Physica E 64 (2014) 246–253

Contents lists available at ScienceDirect

Physica E

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

Optical precursors with competing linear and nonlinear dispersions in quantum dot molecules

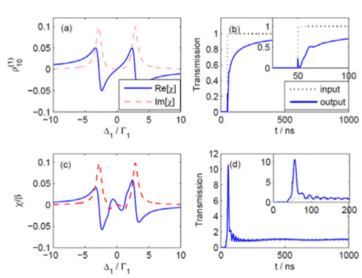
Yandong Peng [a,b,*], Aihong Yang [a], Bing Chen [a,**], Yan Xu [a], Luyin Zhang [a]

[a] Department of Applied Physics, Shandong University of Science and Technology, Qingdao, Shandong 266590, China
[b] State Key Laboratory of Mining Disaster Prevention and Control Co-founded by Shandong Province and the Ministry of Science and Technology, Shandong University of Science and Technology, Qingdao, 266590, China

HIGHLIGHTS

- Optical precursors could be controlled in quantum-dot molecules by voltage.
- Precursors are separated from delayed main signal in linear case.
- Total susceptibility shows anomalous dispersion in nonlinear case.
- Main signal constructively interferes with precursors in nonlinear case.
- Competing linear and nonlinear dispersions leads to different interferences.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 4 April 2014
Received in revised form
16 June 2014
Accepted 7 July 2014
Available online 26 July 2014

Keywords:
Tunneling induced transparency
Self-Kerr nonlinearity
Optical precursor
Normal dispersion
Anomalous dispersion

ABSTRACT

We theoretically investigate coherent control of optical precursors in quantum-dot molecules by voltage-controlled tunneling. When the probe field is weak, the linear susceptibility shows normal dispersion. The main signal is delayed due to slow-light effect and optical precursors are separated from the incident pulse. As increase of the probe-field intensity, the nonlinearity arises. The enhanced self-Kerr nonlinearity exhibits anomalous dispersion, then the main signal is accelerated and constructively interferes with the precursors, so a strong transient pulse appears. Simulation result shows that its peak value is about one order of magnitude larger than that of the incident pulse. The competition between the linear and nonlinear dispersions contributes to the separation and enhancement of the optical precursors.

1. Introduction

Coherent control of optical pulses through a dispersion medium is the basis for optical communications [1,2] and medical imaginary [3]. If a step-modulated incident pulse is applied, there is precursor part in the transmitted pulse. Optical precursors, in frequency domain, originate from spectral components far away from the medium resonance, containing high-frequency Sommerfeld precursor and low-frequency Brillouin precursor [4]. They were first obtained in cold atoms with the aid of electromagnetically induced transparency (EIT) technology [5], where the main signal was delayed due to slow-light effect and optical precursors were well separated from the incident pulse [6]. Later, optical precursors were examined in a single-photon level [7], and enhanced precursors were observed from a sequenced on–off step pulses [8]. Most recent studies on optical precursors were performed with atomic system, such as their generation via EIT [9], propagation dynamics in anomalous dispersion medium [10] and particular cases [11–13], etc.

In terms of applications, solid materials may be preferred for the generation of optical precursors. Through GaAs crystal, precursor signals were observed with near-resonant excitation, but

* Corresponding author. Tel.: +86 532 86057555.
** Corresponding author.
E-mail addresses: pengyd@sdust.edu.cn (Y. Peng), chenbingphys@gmail.com (B. Chen).

http://dx.doi.org/10.1016/j.physe.2014.07.004
1386-9477/

they did not well separated from the main signal due to the weak dispersion [14]. Also, the precursor behaviors have been reported in ZnTe crystal [15] and optically pumped crystals [16]. Nowadays, new experiments push optical precursors to applications further, such as the speed of precursors was measured using polarization-based interference [17], and the causal information velocity involving precursors was examined by encoding nonanalytical points on Gaussian pulses in an optical ring resonator [18]. But the above works are studied in linear regime and few works cover nonlinear effects on propagation dynamics of optical precursors in solid materials.

Semiconductor nanostructure has confined electrons or holes exhibiting discrete energy levels. The atom-like property allows us to study many quantum-optical phenomena, including EIT [19], self-induced transparency [20], Rabi oscillation [21], and their applications in all-optical switch [22], four-wave mixing [23], Kerr nonlinearity [24,25] and higher-order sidband generation [26,27]. The interacting QDs consist of a QD molecule (QDM). Laterally and vertically coupled QDMs have been produced opening the possibility to upscale a large number of QDs [28]. Spectroscopic technique was used to monitor electron transfer between discrete quantum states in QDMs allowing ultrafast charge memory based nanostructure [29]. The pioneering studies on QDMs also include coherent control of tunneling [30,31], slow light [32], tunneling induced transparency (TIT) [33], and so on.

