Title	ダイヤモンド中の窒素-空孔中心を用いた局所核磁気共鳴計測に関する研究
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Abstract

The NV center in diamond has emerged as a leading solid-state quantum system for magnetic sensing and imaging applications, including nuclear magnetic resonance (NMR) measurement via NV center (NV-NMR). Previous studies have measured nuclear spin measurements of ^{1}H, ^{13}C and ^{19}F using NV centers with pulse sequences for laser and microwave excitation. However, ^{13}C nuclear spin in the diamond shorten the spin-spin relaxation time (T_2), and the NMR signal from ^{13}C (natural abundance: 1%) in diamond overlaps by the electron-spin-echo envelope modulation with the NMR signal from the target sample in NV-NMR measurements. Then, ^{12}C-enriched diamond thin layers were exploited to eliminate the ^{13}C NMR signal in NV diamonds and extend the NVs' T_2 times.

NV centers created in a thin layer of diamond can be fabricated mainly by two methods: Chemical vapor deposition (CVD) growth with nitrogen incorporated into the gas phase and post-growth nitrogen ion implantation. Due to the reduced lattice damage, the spin properties of shallow ensemble NV centers in a ^{12}C-enriched diamond layer grown by the CVD method typically exhibit NV centers with longer spin coherence times, leading to enhanced magnetic sensitivity compared to implanted NV centers. However, this CVD method is limited by a lower NV center density. For applications such as NMR imaging, which require a near-surface layer of NV centers (< 20 nm), nitrogen ion implantation thus remains the preferred method despite inferior per-NV sensitivities.

We present a study of the spin properties of ^{12}C-enriched surface layers of shallow NV centers in diamond created by nitrogen ($^{15}N^{+}$) ion implantation. The implantation energies were used 2 keV, 3 keV and 5 keV with doses 1×10^{11} ions/cm^2, 10^{12} ions/cm^2, 3×10^{12} ions/cm^2 and 1×10^{13} ions/cm^2. Our findings show that the Rabi contrast is primarily influenced by implantation energy, where higher energy leads to higher contrast (except for 5 keV at the lowest dose). This behavior is attributed to a lower NV^- to NV^0 conversion ratio at lower energies due to proximity to the diamond surface. The spin relaxation (T_1) time depended mainly on the implantation dose, where higher doses lead to shorter values. At lower energies with 2 keV, the shortest T_1 was observed as the NV centers are locating to the diamond near surface, while at 3 keV and 5 keV, T_1 were observed as similar values affected mainly by P1 (electron spin in nitrogen impurity) center concentrations. T_2 time increased with larger implantation energies and smaller doses, as T_2 is determined by magnetic noise generated by P1 center and nuclear (^{15}N) spins within the diamond lattice or fluctuating magnetic noise from electron and nuclear spins at the diamond surface.

From the estimated AC magnetic field sensitivity, we confirmed that even with the near surface NVs creating, conditions 3 keV with high implantation doses $1–3 \times 10^{12}$ ions/cm^2, an optimal condition for high-quality NV spin properties showing lowest value of 44 nT/√Hz and T_2 time of 9.6 μs suitable for future NV-NMR applications can be achieved.

keyword: diamond, NV center, T_1, T_2