Absorption and slow light effect of pulsed light in a triple semiconductor quantum well*

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Under the condition of two different cases, the absorption of a pulsed probe field and its slow propagation in a triple semiconductor quantum well are investigated. The result shows that semiconductor medium becomes transparent due to the action of control field. Another result shows that by choosing appropriate physical parameters, the slow propagation of the input field can be achieved. The proposed scheme has some potential applications and may lead to the development of the controlled technique of optical buffers and optical delay lines.

Keywords: slow light, semiconductor quantum well, group velocity

PACC: 4250, 4265

1. Introduction

In the field of quantum optics, quantum coherence and interference produced due to interactions between matter and light field have induced many interesting and novel phenomena.[1−26] For an atomic system, if atomic levels are prepared in a coherent superposition of states, the system can produce some unexpected consequences,[1−16] such as photo echo, coherent Ramman beats, lasing without inversion, electromagnetically induced transparency, and so on. With the in-depth research about these phenomenon, one finds that the application of quantum coherence can be realized in the system of semiconductor quantum well.[17−23] We know that semiconductor quantum well structures have discrete energy levels which resemble atomic properties, so the quantum coherence and interference effects can occur either by external driving fields or by interference in the tunneling to an electronic continuum. Imamoglu and Ram[17] showed that the gain without inversion in semiconductor nanostructures could be realized. By using the nonradiative coherence between the heavy-hole and the light-hole valence bands, Phillips and Wang[18] demonstrated that electromagnetically induced transparency occurred in the transient optical response in semiconductor quantum well. For an appropriate choice of the quantum well structure and the driving field, Silvestri *et al.*[19] found that the coupled system could produce coherent population trapping and double tunneling-induced transparency. Recent studies showed that under the interaction of an electromagnetic field, the constructive interference of the emission spectrum, the tunneling induced interference and the optical bistability could be produced in a triple semiconductor quantum well.[20,27,28] To the best of our knowledge, no further theoretical and experimental work has been carried out to investigate the transmission of slow light in such a triple quantum well interacting with a weak probe field, a strong control field and a pump field, which motivates us to study these phenomena of quantum coherence.

In the present paper, we theoretically study the behaviour of absorption of a pulsed light in intersubband transition of a triple semiconductor quantum well (TSQW) structure, and propose a scheme to achieve the propagation of slow light. Our results show that the destructive interference and the constructive interference can be effectively controlled, so we may obtain an absorptionless transmission for a weak probe field, that is, we can realize electromagnetically induced transparency. Our another motivation is that we attempt to realize a slow propagation of an optical field which could envision a potential influ-

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ence on the modern optical technique and telecommunication engineering. In particular, well-characterized slow optical waves may lead to important applications such as high fidelity optical buffers, quantum information storage and retrieval, controllable optical delay and all-optical transistor, and so on. In addition, compared with the atomic system, semiconductor quantum well structure has an advantage of easy integration, so the manipulation of absorption and technique of slow light in the system of TSQW has a more practical value. Our work is based on latest theoretical and experimental papers, and maybe our theoretical results have some reference value for the future experiments. In order to highlight the importance of a strong control field, we discuss absorptions and effects of slow light in two different cases.

2. Theoretical model and governing equations

We consider the TSQW (see Fig. 1) that consists of a deep well and two shallow wells coupled by tunneling to a common continuum of energies through a thin barrier. The first excited state in the deep well and the respective ground states in the two shallow wells mix to form three new excited states of this system. The ground state in the deep well and the three excited states created newly are expressed as $|0\rangle$, $|1\rangle$, $|2\rangle$, and $|3\rangle$, respectively, which refer to the electronic wave functions. In two different cases, we consider the system of TSQW interacting with a pulsed light with central frequency $\omega_{\rm p}$ and amplitude $E_{\rm p}$. The first case (case I) is shown in Fig. 2(a) where there are no additional control fields interacting with the system, and the pulsed light interacts with the TSQW, and couplings between the ground state and other three excited states are produced. The second case (case II) is shown in Fig. 2(b) where the transitions $|3\rangle \leftrightarrow |2\rangle$ and $|1\rangle \leftrightarrow |2\rangle$ take place due to a pump field with frequency $\omega_{\rm b}$ and amplitude $E_{\rm b}$ and a strong control field with frequency $\omega_{\rm c}$ and amplitude $E_{\rm c}$, respectively.

