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Negative Refractive Index in Single Quantum Dot System

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Abstract

The results shows Negative refractive index (NRI) is an active field of studding , χ_e it can be used to develop a perfect lens and a lens without imaging. The aim of this thesis is to propose a system to study Negative refractive index In single QD, the NRI is very small compared with that in DQD system, for this reason, the DQD system was used in most researches to obtain a high negative refractive index.

Introduction

the negative refractive index (NRI) is one of the most common significant challenges [1] since Pendry's ideal lens paper [2] was released and Smith's first experimental microwave NRI confirmation [3]. It has been shown in Veselago's pioneering paper that a medium with at the same time negative permittivity and permeability display unusual properties such as the NRI. Today, the dielectric photonic crystals, i.e. periodic media inhomogeneous with a continuous lattice equal to wavelength, the concept of negative refraction was initially demonstrated. Negative refractive materials that Veselago originally proposed have attracted impressive work efforts over the past decades. Products with a negative refractive index offer many unexpected and counterintuitive electromagnetic and optical properties [4].

There have been several solutions to the development of negative refractive index products that can be represented as artificial structures, such as metamaterials and photonic crystals, chiral products, and resonant photonic media [5]. Negative refraction also results with resonant absorption in these negative refractive materials, particularly at higher frequencies, which restricts several potential applications [6, 7]. Involving a periodic variety of electrical and magnetic resonators contributing to serious difficulties in the manufacture of the optical systems of the two-or three-dimensional materials with negative refractive indices [8, 9].

1. Single QD System

A three-level cascade-type QD atomic mechanism can be considered for a single QD system, as shown in Fig. (2.1) .The system consists of three states. The interaction Hamiltonian for this DQD system is written as

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$$H_{\text{int}} = \begin{bmatrix} 0 & -\hbar\Omega_{01}^{m} & -\hbar\Omega_{02} & -\hbar\Omega_{03} & -\hbar A_{04} & 0 \\ -\hbar\Omega_{01}^{m} & \hbar(\Delta_0) & -\hbar\Omega_{12} & -\hbar\Omega_{13} & -\hbar A_{14} & 0 \\ -\hbar\Omega_{02} & -\hbar\Omega_{12} & \hbar(\Delta_0) & -\hbar\Omega_{23}^{m} & 0 & -\hbar A_{25} \\ -\hbar\Omega_{03} & -\hbar\Omega_{13} & -\hbar\Omega_{23}^{m} & \hbar(\Delta_0) & 0 & -\hbar A_{35} \\ -\hbar A_{04} & -\hbar A_{14} & 0 & 0 & \hbar(\Delta_0) & 0 \\ 0 & 0 & -\hbar A_{52} & -\hbar A_{53} & 0 & \hbar(\Delta_0) \end{bmatrix} \qquad (1)$$

here Ω_{01}^{m} and Ω_{23}^{m} are the magnetic Rabi frequencies of the atomic transitions between states $|0\rangle \leftrightarrow |1\rangle$, and $|2\rangle \leftrightarrow |3\rangle$, Ω_{ij} is the Rabi frequency of the optical field applied between states $|i\rangle$ and $|j\rangle$. Note that $A_{ij} = \mu_{ij}^{2}\omega_{ij}^{2} / A$ with $A = 3\pi\hbar\varepsilon_0 c^3$, and c is the speed of light.

$$\dot{\rho}_{00} = -\gamma_0\rho_{00} + i[\Omega_{10}^{m}(\rho_{10} - \rho_{01}) + \Omega_{20}(\rho_{20} - \rho_{02}) + \Omega_{03}(\rho_{30} - \rho_{03}) + \Omega_{04}(\rho_{40} - \rho_{04})] \qquad (2-1)$$

$$\dot{\rho}_{22} = -\gamma_1\rho_{22} + i[\Omega_{20}(\rho_{02} - \rho_{20}) + \Omega_{12}(\rho_{21} - \rho_{11}) + \Omega_{25}(\rho_{52} - \rho_{25})] \qquad (2-2)$$

$$\dot{\rho}_{44} = -\gamma_4\rho_{44} + i[\Omega_{40}(\rho_{04} - \rho_{40}) + \Omega_{41}(\rho_{14} - \rho_{41})] \qquad (2-3)$$

