Optical Orientation Of Electron And Nuclear Spins In Negatively Charged InP QDs

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Abstract. Light-induced spin orientation in negatively charged InP quantum dots is shown experimentally to be conserved for about 1 ms.

INTRODUCTION

The long-term orientation of spin systems in semiconductor structures attract in recent years considerable attention as a promising way of recording and storage of optical information [1]. The most interesting, from this point of view, are the structures with quantum dots (QD), where, due to confinement of the carrier motion, the main spin-relaxation processes appear to be suppressed. According to theoretical estimates [2], the spin lifetime in such structures may reach units of ms and more. The so long lifetimes of the optically oriented electron spins in QDs have not been observed thus far. The longest lifetime of spin orientation (15 ns) was found experimentally in [3] in the studies of n-doped InAs QDs. In this communication, we present the results of experiments demonstrating conservation of the spin orientation for much longer time intervals.

EXPERIMENT AND DISCUSSION

We studied kinetics of circularly polarized photoluminescence (PL) of the negatively charged InP QDs. It was found that the degree of circular polarization of the PL shows a slow component with a decay time of about 1 ns. The amplitude of the slow component was the greatest when each QD possessed, on average, a single resident electron. For the Stokes shift $\Delta E_{st} > 25$ meV, the degree of polarization was negative.

In conformity with conclusions of [3], the negatively polarized PL is emitted by QDs in which spins of the photoexcited and resident electrons are parallel. When the resident electron spin is preferentially oriented along that of the photoexcited electron, the amplitude of the degree of the negative circular polarization (NCP) should increase. Using the amplitude of the NCP as a measure for the degree of orientation of the electron spin, we have carried out a series of experiments to determine the spin orientation lifetime.

In the experiments, the PL was excited by two laser pulse trains obtained by splitting the beam of a mode-locked Ti:sapphire laser. One of these trains was shifted in time using an optical delay line. The time delay was about 1 ns. Polarizations of the beams could be varied independently.

Figure 1a shows the kinetics of the degree of polarization of the PL excited by the second (probe) beam for two different polarizations of the first beam considered as a pump. As is seen, passing from the co-polarized to cross-polarized pump results in more than two-fold decrease of the NCP created by the probe pulse. This means that the spin orientation created by the first beam is held till the moment of arrival of the second beam, i.e., for about 1 ns.

To strongly increase the time interval between the two beams, we used a mechanical chopper, which alternatively blocked the pump and the probe beams with a frequency of 120 Hz. A typical result of the experiment is presented in Fig. 1b. It is seen that the NCP of PL after probe pulse still reveals a well reproducible change, $\Delta\rho \approx 5\%$, caused by the change of polarization of the pump pulse. This result demonstrates in a straightforward way conservation of the spin orientation during the modulation period of units of ms.

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So long conservation of the spin orientation is impossible without a stabilizing factor that suppresses the electron spin precession in random laboratory magnetic fields. In this case, the role of this factor is likely to be played by the fluctuating exchange field produced by nuclear spins [4]. To evaluate the fluctuations of the nuclear field, we have studied the behavior of the NCP at co- and cross-polarized pumping (with no chopper) in small transverse magnetic fields (Voigt configuration).

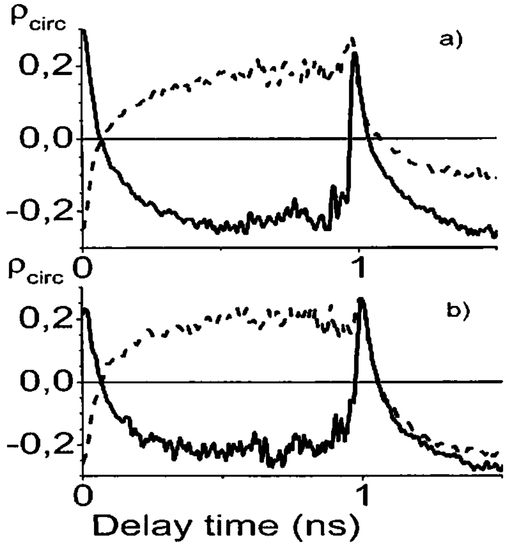

FIGURE 1. Kinetics of circular polarization degree at the two-pulse excitation: (a) without chopper, (b) with chopper blocking the beams alternatively. Solid (dashed) curves are for co- (cross-) polarized pump and probe beams.

The results of these studies are shown in Fig. 2. As one can see, dependences of the NCP on magnetic field, in the Voigt configuration, for the co- and cross-polarized pumping are strongly different. The difference between the values of the NCP for co- and cross-polarized pumping characterizes the spin orientation. Dependence of the degree of orientation on magnetic field is seen to be well described by a Lorentzian with a half-width of 0.01 T (curve 3 in Fig.2). According to conclusions of [4], this value corresponds to the mean value of the exchange field produced by fluctuations of the nuclear spins in the QD.

It follows from the above experimental data that the light-induced spin orientation in the negatively charged InP QDs is held during the time of about 10^{-3} s. This value exceeds by approximately 4 orders of magnitude the value of 150 ns, given in [5], which was considered until now a record value for semiconductor nanostructures.

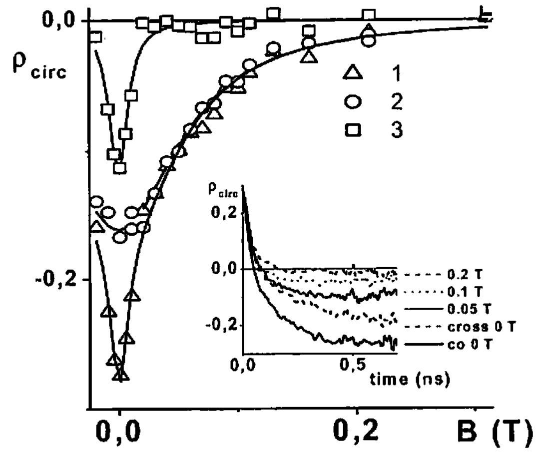

FIGURE 2. Dependences of NCP on trans-verse magnetic field: 1 is for co- and 2 for cross-polarized pump and probe, 3 is the difference between 1 and 2. Dots are experimental data, solid curves are fits by Lorentzians. Inset: kinetics of NCP at various magnetic fields.

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