Optimal quantum manipulation over many-body spin system in diamond with a shaped microwave

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Abstract: We achieved high fidelity control for single qubit and multi qubit by using optimized microwave pulse in a many-body spin system consisting of an NV center and nuclear spins.

1. Introduction

Improving scalability is a long-standing problem in implementing quantum information processing in a solid-state system. The interaction between spins, which are resources of quantum entanglement, gives complex dynamics to the system. Therefore, it is no exaggeration that there is an inverse correlation between the ease of single qubit operation and that of multi qubit operation.

For realizing quantum information technology, we have succeeded in storing photon polarization into a nuclear spin in an NV center in diamond [1]. The storage scheme is based on generation of entanglement between an electron and a ^{14}N nuclear spin and detection of entanglement between a photon and an electron [2], which consists of a geometrical spin under a zero field [3]. However, it is hard to increase the number of memory qubits due to complex time evolution of mutually interacting many-body system.

Here, we tried to solve this problem by gradient ascent pulse engineering (GRAPE) algorithm [4]. This computerized approach allows us to treat many-body complex dynamics straight without bold approximation.

2. Experimental setup

The GRAPE algorithm is the simplest optimization method using the gradient of the evaluation function. This method is comparatively easy to calculate, and partially adaptable even when the external field is dependent on time.

We experimentally demonstrate faithful manipulation of an electron spin interacting with two nuclear spins on ^{14}N and ^{13}C (Fig.1) with optimized microwave pulses based on the GRAPE algorithm. The hyperfine interaction was 6.275 MHz between the electron spin and the ^{13}C nuclear spin and 2.165 MHz between the electron spin and the ^{14}N nuclear spin.

3. Experimental demonstration

First, we optimized the microwave that gives control to the electron spin and attempted to achieve high fidelity single qubit operation. As a result, we succeeded in transitioning the electron spin to the desired state with 98% fidelity under the disadvantageous condition that microwave power was limited and insufficient.

We also demonstrated coherence swap operation between electron spin and nuclear spin as an example of optimized multi qubit operation. Its polarizability was 85% for nitrogen ^{14}N nuclear spin (Fig.2) and 78% for ^{13}C nuclear spin.

4. Conclusion

The demonstrated results indicate the usefulness of control pulse optimization for single and multi-qubit operation to NV center spin many-body system. They also indicate that “exclusive” entanglement generation between an electron and a selected nuclear spin keeping the others unchanged could be realized to build an integrated quantum memory. It is expected that this method will be effective even in the case of controlling electron spin of NV center by optical process [5].

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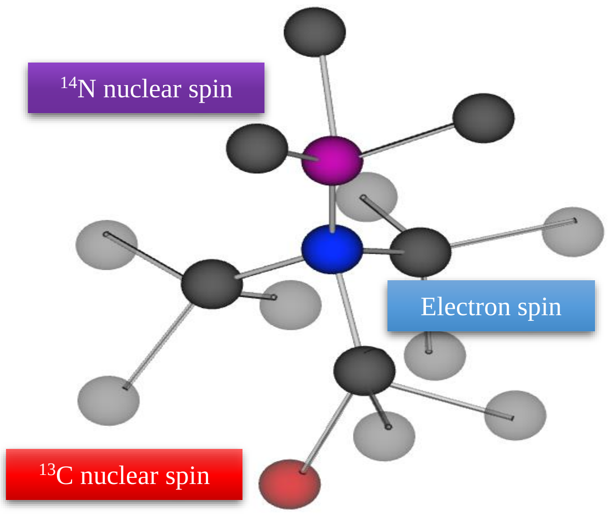

Fig.1. Image of an NV center multi spin system used in the experiment.

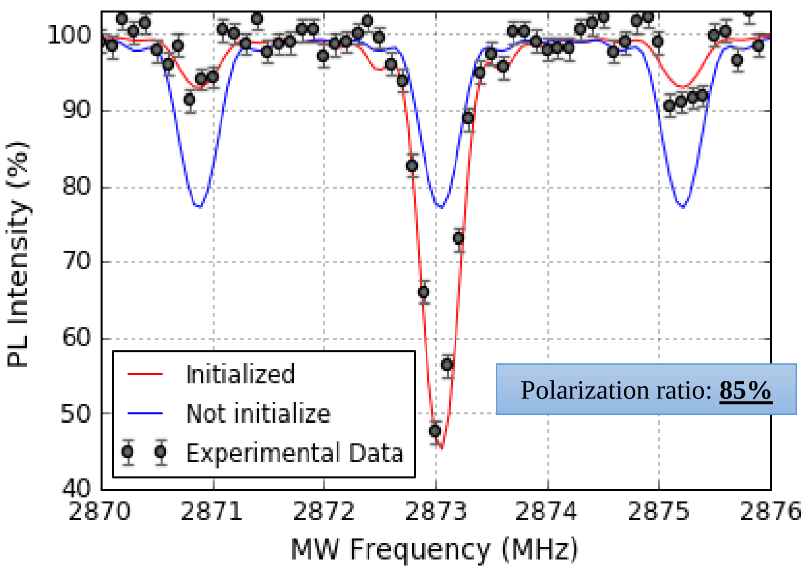

Fig.2 ODMR spectrum showing the polarization ratio of a ^{14}N nuclear spin.