Electrical detection of nuclear magnetic resonance in GaAs using Heusler alloy Co_2MnSi

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1. Introduction

Nuclear spins in semiconductors are an ideal system for implementing quantum bits because of their extremely long coherence time. Highly polarized nuclear spins using dynamic nuclear polarization (DNP) and coherent control of nuclear spins using nuclear magnetic resonance (NMR) have attracted much interest for creating scalable semiconductor-based nuclear spin quantum bits. Recently, we demonstrated efficient spin injection from a Heusler alloy Co_2MnSi into GaAs, and resultant efficient DNP.[1,2] The purpose of the present study was to develop scalable semiconductor-based NMR devices, in which nuclear spins were electrically polarized and detected using spin injection techniques.

2. Experimental methods

The layer structure consisting of (from the top) Co_2MnSi (5 nm)/CoFe (1.1 nm)/n^+-GaAs (30 nm, Si = 5×10^{18} cm^{-3}) /n^--GaAs (2500 nm, Si = 3×10^{16} cm^{-3})/ud-GaAs (250 nm) was prepared on a semi-insulating GaAs(001) substrate. Using Ar ion milling technique and EB lithography, spin injection devices were fabricated as shown in Fig. 1. The creation and detection of nuclear spins in GaAs were evaluated using oblique Hanle effect measurements in a four-terminal nonlocal geometry where nonlocal voltage (V_{NL}) between contact-3 and contact-4 was measured under a constant current (I) supplied between contact-2 and contact-1 with a static magnetic field (**B**) and an rf magnetic field ($\mathbf{B}_{ac}$) at 4.2 K.

3. Results and Discussion

Figure 2 shows oblique Hanle signals without and with an rf magnetic field of 200 kHz. Without $\mathbf{B}_{ac}$, we observed clear side peaks at B_{ob} = +24.3 and –6.8 mT, indicating that nuclear spins in GaAs are dynamically polarized by electron spins injected from a Co_2MnSi electrode. On the other hand, under the irradiation of $\mathbf{B}_{ac}$, the satellite peaks originating from the nuclear polarization decreased. In particular, dip structures indicated by arrows in Fig. 2 were observed at B_{ob} = 30.6, 22.0, and 17.6 mT. These values are close to the resonant magnetic field of NMR for ^{75}As, ^{69}Ga, and ^{71}Ga, respectively, indicating that the change of V_{NL} by irradiation of $\mathbf{B}_{ac}$ is due to the NMR effect; *i.e.*, when the generated nuclear field decreased through the NMR, the total magnetic field experienced by electron spins increased, and the spin precession was enhanced, resulting in the decrease of V_{NL}.

Compare to a sample with an Fe spin source,[3] the sample with the Co_2MnSi spin source exhibited much larger NMR signals. This result indicated that a Heusler alloy Co_2MnSi have an advantage for a spin source of scalable semiconductor-based nuclear spin quantum bits.

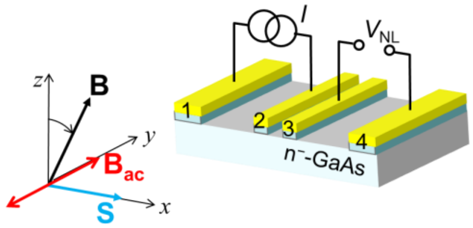

Figure 1: Schematic diagram of a device structure and circuit configuration for oblique Hanle effect measurements.

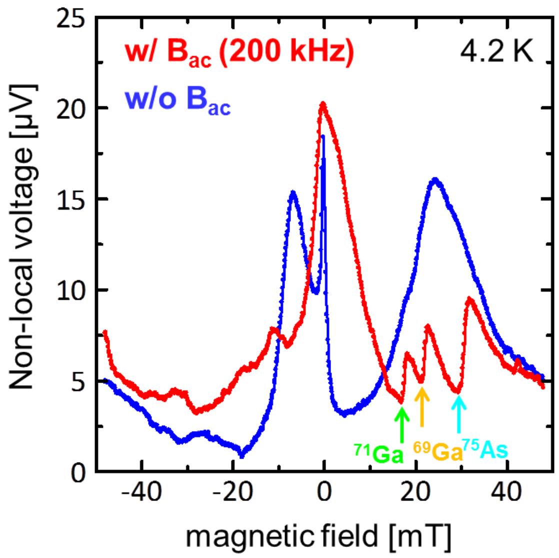

Figure 2: Oblique Hanle signals without RF magnetic field and with RF magnetic field at a frequency of 200 kHz.

Reference

[1] Y. Ebina et al., APL **104**, 172405 (2014).
[2] T. Akiho et al., PRB **87**, 235205 (2013).
[3] T. Akiho et al., The 75th JSAP Autumn meeting, 19p-S2-3, (2014)

Acknowledgments

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