Design of all-optical switch using Kerr nonlinearities and dipole induced(DIT) transparency with 5-level nanocrystals

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Abstract

We propose a novel two state and all-optical controllable switch using DIT, Kerr effect and interaction between quantum dots (QD) with quantum electrodynamics cavity (CQED).

The two state and all-optical controllable switch is coupled to photonic waveguide from a rapid nonlinear environment (photonic crystal) and CQED. We consider the nanocrystal which are doped to crystal photonic cavity as a 5-level atomic system then design the proposed all-optical switch with quantumatic methods. We Wright Hamiltonian of the system and realize the dynamic equation then we show the optical switching operation by calculating the transition probability for two waveguides with simulations in MATLAB. Simulation results were different with 4-level nanocrystals.

In this paper by choosing the proper values for basic parameters an improved all-optical switch were obtained for example the switching speed is increased 7 times rather than previous designs with first control field, 75% with second control field and 60% with third control field for intended 5-level atomic system.

Key words: all-optical switch, EIT

1. Introduction:

The studies of the interactions between two distinct electromagnetic fields are fundamentally important. Especially, the strong interaction at the few-photon level is significant for quantum information processing [1]. Because of the weakness of optical nonlinearities in conventional media, it is difficult to achieve larger power that is required for optical switching and coupling. A promising avenue to approach this purpose is to enhance nonlinear coupling via electromagnetically induced transparency (EIT) in atomic medium [2, 3]. These studies have predicted the ability to achieve a nonlinear phase shift of weak optical fields [4] or a two-photon switch [5]. However, one of the main obstacles of such schemes is the mismatch between the group velocities of the fields, which limits their effective interaction length [6]. An effective way to overcome the above obstacle is using cavity-QED since the weakness of optical nonlinearities can be compensated by photon confinement in a cavity [7, 8].

Recently, using cavity-QED Waks and Vuckovic theoretically demonstrated dipole-induced transparency (DI T) in a photonic crystal cavity–waveguide system and showed that the path of an optical field propagating in a wave guide can be switched by the

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presence of a dipole emitter (quantum dot) [9] . In the present work, we extend the idea of DIT to an all-optical switching, i.e. the spatial mode of an optical field can be switched by the intensity of another optical field.
The strong coupling between the two distinct optical fields is achieved based on the DIT effect and an optical Stark shift. In the DIT, the transparency is caused by destructive interference of the two dressed states of a cavity [10]. I t is different from the EIT [11] in which the interference occurs between the two dressed states of an atomic lambda system [12]. Because of the effective coupling between the cavity and the dipole emitter, a strong coupling field [5,13] would be not necessary in the present all-optical switching and the scheme allows the dipole emitter is just three-level. Besides, the optical switching works in a low-Q cavity (total Q factor) where coupling strength between the dipole emitter and the cavity is smaller than the cavity decay rate and this condition allows more practical parameter range for solid-state materials.

2. Theory of operation

In this paper, we propose an all-optical controllable switch which is illustrated in fig.1.

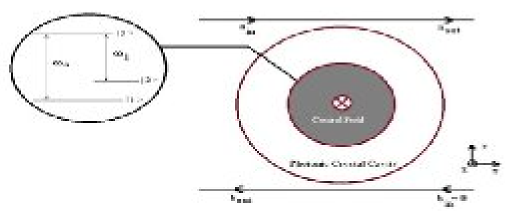

Fig. 1: Proposed PC cavity–waveguide switch system, including schematic of 3-level Λ ty**pe** nanocrystal doped in PC cavity.

Where, two waveguides a and b using a two dimensional photonic crystal cavity doped with 3 and 5-level nanocrystals (quantum dots) are coupled together. In this configuration input signal propagate in waveguide a, and the control field are applied in perpendicular direction to the PC cavity. In the absence of control field, waveguides are transparent and PC cavity is opaque, so the input signal field propagates in waveguide a. While in the presence of control field the cavity becomes transparent to the input signal field, that the input signal field is switched to the waveguide b via PC cavity. To illustrate this process, we consider 3-level atomic system that can be realized using suitable quantum dots structures. In absence of control field, the nanocrystal state can be described using levels $|1\rangle$, $|2\rangle$ and $|3\rangle$ bare states. After applying the control field, nanocrystal sate evolved to dressed state which can be explained using levels $|a^0\rangle$, $|a^+\rangle$ and $|a^-\rangle$. Dressed states are given by the following relations [15-20] in terms of bare states:

