論文 / 著書情報
Article / Book Information

題目(和文)	量子センサに向けた炭素材料中のスピン状態制御
Title(English)	Spin state control of carbon materials for quantum sensors
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
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論 文 要 旨

THESIS SUMMARY

専攻： Department of	電子物理工学　専攻	申請学位（専攻分野）： Academic Degree Requested	博士（工学） Doctor of
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In this thesis, we present the spin state control of electrons in carbon materials toward quantum sensor applications. Crystalline carbon materials, graphene and diamond, are employed as the platforms of spin state control because of small spin-orbit interaction and lack of nuclear spin in the most abundant isotope (^{12}C). The key for the spin state control is the introduction of paramagnetic impurities. The fluorine impurity controls the charge and spin current in graphene. The nitrogen-vacancy (NV) center in diamond serves as the localized electron spin state for sensing.

In former part of this thesis, we examine the control of charge and spin current in graphene by using fluorine atom impurities. In chapter 2, we develop fluorination method of graphene using Ar/F_2 plasma. It is shown that the fluorine concentration is controllable and reversible by characterizations using Raman spectroscopy and X-ray photoelectron spectroscopy. We fabricate fluorinated graphene field effect transistor (FET) devices with different fluorine concentrations and characterize charge transport properties in chapter 3. Resistivities of fluorinated graphene FETs are dependent on fluorine concentrations, and controllable over 3 orders of magnitude at room temperature. Conduction mechanism is also dependent on fluorine concentrations. Metallic conduction like pristine graphene is maintained at low fluorine concentration, while temperature dependence follows variable range hopping mechanism at high fluorine concentration. We have found characteristic electron-hole asymmetry at high fluorine concentration, which can be ascribed to the existence of midgap impurity states. On/off ratio of the device at room temperature is not very different from that of pristine graphene FET. However, the on/off ratio can be enhanced by using ionic liquid gating. In chapter 4, we explore the possibilities of spin state control using fluorine impurities. We use fluorinated graphene FET with lower fluorine concentration, which retains metallic conduction mechanism. Magnetotransport measurements suggest that spin relaxation time can be controllable by one order of magnitude by gate voltages. We also try to observe spin Hall effect using non-local resistance measurement of Hall bar device. We have found the possibility of the existence of spin Hall effect in fluorinated graphene. However, further evidence should be provided in the future.

Toward quantum sensor application of high density NV center ensemble, we develop chemical vapor deposition (CVD)-based fabrication techniques and demonstrate magnetometer action in the latter part of this thesis. In chapter 5, we propose a new umbrella shaped diamond micro-structure for photon collection efficiency improvement, which has the effect similar to solid immersion lens. The simulation suggest about one-order improvement of photon collection efficiency in proposed structure. The structure is fabricated by using anisotropic CVD-growth on mask-patterned diamond. The confocal microscopy and photoluminescence spectroscopy measurements reveal about from 3 to 5 times larger luminescence intensity from the micro-structure than that from bulk diamond. Chapter 6 is devoted to the selective alignment of high density NV ensemble. We propose a quantification method of the alignment ratio based on ensemble optically detected magnetic resonance measurement. After calibration measurements using samples synthesized by high-temperature high-pressure methods, we characterize our CVD samples. One of the CVD samples has selective alignment ratio over 80 % and NV density over 10^{15} cm^{-3}. We demonstrate the quantum sensor (AC magnetometer) action of the CVD samples in chapter 7. We also show the results using ensemble NV center fabricated by ion-implantation and a grow-in single NV center for comparison. Important parameters for sensor performance, contrast, coherence time, and luminescence intensity are characterized first. The estimated sensitivity is calculated by these parameters, which suggests that CVD sample can exhibit about one-order better performance than implantation ensemble or single NV. We characterize actual sensitivities of AC magnetic field (at frequency of 1.5625 MHz) using dynamical decoupling sequences (CPMG and XY8). The results are consistent with the estimated sensitivity, and CVD sample showed the best performance: sensitivity (minimum detectable magnetic field within acquisition time of 1 second) of 34 $nT/Hz^{1/2}$ with XY8 sequence.

備考 ： 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。
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