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DETERMINATION OF ELECTRON EXCHANGE ENERGY IN A 2DES BY NUCLEAR MAGNETIC RELAXATION

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Abstract

The relaxation of nuclear spin polarization in Ga- and As-nuclei in the vicinity of the 2DES in GaAs-AlGaAs-heterostructures is determined by hyperfine interaction between nuclei and 2D-electrons. The relaxation rate is sensitive to the energy difference of spin-splitted electron states which is determined in 2DES not only by simple spin-Zeeman-splitting in a magnetic field but also by the exchange part of the electron-electron interaction ("g-factor enhancement"). The comparison of the experimental data for the temperature dependence of the nuclear spin lattice relaxation with the results of numerical calculations based on a Hartree-Fock-type model for the 2D-DOS delivered quantitative data for the electron exchange energy in a 2DES.

In the past especially electronic magnetotransport and optical-spectroscopic methods were used to investigate two-dimensional electron systems (2DES) in $GaAsAl_xGa_{1-x}As$ heterostructures [1]. In principal nuclear methods also provide the experimental access to electronic properties of solids [2] by means of hyperfine interaction. However the local type of this interaction (Fermi-contact interaction) limits the fraction of nuclei taking part in electron-nuclei interaction processes to those in the vicinity of the 2DES. As a consequence conventional NMR techniques cannot be used for investigations of 2DES because they are sensitive to the whole bulk nuclei, the most of which are far distant from the 2D-electrons.

Nevertheless recent experiments [3] revealed that it is possible to detect nuclear spin polarization in the vicinity of a 2DES by means of conducting electron spin resonance experiments (CESR). Hyperfine interaction between electrons and nuclei causes a shift of the ESR-line (Overhauser-Shift ΔB_N) which is a direct measure for the averaged nuclear spin polarization: $\Delta B_N = A\frac{\langle I \rangle}{g\mu_B}$.

It could be proved [4] that the dominant nuclear spin relaxation mechanism is mediated by hyperfine interaction between nuclei and the 2DES (Korringa-Relaxation). The observed nuclear spin relaxation rates could theoretically only be explained by taking into account the exchange part of the electron-electron Coulomb interaction which leads to an enhanced spin splitting of the electron energy (g-factor enhancement). The enhancement depends on the difference in occupation of the spin up and spin down levels which is sensitive to the temperature via the electron Fermi-function. These considerations represented the basic idea for carrying out temperature dependent measurements of the nuclear spin relaxation rate in order to receive information about electron exchange interaction.

The experimental method for investigating the nuclear spin relaxation is based on time dependant measurements of the Overhauser-shift which is proportional to the nuclear spin polarization.

The theoretical simulations for the nuclear spin relaxation are founded on an adaption of Slichter's

formula [2] for the nuclear spin relaxation in metals [4] (equation 1) :

$$\frac{1}{T_1} = \frac{\pi}{\hbar} A^2 \Omega^2 \mid \Phi(z) \mid^4 \int_{-\infty}^{\infty} D_{\downarrow} D^{\uparrow} f(E)(1 - f(E) dE \tag{1}$$

Ω denotes the volume of the unit cell in GaAs ($\Omega = 45.2 * 10^{-30} m^-3$). $\Phi(z)$ describes the envelope part of the 2D-electron wave function perpendicular to the interface. f(E) represents the Fermi function. $D^{\downarrow}(E)$ and $D^{\uparrow}(E)$ are the densities of states (DOS) for spin-up and spin-down electrons. The DOS is assumed to be a Gaussian,($D^{\uparrow,\downarrow} \propto exp[-(E - E_n^{\uparrow,\downarrow})^2 / 2\Gamma^2]$). The broadening parameter $\Gamma = (0.2meV)[B_{\perp}/T]$ is deduced from the mobility of our sample [5]. The enhanced electronic spin splitting due to exchange interaction is taken into consideration by the Ansatz [1] : $E_n^{\uparrow} - E_n^{\downarrow} = g\mu_B B + E_{xc} * (N^{\uparrow} - N_{\downarrow}) N_S$. The equation is evaluated self-consistently together with the chemical potential from the conditions $N^{\uparrow,\downarrow} = \int_{-\infty}^{\infty} D^{\uparrow,\downarrow}(E) f(E) dE$ and $N^{\uparrow} + N_{\downarrow} = N_S$.
Fitting the experimental data by the described two-parameter model, one parameter representing the prefactor $A^2\Omega^2 \mid \Phi(z) \mid^4$ and the other parameter the exchange energy, yields : $E_{xc} = 1.68meV$ (fig. 1).

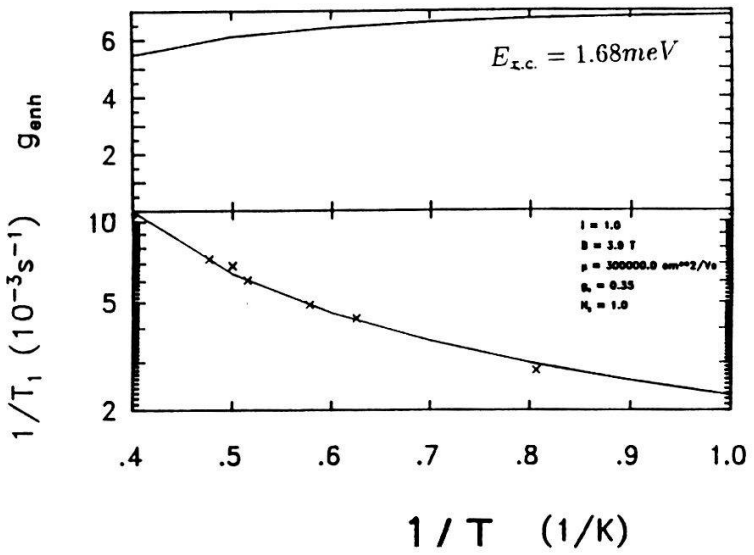

Figure 1:
lower part: *Nuclear spin lattice relaxation in a semi- logarithgmic plot of the relaxation rates versus reciprocal temperature. The crosses denote the experimental data. The solid line interpolates the results of numerical simulations according to equation 1. The two parameter fit yields an exchange energy for the 2DES of* $E_{xc} = 1.68meV$
upper part : *Enhanced g-factor* ($g_{enh} = (E_n^{\uparrow} - E_n^{\downarrow})/(\mu_B * B)$) *versus reciprocal temperature*

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