$$\dot{\rho}_{55} = -\gamma_5\rho_{55} + i[\Omega_{52}(\rho_{25} - \rho_{52}) + \Omega_{53}(\rho_{35} - \rho_{53})] \qquad (2-4)$$

$$\dot{\rho}_{20} = -i[(\Delta_{20}\rho_{20}) - (\gamma_0 + \gamma_2)\rho_{20}] + i[\Omega_{20}(\rho_{00} - \rho_{22}) + (\Omega_{21}\rho_{210} + \Omega_{23}\rho_{30} + \Omega_{25}\rho_{25})\Omega_{10}^{m}\rho_{21} + \Omega_{30}\rho_{23} + \Omega_{25}\rho_{25}] \qquad (2-5)$$

$$\dot{\rho}_{40} = -[i\,\Delta_{40} + (\gamma_4 + \gamma_0)\rho_{40}] + i[\Omega_{40}(\rho_{00} - \rho_{44}) + \Omega_{41}\rho_{10} + \Omega_{10}^{m}\rho_{41}] \qquad (2-6)$$

$$\dot{\rho}_{50} = -[\mathrm{i}\Delta_{51} - (\gamma_5 + \gamma_0)\rho_{50}] + i[\Omega_{52}\rho_{20} + i\,\Omega_{53}\rho_{30} - \Omega_{10}^{m}\rho_{50} - \Omega_{20}\rho_{52} - \Omega_{30}\rho_{53}] \qquad (2-7)$$

$$\dot{\rho}_{25} = -[\mathrm{i}\Delta_{25} + (\gamma_2 + \gamma_5)\rho_{25}] + i[\Omega_{25}(\rho_{55} + \rho_{22}) + \Omega_{23}^{m}\rho - \Omega_{35}\rho_{23}] \qquad (2-8)$$

With the condition

$$\rho_{00} + \rho_{22} + \rho_{44} + \rho_{55} = 1 \qquad (2-9)$$

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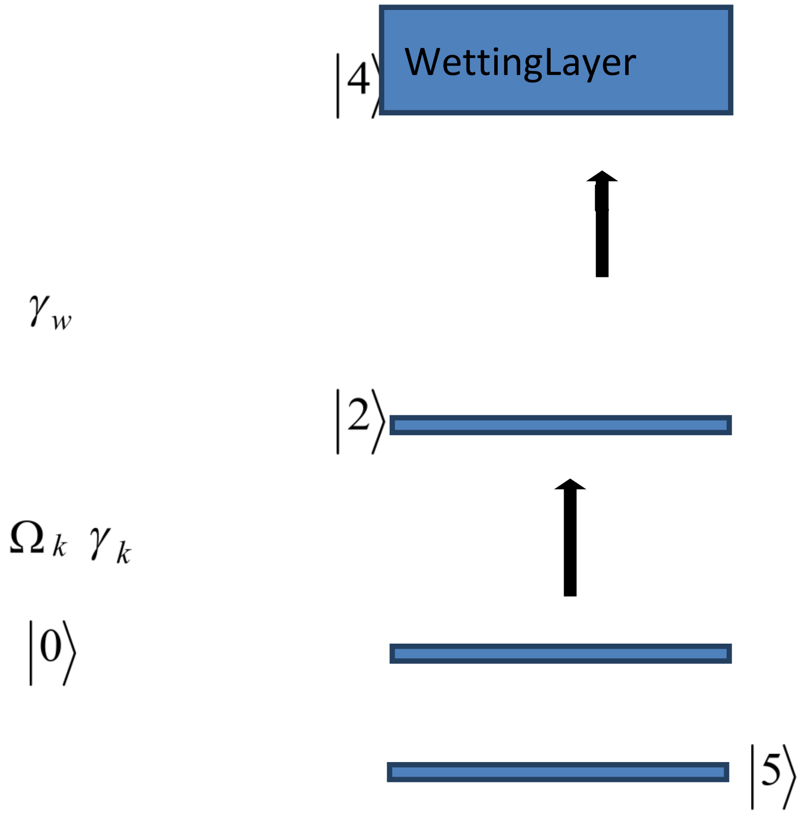
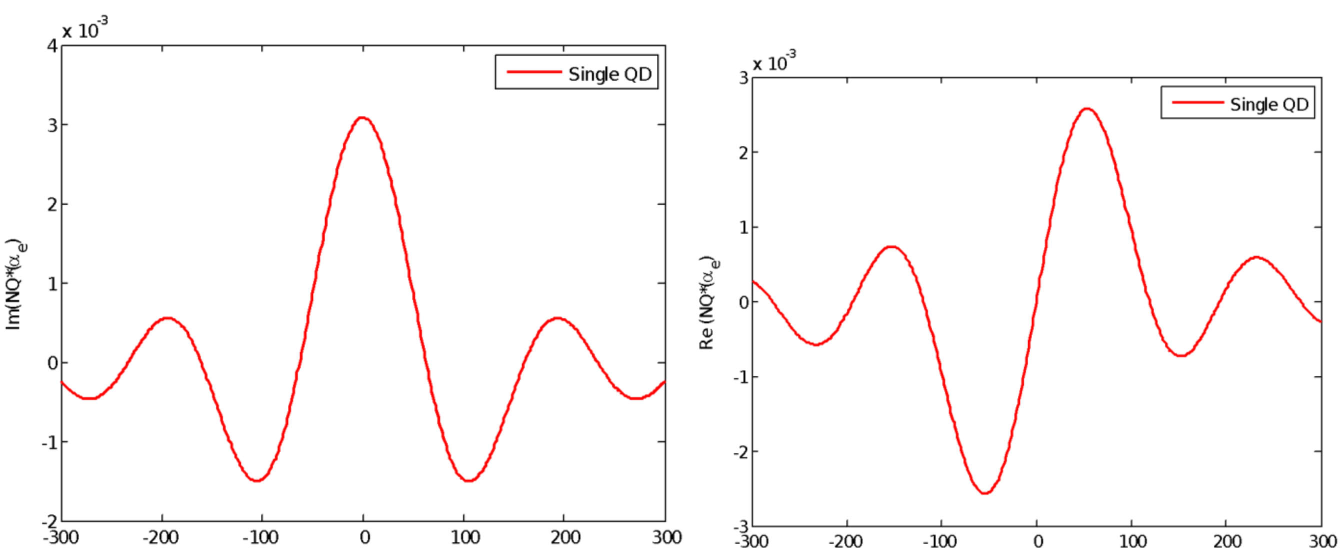


