing. In this paper, we switched on a new type of CS as excitable cavity soliton in the cavity soliton laser (CSL). Also, we compared the behavior of excitable CS with self-pulsing and stable CSs by using of suitable values for system parameters and then we designed logical gates (AND, OR) with excitable CSs in the CSL. The capabilities of excitable CSs has been studied to improve possibilities for designing of all optical gates.

1. Introduction

Cavity solitons (CSs) are localized light peaks on a low-intensity, homogeneous background that can be controlled and produced with specified intensity and location in the transverse plane of cavity, orthogonal to the propagation direction of the beam [1]. Using CSs for information storage produce more compact optical schemes and each bit of information is represented by a CS [2].This is especially attractive in nonlinear photonics after CSs have been observed in semiconductor lasers [3]. The presence of a CS is considered as a bit ‘1’ and the absence of it’s as a bit ‘0’. Moreover computing by CSs is a way of achieving ultra-fast performance because photons travel faster than electrons and do not radiate energy, even at fast frequencies.

Several researchers switched on CSs in the vertical cavity surface emitting semiconductor laser with holding beam [4–7]. In this system, semiconductor laser only acts as an amplifier and spatial modulator for the holding beam that injected from out and perpendicular to the cavity. Recently, switching on the CS in the vertical cavity surface emitting laser (VCSEL) without holding beam and with saturable absorber has been demonstrated experimentally and theoretically [8–10]. This system is known as a cavity soliton laser (CSL) [11]. The control and application of CSs studied at the CSL for optical computing [12–14]. When we remove the holding beam, it reduces spatial volume of system and increase flexibility of system. .In CSL, CSs are in darker background of the before state that is corresponding to spontaneous emission. In this case, difference of intensity between peak of CS and background will be optimized. Nowadays, three type of laser have been experimentally and theoretically realized that are included CSL with frequency selective feedback [15], CSL in face to face configuration [10] and monolithic CSL with saturable absorber [16]. The CSL with frequency selective feedback leads to first show of CSL in semiconductor system [15]. In 2008, P. Genevet et al. [10], are demonstrated experimentally realization of CSL by using of two mutually coupled micro resonators that one micro resonator is amplifier and other is saturable absorber.

In previous studies, logical gates were found in the cavity with holding beam [17–19]. In ref. [20], A. Jacobo et al. consider a Kerr cavity driven by a broad holding beam and show how to use excitable regimes mediated by localized structures to perform AND, OR and NOT logical operations. Here, we focus to the excitable CS in the cavity with saturable absorber without holding beam. We switch on excitable CS and then it is compared with stable and self-pulsing CSs. Finally, the logic gates (AND and OR) has been proposed by using of excitable CSs.

The CS behavior is dependent on “r” parameter that is ratio between the carrier lifetime in the active and passive medium [21]. By fixing all other parameters and different values of “r” parameter we can see different type of CSs in the forms of stable, self-pulsing and excitable CSs. Excitability is a concept arising originally from biology (e.g. in neuroscience), and found in a large variety of nonlinear system [22]. A system is said to be excitable if perturbation below a certain threshold decay exponentially while perturbations above induce a large response before going back to a resting state [20]. In this work, firstly we switch on excitable CS in the CSL. Then we compare the intensity evolution of stable, self-pulsing and excitable CSs. Finally, we propose to design an all optical gate based on the excitable CSs in the CSL .The paper is organized as follow. In Section 2 we introduce the model. In Section

