Division of Materials Chemistry
– Inorganic Photonics Materials –

http://mizuochilab.kuicr.kyoto-u.ac.jp/indexE.html

Prof
MIZUOCHI, Norikazu
(D Sc)

Assist Prof
MORISHITA, Hiroki
(D Eng)

Assist Prof
FUJIWARA, Masanori
(D Sc)

Program-Specific Res
HERBSCHLEB, Ernst David
(Ph D)

Res (pt)
SIMO-OKA, Takaaki
(D Sc)

Students

HAYASHI, Kan (D3)*
MARUYAMA, Yuuichi (D1)
DANJYO, Takuya (M2)
FUJIMOTO, Syou (M2)
MIMA, Daisuke (M2)
ASHIDA, Takaki (M1)
ISHIMOTO, Shintaro (M1)
NISHIKAWA, Tetsuri (UG)
WATANABE, Akira (UG)

*Special Research Students

Scope of Research

NV center in diamond has been extensively interested because the single spin of it can be manipulated and detected at room temperature. Furthermore, spin coherence time of the NV center is very long. The coherence time is the time to retain coherence (superposition state) and directly relates to the sensitivity of sensor of magnetic field, electric field and temperature. Therefore, the unique and excellent properties of the NV center are expected to be applied for quantum computing, quantum communication, bio-imaging, and high-sensitive sensor with nano-scale resolution.

KEYWORDS

Diamond
Quantum Materials
NV Center
Quantum Sensing
Quantum Information Science

Selected Publications

Fukui, T.; Doi, Y.; Miyazaki, T.; Miyamoto, R.; Kato, H.; Matsumoto, T.; Makino, T.; Yamasaki, S.; Morimoto, R.; Tokuda, N.; Hatano, M.; Sakagawa, Y.; Morishita, H.; Tashima, T.; Miwa, S.; Suzuki, Y.; Mizuochi, N., Perfect Selective Alignment of Nitrogen-vacancy Center in Diamond, *Applied Physics Express*, **7,** [55201-1]-[55201-4] (2014).

Doi, Y.; Makino, T.; Kato, H.; Takeuchi, D.; Ogura, M.; Okushi, H.; Morishita, H.; Tashima, T.; Miwa, S.; Yamasaki, S.; Wrachtrup, J.; Suzuki, Y.; Mizuochi, N., Deterministic Electrical Charge State Initialization of Single Nitrogen-vacancy Center in Diamond, *Phys. Rev. X*, **4,** [11057-1]-[11057-11] (2014).

Mizuochi, N.; Makino, T.; Kato, H.; Takeuchi, D.; Ogura, M.; Okushi, H.; Nothaft, M.; Neumann, P.; Gali, A.; Jelezko, F.; Wrachtrup, J.; Yamasaki, S., Electrically Driven Single Photon Source at Room Temperature in Diamond, *Nat. Photonics.*, **6,** 299-303 (2012).

Zhu, X.; Saito, S.; Kemp, A.; Kakuyanagi, K.; Karimoto, S.; Nakano, H.; Munro, W. J.; Tokura, Y.; Everitt, M. S.; Nemoto, K.; Kasu, M.; Mizuochi, N.; Semba, K., Coherent Coupling of a Superconducting Flux-qubit to an Electron Spin Ensemble in Diamond, *Nature*, **478,** 221-224 (2011).

Neumann, P.; Mizuochi, N.; Rempp, F.; Hemmer, P.; Watanabe, H.; Yamasaki, S.; Jacques, V.; Gaebel, T.; Jelezko, F.; Wrachtrup, J., Multipartite Entanglement Among Single Spins in Diamond, *Science*, **320,** 1326-1329 (2008).

Hybrid Quantum Magnetic-field Sensor with an Electron Spin and a Nuclear Spin in Diamond

Recently, magnetic-field sensors based on an electron spin of a nitrogen vacancy center in diamond have been studied both from an experimental and theoretical point of view. This system provides a nanoscale magnetometer, and it is possible to detect a precession of a single spin. In this research, we propose a sensor consisting of an electron spin and a nuclear spin in diamond as shown in Figure 1. Although the electron spin has a reasonable interaction strength with magnetic field, the coherence time of the spin is relatively short. On the other hand, the nuclear spin has a longer lifetime while the spin has a negligible interaction with magnetic fields. We show that, through the combination of such two different spins via the hyperfine interaction, it is possible to construct a magnetic-field sensor with the sensitivity far beyond that of previous sensors using just a single electron spin. We revealed that if the gate error is below 0.1%, the sensitivity of our sensor is one order of magnitude better than the conventional one.

