【Grant-in-Aid for Scientific Research (S)】
Science and Engineering (Interdisciplinary Science and Engineering)

Title of Project : Diamond Quantum Sensing

Kohei M. Itoh
(Keio University, Faculty of Science and Technology, Professor)

Research Project Number : 26220602 Researcher Number : 30276414
Research Area : Quantum Information, Solid-State Physics, Measurement Technology
Keyword : Quantum Sensor, Nanotechnology, Magnetic Resonance

【Purpose and Background of the Research】

Recent advancement in nanotechnology has allowed scientists to prepare and explore quantum states of single "artificial atoms" or "quantum bits" in solids. The atomic states of dopants in semiconductors and macroscopic atom-like states realized by superconducting circuits are the two representing examples. Since the field has reached the multiple qubit manipulation stage and realization of a useful quantum computer requires integration of a very large number of qubits, interests are emerging to utilize a small number of qubits in solids to realize a mission impossible by the classical means; establishment of quantum (or quantum mechanically enhanced) sensors that can exceed the classical limits by utilizing single qubits (or entanglement of multiple qubits) in solids.
The present project aims to utilize nitrogen vacancy (NV) centers in extremely thin (<5nm) isotopically purified diamond films as quantum sensors, and develop diamond chips that will allow for single atom/molecule nuclear magnetic resonance measurements, electric field detections, and temperature sensing.

【Research Methods】

As shown in Fig. 1, target atoms/molecules are placed on the surface of diamond and a single NV pair (the arrow in Fig. 1) situating within a few nm from the target atom/molecule will have enough dipole interaction to detect the change in the nuclear moment direction induced by the NMR of the target single atom/molecule. It is also possible to place many NV pairs as shown in Fig. 2, and image the magnetic field, electric field, and temperature distribution within each molecule, using each NV as a pixel. The whole diamond chip is placed under an optical microscope and the manipulation of each NV state is performed by the local pulse electron spin resonance while read out of the quantum state of each NV center can be performed by irradiation of the excitation green laser followed by detection of the red photons coming from the NV center.

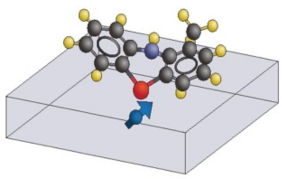

Fig. 1

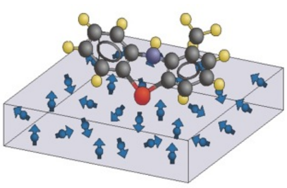

Fig. 2

【Expected Research Achievements and Scientific Significance】

Investigation of the quantum mechanical couplings between NV electron spins and target nuclear spins are essential and understanding of their interaction with external perturbation by the magnetic field, mechanical force, and electric field is needed for the quantum sensor applications. Therefore, such steps alone contribute greatly to the advancement of science. From the application point of view, while the standard NMR requires ~10^{18} spins, our diamond chip will allow NMR of very small numbers of molecules at room temperature simply by placing or dropping the target substance on the diamond chip surface. Clearly, this will have a strong impact on pharmaceutical, chemical, and geological engineers working in industry.

【Publications Relevant to the Project】

K. Ohashi, T. Rosskopf, H. Watanabe, M. Loretz, Y. Tao, R. Hauert, S. Tomizawa, T. Ishikawa, J. Ishi-Hayase, S. Shikata, C. L. Degen, and K. M. Itoh, *"Negatively Charged Nitrogen-Vacancy Centers in a 5 nm Thin ^{12}C Diamond Films,"* Nano Letters, vol. **13**, 4733-4738 (2013).

【Term of Project】 FY2014-2018

【Budget Allocation】 165,200 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.appi.keio.ac.jp/Itoh_group/
kitoh@appi.keio.ac.jp