Physica E 81 (2016) 248–252

Contents lists available at ScienceDirect

Physica E

journal homepage: www.elsevier.com/locate/physe

Two-dimensional probe absorption in coupled quantum dots

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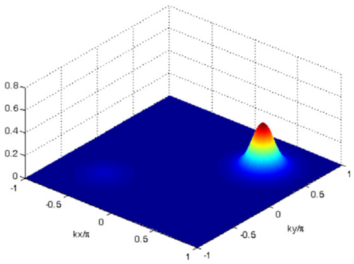
HIGHLIGHTS

- Two-dimensional probe absorption in coupled quantum dots is investigated.
- The 2D optical absorption can be easily controlled at a particular position.
- The scheme shows the underlying probability for the applications in solid-state optic communication.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 28 December 2015
Received in revised form
15 March 2016
Accepted 17 March 2016
Available online 19 March 2016

Keywords:
Quantum dots
Probe absorption
Standing wave

ABSTRACT

We investigate the two-dimensional (2D) probe absorption in coupled quantum dots. It is found that, due to the position-dependent quantum interference effect, the 2D optical absorption spectrum can be easily controlled via adjusting the system parameters. Thus, our scheme may provide some technological applications in solid-state quantum communication.

1. Introduction

In the past few decades, the precision position measurement of an atom has been the subject of many recent studies because of its potential applications in laser cooling and trapping of neutral atoms [1], atom nano-lithography [2] and quantum information science [3]. In some pioneering works, Thomas and colleagues have suggested and experimentally demonstrated subwavelength position localization of atoms using spatially varying energy shifts [4,5]. Walls and coworkers have discussed subwavelength atom localization using the measurement of the phase shift [6] after the passage of the atom through an off-resonant standing-wave field. In addition, two schemes for position measurement were performed, using absorption light masks [7,8], in which the precision of measurement achieved was nearly tens of nanometers.

On the other hand, it is well understood that atomic coherence can give rise to many interesting phenomena [9–12]. Based on atomic coherence, a variety of schemes for the precise localization of the atom in one-dimensional (1D) space have been proposed. For example, Paspalakis and Knight proposed a quantum-interference-induced sub-wavelength atomic localization of a three-level Λ-type atom, and they found that the atomic position with high precision can be achieved via the measurement of the upper-state population of the atom [13]. Zubairy and coworkers have discussed atom localization using resonance fluorescence and phase and amplitude control of the absorption spectrum [14–16], and Agarwal and Kapale presented a scheme [17] based on coherent population trapping. Also, 1D atom localization can be realized via dual measurement of the field and the atomic internal state [18], double-dark resonance effects [19], phase and amplitude control of the driving field [20,21], or coherent manipulation of the Raman gain process [22]. Recently, atom localization has been demonstrated in a proof-of-principle

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http://dx.doi.org/10.1016/j.physe.2016.03.030

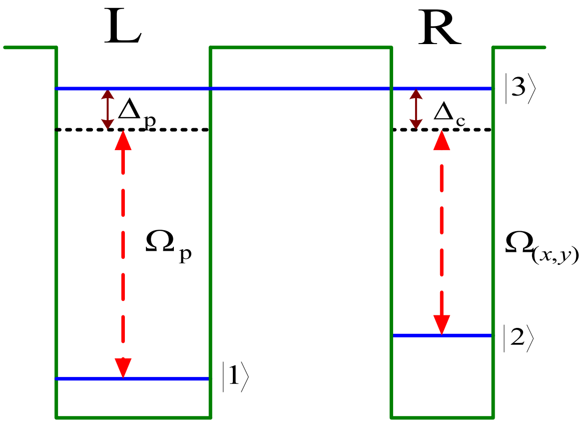

Fig. 1. Schematic diagram of the asymmetric coupled quantum dot structure.

experiment using the technique of electromagnetically induced transparency (EIT) [23]. Apart from the above-mentioned 1D atom localization, more recently, some schemes have been put forward for two-dimensional (2D) atom localization by applying two orthogonal standing-wave laser fields. For instance, a scheme for 2D atom localization was proposed by Ivanov and Rozhdestvensky using the measurement of the population in the upper state or in any ground state in a four-level tripod system [24]. Another related 2D localization schemes have been studied by Wan, Ding, Qamar and their coworkers [25–27].

It should be noted that similar quantum-interference-induced phenomena in many artificial nanostructures have also attracted great attention due to the potentially important applications in solid-state quantum information science. In fact, the analogies between coherent nonlinear phenomena in atomic systems and nanostructures have been successfully exploited over the past few years, various effects including gain without inversion [28,29], EIT [30], Kerr nonlinearity [31], optical soliton [32], and other novel phenomena [33–42] have been extensively investigated by many groups. In this paper for the first time, to our knowledge, we investigate the 2D probe absorption via two orthogonal standing-wave lasers in a coupled quantum dots. More recently, some schemes [43–47] have discussed the 2D probe absorption in different QWs, however, our scheme is different from those works. First, we are interested in showing the 2D optical absorption in coherently driven quantum dots. Second, due to the position-dependent quantum interference, the 2D optical absorption can be easily controlled at a particular position in one period of the standing-wave fields. Third, the ideas proposed in this paper are new, which may provide some applications in solid-state quantum information science.