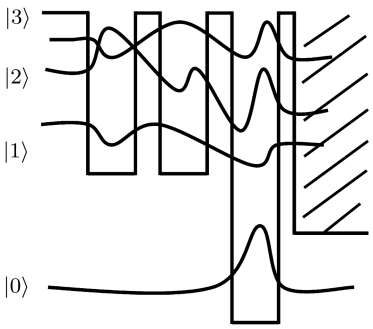


Fig. 1. Band diagram of a triple semiconductor quantum well. It consists of a deep well and two shallow wells coupled by tunnelling to a common continuum of energies through a thin barrier. The first excited state in the deep well and the respective ground states in the two shallow wells mix to form three new excited states of this system. The ground state in the deep well and the three excited states created newly are expressed as $|0\rangle$, $|1\rangle$, $|2\rangle$, and $|3\rangle$, respectively, which represent the electronic wave functions.

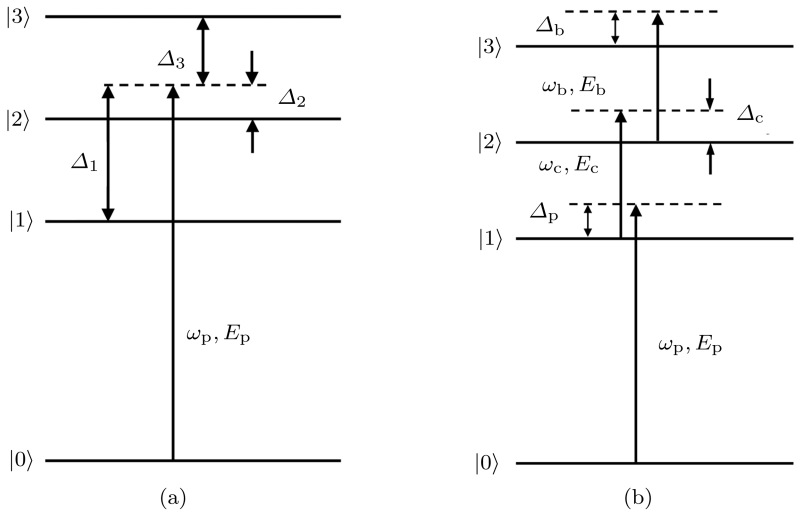


Fig. 2. (a) Schematic diagram of the energy level arrangement for the case I. A weak pulsed light is used to couple the ground state to three excited states. All parameters are shown in Section 2 of this paper. (b) Schematic diagram of the energy level arrangement for the case II. A weak pulsed light couples the states $|0\rangle$ to $|1\rangle$, the transition between $|2\rangle$ and $|1\rangle$ is driven by a strong control field, and the transition between $|2\rangle$ and $|3\rangle$ is driven by a pump field. All parameters are shown in Section 2 of this paper.

Here we first consider the case I. In the interaction picture, choosing $\hbar = 1$ and the energy of the ground state $\varepsilon_0 = 0$, we can start with the Hamiltonian

$$\begin{aligned} & H \\ &= \Delta_1 |1\rangle\langle 1| + \Delta_2 |2\rangle\langle 2| + \Delta_3 |3\rangle\langle 3| \\ &\quad - (\Omega_{\rm p1} |1\rangle\langle 0| + \Omega_{\rm p2} |2\rangle\langle 0| + \Omega_{\rm p3} |3\rangle\langle 0| + {\rm h.c.}), \end{aligned} \tag{1}$$

where $\Omega_{{\rm p}j}$ denotes the one-and-a-half frequencies for the intersubband transitions $|0\rangle \leftrightarrow |j\rangle$ $(j = 1, 2, 3)$ and is expressed as $\Omega_{{\rm p}j} = \mu_{j0} E_{\rm p}/2\hbar$ where the dipole moment $\mu_{j0} = \boldsymbol{\mu}_{j0} \cdot \hat{\boldsymbol{e}}_L$ with $\hat{\boldsymbol{e}}_{\rm L}$ being the polarization unit vector of the laser field. $\Delta_j = \varepsilon_j/\hbar - \omega_{\rm p}$ is the detuning of the input field from the corresponding optical transitions, where ε_j is the energy of the subband level $|j\rangle$.

