Detection and Manipulation of Nuclear Spins via Electrical and Optical Methods

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The ability to measure and manipulate nuclear spins in a nanoscale region is vital in the ongoing effort to achieve true quantum computing. Traditional Nuclear Magnetic Resonance spectroscopy lacks the sensitivity required for such a task. Previous research has shown that an alternative method of NMR based on changes in resistance across a nanoscale single point contact contained in a hetero-structure though which electrons are forced to pass allows for a precise measurement of NMR signal at that point contact. This current research is focused on expanding such a procedure to include multiple point contacts in parallel with each contact experiencing a differing magnitude of magnetic field, with the aim of using a simple radio frequency to separate the unique frequency corresponding to each point contact. In addition to these electrical methods, we are also investigating optical methods of spin detection by examining changes in photoluminescence signal in a fluctuating magnetic field and current passing through these same point contacts. Such pinpoint accuracy in spin detection paves the way for precise spin alteration through complex RF pulse trains.

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Abstract

The ability to measure and manipulate nuclear spins in a nanoscale region is vital in the ongoing effort to achieve true quantum computing. Traditional Nuclear Magnetic Resonance spectroscopy lacks the sensitivity required for such a task. Previous research(1) has shown that an alternative method of NMR based on changes in resistance across a nanoscale single point contact contained in a hetero-structure though which electrons are forced to pass allows for a precise measurement of NMR signal at that point contact. This current research is focused on expanding such a procedure to include multiple point contacts in parallel with each contact experiencing a differing magnitude of magnetic field, with the aim of using a simple radio frequency to separate the unique frequency corresponding to each point contact. In addition to these electrical methods, we are also investigating optical methods of spin detection by examining changes in photoluminescence signal in a fluctuating magnetic field and current passing through these same point contacts. Such pinpoint accuracy in spin detection paves the way for precise spin alteration through complex RF pulse trains.

Motivation

- •Nuclear spin detection and manipulation required for quantum computation
- •Understanding photoluminescence (PL) peak behavior necessary for using PL for spin detection
- •Must be able to calculate peak positions to verify experimental results

Sample Structure and Experimental Setup

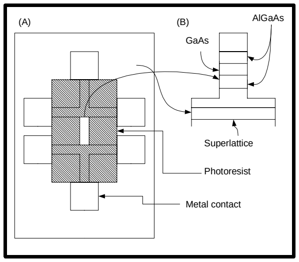

Figure 1: Sample Diagram in Real Space

A. Top view of sample, hall bar etched into sample, metal contacts at each end, and photoresist covering all but center section of hall bar
B. 20 nm GaAs quantum well between layers of AlGaAs within hall bar

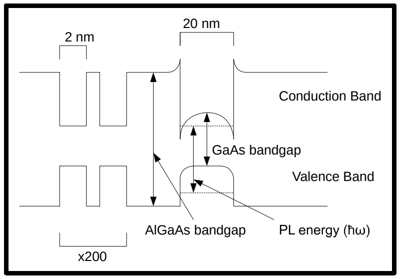

Figure 2: The band diagram of AlGaAs/GaAs

shape of quantum well due to doping of sample, theoretical PL energy calculated using several simplifications (2,3)

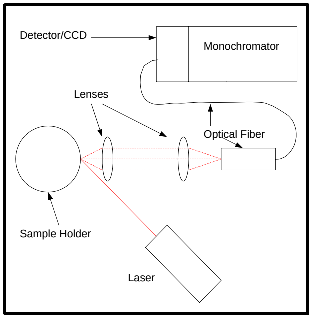

Figure 3: Experimental Setup.

Green laser (532 nm, 5mW power) or HeNe (633 nm, 12mW power) used, sample kept at 77K or RT, PL energy illuminated on to lenses and collected in optical fiber, detector cooled to 77K

Experimental Result

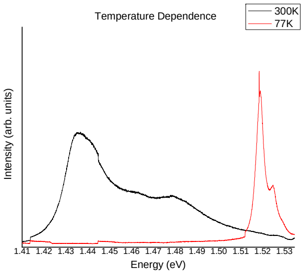

Figure 4: Temperature Dependence

PL spectra taken at two temperatures, 77K and RT with green laser. Relative intensities not comparable due to exposure time differences

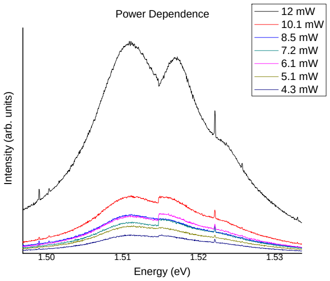

Figure 5: Power Dependence

Spectra taken at 77K using HeNe laser with ND filter to reduce power

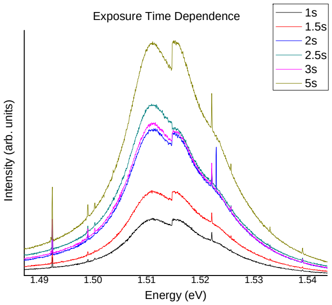

Figure 6: Exposure Time Dependence

Spectra taken at 77K with HeNe laser at 10.1 mW

Discussion

- •Calculated peak position (1.515 eV) vs. experimental values (1.519 eV with green laser and 1.511 eV with HeNe laser at 12mW)
- •Calculated light hole/heavy hole splitting is 3.36 meV vs. 5 meV experimentally (with green laser)
- •Peak width broadening due to temperature, as bandgap changes with temperature, peak widths are limited by temperature (RT = 25 meV, 77K = 6.6 meV)
- •Temperature and power dependence of peak indicate that it is from quantum well (QW)
- •Difference in peak position from green and HeNe laser excitation confirms that band structure is not flat due to number of carriers generated (Stark effect)
- •Future changes to make: photoresist does not prevent PL emission so must be replaced by metal

References

(1)Yusa, Go, et al. *Controlled multiple quantum coherences of nuclear spins in a nanometer-scale device.* Nature: Vol 434, 1001-1005.

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Acknowledgements

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