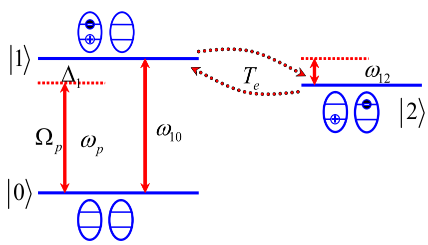


Fig. 1. Three-level QDM system with coupling scheme.

In this paper, we investigate one-dimensional propagation of optical precursors through a lateral-coupled double QD system [30] in nonlinear regime. The basic idea is to combine the enhanced self-Kerr nonlinearity with TIT. The main difference from other atomic schemes is that the resonant tunneling induces inherent coherence of the QDMs, which leads to quantum interference contributing to the main results. Due to resonant tunneling, the QDM system shows a TIT window with normal dispersion. When a weak step-modulated pulse passes through the TIT window, the main signal is delayed due to the slow-light effect. While the precursor signals first appear just following the rise edge of the incident pulse. Because they arise from the high/low-frequency components and travel through the medium with light velocity in vacuum approximately, so the precursors can be separated from the incident pulse. We further discuss the linear case in weak- and strong-coupling regimes. When the probe-field

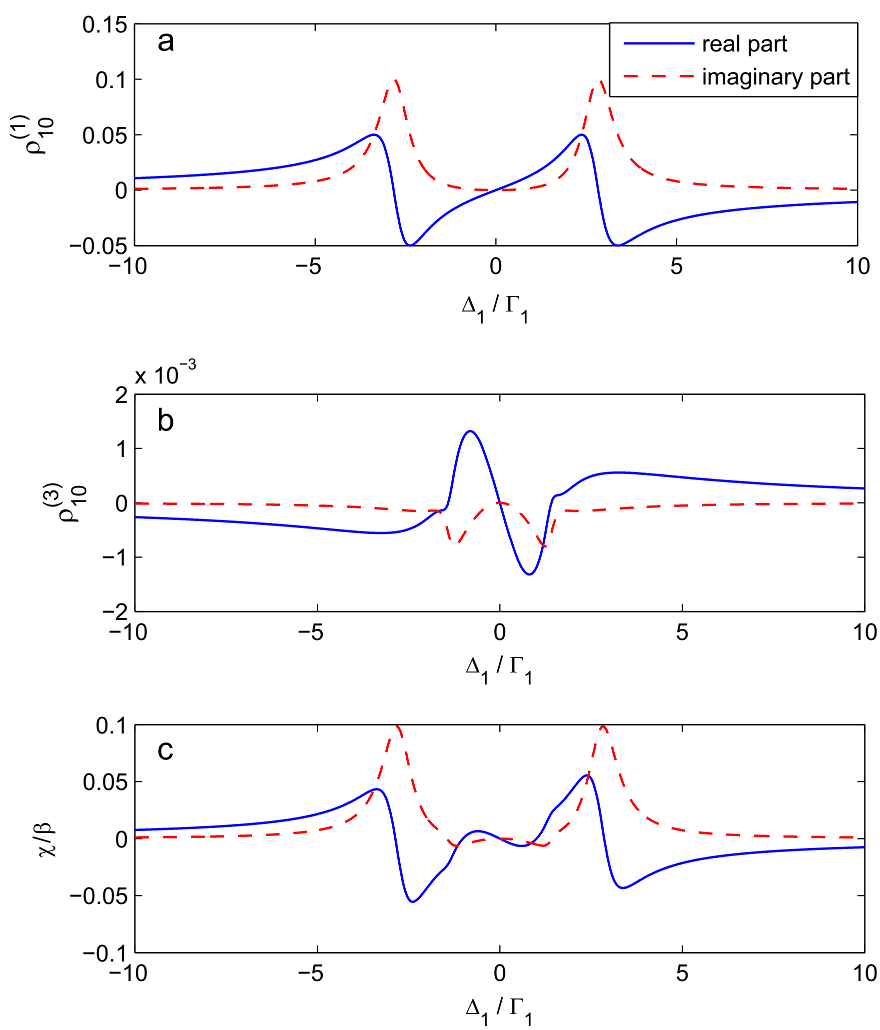


Fig. 2. (a) Linear part $\rho_{10}^{(1)}$ in limit of weak probe field; (b) nonlinear part $\rho_{10}^{(3)}$ and (c) total susceptibility χ/β with $\Omega_p=0.5\Gamma_1$. $T_e=2\Gamma_1$, $\Gamma_1=0.01$ meV, $\Gamma_2=10^{-4}\Gamma_1$ and $\omega_{12}=0$.