Defining the original state of the TSQW

$$|\Psi\rangle = A_0 |0\rangle + A_1 |1\rangle + A_2 |2\rangle + A_3 |3\rangle . \tag{2}$$

We have the equations of motion for the amplitudes A_0, A_1, A_2 and A_3 that may be written respectively as

$$\frac{\partial A_0}{\partial t} = {\rm i}\Omega_{\rm p}^* A_1 + {\rm i} f_1^* \Omega_{\rm p}^* A_2 + {\rm i} f_2^* \Omega_{\rm p}^* A_3, \tag{3a}$$

$$\frac{\partial A_1}{\partial t} = {\rm i}\Omega_{\rm p} A_0 - ({\rm i}\Delta_1 + \gamma_1) A_1, \tag{3b}$$

$$\frac{\partial A_2}{\partial t} = {\rm i} f_1 \Omega_{\rm p} A_0 - ({\rm i}\Delta_2 + \gamma_2) A_2, \tag{3c}$$

$$\frac{\partial A_3}{\partial t} = {\rm i} f_2 \Omega_{\rm p} A_0 - ({\rm i}\Delta_3 + \gamma_3) A_3, \tag{3d}$$

where γ_j ($j = 1$, 2, 3) represent the total decay rates of the subband level $|j\rangle$ respectively. In the quantum well structures, $\gamma_{j=1,2,3}$ include the population decay rates $\gamma_{j{\rm l}}$ and dephasing decay rates $\gamma_{j{\rm d}}$ and are given by $\gamma_1 = \gamma_{1{\rm l}} + \gamma_{1{\rm d}}$, $\gamma_2 = \gamma_{2{\rm l}} + \gamma_{2{\rm d}}$, and $\gamma_3 = \gamma_{3{\rm l}} + \gamma_{3{\rm d}}$, where $\gamma_{j{\rm d}}$ are determined by electron–electron, interface roughness, and phonon scattering processes.[27−30] In addition, in Eqs. 3(a)–3(c), $f_{1(2)} = \mu_{2(3)0}/\mu_{10}$ is the ratio of two dipole moments, and $\Omega_{\rm p1}$ is replaced by $\Omega_{\rm p}$.

In the slowly varying envelope approximation, the dynamic response of the input pulsed light is governed by Maxwell's equation

$$\partial E_{\rm p}/\partial t + c\partial E_{\rm p}/\partial z = {\rm i} N \omega_{\rm p} \mu_{01} (A_1 + f_1^* A_2 + f_2^* A_3) A_0^*.$$

According to $\Omega_{\rm p} = \mu_{10} E_{\rm p}/(2\hbar)$, the Maxwell's equation is rewritten as

$$\frac{\partial \Omega_{\rm p}}{\partial z} + \frac{1}{c}\frac{\partial \Omega_{\rm p}}{\partial t} = {\rm i}\kappa (A_1 + f_1^* A_2 + f_2^* A_3) A_0^*, \tag{4}$$

where $\kappa = N\omega_{\rm p} |\mu_{10}|^2 /2\hbar c$, N is the electron density in the coupled quantum well sample.

We now assume that the input field is weak enough so that we can perform a perturbation expansion of the amplitude. Here we retain the first order of the input pulsed field $\Omega_{\rm p}$ and $A_{j=1,2,3}$ (i.e., linear term) and assume that the system of quantum well is initially in the state $|0\rangle$ ($A_0 \approx 1$). Under the condition of weak field, we carry out Fourier transformations

$$A_j(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \alpha_j(\omega)\, {\rm e}^{-{\rm i}\omega t} {\rm d}\omega$$

with the Fourier transformation variable ω for Eqs. 3(a)–3(c) and

$$\Omega_{\rm p}(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \Lambda_{\rm p}(\omega)\, {\rm e}^{-{\rm i}\omega t} {\rm d}\omega$$

for Eq. (4). We have results

$$\alpha_1 = -\frac{\Lambda_{\rm p}}{{\rm i}\gamma_1 + \omega - \Delta_1} , \tag{5a}$$

$$\alpha_2 = -\frac{f_1 \Lambda_{\rm p}}{{\rm i}\gamma_2 + \omega - \Delta_2}, \tag{5b}$$

$$\alpha_3 = -\frac{f_2 \Lambda_{\rm p}}{{\rm i}\gamma_3 + \omega - \Delta_3}, \tag{5c}$$

$$\frac{\partial \Lambda_{\rm p}}{\partial z} - {\rm i}\frac{\omega}{c}\Lambda_{\rm p} = {\rm i}\kappa(\alpha_1 + f_1^* \alpha_2 + f_2^* \alpha_3). \tag{6}$$

Substituting Eqs. (5) into Eq. (6), we then obtain

$$\frac{\partial \Lambda_{\rm p}}{\partial z} = {\rm i} K_{\rm I}(\omega) \Lambda_{\rm p}, \tag{7}$$

where the subscript I means the case I and the frequency-dependent propagation factor $K_{\rm I}(\omega)$ may be expressed as

$$K_{\rm I}(\omega) = \frac{\omega}{c} - \left(\frac{\kappa}{{\rm i}\gamma_1 + \omega - \Delta_1} + \frac{\kappa |f_1|^2}{{\rm i}\gamma_2 + \omega - \Delta_2} + \frac{\kappa |f_2|^2}{{\rm i}\gamma_3 + \omega - \Delta_3} \right). \tag{8}$$

In order to obtain the properties of the propagation for the pulsed light, the propagation factor is expanded

into a Taylor series as a function of the angular frequency ω, so we obtain

$$K_{\rm I}(\omega) = K_i(0) + K'_{\rm I}(0)\omega + \frac{1}{2}K''_{\rm I}(\omega)\omega^2 + {\rm O}(\omega^3),$$

where

$$K_{\rm I}(0) = -{\rm i}\kappa\left(\frac{1}{{\rm i}\gamma_1 - \Delta_1} + \frac{|f_1|^2}{{\rm i}\gamma_2 - \Delta_2} + \frac{|f_2|^2}{{\rm i}\gamma_3 - \Delta_3}\right), \tag{9}$$

$$K'_{\rm I}(0) = \frac{1}{c} + \kappa\left(\frac{1}{({\rm i}\gamma_1 - \Delta_1)^2} + \frac{|f_1|^2}{({\rm i}\gamma_2 - \Delta_2)^2} + \frac{|f_2|^2}{({\rm i}\gamma_3 - \Delta_3)^2}\right), \tag{10}$$

$$K''_{\rm I}(0) = -\kappa\left(\frac{1}{({\rm i}\gamma_1 - \Delta_1)^3} + \frac{|f_1|^2}{({\rm i}\gamma_2 - \Delta_2)^3} + \frac{|f_2|^2}{({\rm i}\gamma_3 - \Delta_3)^3}\right), \tag{11}$$

and the terms of the high order $O(\omega^3)$ are neglected. According to the theory of propagation of a light pulse in medium, the corresponding phase shift ϕ per unit length, energy absorption coefficient β, and the group velocity $V_{\rm g}$ are expressed as

$$\phi = {\rm Re}(K_{\rm I}(0)), \tag{12}$$

$$\beta = {\rm Im}(K_{\rm I}(0)), \tag{13}$$

$$V_{\rm g} = {\rm Re}(1/K'_{\rm I}(0)), \tag{14}$$

respectively. $K''(0)$ (here we do not study it) is called the group velocity dispersion which contributes to the input pulse shape change and additional loss of the pulsed intensity.

For the case II, the Hamiltonian of the system can be expressed as

$$H = \Delta_{\rm p}\left|1\right\rangle\left\langle 1\right| + (\Delta_{\rm p} + \Delta_{\rm c})\left|2\right\rangle\left\langle 2\right| + (\Delta_{\rm p} + \Delta_{\rm b} + \Delta_{\rm c})\left|3\right\rangle\left\langle 3\right| - (\Omega_{\rm p}\left|1\right\rangle\left\langle 0\right| + \Omega_{\rm c}\left|2\right\rangle\left\langle 1\right| + \Omega_{\rm b}\left|3\right\rangle\left\langle 2\right| + {\rm h.c.}),$$

then, the equations of evolution of amplitudes A_0, A_1, A_2 and A_3 may be expressed as

$$\begin{aligned}
\frac{\partial A_0}{\partial t} &= {\rm i}\Omega^*_{\rm p}A_1,\\
\frac{\partial A_1}{\partial t} &= {\rm i}\Omega_{\rm p}A_0 + {\rm i}\Omega^*_{\rm c}A_2 - ({\rm i}\Delta_{\rm p} + \gamma_1)A_1,\\
\frac{\partial A_2}{\partial t} &= {\rm i}\Omega_{\rm c}A_1 + {\rm i}\Omega^*_{\rm b}A_3 - ({\rm i}\Delta_{\rm p} + {\rm i}\Delta_{\rm b} + \gamma_2)A_2,\\
\frac{\partial A_3}{\partial t} &= {\rm i}\Omega_{\rm b}A_2 - ({\rm i}\Delta_{\rm p} + {\rm i}\Delta_{\rm b} + {\rm i}\Delta_{\rm c} + \gamma_3)A_3.
\end{aligned}$$

Using a similar method to the previous one, we can obtain

$$K_{\rm II}(0) = -\frac{D + |\Omega_{\rm b}|^2}{F}, \tag{15}$$

$$K'_{\rm II}(0) = \frac{1}{c} + \kappa\frac{AC - B(D+E)}{AF}, \tag{16}$$

where

$$\begin{aligned}
A =\ & \gamma_3(\gamma_2\Delta_{\rm p} - {\rm i}\left|\Omega_{\rm c}\right|^2 + \gamma_1\Delta_{\rm p} + \gamma_1\Delta_{\rm c} + {\rm i}\Delta_{\rm c}\Delta_{\rm p} - {\rm i}\gamma_1\gamma_2 + {\rm i}\Delta_{\rm p}^2)\\
&+ \gamma_1(\gamma_2\Delta_{\rm c} + \gamma_2\Delta_{\rm b} + {\rm i}2\Delta_{\rm p}\Delta_{\rm c} + {\rm i}\Delta_{\rm p}\Delta_{\rm b} + {\rm i}\Delta_{\rm c}\Delta_{\rm b} - {\rm i}\left|\Omega_{\rm b}\right|^2 + {\rm i}\Delta_{\rm p}^2 + {\rm i}\Delta_{\rm c}^2 + \gamma_2\Delta_{\rm p})\\
&+ \Delta_{\rm b}({\rm i}\gamma_2\Delta_{\rm p} - \Delta_{\rm p}\Delta_{\rm c} + \Delta_{\rm p}^2 + |\Omega_{\rm c}|^2) + \Delta_{\rm p}(|\Omega_{\rm p}|^2 - 2\Delta_{\rm p}\Delta_{\rm c} - \Delta_{\rm c}^2 + {\rm i}\Delta_{\rm p}\gamma_2 + {\rm i}\Delta_{\rm c}\gamma_2),\\
C =\ & -2\Delta_{\rm p} - 2\Delta_{\rm c} - \Delta_{\rm b} + {\rm i}\gamma_3 + {\rm i}\gamma_2,\\
B =\ & \Delta_{\rm p}({\rm i}\gamma_3 - \Delta_{\rm p} - 2\Delta_{\rm c} - {\rm i}\gamma_2 - \Delta_{\rm b}) + \Delta_{\rm c}({\rm i}\gamma_2 - \Delta_{\rm c} - \Delta_{\rm b} - {\rm i}\gamma_3) + {\rm i}\Delta_{\rm b}\gamma_2 + \gamma_2\gamma_3 + \left|\Omega_{\rm b}\right|^2,\\
D =\ & -(\Delta_{\rm p} + \Delta_{\rm c} - {\rm i}\gamma_2)(\Delta_{\rm p} + \Delta_{\rm c} + \Delta_{\rm b} - {\rm i}\gamma_3),\\
E =\ & (-2\Delta_{\rm p} - 2\Delta_{\rm c} - \Delta_{\rm b} + {\rm i}\gamma_3 + {\rm i}\gamma_2)(\Delta_{\rm p} - {\rm i}\gamma_1) + \left|\Omega_{\rm b}\right|^2 + \left|\Omega_{\rm c}\right|^2,\\
F =\ & (\Delta_{\rm p} + \Delta_{\rm c} + \Delta_{\rm b} - {\rm i}\gamma_3)[(\Delta_{\rm p} + \Delta_{\rm c} - {\rm i}\gamma_2)(\Delta_{\rm p} - {\rm i}\gamma_1) + |\Omega_{\rm c}|^2] - \left|\Omega_{\rm b}\right|^2(\Delta_{\rm p} - {\rm i}\gamma_1).
\end{aligned}$$

