OPTICAL RESPONSE OF AN ASYMMETRIC QUANTUM DOT MOLECULE UNDER PUMP-PROBE EXCITATION

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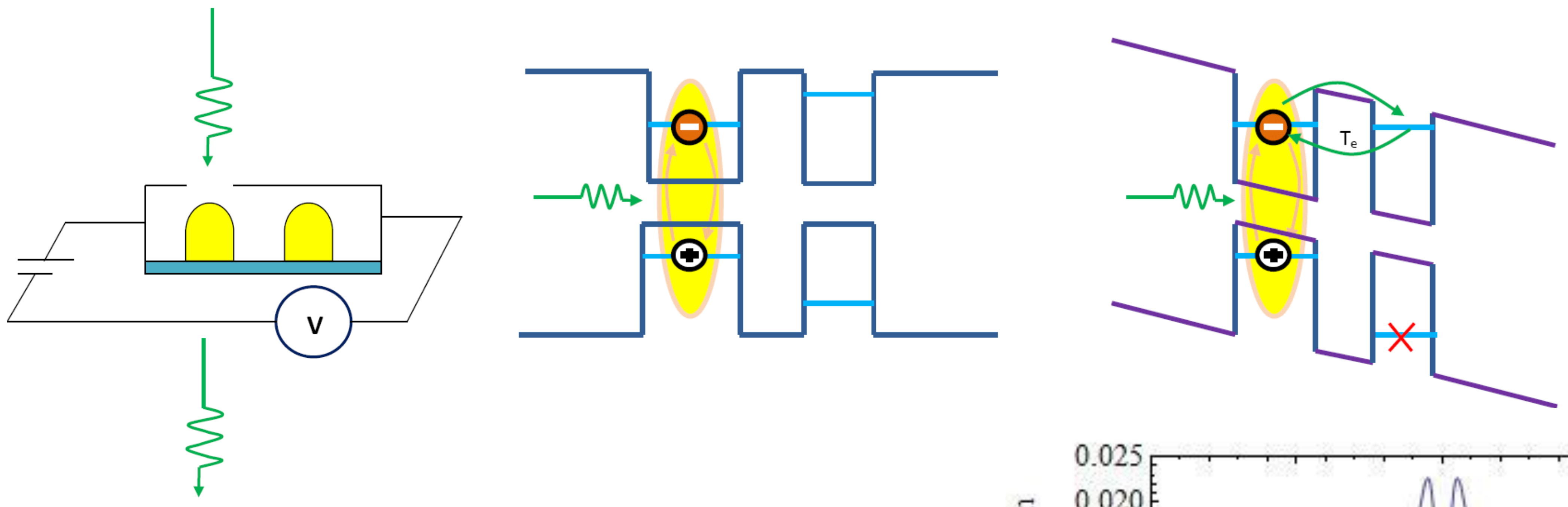
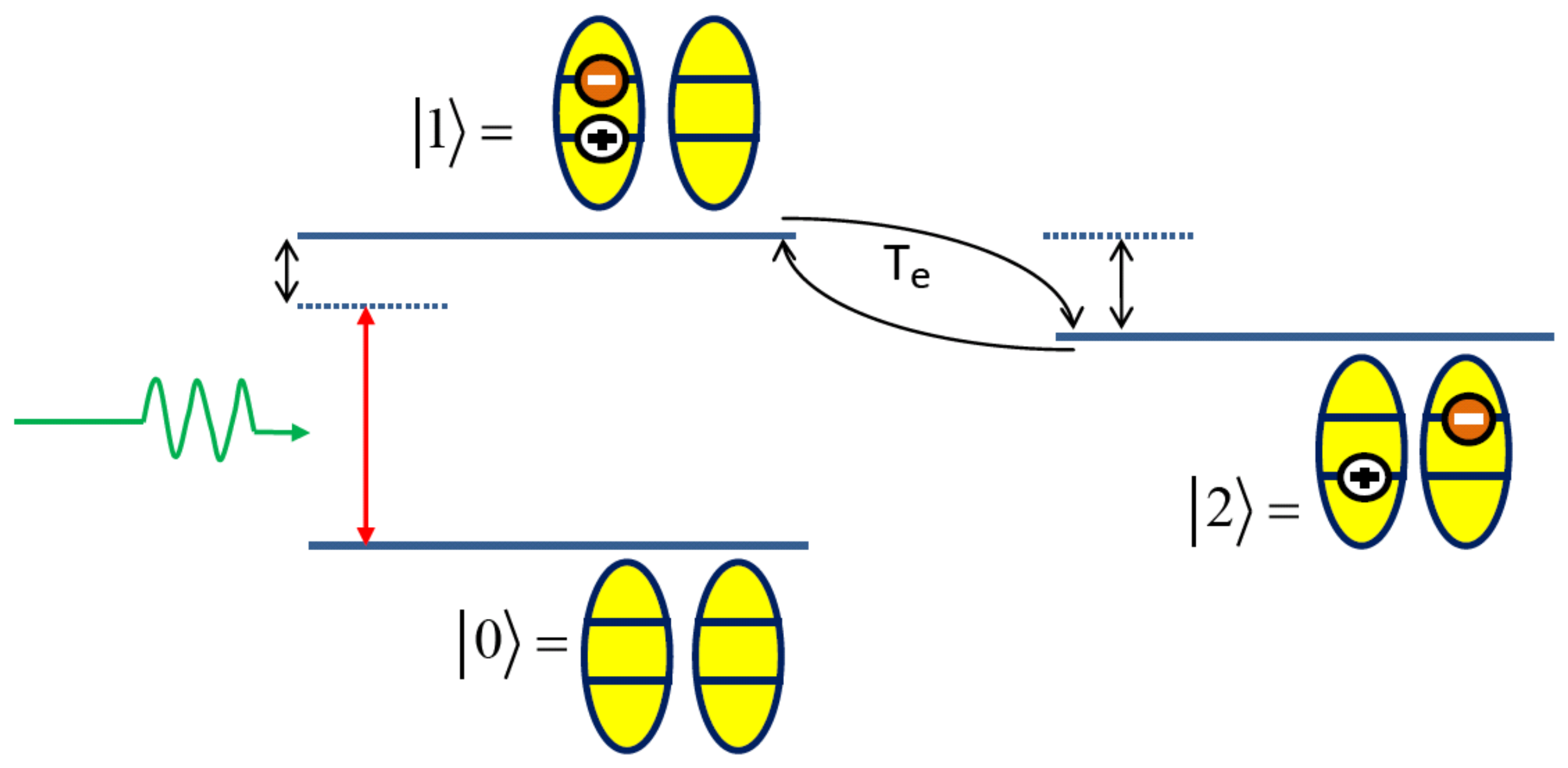
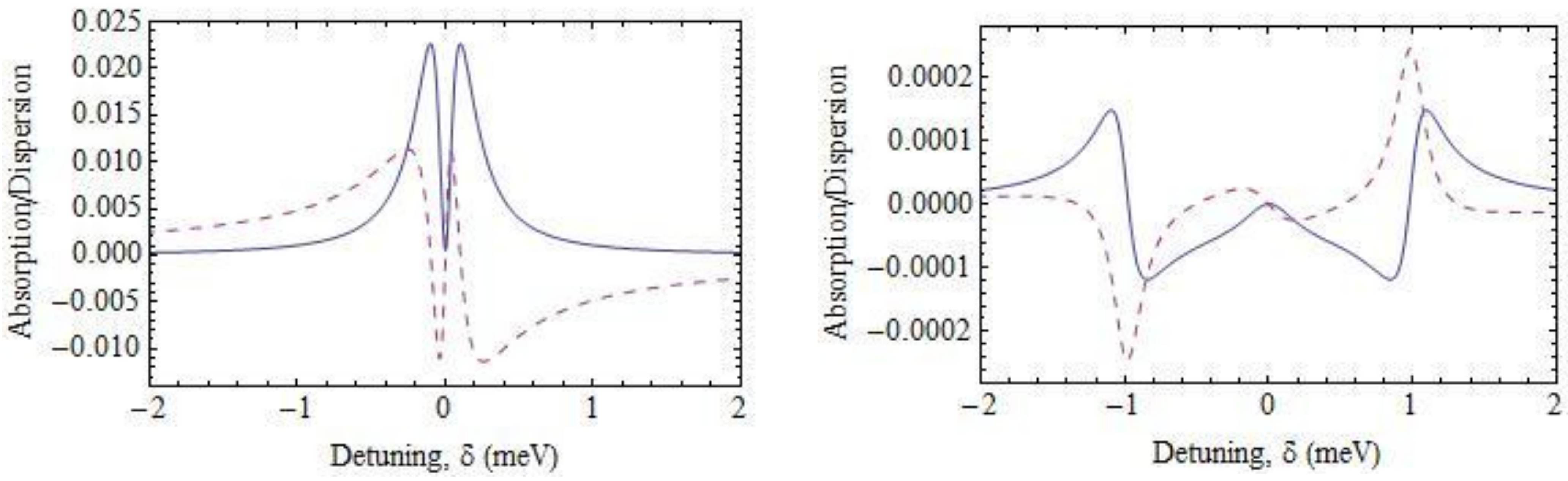
SCOPE OF THIS WORK: The nonlinear optical response of a two-level system interacting with a strong pump field and a weak probe field can lead to absorption, the ac-Stark effect, optical gain, enhanced nonlinear mixing processes, enhanced index of refraction without absorption, enhanced Kerr nonlinearity with low absorption and slow light. Some of these effects have been also studied in semiconductor quantum dots [1,2]. Here, we consider an asymmetric double semiconductor quantum dot molecule [3-5] that interacts with a weak probe field and a strong pump field. The nanostructure 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. In this system tunneling induced transparency and slow light have been analyzed under its interaction with a weak probe field [3-5]. For the theoretical analysis of the optical properties of the system under pump and probe excitation we use a density matrix approach where we assume that the pump field is strong and should be treated to all the orders, while the probe field is weak and should be treated to first order [6-8]. We show that the optical response of the system can be controlled by the gate voltage and the pump field. For example, we find that the application of the pump field leads to probe absorption, optical gain and the ac-Stark effect for weak tunneling rates, while for stronger tunneling rates optical gain disappears.



