Electrical detection of nuclear spin-echo signals in an electron spin injection system

°Zhichao Lin, Mahmoud Rasly, Tetsuya Uemura
Graduate School of Information Science and Technology, Hokkaido Univ.
E-mail: lin-zhichao@ist.hokudai.ac.jp

1. Introduction

Coherent manipulation of nuclear spins in semiconductors by nuclear magnetic resonance (NMR), which is indispensable for implementing solid-state quantum bits (qubits), has been demonstrated through observing the Rabi oscillation and spin-echo signals optically in AlGaAs/GaAs quantum well [1]. Recently we have developed a novel NMR system that uses spin injection from a highly polarized spin source, and detected the Rabi oscillation electrically [2]. The purpose of the present study is to clarify the phase coherence time (T_2) in GaAs through the spin-echo measurement.

2. Experimental methods

A lateral spin transport device having Co_2MnSi/CoFe/GaAs heterojunctions was fabricated (Fig. 1.). The spin-echo signals were measured as follow. Initially, the nuclear spins in GaAs was dynamically polarized along *z* axis by electron spins injected from Co_2MnSi electrode. Then, a series of pulses consisting of $\pi/2$, π, and $\pi/2$ pulses (Fig. 2(a)) was applied for the spin-echo. The first $\pi/2$ pulse rotates the total nuclear spin into the *x-y* plane, and the nuclear spin starts to dephase. After a time of $\tau/2$, nuclear spins flip to the opposite side in the *x-y* plane by the application of a π pulse, and they start to refocus during a time of $\tau/2$. Then, a complete refocusing, or spin echo, occurs after a time of $\tau/2$. Finally, the second $\pi/2$ pulse rotates the nuclear spin back to *z* axis for the readout. The final nuclear spin states were readout through the detection of nuclear field acting on the electrons spins.

3. Results and Discussion

From the Rabi oscillation (*not shown*), the duration of $\pi/2$ pulse was determined to be 40 μs. Fig. 2(b) shows time evolution of V_{NL} when the spin-echo pulse sequences with τ = 60 and 200 μs, respectively, were applied. The V_{NL} changed rapidly by ΔV_{NL} = 8.5 and 16 μV, respectively, after applying the pulse sequences, then it gradually recovered to its initial state. The ΔV_{NL} shows an exponential dependence on τ, as shown in Fig. 2(c). From the fitting results, the intrinsic dephasing time T_2 = 167 μs is obtained, which is comparable with the values reported in Ref. [1].

In conclusion, we have demonstrated spin echo of nuclear spins in bulk GaAs using spin injection from a half-metallic spin source. Efficient spin injection enabled efficient DNP and a sensitive detection of the NMR signal, leading to a sizable spin echo signal even at a low magnetic field (114 mT). This study provides a novel all-electrical NMR system for nuclear-spin-based qubits.

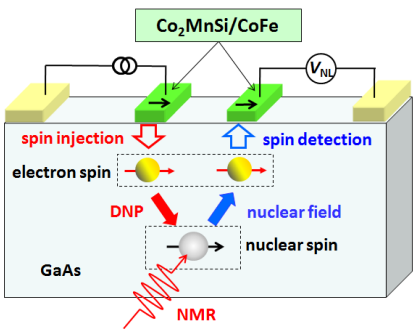

Fig. 1. Schematic of a lateral spin transport device.

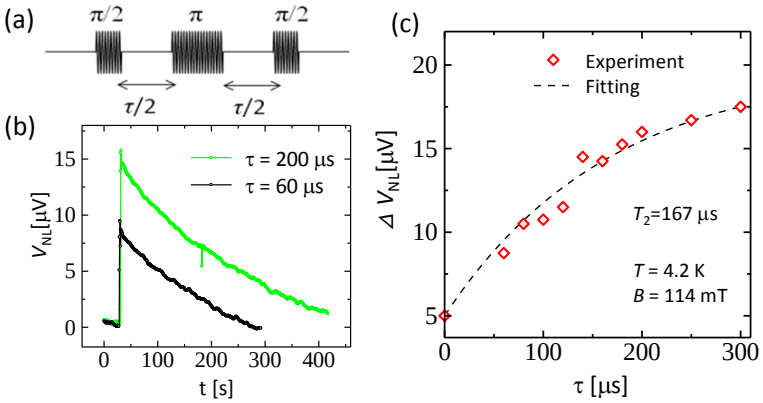

Fig. 2. (a) Spin-echo pulse sequence. (b) Time evolution of V_{NL} after applying spin-echo pulse sequence. (c) τ dependence of ΔV_{NL}.

Acknowledgments

This work was partly supported by JSPS KAKENHI (Grant Nos. 25286039 and 15K13960).

References

[1] H. Sanada, *et al.*, Phys. Rev. Lett. **96**, 067602 (2006).
[2] T. Uemura, *et al.*, Phys. Rev. B **91,** 140410 (R) (2015).