$$| a^0 >= \cos\theta\, | 1 > - \sin\theta\, | 2 > \tag{1}$$

$$| a^+ >= \sin\theta \sin\varphi\, | 1 > + \cos\varphi\, | 3 > + \cos\theta \sin\varphi\, | 2 > \tag{2}$$

$$| a^- >= \sin\theta \cos\varphi\, | 1 > - \sin\varphi\, | 3 > + \cos\theta \cos\varphi\, | 2 > \tag{3}$$

where $|a^0\rangle$ is dark state and two states $|a^+\rangle$ and $|a^-\rangle$ are up and down shifted of two upper states with energies $\hbar\omega^+$ and $\hbar\omega^-$, respectively which is given as [15-20]:

$$\hbar\omega^{\pm} = \frac{h}{2}\left(\Delta \pm \sqrt{\Delta^2 + \Omega_P^2 + \Omega_C^2}\right). \tag{4}$$

These states are corresponding excited dressed states. The θ and ϕ angles are defined by the following relations:

$$\tan\theta = \frac{\Omega_P}{\Omega_C} \tag{5}$$

$$\tan 2\varphi = \frac{\sqrt{\Omega_P^2 + \Omega_C^2}}{\Delta}. \tag{6}$$

The rabi oscillation frequencies of electron population, between two nanocrystal states, are introduced by the following relations.

Where Ω_P, Ω_C, d_{13}, d_{23} and Δ Rabi frequencies of the signal and control fields, dipole moment of transition $|1\rangle - |3\rangle$, dipole moment of transition $|2\rangle - |3\rangle$ detuning of signal frequency of the resonance, respectively.

Now, we can see that how the PC cavity changes from an opaque material to a transparent one, which is a result of changing the nanocrystal states by applying strong control field. Thereby after shifting the probe signal resonant with the energy between excited and ground atomic states. Then the input field transmits from original waveguide into another through the cavity, and the switching process is completed.

The Hamiltonian of the 3-level system, by using Rotating wave approximation, can be written as [21]:

$$\begin{aligned} H = \hbar[\ (\omega_{13} - i\frac{\Gamma}{2}|3\rangle\langle 3|) + (\hbar\omega_{12})|2\rangle\langle 2| + \hbar(\omega_0 - i\frac{\kappa}{2})\overset{+}{C}C + ig\hbar(\overset{+}{C}\sigma_-^{13} + C\sigma_+^{13}) + \\ \hbar\Omega_1(\sigma_+^{23}e^{-i\omega_1 t} + \sigma_-^{23}e^{-i\omega_1 t}) + \int_{-\omega_a}^{\omega_a} \hbar\omega\,\overset{+}{a}(\omega)\,a(\omega)\,d\omega + \int_{-\omega_b}^{\omega_b} \hbar\omega\,\overset{+}{b}(\omega)\,b(\omega)\,d\omega \\ i\hbar\sqrt{\frac{\gamma}{2\pi}}\int_{-\omega_a}^{\omega_a}(\overset{+}{a}(\omega)C + a(\omega)\overset{+}{C})\,d\omega + i\hbar\sqrt{\frac{\gamma}{2\pi}}\int_{-\omega_b}^{\omega_b}(\overset{+}{b}(\omega)C + b(\omega)\overset{+}{C})\,d\omega, \end{aligned} \tag{7}$$

where σ_-^{13}, σ_+^{13}, σ_-^{23} and σ_+^{23} are corresponding transition operators for the dipole emitter. C and C^+ are annihilation and creation operators for the cavity mode, ω_0 is the cavity frequency, $k = \omega_0 / Q$ is the intrinsic decay rate of the cavity (in the absence of coupling to the waveguides) and Q is the cavity quality factor. $\hat{a}(\omega)$ and $\hat{b}(\omega)$ denote the field operators for the modes of the two waveguides with a definite bandwidth, respectively which satisfy the following commutation relations:

$$\left[\hat{a}^+(\omega), \hat{a}(\omega')\right] = \delta(\omega - \omega'), \tag{8}$$

$$\left[\hat{b}^+(\omega), \hat{b}(\omega')\right] = \delta(\omega - \omega'). \tag{9}$$