Fig. 2-1: Schematic representation of the three energy level arrangement.

2. Results and discussion

Fig. 1shows the case under similar six fields. shows the case of single QD. The NRI is very small compared with the above results of DQD system. Here NRI becomes (-1.0001).This explains the reason of proposing DQD system.



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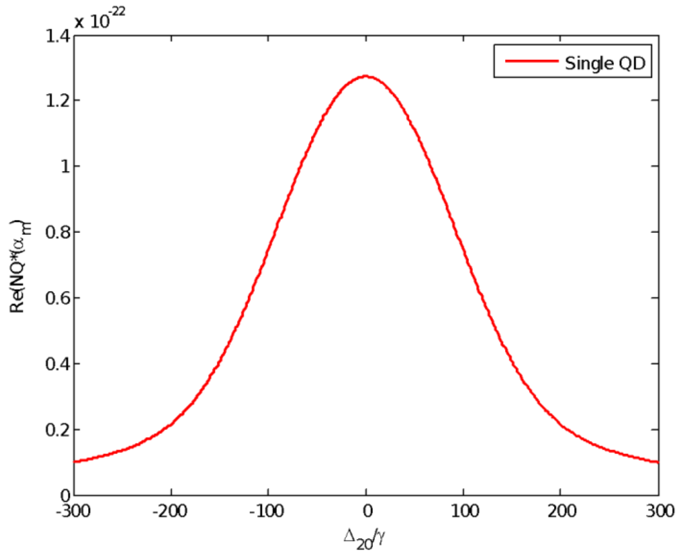

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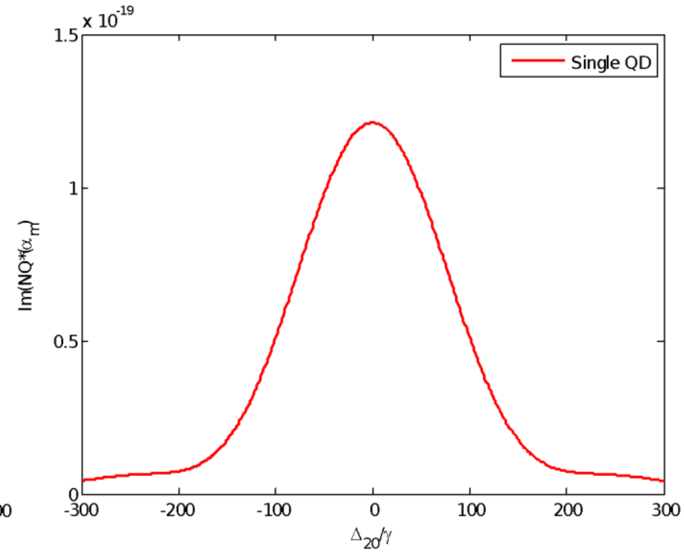

