EPJ Web of Conferences **161**, 03005 (2017)
PECS-2017
DOI: 10.1051/epjconf/201716103005

Multichannel all-optical switch based on a thin slab of resonant two-level emitters

Ramil Malikov[1,*], and *Victor* Malyshev[2]

[1]M. Akmullah State Pedagogical University of Bashkortostan, 450000 Ufa, Russia
[2]Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

Abstract. We discuss the possibility of using a thin layer of inhomogeneously broadened resonant emitters as a multichannel all-optical switch. Switching time from the lower stable branch of the system's bistable characteristics to the upper one and vice versa, which determines the speed of operation of a bistable device, is studied.

Bistability of an optical system is an extraordinary nonlinear effect, the essence of which is that the system has two stable states of transmission at the same value of the external field [1]. This phenomenon is of ongoing interest for optical technologies, in particular, for creation of fully optical switches, optical transistors, and optical memory.

In this work, we model the optical response of a thin resonant slab (TRS) of thickness L with inhomogeneously broadened two-level emitters of density N_0. As is well known, for such systems, the local field correction (LFC) to the field acting on an emitter is of importance [2,3]. The basis of our model consists of equations for the density matrix elements ρ_{ab} (a,b = 1,2) of a two-level emitter and the field E inside the slab, which in the rotating wave approximation reads [2,3]

$$\dot{R} = (i\Delta - \Gamma_2)R - \Omega Z\,, \tag{1}$$

$$\dot{Z} = \frac{1}{2}(\Omega^* R + \Omega R^*) - \Gamma_1(1+Z)\,, \tag{2}$$

$$\Omega = \Omega_0 + (i\Delta_L - \Gamma_R)\langle R\rangle, \tag{3}$$

$$\langle R\rangle = \int R(x,t,\Delta)G(\Delta)d\Delta\,. \tag{4}$$

Here, R is the amplitude of the off-diagonal density matrix element $\rho_{ab} = -(i/2)Re^{-i\omega t}$; $Z = \rho_{22} - \rho_{11}$; Γ_1 and Γ_2 are the relaxation constants of the population and coherence, respectively; $\Omega_0 = dE_0/\hbar$ and $\Omega = dE/\hbar$ are the external field E_0 and the field E inside the slab in frequency units; d is the transition dipole moment of the emitter; $\hbar$ is the reduced Plank constant; $\Delta = \omega - \omega_{21}$ is the detuning away from resonance of an isolated emitter, ω_{21}; $\Gamma = 2\pi d^2 N_0 kL/\hbar$ is the superradiant constant [2,3] and $\Delta_L = 4\pi d^2 N_0/(3\hbar)$ is the LFC [2,3]; $G(\Delta)$ is the inhomogeneous contour, in what follows, a Lorentzian of width Γ_2^*.

---

[*] Corresponding author: rfmalikov@mail.ru

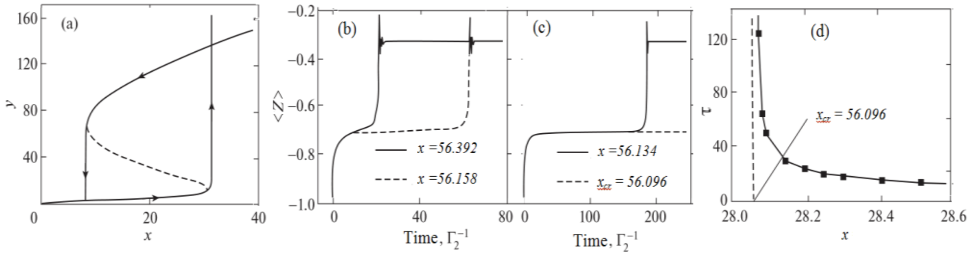

Fig. 1. (a) – Optical hysteresis of the field intensity $y =| \Omega|^2/(\Gamma_1\Gamma_2)$ inside the slab, obtained Under adiabatically sweeping the external field intensity $x = \Omega_0^2/(\Gamma_1\Gamma_2)$ up and down (shown by arrows). The parameters of calculations are : $\Delta_L = 20\Gamma_2$, $kL = 0.1$, $\Delta_0 = - 5\Gamma_2$, $\Gamma_1 = 2\Gamma_2$, $\Gamma_2^* = 0.5\Gamma_2$. (b) and (c) – Time evolution of the integrated population difference $\langle Z\rangle$ after an abrupt switching of the external field intensity x from zero to a value that exceeds the critical intensity $x_{cr} = (\Omega_0^{cr})^2/(\Gamma_1\Gamma_2) = 56.096$. The parameters of calculations are the same as in (a), except $\Gamma_2^* = 2\Gamma_2$. (d) – Intensity dependence of the switching time τ.

Examples of numerical calculations of the optical response of the TRS are presented in Fig. 1. Plot (a) shows the optical hysteresis of the system: a sudden switching from one stable state to the other one and back under the adiabatically sweeping the driving field Ω_0 up and down (shown by arrows), occurring at different magnitudes of Ω_0. So the system is bistable. Plots (b) and (c) display the dynamics of switching at the high-intensity switching point $x_{cr} = (\Omega_0^{cr})^2/(\Gamma_1\Gamma_2) = 56.096$ (for the parameters specified in the figure caption). Plot (d) shows the intensity dependence of the switching time τ. Conspicuous is the fact that the dynamics of switching reveals a critical slowing down around the high-intensity switching point x_{cr}. Switching down always occurs during a time interval on the order of Γ_1^{-1}.

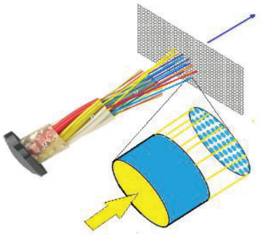

Fig. 2. Schematics of a multichannel all-optical switch (see details in the text).

Bistable properties of a thin resonant slab allow one to view this system as an all-optical switch. Apparently, different regions of the TRS are switched independently of each other. Then, this system may operate as a multichannel all-optical switch that is of importance from the viewpoint of optical information processing and optical computing. As an implementation of a device of such a type, an array of dielectric optical waveguides coupled with a TRS could be proposed, as illustrated in Fig. 2.

R. F. M. acknowledges the M. Akmullah State Pedagogical University of Bashkortostan for a support.

References

[1] S. L. McCall, Phys. Rev. A **9**, 1515 (1974)
[2] M.G. Benedict, A.I. Zaitsev, V.A. Malyshev et al., Opt. Spectrosc. **68**, 473 (1990)
[3] R.F. Malikov and V.A. Malyshev, Opt. Spectrosc. **122**, 955 (2017)