# 論文 / 著書情報
# Article / Book Information

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| 題目(和文) | 磁性材料とダイヤモンド量子センサのハイブリッド系による量子スピントロニクスの研究 |
| Title(English) | Study on quantum spintronics with hybrid systems of magnetic materials and diamond quantum sensors |
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# 論 文 要 旨

THESIS SUMMARY

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| 系・コース：<br>Department of, Graduate major in | 電気電子<br>エネルギー | 系<br>コース | 申請学位（専攻分野）：<br>Academic Degree Requested | 博士<br>Doctor of | （ 工学 ） |
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要旨（英文800語程度）
Thesis Summary（approx.800 English Words ）


In recent years, with the development of quantum technology, interdisciplinary attempts to hybridize quantum and spintronics technology have been made to create new value. This fusional research field is called Quantum Spintronics. Research topics in quantum spintronics include extending the function of quantum systems through quantum-spin hybrid systems and observing the physical properties of spin systems by quantum sensors.

The nitrogen-vacancy (NV) center in diamonds is one of the most developed quantum systems. The strength of NV center is widefield imaging of physical quantity such as magnetic field and pressure, derived from NV center's optical accessibility.

Quantum spintronics research has been conducted using NV centers. However, there is still room for further exploration in engineering applications. This study pioneers two kinds of new engineering applications of quantum spintronics based on widefield imaging with NV centers. One is high-sensitivity pressure imaging using a magnetostrictive (MS) and NV hybrid structure. The other is imaging the magnetization response of soft magnetic materials for power electronics using NV centers.

Firstly, the hybrid pressure sensor was demonstrated. Improving pressure sensitivity is the key to expanding the application of NV centers as pressure sensors. This study focused on the MS-NV hybrid imager, where the MS layer facilitates pressure-to-magnetic field conversion, detected by NV centers. Hybrid materials comprising in-plane magnetized $SmFe_2$ as an MS layer and diamond with NV centers perfectly aligned in the vertical [111] orientation to effectively detect the pressure-to-magnetic field conversion were used. The pressure coefficient, defined as the change in the resonant frequency of the optically detected magnetic resonance in response to pressure, is imaged by widefield imaging while varying the pressure applied to the MS–NV structure. A pressure-dependent change in the resonant frequency was observed. Through widefield imaging, the pressure coefficients are found to be correlated with the multidomain structure of the MS layer, which must be considered in widefield pressure imaging. The highest pressure coefficient is 8.2 kHz $kPa^{-1}$ in a domain—550 times greater than that achieved by a single structure of the NV center. This study proposes and discusses the approach of using MS disk arrays consisting of a single domain to improve sensitivity and controllability and to enable accurate calibration of pressure imaging. The highly-sensitive pressure imaging would open up new applications such as imaging of cell weight.

Secondly, the imaging of the DC/AC magnetization response was demonstrated. