Optical deterministic measurement of a nitrogen nuclear spin in diamond

Riyo Enyo[1], Takaaki Nakamura[1], Yuhei Sekiguchi[1], and Hideo Kosaka[1*]
[1]Yokohama National University, 79-5 Tokiwadai, Hodogaya, Yokohama 240-8501, Japan
**Corresponding author: kosaka-hideo-yp@ynu.ac.jp*

Abstract: We demonstrate the deterministic measurement of the quantum state of a nitrogen nuclear spin in a nitrogen vacancy (NV) center in diamond under a zero field. We succeeded to measure the nuclear spin state of a target ^{14}N impurity atom by repeatedly measuring the spin state of an entangled ancillary electron. It indicates that we can perform deterministic measurement of a nuclear spin with one measurement as faithful as 97% fidelity.

1. Introduction

Quantum repeaters, which enables long-distance quantum communications, require complete Bell measurement with extremely high fidelity for the entanglement swapping or the quantum teleportation [1,2]. However, it is impossible to measure a quantum state to any arbitrary accuracy by itself. We thus need to develop the technique called quantum-non-demolition measurement to perform a single-shot measurement, which allows single preparation and repeated measurement.

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. A 25-μm copper wire mechanically attached to the surface of the diamond was used to apply a microwave. An external magnetic field was applied to carefully compensate the geomagnetic field of about 0.045 mT using a permanent magnet. The NV center used in the experiment showed hyperfine splittings caused by ^{14}N nuclear spin at 2.2 MHz. All experiments were performed at 5 K to reduce the optical linewidth of the *Ex* and A_1 transition to as narrow as 35 MHz. All the light beams were focused onto the sample using a 0.8 NA 100x objective inside the vacuum.

The experimental setup was the same as in Kosaka and Niikura [3]. A green laser (532nm, 100 μW) and a red light resonant to the A_1 state were first used to initialize the electron spin states to the ground m_s=0 state (bright state), and then a microwave (2.878 GHz) was used to excited the nitrogen nuclear spin state $m_I=\pm1$ states leaving only the m_I=0 state. Finally, a red light resonant to the *Ex* state was used to read out the m_I=0 state for 10 μs. Then the A_1 initialization and the *Ex* readout sequence was repeated for N times (Fig. 1).

3. Experimental results

We demonstrate the single-shot measurement of the quantum state of a nuclear spin in a nitrogen vacancy (NV) center in diamond under a zero field [4,5]. We were able to measure the nuclear spin state of a target ^{14}N impurity atom by repeatedly measuring the spin state of an entangled ancillary electron. After preparing the nuclear spin into the m_I=0 state, we observed 3.7 photons in average with 44-time repeated optical readouts of the electron spin in the m_S=0 state (Fig. 2). From the time decay of the photon counts, we estimated the signal includes 0.03 photon from the $m_s=\pm1$ state (dark state). This indicates that we can optically perform the single-shot measurement to determine the nuclear spin state whether m_I=0 or ±1 with the fidelity of 95% in average even under a zero field.

4. Acknowledgements

We thank Yuichiro Matsuzaki, Kae Nemoto, William Munro, Norikazu Mizuochi, Fedor Jelezko, and Joerg Wrachtrup for their discussions and experimental help. This work was supported by National Institute of Information and Communications Technology (NICT) Quantum Repeater Project, and by Japan Society for the Promotion of Science (JSPS) Grant-in-Aid for Scientific Research (24244044, 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

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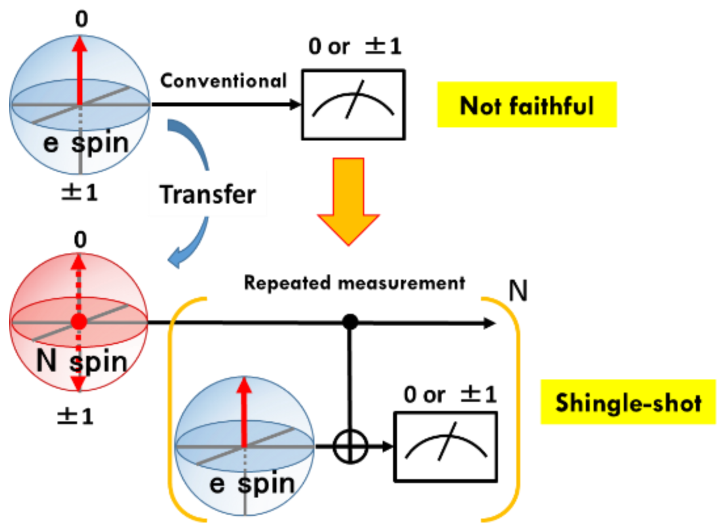

Fig.1. Quantum circuit for the conventional (upper) and single-shot (lower) measurements.

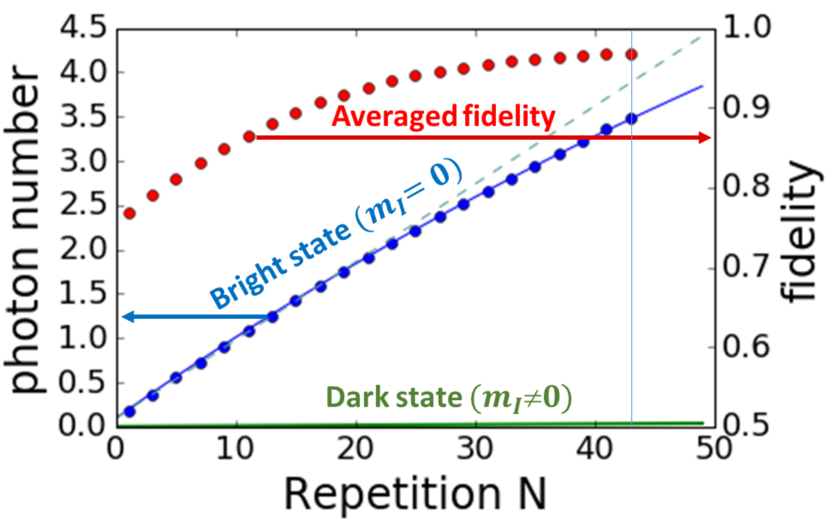

Fig.2 Accumulated photon counts for the bright and dark states and the corresponding measurement fidelity in average.