Finally, we obtain the absorption coefficient $\beta = {\rm Im}(K_{\rm II}(0))$, and the group velocity $V_{\rm g} = {\rm Re}(1/K'_{\rm II}(0))$.

3. Numerical results

Next, according to the various physical parameters of the system, we investigate the absorption for the pulsed light and the propagation of slow light in the two different cases. Our model consists of a deep 7.1-nm-think GaAs well adjacent to two shallow 6.8-nm-thick $Al_{0.2}Ga_{0.8}As$ wells separated by two $Al_{0.4}Ga_{0.6}As$ barriers of thicknesses 2.0 nm and 2.5 nm with the thick barrier neighbouring the deep well. The deep well is connected to the continuum $Al_{0.165}Ga_{0.835}As$ by an $Al_{0.4}Ga_{0.6}As$ barrier, and the shallow well on the far side is in contact with an $Al_{0.4}Ga_{0.6}As$ barrier. Note that in the following numerical calculations the parameters are chosen according to the investigation in Ref. [27]. Furthermore, our parameters include the physical parameters of quantum well and intensity of a pulsed light. For the former, we assume that the population decay rate and dephasing rate can be controlled. Our assumption is based on the development of technology of quantum coherence in semiconductor quantum well.[27−30] We know that the population decay rate is dominated by the inelastic emission of longitudinal optical phonons, and the dephasing rate is determined by electron-electron, interface roughness, and phonon scattering processes. For the latter, the intensity of pulsed light can be easily changed. Through choosing appropriate parameters, we attempt to acquire optimal results.

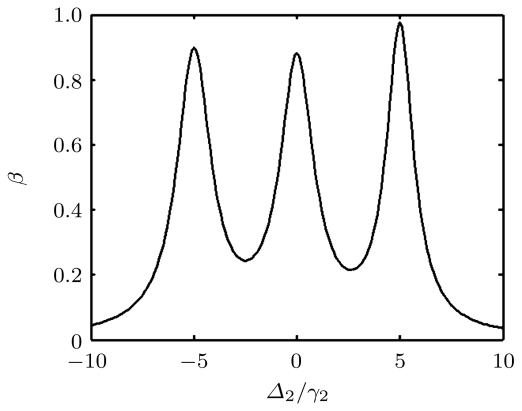


Fig. 3. Absorption curve for the case I.