In the Hamiltonian, the first term describes the energy of the excited state $|3\rangle$ of the dipole emitter with spontaneous decay rate Γ. The second term represents the energy of the long lived metastable state $|2\rangle$ and the energy of the ground state $|1\rangle$ is taken to be zero. The third term is cavity mode energy with intrinsic decay rate of j. In the fourth term, the transition between $|1\rangle$ and $|3\rangle$ of the dipole emitter is coupled resonantly to the cavity mode with a coupling rate g. In fifth term, the control field off-resonantly drives the transition between $|2\rangle$ and $|3\rangle$ of the dipole emitter through the cavity with frequency ω_1 and Rabi oscillation frequency Ω . Sixth and seventh terms represent the energy of the optical modes of the two wave-guides with the finite bandwidths $[\omega_\omega - \omega_a, \omega_\omega + \omega_a]$ and $[\omega_\omega - \omega_b, \omega_\omega + \omega_b]$ respectively. Within this bandwidth, in the eighth and ninth terms, the coupling strength between the cavity and each waveguide is regarded as a constant.

The radiation decay rate of the system, caused by the interaction of the system with external fields, is proportional to the coupling strength and the state density of external fields. So, the radiation decay rate from the cavity into each waveguides is assumed to be constant by γ. Two waveguides are identical, so we have taken ω_ω, as center frequency, for both of them. Based on the considered Hamiltonian, dynamics of the $\hat{C}$, σ_-^{13} and σ_-^{23} Operators using the Heisenberg equation are given as:

$$\frac{dC}{dt} = (i\ \omega_0 + \gamma + \frac{\kappa}{2})\ C - \sqrt{\gamma}\ \ (a_{in} + b_{in}) - ig\ \sigma_-^{13} \tag{10}$$

(11)

$$\frac{d\sigma_-^{13}}{dt} = -(i\ \omega_{13} + \frac{\Gamma}{2})\ \sigma_-^{13} - ig\ \sigma_z^{13} C - i\ \Omega\ \sigma_-^{23}\sigma_+^{13}\ e^{-i\omega_1 t}$$

$$\frac{d\sigma_-^{23}}{dt} = -(i\ \omega_{23} + \frac{\Gamma}{2})\ \sigma_-^{23} + ig\ \sigma_-^{23}\sigma_+^{13} C - i\ \Omega\ \sigma_z^{23}\ e^{-i\omega_1 t} \tag{12}$$

Where the input fields $\hat{a}_{in}$ and $\hat{b}_{in}$ are related to the output fields $\hat{a}_{out}$ and $\hat{b}_{out}$ by:

$$a_{out} - a_{in} = \sqrt{\gamma}C \tag{13}$$

$$b_{out} - b_{in} - \sqrt{\gamma}C \tag{14}$$

By using Fourier transformation with some approximations and mathematical manipulations, the following relations are given for output modes of the waveguides. Where, we have assumed that the optical signal is very weak to transit electrons from the bottom state to the upper state and the control field is sufficiently far from resonant, so population transition by control field is neglected too [14] .

$$a_{out} = \frac{-\gamma b_{in} + (i\delta_0 + \kappa/2 - \frac{g^2}{-i\delta_{13} + \Gamma/2 - S})a_{in}}{(-i\delta_0 + \gamma + \kappa/2 - \frac{g^2}{-i\delta_{13} + \Gamma/2 - S})} \tag{15}$$

$$b_{out}=\frac{-\gamma a_{in}+(i\delta_0+\kappa/2-\frac{g^2}{-i\delta_{13}+\Gamma/2-S})b_{in}}{(-i\delta_0+\gamma+\kappa/2-\frac{g^2}{-i\delta_{13}+\Gamma/2-S})} \tag{16}$$

where $S\left(\delta_{23},\Omega,\Gamma\right)$ with following equation is the only dependency of the output fields to the control field known as Stark shift.

$$S=\frac{\Omega^2}{-i\delta_{23}+\Gamma/2} \tag{17}$$

where detuning of the cavity mode, the probe and control field frequencies from the corresponding resonant frequencies are defined by:

$$\delta_0=\omega-\omega_0,\delta_{13}=\omega-\omega_{13},\delta_{23}=\omega-\omega_{23} \tag{18,19,20}$$

