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Influence of laser propagating direction on electromagnetic induced transparency

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ABSTRACT

The influence of laser propagating direction on electromagnetically induced transparency (EIT) in a ladder type three-level thermal atomic system is presented. It is found that when the coupling laser beam co-propagates with the probe one, the EIT window at probe resonant frequency will disappear due to Doppler effect. The broadened two peaks beside of the transparent window overlap together and form the maximum value at the resonant point. While as the two laser beams counter-propagate, the probe absorption presents an interesting property, especially when the two lasers are with the same wavelength, we can get a broadened Doppler absorptive profile and a narrowed EIT window. The width of the EIT window decreases with the increase of temperature. But if the wavelengths of the two lasers are different, the EIT window at resonant point will be instead by a broadened dip. This dip will disappear gradually with the increase of the wavelength difference. Thus at thermal environment, when we perform the investigation associated with EIT, we ought to not only let two laser beams counter-propagate, but also select an atomic system owns a cascade equal energy interval as far as possible.

1. Introduction

When a beam of coherent electromagnetic field acts on a pair of transition level of an atomic medium, the medium will has strong absorption to the incident electromagnetic field (called probe field) at the resonant frequency. The absorption curve presents maximum value at this point. But if take another strong coherent electromagnetic field (called coupling field) act on one transition level and the third one, the probe absorption at the resonant frequency will be weaken or even disappear when the coupling and the probe field satisfy double resonant condition. This phenomenon of original opaque medium becomes transparent by the action of electromagnetic field is called EIT. It originates from quantum interference induced by coherent electromagnetic field. Now it has become a research hotspot in the field of quantum optics and laser spectroscopy due to the potential usage in quantum information storage, quantum computing, high resolution laser spectroscopy and so on [1–6].

Up to now, many abnormal phenomena associate with EIT such as fast or slow light transmit, laser without inversion and optical soliton [7] have been discovered and was put into practical application further. However, due to the existence of Doppler effect, most of the investigations have been performed in the cold atomic system. Hau et al. reduced the speed of light to 17 m/s at a temperature of 2.5 K [8], and then Turukhin et al. reduced the speed of light to 45 m/s at an ambient

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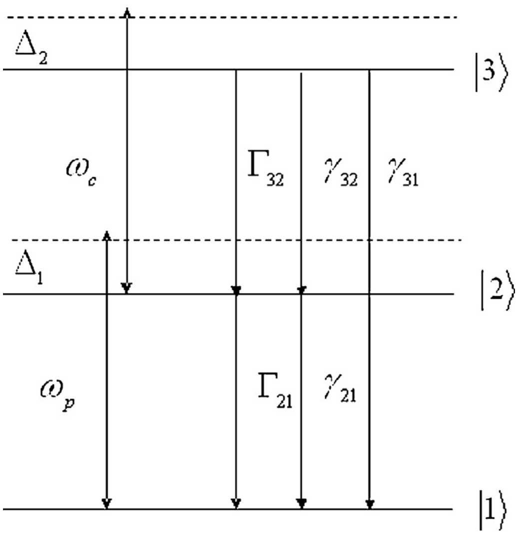

Fig. 1. Dynamic model of ladder-type three energy level.

temperature of 5 K [9]. With the development of research, more and more people have begun to investigate the EIT effect in thermal atoms [10–12]. Iftiquar et al. studied the probe absorption in Λ atomic system of Rb vapor. They found that for stationary atoms, the EIT dip for a resonant control laser is roughly one-half as wide as the control Rabi frequency. But in thermal vapor system, the width of final EIT dip is narrowed and remains sub-natural even the control Rabi frequency is far larger than the natural decay rate [13]. Ye et al. investigated the influence of Doppler broadening on the probe absorption of a Rb N-type four-level atomic systems [14,15] and found that a probe absorption curve with Doppler-free can be observed. Similarly, Bason et al. demonstrated that 100 KHz linewidth of EIT transparent windows can be observed at room temperature in N-type four-level systems [16]. Since the discovery about the influence of Doppler effect on EIT, investigations concerning the variation of EIT with temperature have been carried out theoretically and experimentally [17,18].

In this paper, based on the semi-classical description about the interaction between laser photon and atomic system, we present a theoretical study about the influence of the propagating direction of the coupling and the probe laser beams on EIT in a ladder-type three-level atomic system. It is found that only when the two lasers counter-propagate, we can get narrow EIT window.

2. Model of ladder-type three-level system and method

A closed ladder-type three-level system is shown in Fig. 1. The three levels are coupled by two laser fields. One is the strong coupling field and the other is a weak probe one. Their frequencies are ω_c andω_p, and drives the transition of $|2> \leftrightarrow |3>$ and $|1> \leftrightarrow |2>$ respectively. Γ_{32}andΓ_{21}represent the population decay rate from excited levels, $\gamma_{ij}(i > j)$ is the transverse relaxation rate which relates with the linewidth of spectral transition between two levels. Letting $\Omega_c$and$\Omega_p$denote Rabi frequency of the coupling and the probe fields. They are defined as $\Omega_c = \mu_{23}E_c/\hbar$ and $\Omega_p = \mu_{12}E_p/\hbar$. Here E_c and E_p are the amplitude of the corresponding field. μ_{12} and μ_{23} the dipole matrix element of $|1> \leftrightarrow |2>$ and $|2> \leftrightarrow |3>$ transition respectively. Under rotating-wave and slow varying amplitude approximation, the time evolvement of the density matrix elements about this system can be described by the following equations,

$$\frac{\partial\rho_{11}}{\partial t} = i\frac{\Omega_p}{2}(\rho_{21} - \rho_{12}) + \Gamma_{21}\rho_{22} \tag{1}$$

$$\frac{\partial\rho_{22}}{\partial t} = i\frac{\Omega_c}{2}(\rho_{32} - \rho_{23}) + i\frac{\Omega_p}{2}(\rho_{12} - \rho_{21}) + \Gamma_{32}\rho_{33} - \Gamma_{21}\rho_{22} \tag{2}$$

$$\frac{\partial\rho_{33}}{\partial t} = i\frac{\Omega_c}{2}(\rho_{23} - \rho_{32}) - \Gamma_{32}\rho_{33} \tag{3}$$

$$\frac{\partial\rho_{32}}{\partial t} = d_{32}\rho_{32} - i\frac{\Omega_c}{2}(\rho_{33} - \rho_{22}) - i\frac{\Omega_p}{2}\rho_{31} \tag{4}$$

$$\frac{\partial\rho_{31}}{\partial t} = d_{31}\rho_{31} + i\frac{\Omega_c}{2}\rho_{21} - i\frac{\Omega_p}{2}\rho_{32} \tag{5}$$

$$\frac{\partial\rho_{21}}{\partial t} = d_{21}\rho_{21} - i\frac{\Omega_p}{2}(\rho_{22} - \rho_{11}) + i\frac{\Omega_c}{2}\rho_{31}. \tag{6}$$