Optical Control of Indirect Exciton Population in an Asymmetric Quantum Dot Molecule: Application of Controlled Rotation

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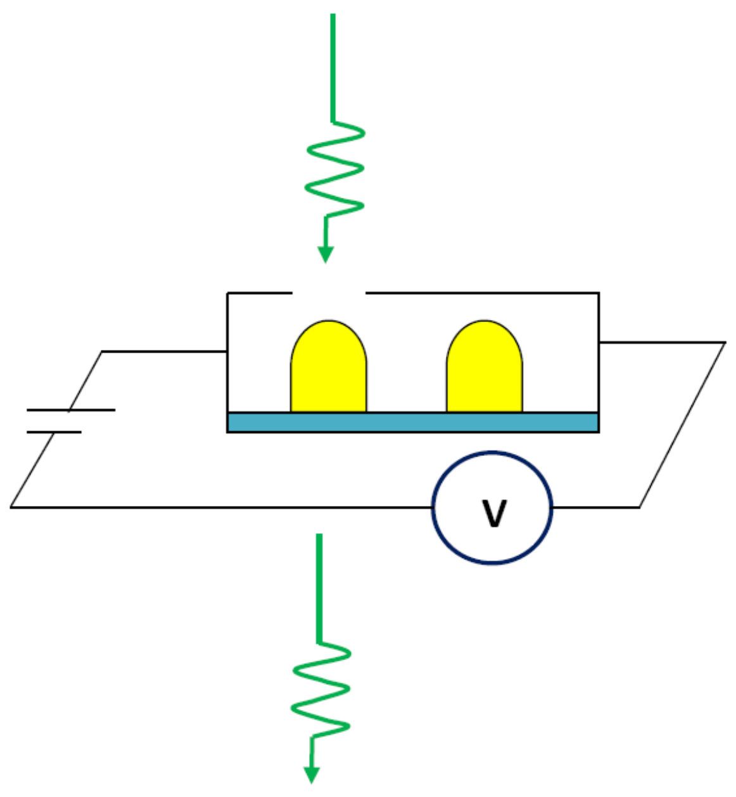
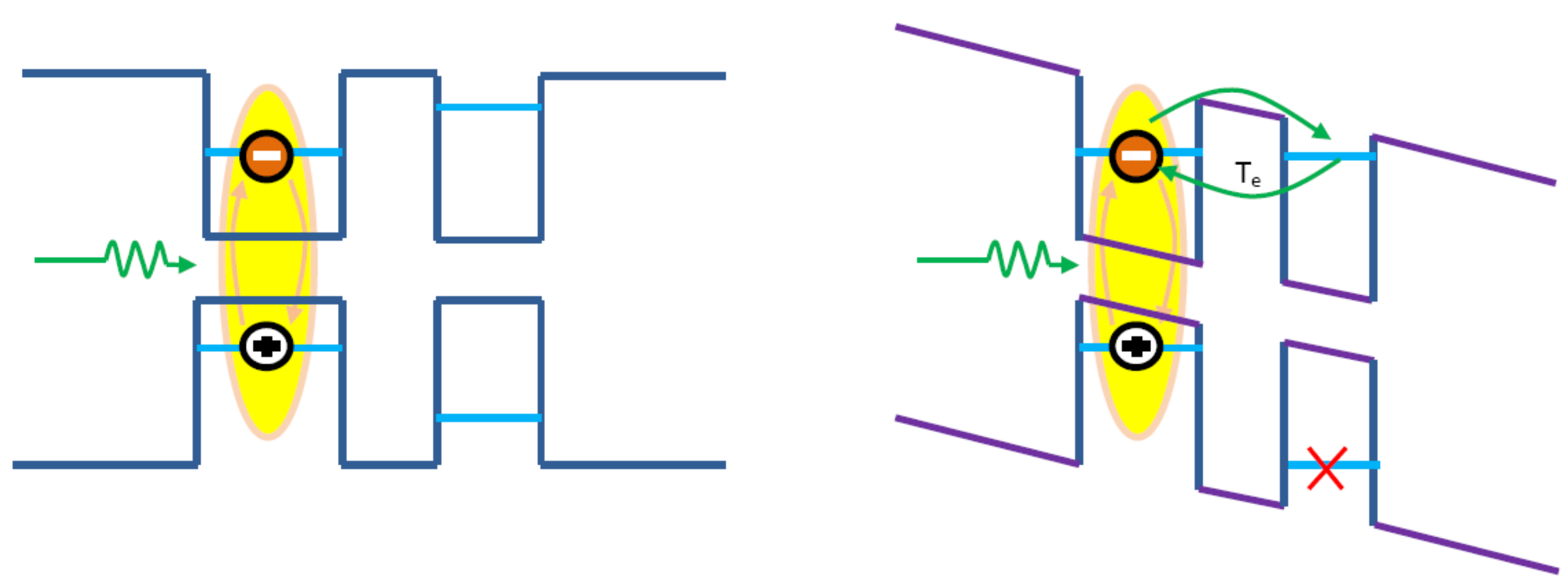
SCOPE OF THIS WORK: The coherent control of the population dynamics in an asymmetric double semiconductor quantum dot molecule that interacts with a strong electromagnetic field has attracted some attention in recent years [1-3]. The semiconductor nanostructure [1-3] consists of two quantum dots with different band structures coupled by tunneling. At nanoscale interdot separation the hole states are localized in the quantum dots and the electron states are rather delocalized. With the application of an electromagnetic field an electron is excited from the valence band to the conduction band of one of the quantum dots. This electron can be transferred by tunneling to the other quantum dot. The tunneling barrier can be controlled by placing a gate electrode between the two quantum dots. Particular attention has been given to the potential of complete or highly efficient population transfer to the indirect exciton state (|2>, electron and hole in different quantum dots) [1-3].