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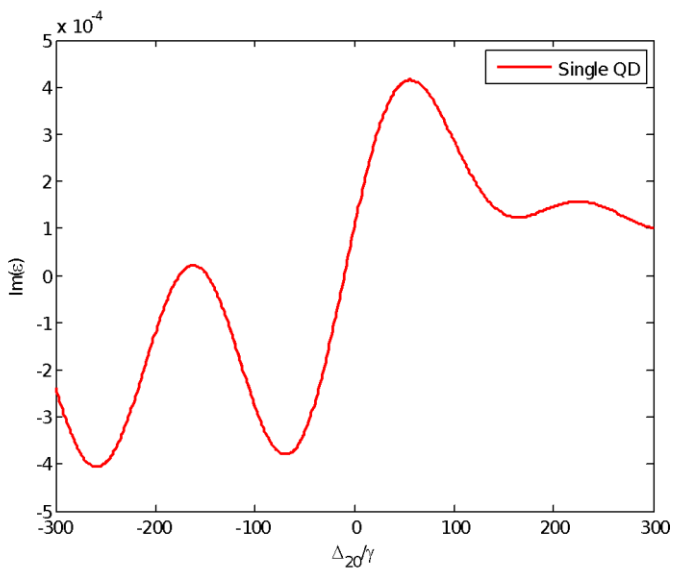

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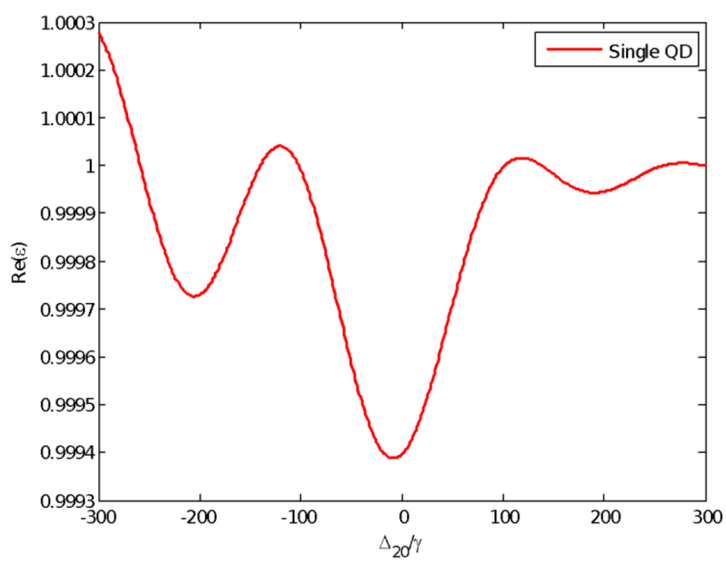

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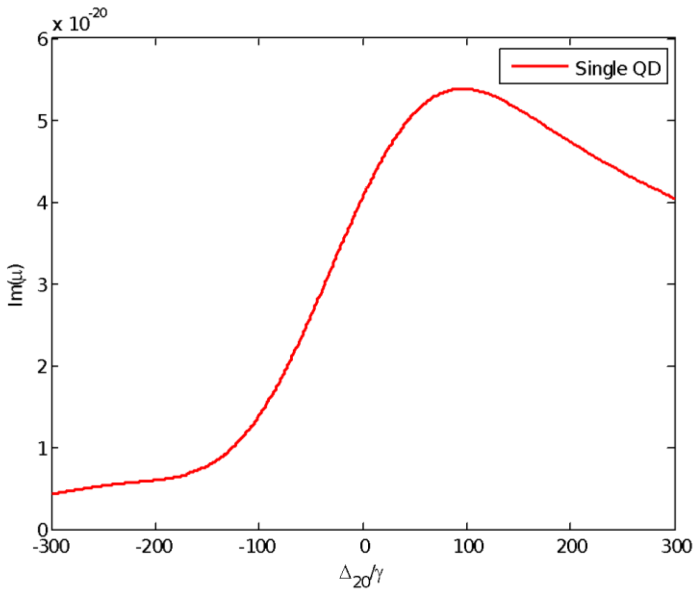

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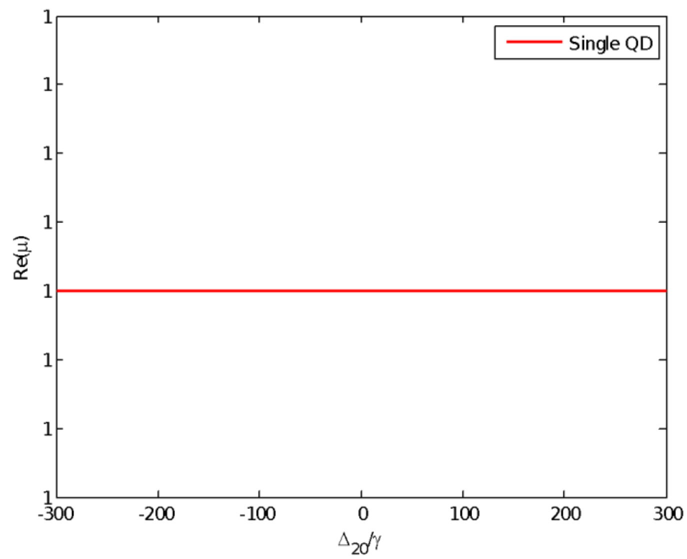

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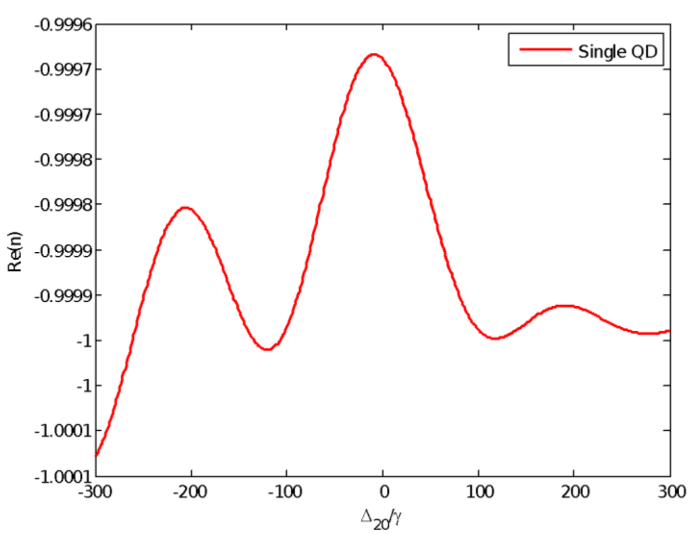

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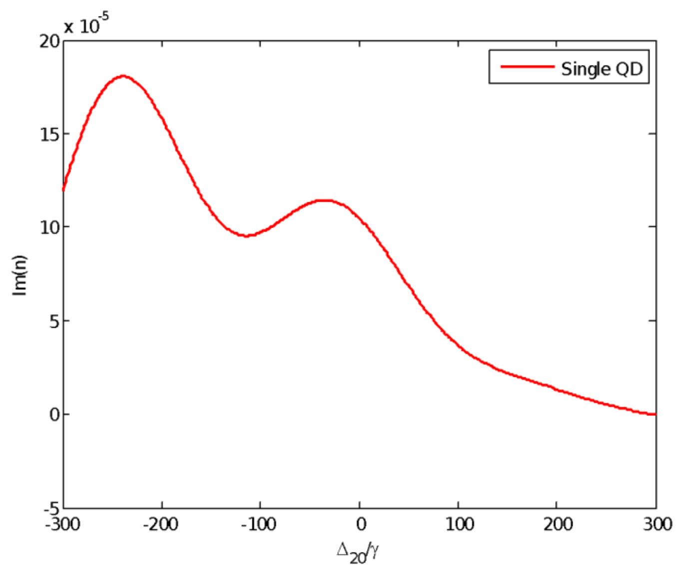

