JG2 Optically detected nuclear magnetic resonance of spatially selected lattice nuclei within a GaAs quantum well

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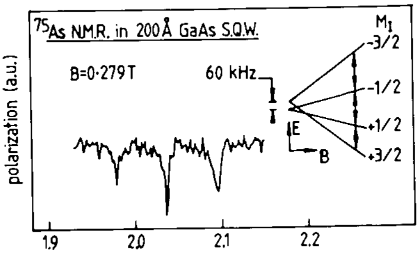
The spectra of nuclear resonances provide a powerful microscopic probe of condensed matter, yet nuclear magnetic resonance (NMR) techniques have not so far been used to study semiconductor heterostructures. That is because only a tiny fraction of all the nuclei lie in the region of interest, and conventional NMR cannot distinguish these. We report the first observation of optically detected NMR (ODNMR) of spatially selected nuclei in a semiconductor quantum well using an optical pumping technique which has the sensitivity and selectivity to overcome the limitations of conventional NMR. The sample is a 200-Å thick single quantum well made *p*-type by applied electrical bias with a degenerate hole population of 10^{11} cm^{-2}. The spectrum contains resonances corresponding to the three isotopes which make up the lattice: ^{69}Ga, ^{71}Ga, and ^{75}As. It differs strikingly from that reported for bulk GaAs[1] in that there is a 60(7)-kHz quadrupole splitting of the ^{75}As resonance, shown in Fig. 1, which we attribute to the residual strain present in the GaAs layer.

In these experiments the sample was immersed in liquid helium at 2 K in a superconducting magnet Dewar. Circularly polarized light from a Styryl 9 dye laser was used to excite electrons with a single spin orientation resonantly out of the heavy hole valence band into the conduction band. The degree of electron spin polarization in equilibrium is monitored by analyzing the proportions of right and left circularly polarized recombination radiation using a gated photon-counting technique. To observe ODNMR a static magnetic field of $\simeq 0.2$ T is applied perpendicular to the plane of the well and an rf field of 10^{-5} T in the plane.

The fine structure of the ^{75}As line is shown in Fig. 1 measured in a 0.279-T field. Three lines appear at frequencies of 1.980(5), 2.037(6), and 2.097(7) MHz. Inset in the figure is an energy level diagram for the $I = 3/2$ ^{75}As nucleus in an applied magnetic field showing the observed transitions. The 60-kHz quadrupole splitting between the $M_I = \pm 3/2, \pm 1/2$ levels is indicated. From the known quadrupole moment of the ^{75}As nucleus, $Q = 0.3 \times 10^{-28}$ m^2, and the observed line splitting of 60 kHz, we calculate an electric field gradient at the nucleus of $\simeq 2 \times 10^{18}$ V m^{-2}. This is too large to be associated with carriers present in the well or the external bias voltage. However, earlier work on bulk GaAs[2] has shown that elastic deformation of the lattice can give rise to quadrupole splittings. From these results we deduce that an elastic deformation of $\simeq 10^{-4}$ in the quantum well could be responsible for the quadrupole splitting that we observe. This interpretation would call into doubt the usual assumption that the AlGaAs barriers accommodate all the lattice mismatch with the GaAs substrate, leaving the wells unstrained. **(12 min)**



JG2 Fig. 1. Fine structure of the ^{75}As line. Quadrupole splitting in the ^{75}As NMR spectrum.

1. F. Meier and B. P. Zakharchenya, *Optical Orientation* (North-Holland, Amsterdam, 1982).
2. V. L. Bogdanov and V. V. Lemanov, Sov. Phys. Solid State **10**, 159 (1968).