Here, we also address the problem of population transfer to the indirect exciton state |2>. Using the *controlled rotation method* [4,5], we obtain analytical solutions of the time-dependent Schrödinger equation and determine new closed-form conditions for the frequency and intensity of the applied field that lead to complete population transfer to the indirect exciton state, in the absence of decay and dephasing mechanisms. Then, by numerical solution of the relevant density matrix equations we study the influence of decay and dephasing mechanisms to the efficiency of population transfer, and show that the efficiency depends critically on the tunneling coefficient.





Left Figures: Left: Schematic of the setup. An electromagnetic field drives strongly the left quantum dot. V is a bias voltage. Center and right: Schematic of the band structure. Center: without a gate voltage, electron tunneling is weak. Right: with applied gate voltage, conduction band levels get into resonance, increasing their coupling, while valence-band levels become even more off-resonance, resulting in effective decoupling of those levels.

$$\frac{\hat{H}}{\hbar} = \sum_{j=0}^{2} \omega_j \,|j\rangle\langle j| + \left(\frac{\Omega}{2} e^{i\omega t} |0\rangle\langle 1| + T_e |1\rangle\langle 2| + H.c. \right)$$

General conditions for *complete* population transfer (without population decay and dephasing):

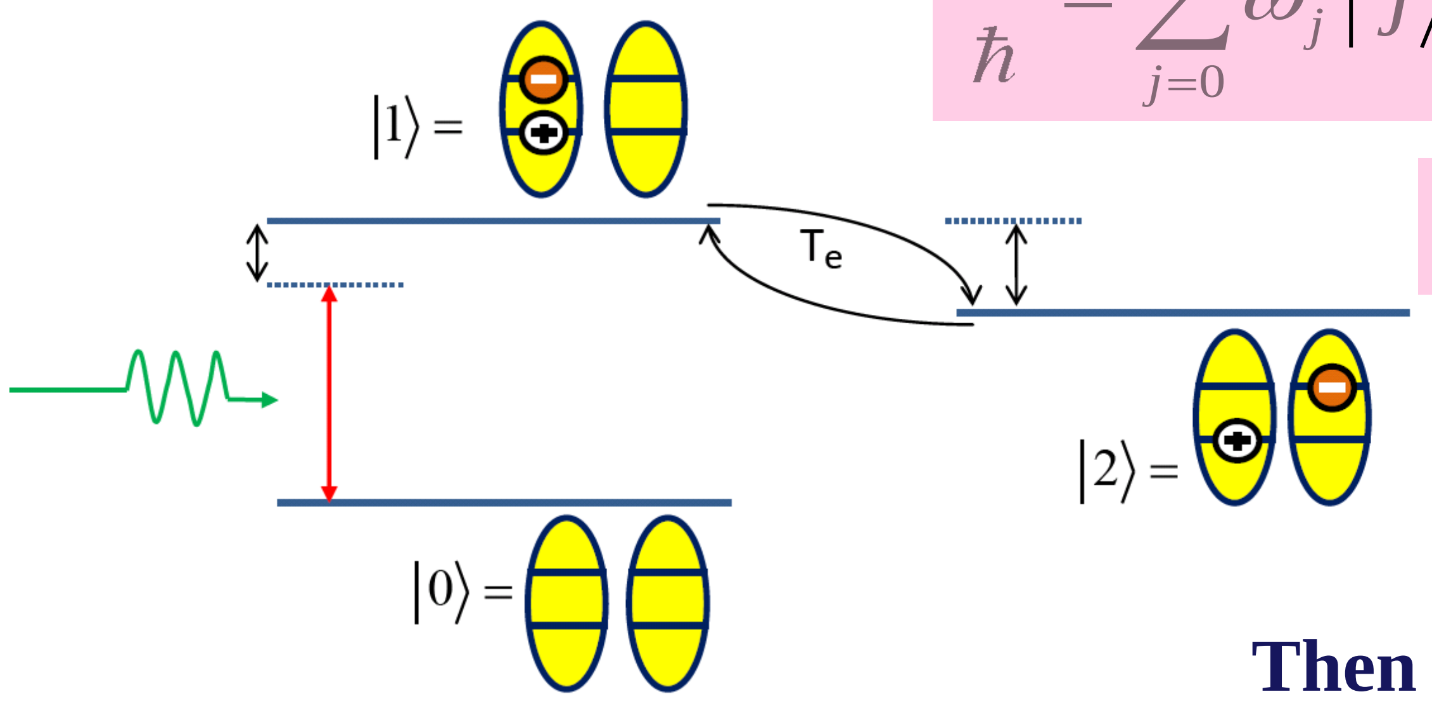
$$\omega = \omega_2 - \omega_0 \qquad \Omega = 2T_e$$

$\omega_{12} = \omega_1 - \omega_2 = 0$ **Complete population transfer to state |2> occurs at times** $t_p = n\pi \big/ \left(\sqrt{2} T_e\right)$

$\omega_{12} \neq 0$ **Complete population transfer to state |2> occurs only if**

$$T_e = \sqrt{2m-1}\,\omega_{12} \big/ \left[2\sqrt{2}\,(m-1) \right]$$

Then complete population transfer occurs at times $t_p = n\dfrac{2\pi(m-1)}{\omega_{12}}$ $\quad m = 2,3,4,\ldots \quad n = 1,3,5,\ldots$



Upper Figure: Schematic level configuration of the double quantum dot system. T_e is the electron tunneling coupling coefficient between the two quantum dots. Ω is the Rabi frequency of the 0-1 transition and ω is the angular frequency of the applied electromagnetic field.