1-10

Fig. 1: Real and imaginary part of (1), (2) electric and (3), (4) magnetic susceptibility and electric (5), (6) and magnetic (7), (8) permeability, and refractive index (9) and (10) at weak probe electric field

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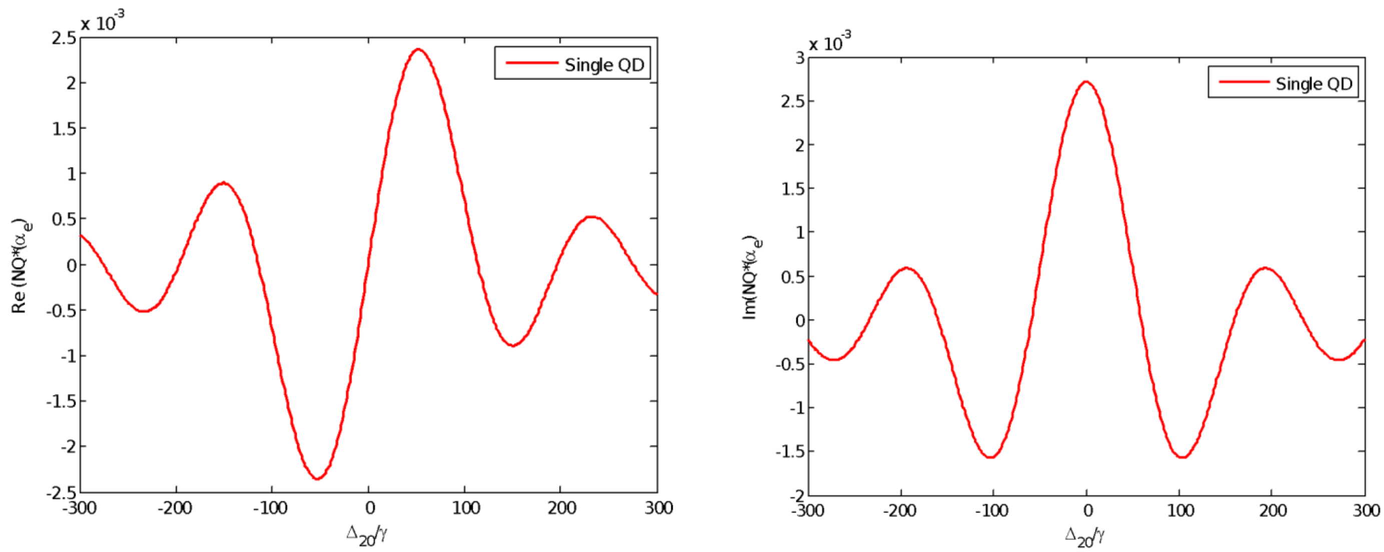
Fig. 2 shows the case under similar six fields ,shows the case of single QD. The NRI is very small compared with the above results of DQD system.Here NRI becomes (-1.0002).This explains the reason of proposing DQD system.



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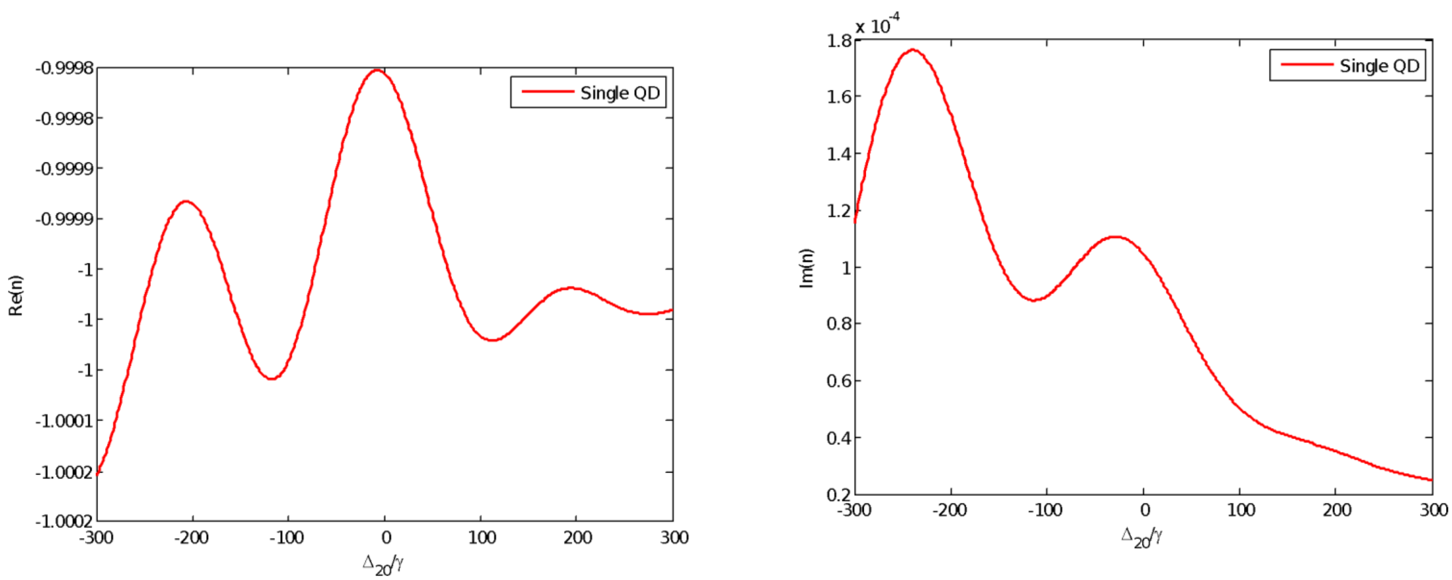