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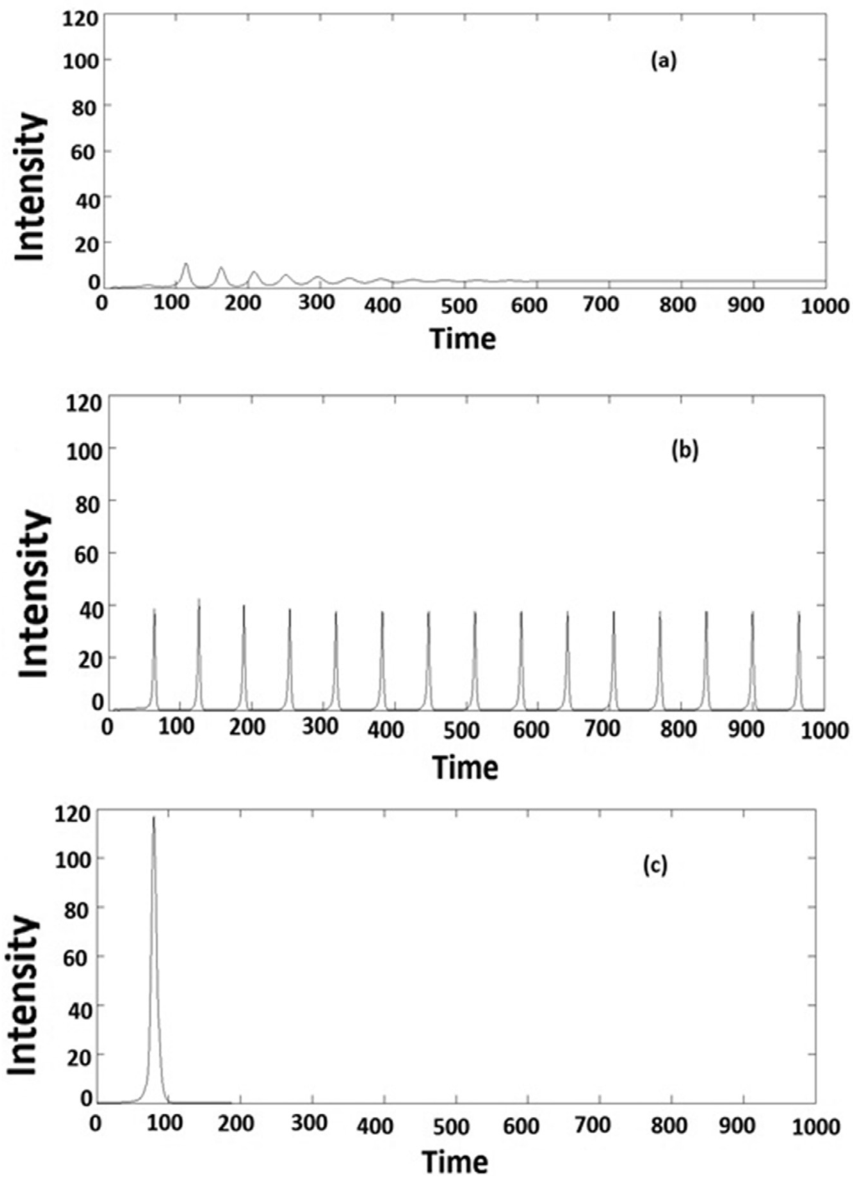

Fig. 1. Time evolution of the field intensity for three types of CSs. a) Stable CS r = 1.4, b) self-pulsing CS r = 1.7, c) excitable CS r = 2.

5 we switch on excitable CSs in the CSL and then we compare the intensity evolution of stable, self-pulsing and excitable CSs. In Section 4 we propose to design an optical logic gate based on excitable CSs in the CSL and find conditions for realization of it.

2. Dynamical equations of CSL

The dynamics of VCSEL with saturable absorber that work as a CSL are described by a set of equations [9]:

$$\dot{F} = \left[(1 - i\alpha)D + (1 - i\beta)d - 1 + i\nabla_\perp^2\right]F \tag{1-a}$$

$$\dot{D} = b_1\left[\mu - D\left(1 + |F|^2\right) - BD^2\right] \tag{1-b}$$

$$\dot{d} = b_2\left[-\gamma - d\left(1 + s|F|^2\right) - Bd^2\right] \tag{1-c}$$

F is the slowly varying amplitude of the electric field and D and d are population variables related to the carrier densities in the active and passive materials, respectively. The parameters α and b_1 (β and b_2) are the line width enhancement factor and the ratio of the photon lifetime to the carrier lifetime in the active (passive) material, μ is the pump parameter of the active material, γ measures absorption in the passive material and s is the saturation parameter. Time is scaled to the photon lifetime in empty cavity (~3 ps) and space to diffraction length (~5 µm). These three equations are dimensionless. For more details on the definition of the parameters and the variables see [8].

In this paper, we consider the set of parameters B = 0.1, $\beta = 1$, $\gamma = 2$and s = 1 [9]. To study dynamical behaviors of system, (1-a) to (1-c) are solved by use of split-step method with periodic boundary conditions in two-dimensional spatial network 128 × 128. In this method, we are separating the algebraic and Laplacian terms on the right-hand part of the equations. The algebraic term is integrated using a Runge–Kutta algorithm, while for the Laplacian operator a two-dimensional Fast Fourier transform is adopted. We select a time step 0.01 and a space step 0.25 to ensure stability of convergence of the algorithm ($\delta t^2 \le \delta s^2/4$). For simple presentation, we select the center of transverse plane as