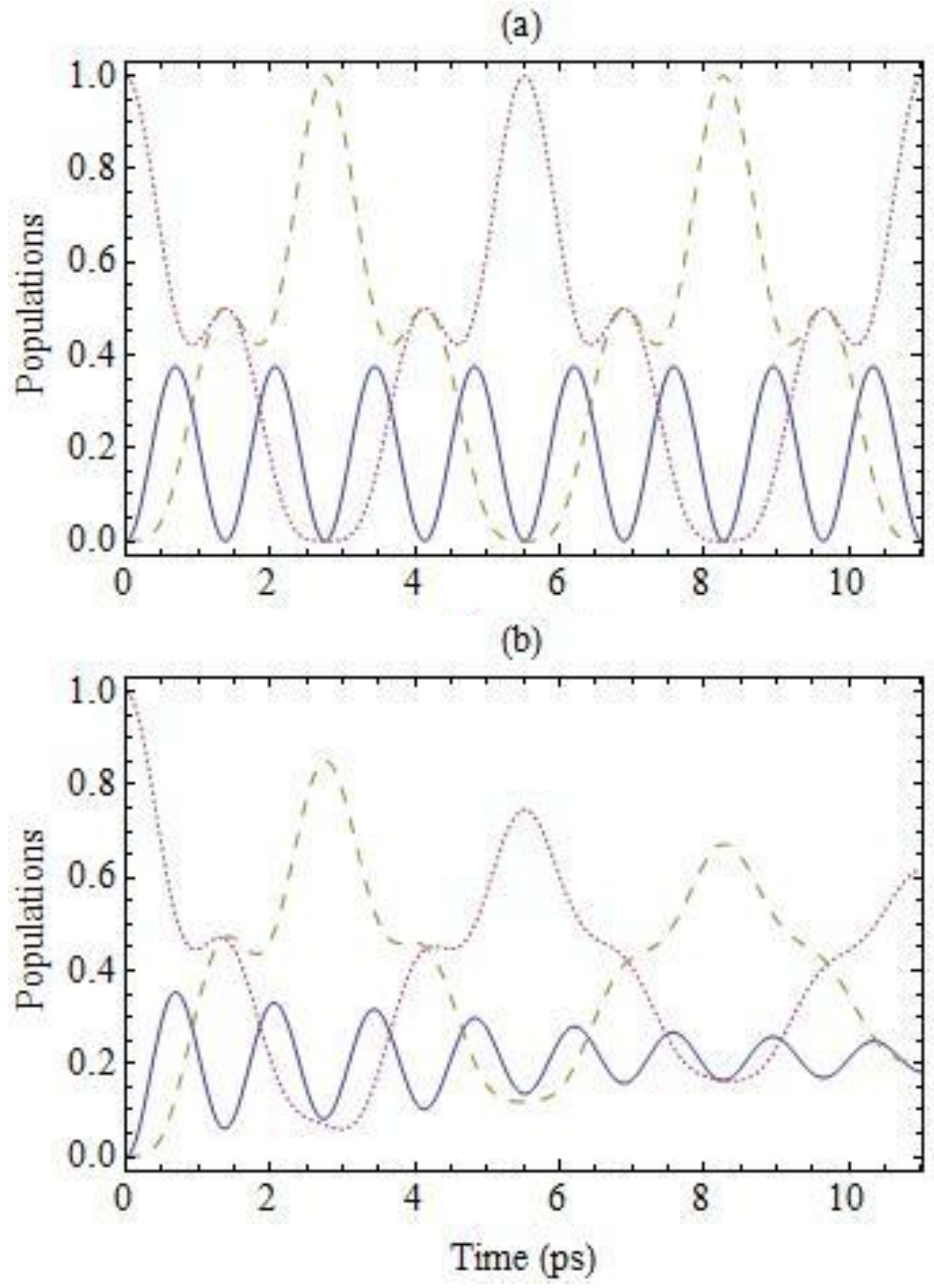


Figure 2: The same as in Fig. 1 for $\hbar\omega_{12}$ = 1.5 meV and T_e fulfilling the above condition for m = 2.