2-3 2-4

Fig. 2: Real and imaginary part of (1), (2) electric susceptibility and refractive index (3) and (4). The applied electric fields are

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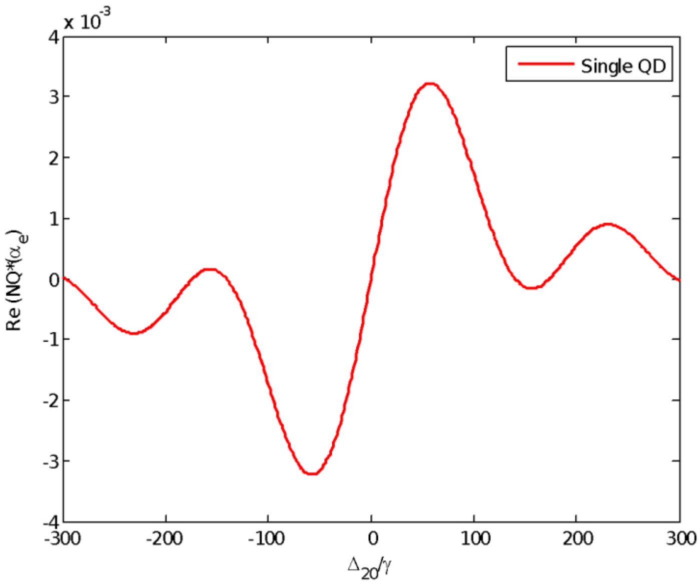
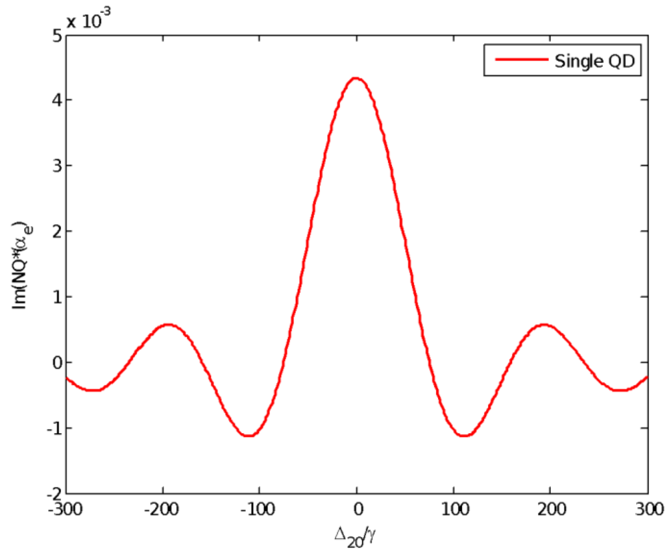
Fig. 3 shows the case under similar six fields ,shows the case of single QD. The NRI is very small compared with the above results of DQD system.Here NRI becomes (-1).This explains the reason of proposing DQD system.



