FOUR-WAVE MIXING IN INTERSUBBAND TRANSITIONS OF SEMICONDUCTOR QUANTUM WELLS: TRANSIENT EFFECTS

Spyridon G. Kosionis[a], Andreas F. Terzis[a] and Emmanuel Paspalakis[b]

[a] *Department of Physics, School of Natural Sciences, University of Patras, Patras 265 04, Greece*

[b] *Materials Science Department, School of Natural Sciences, University of Patras, Patras 265 04, Greece*

SCOPE OF THIS WORK: Our group has recently studied theoretically the nonlinear optical response of strongly-driven intersubband transitions of symmetric double semiconductor quantum well structures, taking into account the effects of electron-electron interactions [1-3]. In the present work we continue this work and analyze the nonlinear optical response of strongly driven intersubband transitions of semiconductor quantum wells in the transient regime [4]. Specifically, we study the time evolution of the four-wave mixing of a strongly-driven two-subband system. The theoretical model is based on the interaction of two rectangular shaped electromagnetic fields, a strong pump and a weak probe field, with two quantum well subbands. In order to describe the dynamics of this system, we use the effective nonlinear Bloch equations [5] and derive the relevant density matrix equations for the several nonlinear optical processes [1-3]. The interaction with the weak probe field is treated to first perturbative order, while the interaction with the pump field is treated in all orders. These equations are solved numerically, for a specific semiconductor quantum well structure, for different values of the electron sheet density, the frequency and the intensity of the pump field. All these parameters have significant influence on the time evolution of the four-wave mixing spectrum. We find that even in the case in which the spectral form in the steady state case is almost identical for two different sets of parameters, their evolution can be quite different, according to the precise value of these parameters.

EFFECTIVE NONLINEAR OPTICAL BLOCH EQUATIONS FOR INTERSUBBAND TRANSITION DYNAMICS IN A QUANTUM WELL

$$dS_1(t)/dt = [\omega_{10} - \gamma S_3(t)]S_2(t) - S_1(t)/T_2$$

$$dS_2(t)/dt = -[\omega_{10} - \gamma S_3(t)]S_1(t) + 2[\mu E(t)/\hbar - \beta S_1(t)]S_3(t) - S_2(t)/T_2$$

$$dS_3(t)/dt = -2[\mu E(t)/\hbar - \beta S_1(t)]S_2(t) - [S_3(t)+1]/T_1$$

- μ is the electric dipole matrix element between the two subbands.
- $E(t)$ is the total electric field applied to the quantum well structure.
- $\omega_{10}, \beta, \gamma$ are parameters defined by means of the envelope functions of the ground and excited states in the quantum well system and depend on electron sheet density.
- The relaxation processes in the system are described phenomenologically by the population decay time T_1 and the dephasing time T_2.