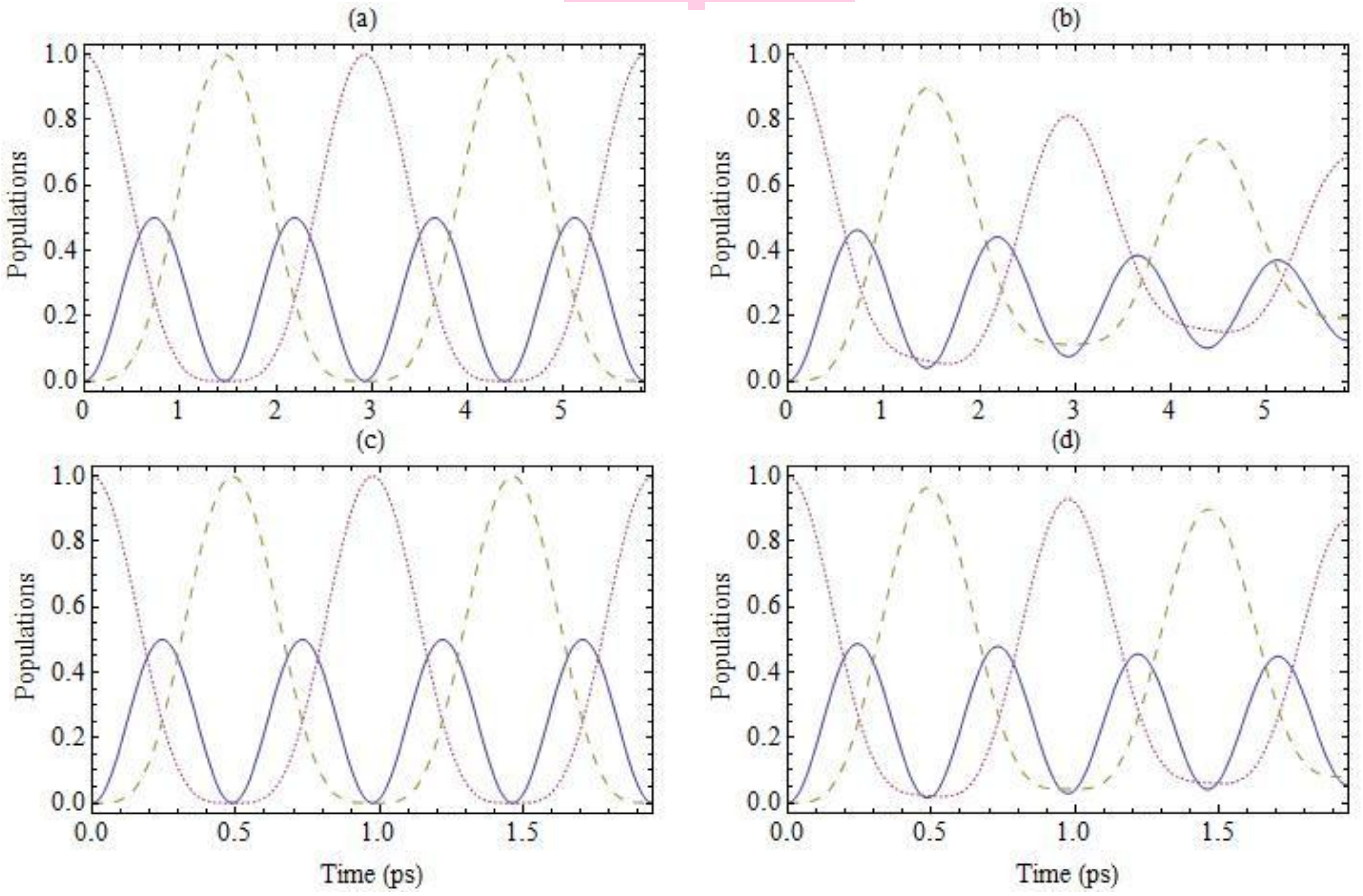


Figure 1: The population in state |0> (dotted curve), |1> (solid curve) and |2> (dashed curve) as a function of time for ω_{12} = 0 and (a), (b) $\hbar T_e$ = 1 meV, (c), (d) $\hbar T_e$ = 3 meV. (a) and (c) are without population decay or dephasing effects and in (b) and (d) typical parameters for InAs/GaAs quantum dots are used for decay and dephasing times [3].

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