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Some phenomena in susceptibility of atomic medium via the phases and direction of the Gaussian near-field

Somia Abd-El-Nabi

Department of Mathematics, Faculty of Science (Womens Section), Al-Azhar University, P.O.Box 11754, Nasr City, Cairo, Egypt

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ABSTRACT

We display the phenomena of dark state, vanishing absorption and dispersion as well as the up-conversion and large refractive index with low absorption in a Doppler broadened four-level N-type atomic system which interacts with three fields. We take three cases for the field which representing by the spontaneously generated coherence and Gaussian near-field. The effect of the relative phase of the fields and the Gaussian field parameter on the spectrum of the probe field in the three cases of the field are discussed. The direction and magnitude of the pump field have an important role when we discuss these phenomena. The chance of obtaining the large refractive index with low absorption is achieved at specific conditions. Then the interesting results can be observed on the spectrum of the probe field depending on kind of the field.

1. Introduction

The propagation of laser beams for a coherent beam through generating coherent atomic media have attracted increasing attention in many investigations in order to characterize the optical properties of materials such as nonlinear refraction, electromagnetically induced transparency and absorption coefficients [1–9], for example there are a technique for further reducing the line width in room-temperature vapor, namely, by the application of a longitudinal magnetic field, the presence of the magnetic field then Zeeman shifts the sublevels to create multiple three-level subsystems, which causes the EIT dip to split into narrower resonances symmetrically about the line center. Narrow EIT resonances are important for high-resolution spectroscopy and tight locking of lasers [10]. Many researches study the characteristics of the propagation of laser beams without look to the interaction between the laser beam and the matter or atomic system [11–20], when the propagation of the Airy-Gaussian beams are studied in a quadratic-index medium, and the refractive index distribution of the medium is quadratic-index which represents a periodic system, also the linear momentum, the beam width and the beam center are discussed [21]. A theory of coherence and particularly the coherent of dark state, vanishing absorption and dispersion phenomena has been discussed through an atomic medium. We have a large amount of works have been devoted to the investigation the dark state, vanishing absorption and the deep holes phenomena under various considerations [22–29]. The behavior of an atomic medium to switch between transparent and enhanced-absorption at multiple frequencies can be controlled. This process relies on the quantum interference between multiple dark states, which can be constructive or destructive at different frequencies and can be altered dramatically by changing the phase difference between the two circularly polarized components of a single coherent field (this is shown in [30]). The effects of the incoherent pumping on the Kerr nonlinearity in a four-level tripod-type atomic system are investigated, the results show that it can be get the symmetrical large self- and cross-Kerr nonlinearity with completely suppressed absorption at two different probe frequencies in certain parameters [31]. The spectral hole and side-hole burning have been observed, and have produced slow and fast light propagation in the system under different parameters, which demonstrated that the hole burning in the system is strongly affected by the Doppler broadened medium,

E-mail address: dr_somia_s@hotmail.com.

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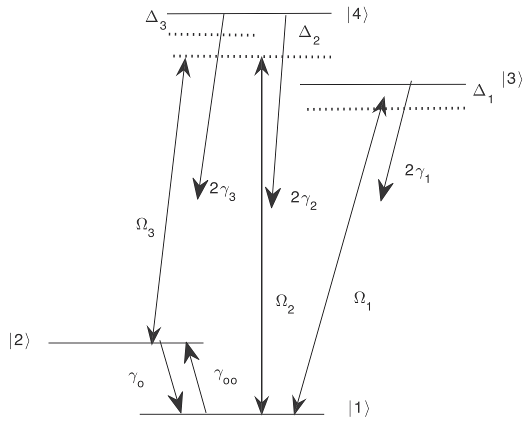

Fig. 1. The scheme of a four-level N-type atom interacting with three fields.

in the presence of SGC and fields transverse profile [32]. On the other hand, the relative phase of the electric field can be considered in many researches [33–40]. A scheme based on four-level EIT in which it can be switched the propagation of light from subluminal to superluminal by changing the phase of one of the driving fields are proposed in [41].The third-order susceptibility is investigated in a five-level atomic system in which the laser beams couple the ground state to a four-level closed-loop system. It is demonstrated that the third-order susceptibility is very sensitive to the relative phase of the applied fields. An analytical model is presented to elucidate such phase control of the Kerr nonlinearity [42]. In this paper, we investigate the probe susceptibility spectrum for a four-level *N*-type atomic system interacting with three fields and discuss the coherent of dark state, vanishing absorption and dispersion as well as the up-conversion and the large refractive index with low absorption phenomena by taking three cases for the field which representing by the spontaneously generated coherence and Gaussian near-field. The relative phase of the fields, with consideration the three cases for the field, play an important role when we discuss these phenomena. The motivation of this paper, we report theoretically that the coherent of dark state, vanishing absorption and dispersion, the large refractive index with low absorption and the up-conversion phenomena depend on the kind of the fields, the parameter of Gaussian beam, the relative phases, the direction, and Rabi frequency of the pump field under some hypotheses. The paper is organized as follows: In Section 2, Atomic model is obtained analytically. The discussion of the numerical results is given in Section 3. Finally, a conclusion is obtained in Section 4.