For the case I, assuming that $\omega_{32} = \omega_{21} = 5\gamma_2$, we consider a system with the parameters being $\kappa = 0.75\gamma_2$, $\gamma_1 = 0.8\gamma_2$, $\gamma_3 = \gamma_2$, $f_1 = 1.1$, and $f_2 = 1.15$. Based on this set of parameters, the curve of absorption coefficient β versus parameter Δ_2/γ_2 is plotted in Fig. 3. Three absorption peaks are produced in this case, and their intensities are not equal to each other because processes of absorption each have their own dipole moments that are different from each other. In addition, we obtain the minimum value of absorption which is not equal to zero, that is, transparent medium cannot be achieved. If we choose a set of appropriate physical parameters: $\kappa = 0.75 \times 10^6$ s^{-1}, $\gamma_1 = 0.8 \times 10^6$ s^{-1}, $\gamma_2 = \gamma_3 = 1.5 \times 10^6$ s^{-1}, $d_1 = 1.0 \times 10^6$ s^{-1}, $d_2 = 4.0 \times 10^6$ s^{-1}, $d_3 = 9.0 \times 10^6$ s^{-1} and f_1 and f_2 remain the same as the above, we can acquire the slow group velocity $V_g/c = 0.0019$ (about 10^{-3}), that is, the propagation of slow light can be realized in TSQW of the case I.

For the case II, we consider that the pulsed light interacts with the TSQW driven by a control field and a pump field. Under the different conditions, the curves of absorption for the pulsed light are shown in Figs. 4(a) and 4(b). In Fig. 4(a), physical parameters of the system are arranged as $\kappa = 0.75\gamma_1$, $\gamma_1 = 0.8 \times 10^6$ s^{-1}, $\Delta_c = 0.1\gamma_1$, $\Delta_b = 3\gamma_1$, $\gamma_2 = 0.2\gamma_1, \gamma_3 = 0.05\gamma_1$, $\Omega_b = 3\gamma_1$, and $\Omega_c = 2\gamma_1$ and the absorption coefficient β is a function of variable Δ_p/γ_1. This figure shows that three absorption peaks still exist. In the place of negative detuning, the absorption peak is lowest, where the system is far from resonance with the pulsed light. We also find that the minimum value of the absorption approaches to zero, but is not equal to zero. That is, the absorption is not cancelled, which is the same as that in the case I. If we reduce the intensity of pump light ($\Omega_b = 2\gamma_1$), increase the intensity of control light ($\Omega_c = 6\gamma_1$) and keep other parameters unchanged, the curve of absorption versus dimensionless detuning Δ_p/γ_1 may be plotted as shown in Fig. 4(b). From this figure it follows that the absorption is completely inhibited when the detuning Δ_p is equal to zero. Thus the medium becomes transparent. This phenomenon occurs near the place where $\Delta_p = 0$, so we may obtain a wide transparent window, which is not observed in the case I. Occurrence of transparency originates from the action of the strong control field. With the intensity of the control field increasing, the destructive interference due to quantum coherence takes effect, and electromagnetically induced transparency is finally produced. This destructive interference between different channels is a key element in this paper and is especially important as a channel-opening technique in the case

of optical mixing, controllable optical delay, and so on. If a set of appropriate physical parameters are given, for instance, $\kappa = 0.75 \times 10^6$ s^{-1}, $\gamma_1 = 1.0 \times 10^6$ s^{-1}, $\gamma_2 = 0.5 \times 10^6$ s^{-1}, $\gamma_3 = 0.01 \times 10^6$ s^{-1}, $\Delta_c = 0.01 \times 10^6$ s^{-1}, $\Delta_b = 0.1 \times 10^6$ s^{-1}, $\Delta_p = 0$, $\Omega_b = 2\gamma_1$, and $\Omega_c = 6\gamma_1$, the propagation of slow light can be obtained ($V_g/c = 6.1 \times 10^{-4}$), and this value is smaller than one in the case I. Under the condition of the action of strong control light, slow light effect becomes more obvious.