3-1



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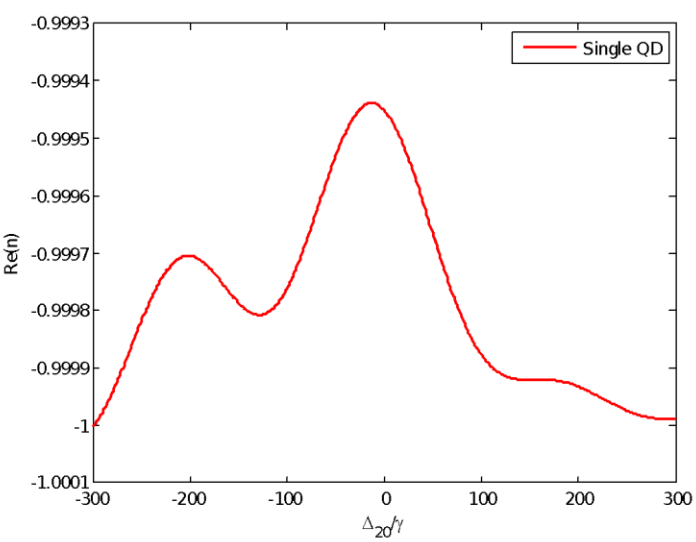

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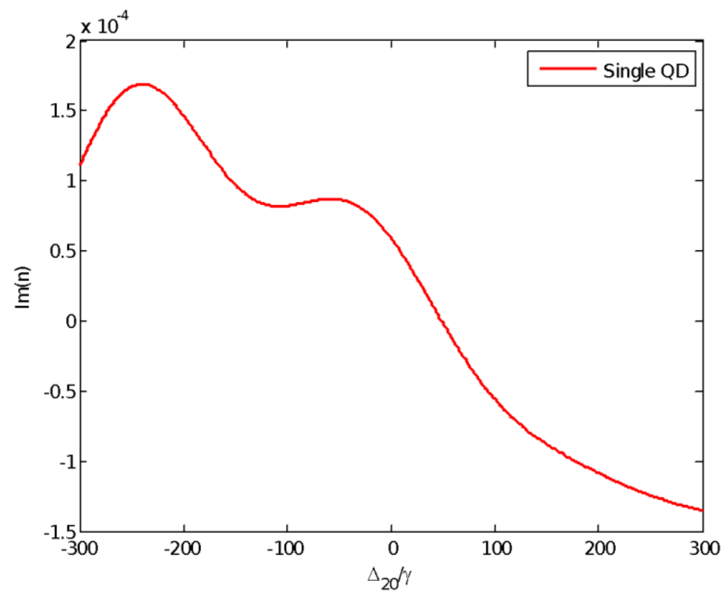

3-4

Fig.3: Real and imaginary part of (1), (2) electric susceptibility and refractive index (3) and (4). The applied electric fields are

4-1 Conclusions

DQD system is proposed for NRI. This system has a single state in the CB and a state in the VB in each dot. So, there are for QD states two in each of CB and VB. Additionally, the WL is considered as a single state in the CB and VB. An electric fields: the pump Ω_{31} and the probe Ω_{20} and the magnetic (Ω_{23}) field are applied. These fields are applied between QD states as referred from their subscript numbers. Additionally, other electric fields are applied between WL-QD states. The following findings are stated:

1. The DQD system exhibits NRI under pump and probe fields but it is not high due to high absorption.
2. In all the studied cases, magnetic susceptibility is very low.
3. The real part of magnetic permeability is near zero and its imaginary part is nearly neglected.
4. In all the figures, the range of detuning is so wide. This wide range is also shown in another work
5. For each CB and VB there are two possible WL-QD applied electric fields since there are two QD states in each CB and VB.
6. The field Ω_{25} WL-QD VB is shown to be important in increasing NRI where it removes the EIT window. So, a quantum coherence between DQD states is expected to be reduced and the DQD system is works as decoupled two single-QDs.
7. The Ω_{14} WL-QD CB applied electric field reduces the NRI by more than three orders. This is since both electric absorption and dispersion are increased but the magnetic ones can be neglected.
8. Under six fields between QD-QD, the CB WL-QD, and the VB WL-QD fields a high NRI is correspond to neglected absorption.
9. It is shown that higher fields especially, Ω_{35} gives high NRI.
10. Neglecting WL gives zero absorption but the NRI is small by ~16 times than that in the case of considering WL.
11. The NRI in single QD is very small compared with that in DQD system.

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