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)

Program-Specific Res
OHKI, Izuru
(D Bioscience)

Res (pt)
HAYASHI, Kan
(D Sc)

Students

ASHIDA, Takaki (M2)
ISHIMOTO, Shintaro (M2)
NISHIKAWA, Tetsuri (M1)
WATANABE, Akira (M1)
YAMASHITA, Syungo (M1)
NAKAMURA, Masaya (UG)
MORITA, Kouki (UG)

Scope of Research

NV centers in diamond have been extensively interested because a single spin of the NV center can be manipulated and detected at room temperature. Furthermore, a spin-coherence time of the NV center is very long. The spin-coherence time is the time to retain coherence (superposition state) and directly relates to the sensitivity of sensors 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

Doi, Y.; Fukui, T.; Kato, H.; Makino, T.; Yamasaki, S.; Tashima, T.; Morishita, H.; Miwa, S.; Jelezko, F.; Suzuki, Y.; Mizuochi, N., Pure Negatively Charged State of NV Center in n-Type Diamond, *Phys. Rev. B*, **93,** [081203(R)-1]-[081203(R)-6] (2016).
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, *Appl. Phys. Express*, **7,** [55201-1]-[55201-4] (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, *Nature 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).

Optimization of Temperature Sensitivity Using the Optically Detected Magnetic Resonance Spectrum of a Nitrogen-vacancy Center Ensemble

Temperature sensing with nitrogen-vacancy (NV) centers using quantum techniques is very promising and further development is expected. Recently, the optically detected magnetic resonance (ODMR) spectrum of a high-density ensemble of the NV centers was reproduced with noise parameters [inhomogeneous magnetic field, inhomogeneous strain (electric field) distribution, and homogeneous broadening] of the NV center ensemble. In this study, we use ODMR to estimate the noise parameters of the NV centers in several diamonds. These parameters strongly depend on the spin concentration. This knowledge is then applied to theoretically predict the temperature sensitivity. Using the diffraction-limited volume of 0.1 μm^3, which is the typical limit in confocal microscopy, the optimal sensitivity is estimated to be around 0.76 mK/$\sqrt{\text{Hz}}$ with an NV center concentration of 5.0×10^{17}/cm^3 as shown in Figure 1. This sensitivity is much higher than previously reported sensitivities, demonstrating the excellent potential of temperature sensing with NV centers.

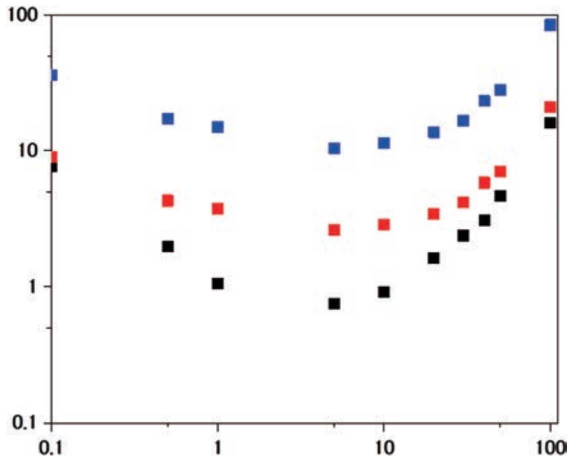

Figure 1. Numerically estimated sensitivity with respect to the NV concentration with a low microwave power ODMR. Black squares are the sensitivity of the approach using the sharp dip without an applied magnetic field. Red squares are the sensitivity using the peak structure observed in the normal ODMR under an external magnetic field exactly applied along the [001] direction. Blue squares show the results using the peak structure observed in the normal ODMR with an arbitrary direction of the magnetic field and the ODMR signal of only one of four NV axes is measured.

Engineering of Fermi Level by *nin* Diamond Junction for Control of Charge States of NV Centers

Charge-state control of NV centers in diamond is very important toward its application, because the NV centers undergo stochastic charge-state transitions between the negative charge state (NV$^-$) and the neutral charge state (NV^0) of the NV center upon illumination. In this letter, engineering of the Fermi level by a *nin* diamond junction was demonstrated for control of the charge state of the NV centers in the intrinsic (*i*) layer region as shown in Figure 2. By changing the size (*d*) of the *i*-layer region between the phosphorus-doped *n*-type layer regions (*nin*) from 2 μm to 10 μm, we realized the gradual change of the NV$^-$ charge-state population in the *i*-layer region from 60% to 80% under 532 nm excitation, which can be attributed to the band bending in the *i*-layer region as shown in Figure 3. Also, we quantitatively simulated the changes of the Fermi level in the *i*-layer region depending on *d* with various concentrations of impurities in the *i*-layer region.

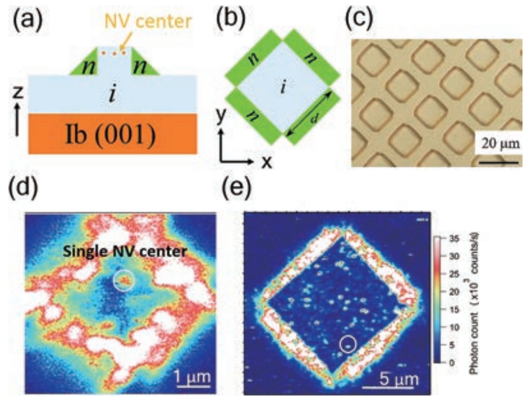

Figure 2. (a) Schematic illustration of the *nin* diamond junction in the *xy*-plane and in the (b) *z*-plane. (c) Optical microscope image of the *nin* diamond. (d) Scanning confocal microscope images of the mesa structures of *d* = 2 μm and (e) *d* = 10 μm.

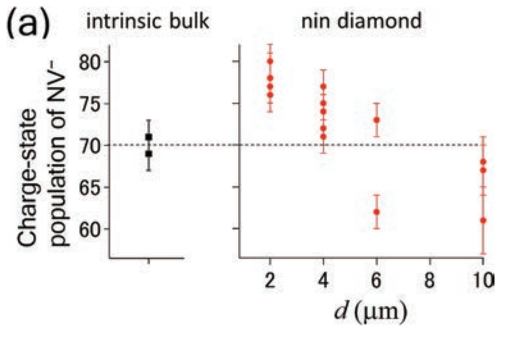

Figure 3. The dependence of the charge-state population of NV$^-$ on *d*. As reference, on the left, the estimate for the population in intrinsic bulk diamond is shown.