$$E(t) = \mathrm{E}_1 \cos(\omega_1 t) + \mathrm{E}_2 \cos(\omega_2 t),$$

$$L_{ijkl} = \iint dz dz' \xi_i(z)\xi_j(z')|z - z'|\xi_k(z')\xi_l(z),$$

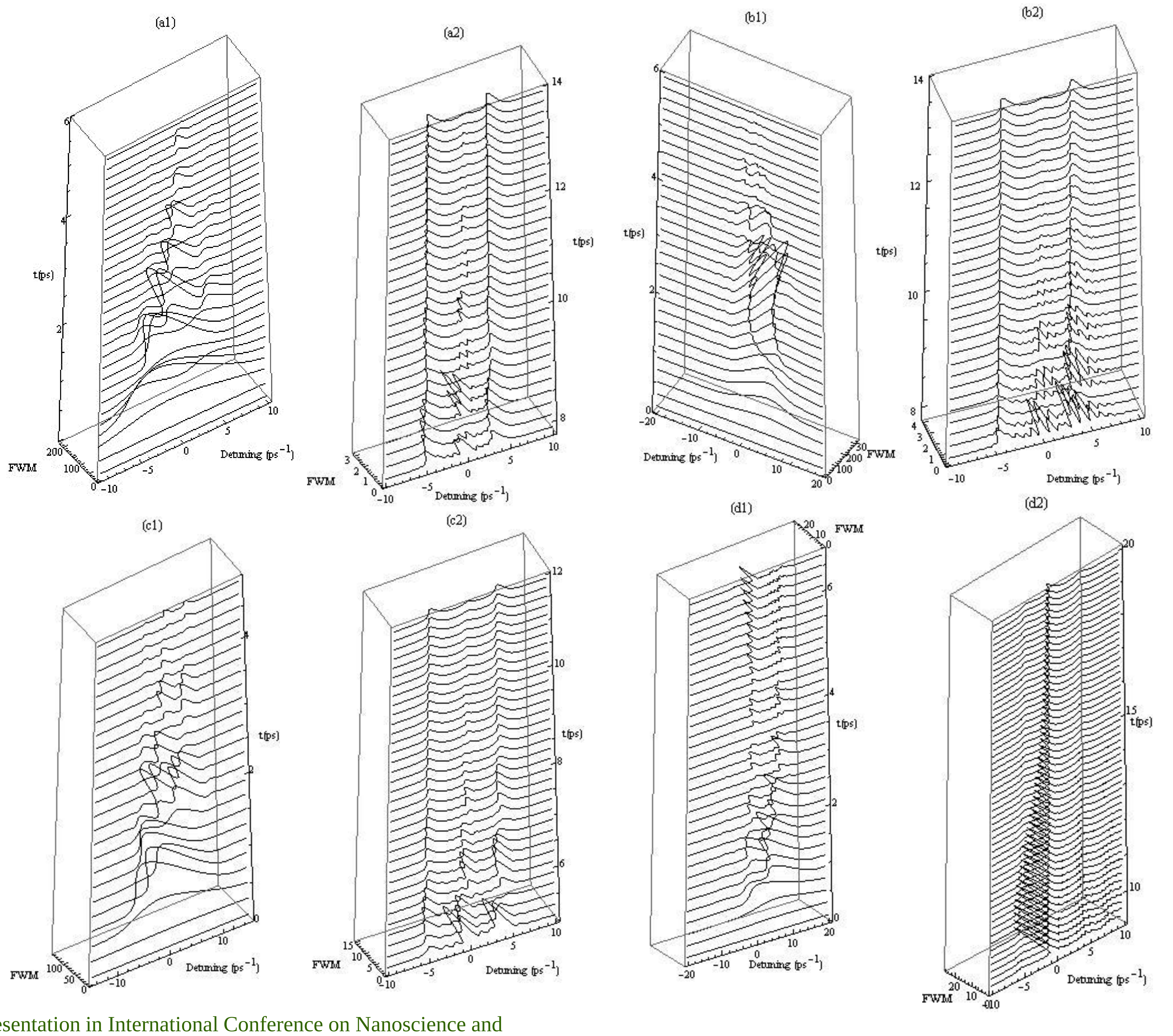
$$\omega_{10} = \frac{E_{10}}{\hbar} + \frac{\pi e^2 N}{2\hbar\varepsilon}(L_{1111} - L_{0000}),$$

$$\gamma = \frac{\pi e^2 N}{2\hbar\varepsilon}(2L_{1001} - L_{1111} - L_{0000}),$$

$$\beta = \frac{\pi e^2 N}{\hbar\varepsilon} L_{1100}$$

- N is the **electron sheet density**
- L_{ijkl}, is defined as the relevant length elements by means of the envelope functions
- $\xi_i(z)$ of the ground (n = 0) and first excited (n = 1) states in the quantum well

QUANTUM WELL STRUCTURE UNDER STUDY AND THEORETICAL PROCEDURE: We consider a **GaAs/AlGaAs** double quantum well. The structure consists of two GaAs square wells of width 5.5 nm and height 219 meV. The wells are separated by a AlGaAs barrier of width 1.1 nm. For this system we take T_1 = 5 ps and T_2 = 1 ps. We study the interaction of the quantum well structure with two rectangular shaped applied electromagnetic fields, a strong pump field and a weak probe field. The FWM spectrum is calculated by numerically solving the appropriate density matrix equations [1-3] for different intensities and frequencies of the pump field and different electron sheet densities. Typical results are presented below.



FIGURES: Transient FWM spectra (arbitrary units), as a function of the detuning $\delta = \omega_2 - \omega_1$, for different values of the electron sheet density [(a), (c): $N = 10^9$ cm^{-2}, (b), (d): $N = 7 \times 10^{11}$ cm^{-2}] and different values of the pump field detuning [(a), (b): Δ = 0 and (c), (d): Δ = 2 ps^{-1}]. We take the Rabi frequency of the pump field Ω = 4 ps^{-1} and the Rabi frequency of the probe field 200 times smaller.

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