Now, we can calculate the transmission coefficients of the wave-guides by following equations:

$$T_a=\frac{\langle a^{\dagger}{}_{out}a_{out}\rangle}{\langle a^{\dagger}{}_{in}a_{in}\rangle},T_b=\frac{\langle b^{\dagger}{}_{out}b_{out}\rangle}{\langle a^{\dagger}{}_{in}a_{in}\rangle} \tag{21,22}$$

Similar to 3-level atomic system, transmission coefficients of the waveguides are given by Eqs. (19) and (20). Corresponding to the following equations, all of the process equations are same for the PC cavity doped by 5-level nanocrystals (see Fig. 2). Where the Hamiltonian of the system is given by:

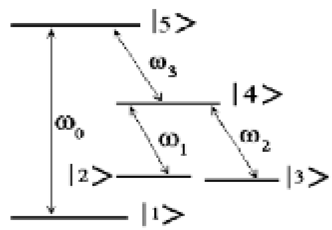

Fig. 2: Schematic of 5-level nanocrystal doped in PC cavity.

$$\begin{aligned}H=\hbar[\ &(\omega_{12}\left|2\right\rangle\left\langle 2\right|+\omega_{13}\left|3\right\rangle\left\langle 3\right|+\omega_{14}\left|4\right\rangle\left\langle 4\right|+\omega_{15}(\left|5\right\rangle\left\langle 5\right|-i\frac{\Gamma}{2})+(\ \omega_0-i\frac{\kappa}{2})\overset{+}{C}\,C+\\ &g\,(\overset{+}{C}\,\sigma_-^{15}+C\sigma_+^{15}\ )+\Omega_1\,(\sigma_+^{24}e^{-i\omega_1 t}+\sigma_-^{24}e^{i\omega_1 t})+\Omega_2\,(\sigma_+^{34}e^{-i\omega_2 t}+\sigma_-^{34}e^{i\omega_2 t})+\\ &\Omega_3\,(\sigma_+^{45}e^{-i\omega_3 t}+\sigma_-^{45}e^{i\omega_3 t})+\int_{-\omega_a}^{\omega_a}\omega\,\overset{+}{a}(\omega)\,a\,(\omega)\,d\omega\ +\int_{-\omega_b}^{\omega_b}\omega\,\overset{+}{b}(\omega)\,b\,(\omega)\,d\omega\\ &i\sqrt{\frac{\gamma}{2\pi}}\int_{-\omega_a}^{\omega_a}(\,\overset{+}{a}(\omega)\,C+a\,(\omega)\,\overset{+}{C}\,)\,d\omega+i\sqrt{\frac{\gamma}{2\pi}}\int_{-\omega_b}^{\omega_b}(\,\overset{+}{b}(\omega)\,C+b\,(\omega)\,\overset{+}{C}\,)\,d\omega].\end{aligned} \tag{23}$$

The Heisenberg equations are given by:

$$\frac{dC}{dt}=(i\ \omega_0+\gamma+\frac{\kappa}{2})\ C-\sqrt{\gamma}\ \ (a_{in}(t)+b_{in}\ (t))-ig\ \sigma_-^{15} \tag{24}$$

$$\frac{d\sigma_-^{15}}{dt}=-(i\ \omega_{15}+\frac{\Gamma}{2})\ \sigma_-^{15}+ig\ \sigma_z^{15}C-i\ \Omega_3\ \sigma_-^{15}\sigma_+^{45}\ e^{-i\omega_3 t} \tag{25}$$

$$\frac{d\sigma_-^{24}}{dt}=-(i\ \omega_{24}+\frac{\Gamma}{2})\ \sigma_-^{24}-i\Omega_1\ (\sigma_-^{24}\ \sigma_+^{24}e^{-i\omega_1 t}+\sigma_+^{24}\ \sigma_-^{24}e^{i\omega_1 t})-i\ \Omega_2\ \sigma_-^{24}\sigma_+^{34}\ e^{-i\omega_2 t} \tag{26}$$
$$-i\ \Omega_3\ \sigma_-^{24}\sigma_-^{45}\ e^{-i\omega_3 t}$$