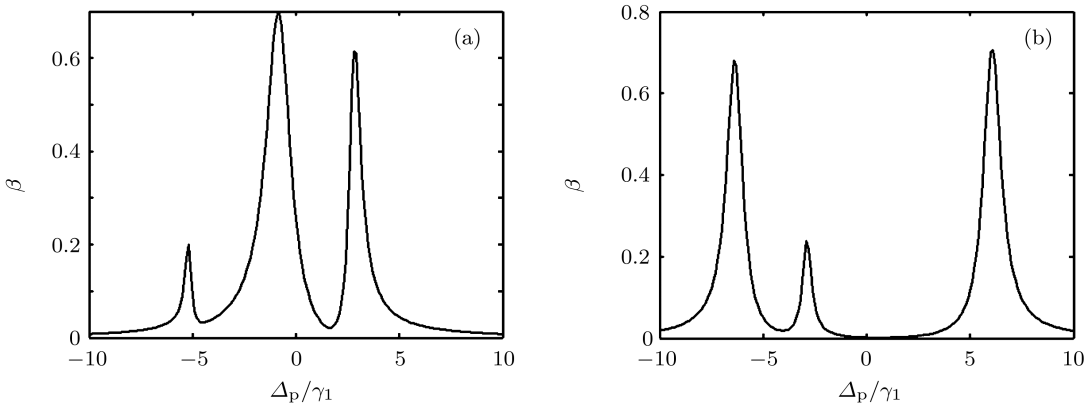


Fig. 4. Absorption curves for (a) case I with physical parameters of the system $\kappa = 0.75\gamma_1$, $\gamma_1 = 0.8 \times 10^6$ s^{-1}, $\Delta_c = 0.1\gamma_1$, $\Delta_b = 3\gamma_1$, $\gamma_2 = 0.2\gamma_1$, $\gamma_3 = 0.05\gamma_1$, $\Omega_b = 3\gamma_1$, and $\Omega_c = 2\gamma_1$, and for (b) case II with physical parameters of the system $\kappa = 0.75\gamma_1$, $\gamma_1 = 0.8 \times 10^6$ s^{-1}, $\Delta_c = 0.1\gamma_1$, $\Delta_b = 3\gamma_1$, $\gamma_2 = 0.2\gamma_1$, $\gamma_3 = 0.05\gamma_1$, $\Omega_b = 2\gamma_1$, and $\Omega_c = 6\gamma_1$.

4. Conclusion

Under the two different cases, we have investigated the absorption for a weak pulsed field interacting with a triple semiconductor quantum well structure. Some results in the two cases are compared with each other. For the case II, our studies show that the transparent media can be achieved under the condition of interaction of strong control field. The technique of electromagnetically induced transparency in semiconductor quantum well has the wide potential applications in diverse fields such as nonlinear spectroscopy at very low light intensity and quantum information science. Compared with the case in atomic system, semiconductor quantum well may easily be designed and integrated, so it has more practical value. In addition, a scheme of propagation of slow light for the input field is proposed. If we consider the interaction of a strong control field, we can obtain ultra-slow group velocity of the input field ($V_g/c \sim 10^{-4}$). The achievement of ultra-slow light is based on an index enhancement due to quantum coherence. Slow light proposed in the present work may lead to important applications such as high fidelity optical delay lines and optical buffers.

Next, we discussed the experimental feasibility of our scheme. In Dynes *et al.*'s[29] studies in a semiconductor quantum well, resonant optical coupling experiments have demonstrated the coherent quantum interference in a synthesized 3-level electronic system. Their sample consisted of 30 periods, each with a 4.8-nm $In_{0.47}Ga_{0.53}As$/0.2-nm $Al_{0.48}In_{0.52}As$/4.8-nm $In_{0.47}Ga_{0.53}As$ coupled quantum well, separated by modulation-doped 36-nm $Al_{0.48}In_{0.52}As$ barriers. A separate absorption saturation intensity measurement can give the decay rate. Subsequent studies[30,31] investigated the properties of coherent population trapping, absorption and dispersion. Our study is a natural extension and our model is for a synthesized 4-level electronic system where some theoretical results have been analysed by some researchers.[20,27,28] Based on the technique of quantum coherence in semiconductor quantum well, our theoretical work maybe has a feasibility in the future.

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