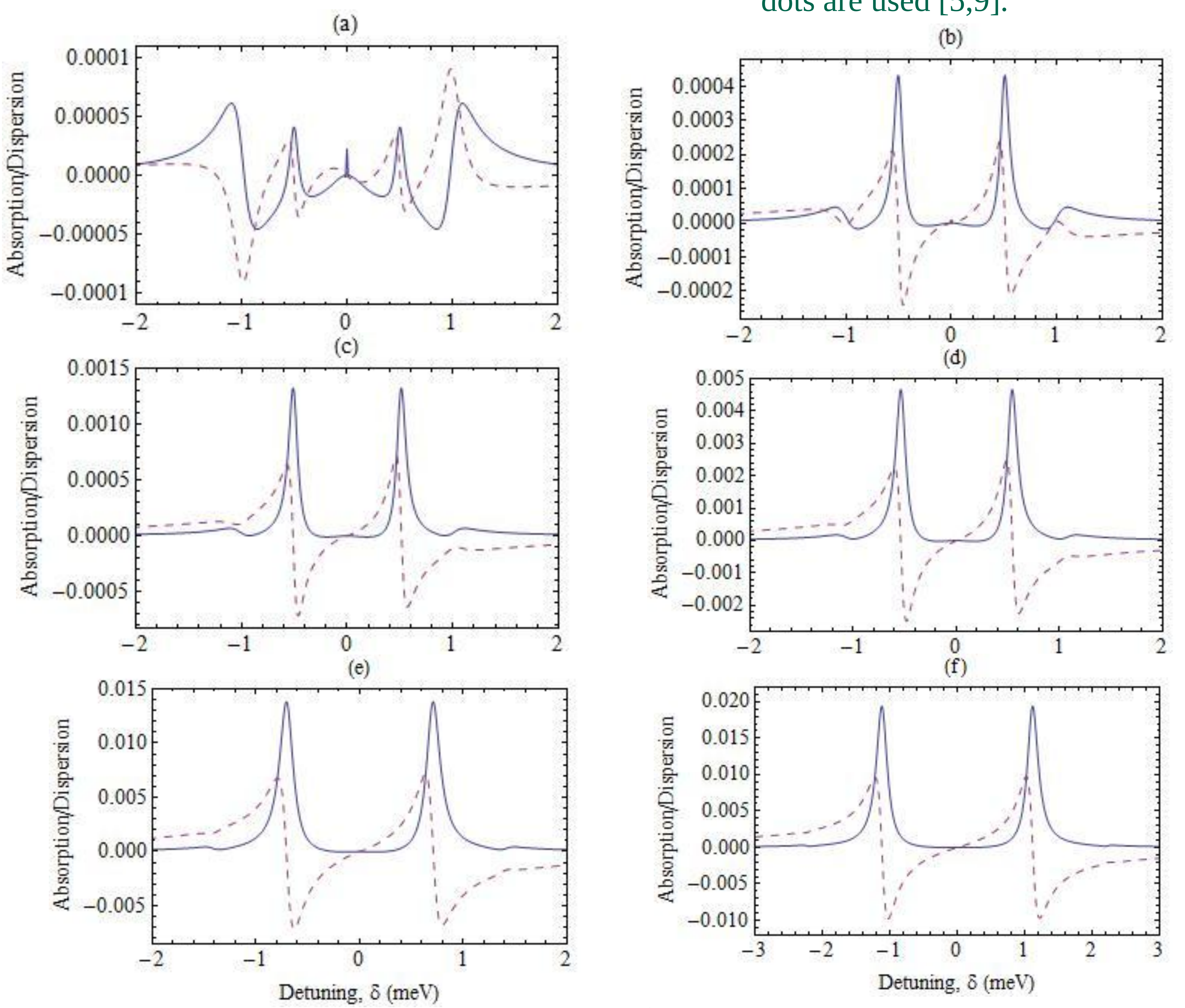
Left Figures: Left: Schematic of the setup. An electromagnetic field drives strongly the left quantum dot. V is a bias voltage. Center and right: Schematic of the band structure. Center: without a gate voltage, electron tunneling is weak. Right: with applied gate voltage, conduction band levels get into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