$$\frac{d\sigma_-^{34}}{dt}=-(i\ \omega_{34}+\frac{\Gamma}{2})\ \sigma_-^{34}-i\Omega_1\ (\sigma_-^{34}\ \sigma_+^{24}e^{-i\omega_1 t})-i\ \Omega_2(\sigma_-^{34}\sigma_+^{34}+\sigma_+^{34}\ \sigma_-^{34})e^{-i\omega_2 t} \tag{27}$$
$$-i\ \Omega_3\ \sigma_-^{34}\sigma_-^{45}\ e^{i\omega_3 t} \tag{28}$$

$$\frac{d\sigma_-^{45}}{dt}=-(i\ \omega_{45}+\frac{\Gamma}{2})\ \sigma_-^{45}-igC(\sigma_-^{45}\ \sigma_+^{15})+i\Omega_1\ (\sigma_-^{24}\ \sigma_-^{45}e^{i\omega_1 t})+i\ \Omega_2(\sigma_-^{34}\sigma_-^{45})e^{i\omega_2 t}$$
$$-i\ \Omega_3(\sigma_-^{45}\sigma_+^{45}+\sigma_+^{45}\sigma_-^{45})\ e^{-i\omega_3 t}$$

Input and output waveguides are related to the cavity mode by Eqs. (13) and (14). So, if we start simplifying with inserting σ_-^{24} and σ_-^{14} after some mathematical manipulation, the outputs of waveguides are calculated as following equations:

$$a_{out}=\frac{-\gamma\quad b_{in}+(i\delta_0+\kappa/2+\dfrac{g^2}{-i\delta_{15}+\Gamma/2-\dfrac{\Omega_3^2}{i\delta_{45}+\Gamma/2-S_1+\dfrac{\Omega_2^2}{-i\delta_{34}+\Gamma/2-S_1}}})a_{in}}{(-i\delta_0+\gamma+\kappa/2+\dfrac{g^2}{-i\delta_{15}+\Gamma/2-\dfrac{\Omega_3^2}{i\delta_{45}+\Gamma/2-S_1+\dfrac{\Omega_2^2}{-i\delta_{34}+\Gamma/2-S_1}}})} \tag{29}$$

$$b_{out}=\frac{-\gamma\quad b_{in}+(i\delta_0+\kappa/2+\dfrac{g^2}{-i\delta_{15}+\Gamma/2-\dfrac{\Omega_3^2}{i\delta_{45}+\Gamma/2-S_1+\dfrac{\Omega_2^2}{-i\delta_{34}+\Gamma/2-S_1}}})a_{in}}{(-i\delta_0+\gamma+\kappa/2+\dfrac{g^2}{-i\delta_{15}+\Gamma/2-\dfrac{\Omega_3^2}{i\delta_{45}+\Gamma/2-S_1+\dfrac{\Omega_2^2}{-i\delta_{34}+\Gamma/2-S_1}}})} \tag{30}$$

(31)

$$S_1 = \frac{\Omega_1^2}{-i\delta_{24} + \Gamma/2}$$

Detuning of the cavity, mode, frequencies of the probe and control fields from the corresponding resonant frequencies are defined by:

$$\delta_0 = \omega_c - \omega_0 \quad (32)$$

$$\delta_{15} = \omega - \omega_{15} \quad (33)$$

$$\delta_{34} = \omega_2 - \omega_{34} \quad (34)$$

$$\delta_{24} = \omega_1 - \omega_{24} \quad (35)$$

$$\delta_{45} = \omega_3 - \omega_{45} \quad (36)$$

3. Simulation results

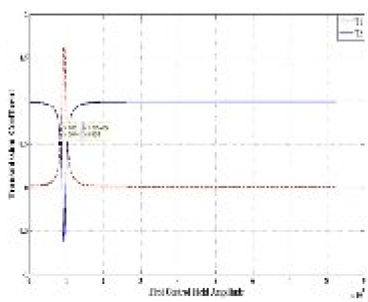

Fig. 3: Switch transmission coefficient in the presence of 5-level nanocrystals in PC cavity versus the first control field.

$$\delta_0 = 0, \delta_{15} = 0\ , \delta_{45} = 6GHz, \delta_{34} = 15GHz\ , \delta_{24} = 3\ GHz, k = 100\ GHz,$$
$$g = 100\ GHz, \gamma = 6\ THz, \Gamma = 1\ GHz\ , \Omega_3 = \Omega_2 = 40\ GHz$$