2. The model and equations

We consider an asymmetric double QD where three-level Λ-type two nonidentical quantum dots structure consisting a wide well (WW) and narrow well (NW) as shown in Fig. 1. The lowest state $|1\rangle$ is coupled by a weak probe field with Rabi frequency Ω_p to excited level $|3\rangle$. We apply a coupling field with Rabi frequency $\Omega(x, y)$ to the transition $|3\rangle \leftrightarrow |2\rangle$. In the interaction picture and

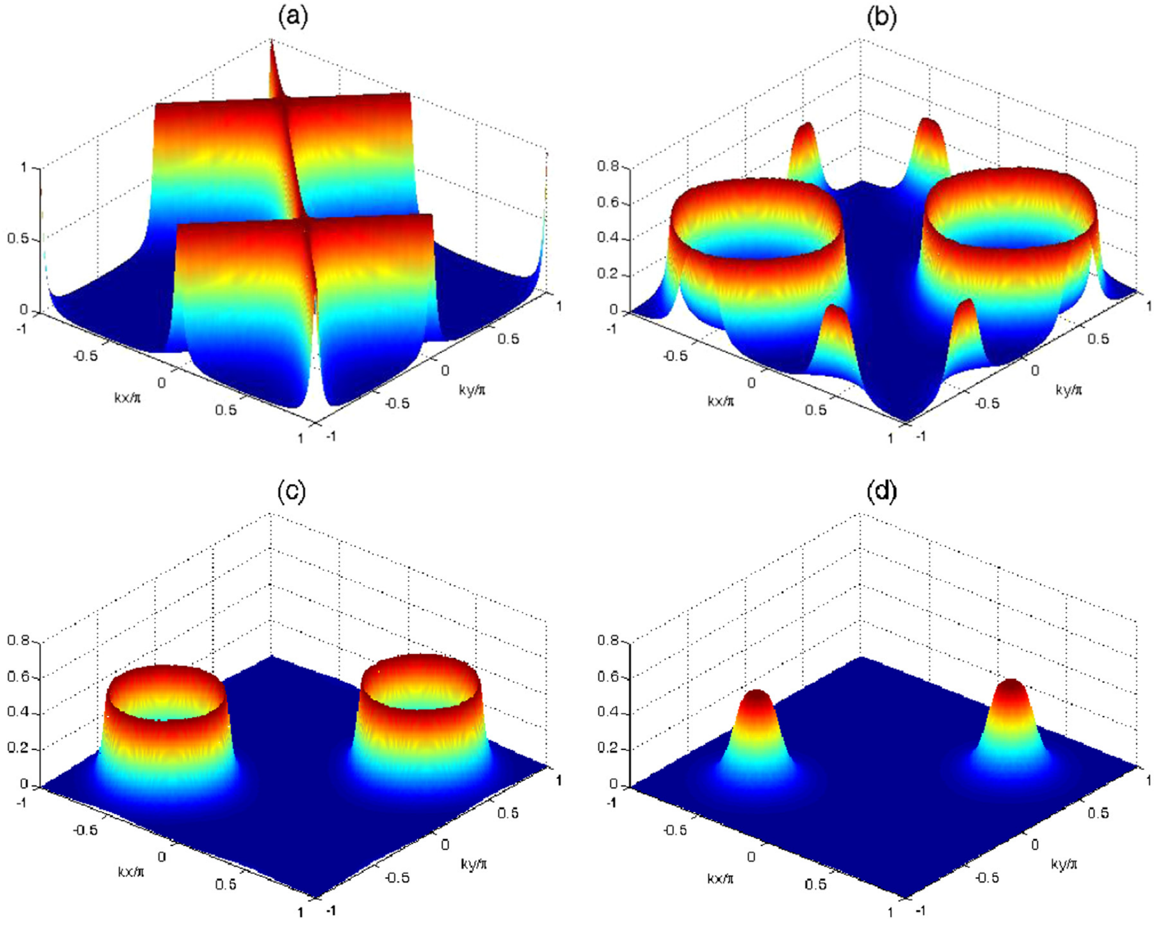

Fig. 2. The probe absorption Im(χ) versus positions ($-1 \le kx/\pi \le 1$, $-1 \le ky/\pi \le 1$) for different values of probe detuning Δ_p, with $\Omega_1 = 0$ μeV, $\Delta = 0$ and $\gamma_3 = \gamma_2 = 1$ μeV. (a) $\Delta_p = 0$, (b) $\Delta_p = 10$ μeV, (c) $\Delta_p = 15$ μeV, (d) $\Delta_p = 20$ μeV.