Orientation efficiency and unavoidable decoherence in optical initialization of hole spins in p-doped quantum wells

Michał Gawełczyk and Paweł Machnikowski

Institute of Physics, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

Hole spin dynamics in semiconductors is a highly explored field in solid state physics due to its possible applications in rapidly developing field of spintronics. Recently, an optical hole spin initializtion scheme for p-doped quantum well or dot systems via coupling to trion states with sub-picosecond circularly polarized laser pulses was demonstrated [1, 2]. In this theoretical study, we analyze the efficiency of spin initialization and predict the intrinsic spin coherence loss due to the pulse excitation itself as well as the phonon-induced spin dephasing, both taking place on the timescale of the driving laser pulse. Such decay of coherence may be important in future applications but it affects also the results of experiments carried out currently, especially those based on the resonant spin amplification effect [1, 3], where the formation of the observed signal depends essentially on the spin coherence.

Spin states under optical excitation may undergo pure dephasing due to dynamical phonon response to the transient charge evolution [4]. Even if not directly coupled to the reservoir, spin is indirectly dephased through the entangling charge evolution caused by the optical pulse. We show that indeed such a dephasing process is present in the considered system. Morover, we find that the laser pulse itself causes a significant amount of decoherence. Therefeore, some degree of dephasing is unavoidably built into the initialization scheme. Since both the degree of dephasing as well as the orientation efficiency are proportional to the excitation power, it is impossible to reduce the relative loss of coherence by using weak excitation.

Therefore, we focus on the ratio of the degree of dephasing to the achieved orientation effect as a resonable figure of merit and study its dependence on both carrier system and laser pulse parameters. We show that it does not depend on the pulse area but is sensitive to the temperature and detuning. Our results alow us to identify the optimal excitation parameters.

The obtained dependence of the degree of dephasing on detuning is in a qualitative agreement with the recent experimental data [1] for resident hole spins in p-modulation-doped GaAs/$Al_{0.3}Ga_{0.7}As$ single QWs.

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