Effects of Strain and Confinement in Optically Pumped Nuclear Magnetic Resonance in GaAs: Interpretation Guided by Spin-Dependent Band Structure Calculations

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Introduction

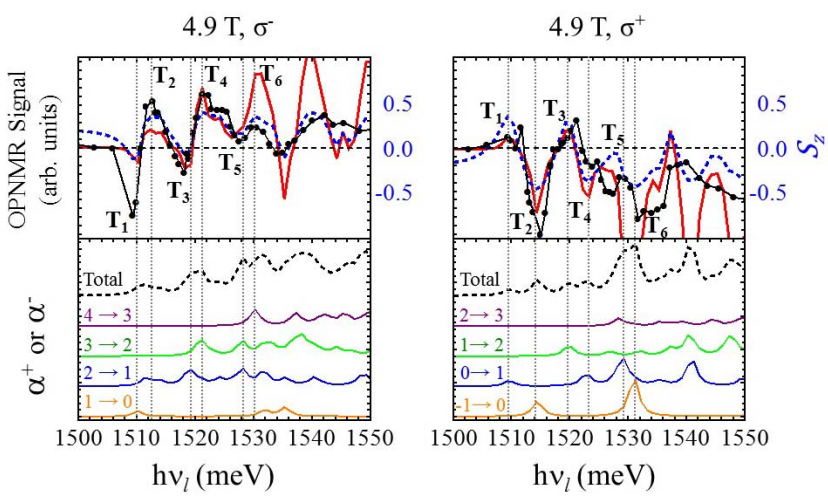
An experimental-theoretical study of optically pumped NMR (OPNMR) was performed on a GaAs/$Al_{0.1}Ga_{0.9}As$ quantum well film epoxy bonded to a Si substrate with thermally induced biaxial strain. The photon energy dependence of the Ga OPNMR signal was recorded at high fields at 4.8-5.4 K. The nuclear spin polarization calculated from the differential absorption to spin-up and spin-down states of the electron conduction band using a modified Pidgeon-Brown model is compared to the experimental data. Assignment of features in the OPNMR energy dependence to specific interband Landau level transitions was facilitated.

Experimental

A film consisting of 21 30 nm wide GaAs wells separated by 360 nm $Al_{0.1}Ga_{0.9}As$ barriers was Si d-doped to a 2D density of ~7×10^{10} cm^{-2}. The film was bonded to a Si single crystal and the growth substrate removed by selective chemical etching. Upon cooling, biaxial tensile strain was induced by differential thermal contraction. The sample was mounted to a sapphire block inside the NMR coil using Apiezon N grease. The sapphire block was mounted in a homebuilt NMR probe. OPNMR experiments were run in SCM-3 at NHMFL. The photon energy dependence of the ^{71}Ga OPNMR signal was recorded at 4.9 and 9.4 T at a temperature of 4.8-5.4 K.

Results and Discussion

Strain along the z-axis produces an electric field gradient along the z-axis, leading to a Ga-71 electric quadrupole splitting. The strain estimated from the quadrupole splitting ($\varepsilon_{zz} = -7\times10^{-4}$) was used as input in the spin-dependent electronic band structure calculations. Nuclear spin polarization was calculated from the differential absorption to spin-up and spin-down states of the electron conduction band using a modified Pidgeon Brown model. Comparisons of the OPNMR photon energy dependence to the theory are shown in Fig. 1. Assignments of the prominent features in the OPNMR data to specific interband transitions are indicated.



Upper panels: Photon energy dependence of the experimental OPNMR data T=5.1 ± 0.3 K (black points, arbitrary units), calculated nuclear spin polarization (red curve, arbitrary units), and the optically pumped electron spin polarization (dashed blue curve) at 4.9 T for σ^- and σ^+ light. Lower panels: Decomposition of the total optical absorption coefficients according to PB manifold, as indicated. Grey dotted vertical lines mark prominent features in the data, which are labeled according to transition, $\mathbf{T_i}$.

Conclusions

With the aid of theory, we are able to assign specific features in the OPNMR photon energy dependence to specific transitions in the band structure. we find that the strained quantum well exhibits a heavy hole/light hole splitting of ~4 meV. This separates the light hole band from the heavy hole bands and as a result, can substantially change the conduction band spin polarization and hence the nuclear polarization. This effect can be used to increase the maximum possible optically-induced electron spin polarization.

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Reference

[1] Wood, R.M., *et al*., Physical Review B, **90**, 155317 (2014).