In Fig. 3 if $T_1 = T_a$ and $T_2 = T_b$, the transmission coefficient of the proposed switch is represented for 5-level nanocrystal doped PC cavity–waveguide system versus the first control field amplitude. We can see that for $\Omega_1 = 0\,GHz$ the input optical field transmits directly without coupling with the PC cavity, i.e. $T_2 \approx 1$. With increase of first control field amplitude , input optical field couples to the PC cavity and therefore T_2 decreases and T_1 increases continuously. When control field amplitude is tuned to the 8360, the input optical field transmits to both outputs equally, $T_1 = T_2 = 0.5$ and again When control field amplitude is tuned to the 10350 the input optical field transmits to both outputs equally $T_1 = T_2 = 0.5$. When the control field amplitude reaches to 15000, T_2 increases to 0.98 and T_1 decreases to 0.02, i.e. Switching occurs.

The speed of switching for considered 5-level atomic system with the first control field is increase about 7 times rather than other optical switches with same design parameters [22]. Also, the threshold of first control field amplitude is decrease about 23% for switching. It should be mentioned that the difference between two amplitudes of control field is decreased about 90% for change in switch state; i.e. the change in switch state is obtained by less change in Rabi frequency. For considered 5-level atomic system with first control field transmission coefficients begin from 1 and reaches to 1, where in previous designs transmission coefficients begin from 0.9 and reach to 0.7.

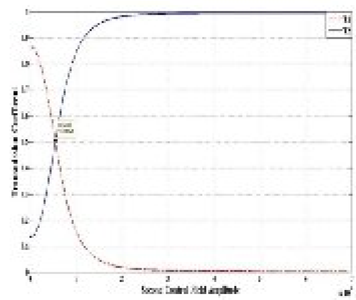

Fig. 4: Switch transmission coefficient in the presence of 5-level nanocrystals in PC cavity versus the second control field.

$$\delta_0 = 0, \delta_{15} = 0 \ , \delta_{45} = 6GHz, \delta_{34} = 15GHz \ , \delta_{24} = 3\ GHz, k = 100\ GHz,$$
$$g = 100\ GHz, \gamma = 6\ THz, \Gamma = 1\ GHz\ , \Omega_3 = \Omega_1 = 40\ GHz$$

In Fig. 4, the transmission coefficient of the proposed switch is represented for 5-level nanocrystal doped PC cavity–waveguide system versus the second control field amplitude. We can see that for $\Omega 2 = 0\,GHz$ the input optical field transmits directly without coupling with the PC cavity, i.e. $T_1 \approx 1$. With increase of second control field amplitude, input optical field couples to the PC cavity and therefore T_1 decreases and T_2 increases continuously. When control field amplitude is tuned to the 5530, the input optical field transmits to both outputs equally, $T_1 = T_2 = 0.5$. When the control field amplitude reaches to 20000, T_2 increases to 0.98 and T_1 decreases to 0.02, i.e. Switching occurs.
The speed of switching for considered 5-level atomic system with the second control field is increase about 75% rather than other optical switches with same design parameters [22]. Also, the threshold of second control field amplitude is decrease about 22% for switching.

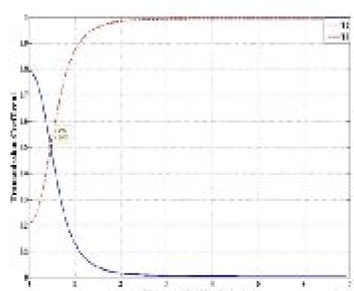

Fig. 5: Switch transmission coefficient in the presence of 5-level nanocrystals in PC cavity versus the third control field.

$$\delta_0 = 0, \delta_{15} = 0 \ , \delta_{45} = 6GHz, \delta_{34} = 15GHz \ , \delta_{24} = 3\ GHz, k = 100\ GHz,$$
$$g = 100\ GHz, \gamma = 6\ THz, \Gamma = 1\ GHz\ , \Omega 1 = \Omega 2 = 40\ GHz$$

In Fig. 5, the transmission coefficient of the proposed switch is represented for 5-level nanocrystal doped PC cavity–waveguide system versus the third control field amplitude. We can see that for $\Omega 3 = 0\,GHz$ the input optical field transmits directly without coupling with the PC cavity, i.e. $T_2 \approx 1$. With increase of third control field amplitude, input optical field couples to the PC cavity and therefore T_2 decreases and T_1 increases continuously. When control field amplitude is tuned to the 4759, the input optical field transmits to both outputs equally, $T_1 = T_2 = 0.5$. When the control field amplitude reaches to 20000, T_1 increases to 0.98 and T_2 decreases to 0.02, i.e. Switching occurs.