Upper Figure: Schematic level configuration of the double quantum dot system. T_e is the electron tunneling coupling coefficient between the two quantum dots.



Upper Figures: Left: The absorption (solid curve) and the dispersion (dashed curve) spectrum, in arbitrary units, with no pump field (Rabi frequency of the pump field $\Omega_a = 0$) and $\hbar T_e = 0.1$ meV. Right: The same for the pump field at exact resonance with the 0-1 transition, $\hbar\Omega_a = 1$ meV and no tunneling ($T_e = 0$). Typical values for InAs/GaAs quantum dots are used [5,9].



Left Figures: The absorption (solid curve) and the dispersion (dashed curve) spectrum, in arbitrary units, for the pump field at exact resonance with the 0-1 transition, $\hbar\Omega_a = 1$ meV and (a) $\hbar T_e = 0.03$ meV, (b) $\hbar T_e = 0.06$ meV, (c) $\hbar T_e = 0.1$ meV, (d) $\hbar T_e = 0.2$ meV, (e) $\hbar T_e = 0.6$ meV and (f) $\hbar T_e = 1$ meV.

REFERENCES

[1] X.-D. Xu *et al*., Phys. Rev. Lett. **101**, 227401 (2008).
[2] S.-W. Chang and S. L. Chuang, Phys. Rev. B **72**, 235330 (2005).
[3] C.-H. Yuan and K.-D. Zhu, Appl. Phys. Lett. **89**, 052115 (2006).
[4] M. Ioannou, J. Boviatsis and E. Paspalakis, Physica E **40**, 2010 (2008).
[5] H. S. Borges *et al*., Phys. Rev. B **85**, 115425 (2012).
[6] S. G. Kosionis, A. F. Terzis, and E. Paspalakis, Appl. Phys. B **104**, 33 (2011).
[7] S. G. Kosionis, A. F. Terzis, and E. Paspalakis, J. Appl. Phys. **112**, 073117 (2012).
[8] S. G. Kosionis, A. F. Terzis, and E. Paspalakis, J. Lumin. **140**, 130 (2013).
[9] H.-F. Yao, N. Cui, Y.-P. Niu, and S.-Q. Gong, Photon. Nanostr.: Fund. Appl., **9**, 174 (2011).

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