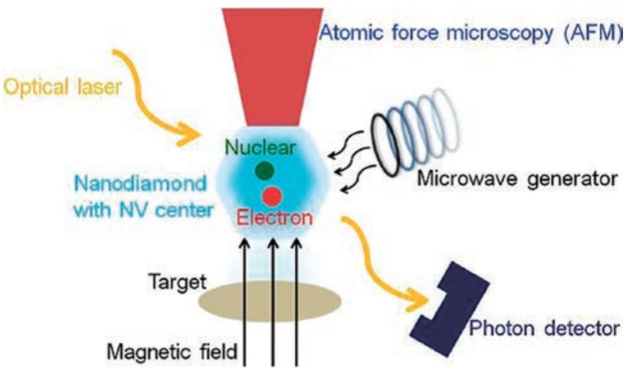

Figure 1. The structure of our hybrid NV center sensor: a diamond containing an NV center with an electron spin and a nuclear spin is attached to an AFM tip. Single qubit rotations and a C-NOT gate can be performed by directing a microwave into the diamond.

Perfect Selective Alignment of Nitrogen-vacancy Center in Diamond

Nitrogen-vacancy (NV) centers in diamond have attracted significant interest because of their excellent spin and optical characteristics for quantum information and metrology. In the diamond crystal structure, the orientations of NV centers are classified according to the alignment along one of four possible crystallographic axes: [111], $[1\bar{1}\bar{1}]$, $[\bar{1}1\bar{1}]$ or $[\bar{1}\bar{1}1]$ as shown in Figure 2. In most diamond samples, NV centers equally occupy these four orientations. To take advantage of the characteristics, the precise control of the orientation of the N–V axis in the lattice is essential. It is because improvement in readout contrast and a magnetic field sensitivity can be expected when compared to with those of standard samples with equal population of all NV orientations. Furthermore, spin and optical characteristics strongly depend on this orientation. In cases where photoluminescence (PL) is detected from the [111] direction, the PL intensity from N–V centers in which the N–V axis is parallel to [111] (NV ∥ [111]) is higher than others because electric dipole transitions are allowed for dipoles in the plane perpendicular to the N–V axis. With respect to spin, it is expected to play a key role at the quantum interface with photon and superconducting flux qubits.

We experimentally showed that the orientation of more than 99 % of the NV centers can be aligned along the [111]-axis by CVD homoepitaxial growth on (111)-substrates. We also discuss about mechanisms of the alignment. We examined the atomistic generation mechanism for the NV defect aligned in the [111] direction of C(111) substrates with first-principles electronic structure calculations. Our result enables a fourfold improvement in magnetic-field sensitivity and opens new avenues to the optimum design of NV center devices.

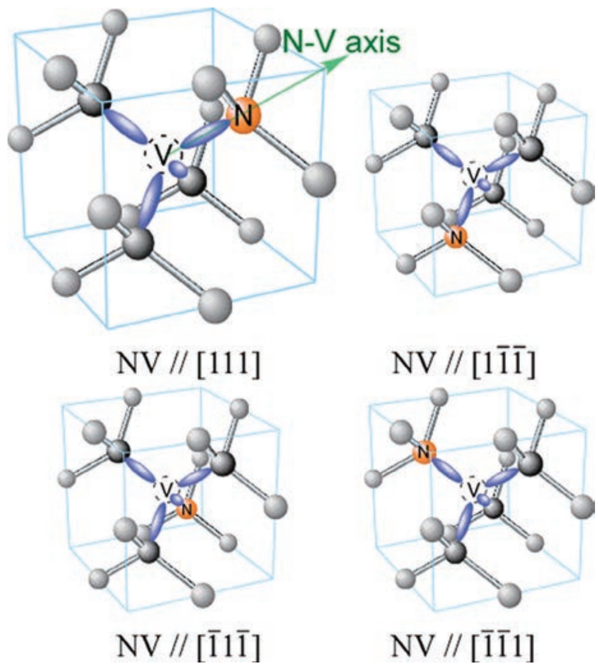

Figure 2. Four possible orientations of NV centers in diamond crystal.