The speed of switching for considered 5-level atomic system with the second control field is increase about 60% rather than other optical switches with same design parameters [22]. Also, the threshold of third control field amplitude is decrease about 32% for switching.

4. Results

In this article, a Λ-type all-quantomatic optical switch, 3 and 5-level atomic systems are investigated. The proposed switch's transition coefficients are presented for 5-level nanocrystals doped in waveguide-PC cavity system versus first and second control fields. The result shows with choosing proper values for basic parameters an improved all-optical switch is obtained. Nevertheless, with less Rabi frequency and as a result less control field amplitude and less power use, the speed of switching by 5-level atomic system is increased about 7 times with first control field rather than other proposed switches.

References:

[1] Nielsen, M.A., Chuang, I.L., (2000), Quantum Computation and Quantum Information, Cambridge University Press, Cambridge, England.
[2] Harris, S.E., (1997), Phys. Today 50 (7) 36.
[3] Cerboneschi, E., Arimondo, E., (1996), Phys. Rev. A54, 5400.
[4] Schmidt, H., Imamoglu, A., (1996), Opt. Lett. 21, 1936.
[5] Harris, S.E., Yamamoto, Y., (1998), Phys. Rev. Lett. 81, 3611.
[6] Harris, S.E., Hau L.V., (1999), phys. Rev. Lett. 82, 4611.
[7] Kimble, H.J., (1998) , Phys. Scripta T 7 6, 127.
[8] Imamoglu, A., Schmidt, H., Woods, G., Deutsch, M., (1997), Phys. Rev. Lett. 79, 1467.
[9] Waks, E., Vuckovic, J., (2006), Phys. Rev. Lett. 96,153601.
[10] Waks, E., Vuckovic, J., quant-ph/0510228.
[11] Harris, S.E., Field, J.E., Imamoglu, A., (1990), Phys. Rev. Lett. 64, 1107.
[12] Fleischhauer, M., Imamoglu, A., Marangos, J.P., (2005), Rev. Mod. Phys. 77 633.
[13] Bermel, P., Rodriguez, A., Johnson, S.G., Joannopoulos, J.D., Soljacic, M., (2006), Phys. Rev. A 7 4, 043818.
[14] Wen-Xi Lai, Hong-Cai Li, Rong-Can Yang, (2008), Optics Communications 281, 4048.281 (2008) 3739.
[15] Rostami, A., Abbasian, K., (2007), All-optical filter design: electromagnetically induced transparency and ring resonator, in: Proceedings of the, IEEE International Conference on Telecommunications and Malaysia
[16] Yadipour, R., Abbasian, K., Rostami, A., KoozehKanani, Z.D., (2007), Progress in Electromagnetics Research, PIER 77, 149.
[17] Yune Hyoun Kim, Nam Su Kim, Youngjoo Chung, Un-Chul Paek, Won-Taek Han, (2004), Optics Express 12 (4), 652.
[18] Abbasian, K., Rostami, A., KoozehKanani, Z.D., (2008), Progress in Electromagnetics Research 5, 25.
[19] Habibiyan, H., Ghafoori-Fard, H., Abbasian, K., Rostami, A., Ultrasmall and tunable all-optical photonic crystal based demultiplexer for DWDM systems, Photonics and Nanostructures – Fundamentals and Applications, in press.
[20] Rostami, A., Abbasian, K., Khodashenas, P.S., Janabi-Sharifi, F., (2008), Proceedings of SPIE 7266, 726613.
[21] Scully, M.O., Zubairy, M.S., (1997), Quantum Optics, Cambridge University Press.
[22] K. Eftekhari, K. Abbasian and A. Rostami, "proposal for all-optical controllable switch using Dipole Induced Transparency (DIT)" optics communications, 283, 9, 2010.