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Coherent light from E-field induced quantum coupling of exciton states in superlattice-like quantum wells

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Coherences and electronic couplings at the quantum level in semiconductor nanostructures are currently investigated intensely because of fundamentally new properties that may become important for new optoelectronic devices. Examples include observations of electric-field-induced level splitting of 1.8 meV, without a bias field as shown in Figure 1(c), because of excitation well above the bandgap, creating electric fields leading to a strong modification of the coherent light emission, in particular at a bias where a superlattice-like miniband is formed. More specifically, we investigate a MBE-grown GaAs sample with a sequence of 15 single quantum wells having a successively increased degree of exciton coherence, in particular at a bias where a superlattice-like miniband is formed. More specifically, we investigate a MBE-grown GaAs sample with a sequence of 15 single quantum wells having a successively increased degree of exciton coherence, in particular at a bias where a superlattice-like miniband is formed.

In resonant four-wave mixing experiments, however, the spectra in Figure 1(c) clearly show consistent shifts of the individual lines as the bias field is increased. Focussing on the partially aligned first six lines as the bias field is increased, we can observe electronic oscillations in superlattices leading to a strong modification of the coherent light emission, in particular at a bias where a superlattice-like miniband is formed. More specifically, we investigate a MBE-grown GaAs sample with a sequence of 15 single quantum wells having a successively increased degree of exciton coherence, in particular at a bias where a superlattice-like miniband is formed.

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Rabi oscillations and Raman coherences in semiconductor quantum wells

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Optical Rabi oscillations are strictly defined in terms of two-level systems (atoms or molecules) that are exposed to a stationary coherent light field in or close to resonance. In these systems the population oscillates harmonically between the lower and the upper electronic level. The observation of excitonic Rabi oscillations (i.e., the semiconductor analog to the case of atomic 2-level systems) has been achieved only recently \(^1\) (see also the invited talk by Schulzgen et al. at this conference).

In contrast to atomic two-level systems and their semiconductor 2-band counterpart, the study of 3-level systems and their semiconductor 3-band counterpart is of fundamental importance in the area of light-induced non-radiative quantum coherences (Raman coherences), which cannot occur in 2-level systems.

In this contribution, we investigate theoretically the relation between generalized Rabi oscillations involving optical transitions in three-band systems and Raman coherences. The theoretical basis can be found in Ref. 3. The system under consideration is a conventional GaAs semiconductor quantum well in which only the lowest subband of the conduction band, the heavy-hole (hh) and the light-hole (lh) bands need to be taken into account. We consider two simultaneous, strong sub-picosecond pulses (770 fs) of opposite circular polarization, spectrally centered at the hh and the lh-exciton, respectively (see Figure 1). In this configuration we create both, the intervalence-band Raman coherence and excitonic optical Rabi oscillations. In order to balance the lower hh-oscillator strength as compared to the lh-exciton, the amplitude of the pulse centered at the lh-exciton has been chosen to be three times larger than that of the other pulse. Figure 2(a) documents the 3-band Rabi oscillations, occurring for the electron, the hh and the lh density. In Figure 2(a), no incoherent processes are taken into account so that the ideal quantum coherence can be analyzed properly. The fast and somehow irregularly looking oscillations are hh-lh quantum beats. In Figure 2(b) the results without Raman coherence show an almost complete suppression of the hh-Rabi oscillations for this choice of light-pulse amplitudes. Figure 2(c) shows the effect of dephasing, which, as usual, reduces significantly the contrast in the Rabi oscillations.


Laser-induced Rabi oscillations in semiconductors

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The microscopic understanding of coherent light-matter interactions is an important goal of solid-state physics which can be exploited in ultrafast optoelectronics. One of the most fundamental coherent effects is that of Rabi oscillations, whereby a strong resonant field induces temporal oscillations of the electron density between ground and excited state.\(^1\) This effect has been studied extensively in atomic and molecular two-level systems. Although, semiconductors differ from ideal two-level systems due to mutual interactions of the extended electronic excitations, modified Rabi oscillations have been predicted theoretically to occur also in semiconductors.\(^2\) However, the short relevant time scales make experimental observation difficult. In previous studies the observations were limited to one or two density maxima due to ultrafast scattering times below 100 fs.\(^3\)\(^4\)

We apply a two-color pump-probe scheme (see Figure 1) that enables the observation of several cycles of clearly resolved excitonic Rabi oscillations in a semiconductor quantum well. A 770 fs \(\sigma^-\) circularly polarized pump pulse with a narrow spectrum excites resonantly heavy hole (hh) excitons consisting of \(m_\text{hh} = 3/2\) holes and \(m_\text{lh} = +1/2\) electrons. The electron population and its dynamics are probed using a 150 fs \(\sigma^+\) pulse with a center frequency at the light hole (lh) exciton transition. The linear transmission spectrum of the In\(_{0.53}\)Ga\(_{0.47}\)As/GaAs sample and the pump spectra are shown in Figure 1(b) and (c), respectively.

Figure 2(a) shows the differential transmission signal (DTS) of the probe pulse at the position of the lh exciton resonance. While the pump pulse drives the population oscillations the shorter probe pulse is time-gating the transmission changes. We can clearly resolve a sequence of eight Rabi oscillations. In contrast to previous work, where 100 pulses were used,\(^3\)\(^4\) our long pump pulses have large (several \(\pi\)) areas at relatively small field intensities. Correspondingly, the induced carrier densities are quite low resulting in weak excitation-induced dephasing, and, accordingly, long time win-