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Microcavity effect on the nonlinear intersubband absorption in multiple-quantum-well structures: The strong coupling regime

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THE linear intersubband response of multiple-quantum-well (MQW) structures embedded in microcavities has been studied by many authors for, both fundamental physics and application reasons. In particular, the strong-coupling-regime, in which the dipole coupling between intersubband excitation and the cavity photon gives rise to coherent mixed modes, often referred to as "intersubband cavity polaritons", has recently received a lot of attention [1-3].

In view of applications for optoelectronic devices, the analysis of the nonlinear intersubband properties is a fundamental and intriguing field of microcavity physics. The previous works devoted to the above mentioned subject concentrated on the systems where conditions for the strong coupling regime (SCR) are not fulfilled [4-7].

In this paper, we discuss theoretically the influence of the cavity effect on the nonlinear intersubband response going beyond the weak coupling regime. For this purpose we employ a non-iterative numerical method developed in our recent paper [6]. It is based on the transfer matrix method and the so-called sheet model. The advantage of this approach is that it not only goes beyond the commonly used slowly varying amplitude approximation (see e.g., Ref. 4) but also automatically includes radiative coupling among QWs. Some preliminary results, obtained for a standard total internal reflection geometry, have already been reported [6,7]. The method is very general and can be used for arbitrary layered structures with embedded MQWs. Nevertheless, performing numerical calculations we neglect for simplicity the influence of the electron-electron interaction on the intersubband response [5,8]. In other words we take into account only the saturation effect associated with the light induced redistribution of electrons between the ground and excited subband. The above approximation has a good justification when, like in the structure studied by Dupont et al. [1], the surface electron concentration is relatively small ($N_s < 10^{11}$ cm^2) [8]. For this reason we will concentrate on the systems with low N_s. However, to fulfill conditions for the SCR, we assume that the MQW contains a large number of QWs.

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We have carried out the calculations of the absorption spectra (at different intensities of the incident light) for microcavities, similar to studied recently by Dupont et al. [1] and Plumridge et al. [2]. In the on-resonant case, we have observed quantitatively an anharmonic evolution from the two vacuum Rabi peaks in the low-intensity regime to the single absorption peak in the high intensity limit. In the transition region, the vacuum Rabi peaks shift and deform and absorption exhibits multistable behavior. Out of the resonance, asymmetry in the peak deformation is observed. The above mentioned evolution is consistent with: (i) the experimentally observed evolution of the vacuum Rabi peaks in the transmission spectrum of an optical cavity filled with two-level atoms [9], and (ii) the theoretical description based on the steady state solution of the Maxwell-Bloch equations [9,10].

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