2. Atomic model description

Let us consider a four-level N-type atomic system which shown in Fig. 1. In this scheme the radiative decay rates from the excited state $|4\rangle$ to the states $|1\rangle$, $|2\rangle$ and $|3\rangle$ to $|1\rangle$ are $2\gamma_2$, $2\gamma_3$ and $2\gamma_1$ respectively. The nonradiative decay rates from the state $|1\rangle$ to the state $|2\rangle$ is γ_{00} and from the state $|2\rangle$ to the state $|1\rangle$ is γ_0. The levels $|1\rangle$, $|2\rangle$ and $|3\rangle$, $|4\rangle$ are closely lying near-degenerate, so the spontaneously generated coherence (SGC), due to the spontaneous emission, can be exist. The term $\gamma_{12} = p_1\sqrt{\gamma_1\gamma_2}$ represents the spontaneously generated coherence (SGC) resulting from the cross coupling between the transitions $|1\rangle \leftrightarrow |3\rangle$ and $|1\rangle \leftrightarrow |4\rangle$. The term $\gamma_{23} = p_2\sqrt{\gamma_2\gamma_3}$ represents the effect of SGC resulting from the cross coupling between the transitions $|1\rangle \leftrightarrow |4\rangle$ and $|2\rangle \leftrightarrow |4\rangle$. The parameters p_1 and p_2 are defined as: $p_1 = d_{13}.\ d_{14}/|\,d_{13}.\ d_{14}|$ and $p_2 = d_{14}.\ d_{24}/|\,d_{14}.\ d_{24}|$, where the parameter $p_1(p_2)$ denotes the alignment of the two dipole moments (d_{ij} are the dipolar moment of the transitions from $|i\rangle$ to $|j\rangle$). The existence of SGC depends on the nonorthogonality of the dipole moments d_{14} and d_{13}(d_{14} and d_{24}), since it becomes maxiumum when $p_1(p_2) = 1$ and disappear when $p_1(p_2) = 0$. We have three coherent fields (pump, probe, control) with the amplitudes E_i ($i = 1, 2, 3$) and frequencies ω_i interact with the transition labeled $|1\rangle \leftrightarrow |3\rangle$, $|1\rangle \leftrightarrow |4\rangle$ and $|2\rangle \leftrightarrow |4\rangle$ respectively. The probe field is taken with the transition $|1\rangle \leftrightarrow |4\rangle$. Under consideration that one field acting on only one transition. The Rabi frequency of the probe field is represented as a constant with: $\Omega_2 = (d_{14}E_2/\hbar)$. The coherent (pump, control) fields can be described with a Gaussian function: $\exp\left(-\frac{r^2}{w_i^2(z)}\right)$. Here, z is the coordinate along the propagation direction, r is the distance from the beam axis whose range of variation is $0 \le r \le r_0$. The spot size of the Gaussian beam (the Gaussian beam radius) varies along the propagation direction according to $w_i(z)$: $w_i^2(z) = w_{0i}^2\left(1 + \frac{z^2}{z_{0i}^2}\right)$ with the Rayleigh length: $z_{0i} = \frac{\pi w_{0i}^2}{\lambda_i}$, and w_{0i} is called the beam waist, ($i = 1, 2, 3$). The smallest value of the spot size $w_i(z)$ is at $z = 0$, where the spot size is equal to the beam waist parameter w_{0i}. We consider the Rabi frequencies of the pump and control fields are related with the spontaneously generated coherence (SGC). We suppose three cases for the coherent (pump, control) fields as follows:

(i) The first case, the pump field only is represented by the Gaussian function: $\exp\left(-\frac{r^2}{w_1^2(z)}\right)$ with Rabi frequency as:

$$\Omega_1(r, z, p_1) = \Omega_{01}\sqrt{1 - p_1^2}\,\exp\left(-\frac{r^2}{w_1^2(z)}\right) \tag{1}$$

where $\Omega_{01} = (d_{13}E_1/\hbar)$, the control field, in this case, is represented by: $\Omega_3 = \Omega_{03} = (d_{24}E_3/\hbar)$