Geometric manipulation with polarized microwaves over an electron and a nuclear spin in diamond

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Abstract: We succeeded to generate and manipulate any arbitrary quantum state with polarized microwaves across a crossed wire over an electron spin and a nuclear spin in nitrogen-vacancy center in diamond. We achieved manipulation fidelity over 80% for both.

1. Introduction

We have recently demonstrated teleportation-based quantum media conversion from a photon to a nuclear spin [1], geometric spin echo [2], and optical single electron quantum gates [3] in a nitrogen vacancy center in diamond. Although these demonstrations use a degenerate ±1 subspace of a spin-1 system of an electron and a nuclear spin as qubits under a zero magnetic field, arbitrary manipulation of these degenerate qubits cannot be performed by using linearly polarized microwaves or radiowaves, which are generated by the conventional a single wire or a strip line. Here we show that we can manipulate the degenerate qubits with polarized microwaves or radiowaves, respectively, instead of energy gaps of two spin sublevels with utilizing the geometric nature of those spins.

2. Experimental setups

We used a native NV center in a high-purity type-IIa chemical-vapor-deposition grown bulk diamond with a <001> crystal orientation (electronic grade from Element Six) without any electron-beam dose or annealing. A negatively charged NV center located at about 30 μm below the surface was found using a confocal laser microscope. Two nearly perpendicularly crossed copper wires of 25-μm in diameter mechanically attached to the surface of the diamond were used to apply microwaves and radiowaves for the optically detected magnetic resonance (ODMR) measurement (Fig. 1). An external magnetic field to the NV axis was applied to compensate the geomagnetic field of about 0.045 mT using a permanent magnet. Careful orientation of the magnet was conducted with monitoring of the ODMR spectrum within 0.1 MHz. All experiments were performed at room temperature.

The spin sublevels ±1 of spin-1 electron and ^{14}N nuclear spins in an NV center completely degenerate under a zero magnetic field. We first initialize those spin states into m_s=0 and m_I=0 states. We then apply a polarized microwave for the electron spin or a polarized radiowave for the nuclear spin, respectively, with using the crossed wires to prepare the corresponding logical qubit state in the ±1 subspace. We then apply another microwave or radiowave to add a geometric phase induced by a cyclic rotation of the bight state corresponding to the polarization via the m_s=0 or m_I=0 states as ancillary states. This allows any arbitrary axis rotation of the degenerate logical qubits with properly selected polarization. We finally perform quantum state tomography and quantum process tomography using the bright state projection technique [4].

3. Experimental results

We succeeded to generate arbitrary quantum states of an electron and a nuclear spin and manipulate them geometrically with a polarized microwave and radiowave, respectively, using crossed wires. We achieved manipulation fidelities of as high as 86% for an electron spin and 93% for a nuclear spin in average based on the quantum state tomography (not shown). Further detailed analysis using the process tomography indicates that the X-axis rotation has the fidelity of 82% and 97% for respectively the electron and nuclear spins (Fig. 2).

4. Acknowledgements

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16H06326 16H01052) and Ministry of Education Culture Sports Science and Technology (MEXT) as "Exploratory Challenge on Post-K computer" (Frontiers of Basic Science: Challenging the Limits).

5. References

[1] S. Yang et al., Nat. Photon. **10** 507-511 (2016).

[2] Y. Sekiguchi, Y. Komura, S. Mishima, T. Tanaka, N. Niikura and H. Kosaka, Geometric spin echo under zero field. *Nat. Commun.* **7**, 11668 (2016).

[3] Y. Sekiguchi, N. Niikura, R. Kuroiwa, H. Kano, and H. Kosaka, *Nat. Photon. in press* (2017).

[4] H. Kosaka and N. Niikura, Entangled Absorption of a Single Photon with a Single Spin in Diamond. *Phys. Rev. Lett.* **114**, 053603 (2015).

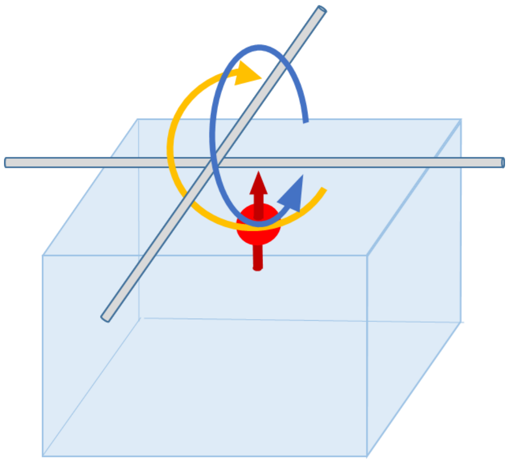

Fig.1. Experimental configuration showing the crossed wire and nitrogen-vacancy center in diamond

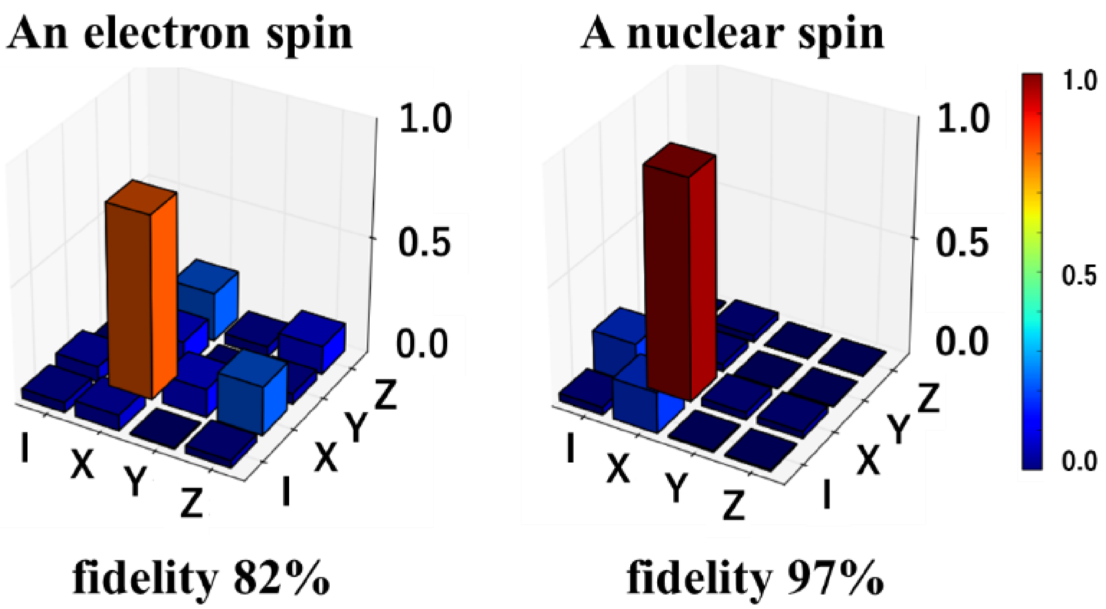

Fig.2. Experimental results showing the fidelity of the electron spin and nuclear spin rotation.