Effects of Confinement and Strain in Optically Pumped Nuclear Magnetic Resonance in GaAs Quantum Wells

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Introduction

The photon energy dependence of optically pumped NMR (OPNMR) was studied in GaAs multiple quantum well (MQW) samples. Data were acquired at 3.9, 4.9, and 9.4 T with circular and linearly polarized light. The OPNMR signals The OPNMR photon energy dependence is compared to the calculated electron spin polarization, allowing the peaks in the data to be assigned to specific optical transitions.

Experimental

Two MQW samples were studied. Sample #1 (EA-124) consists of 21 GaAs wells (30 nm well width) separated by 360 nm wide $Al_{0.1}Ga_{0.9}As$ barriers. A 2D electron density of ~7 × 10^{10} cm^{-2} resulted from Si-δ-doping in the barriers. This MQW film is epoxy bonded to a Si support. Sample #2 is an undoped 60-well multiple quantum well sample of $Al_{0.34}Ga_{0.66}As$/GaAs grown on a GaAs substrate. Ga-69 or Ga-71 OPNMR experiments were carried out in SCM-3 using a Coherent Mira 900 Ti:Sapphire laser operated in cw-mode. A zero-order quarter-wave plate was used to obtain circularly polarized light. The samples were irradiated through an optical window fitted on the bottom of the cryostat. The samples were cooled to 4.2 K in helium exchange gas. Electronic band structure calculations were carried out using a modified Pidgeon-Brown model, which includes the effects of confinement, biaxial strain (in sample #1), and magnetic field. For each optical polarization, the photon energy dependence of the conduction band electron spin polarization was calculated from the spin-up and spin-down absorption coefficients as a function of the photon energy.

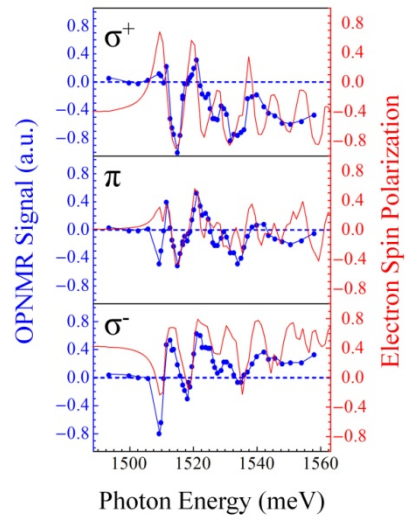

Figure 1. Photon energy dependence of OPNMR signals (blue) and calculated electron spin polarization (red) in sample #1 at 4.9 T and the given polarization of light.

Transition	Energy (meV)
LH1,0 → CB1↑	1510
HH1,-1 → CB1↓	1515
LH1,1 → CB1↑	1521
HH1,0 → CB1↑	1524
HH2,0 → CB1↓	1530
HH2,-1 → CB2↓	1532

Results and Discussion

Samples #1 exhibits a nuclear quadrupole splitting induced by strain caused by differential contraction of the thin film and the Si support to which it is epoxy bonded. We used the splitting to infer the tensile strain in the sample, which is included in the band structure calculations. Fig. 1 shows the OPNMR photon energy dependence in sample #1 acquired at 4.9 T with σ^+, σ^- and linear optical polarizations. Qualitative agreement between the calculated spin polarization and the experimental OPNMR data is obtained. The first few peaks in the OPNMR energy dependence that could be assigned to specific optical transitions are tabulated. Notably, a ~5 meV strain-induced light hole/heavy hole splitting is observed in both samples.

Conclusions

The quadrupole splitting of the OPNMR peak allowed us to determine the strain in the structure with high accuracy. Consistent with theory, strain has the effect of sharpening the peaks in the OPNMR photon energy dependence. This is because the degeneracy of the light hole/heavy hole splitting is lifted, resulting in higher electron spin polarization and higher OPNMR enhancement. With the aid of theory, the evidence of quantum confinement effects can also be discerned in the data.

Acknowledgements

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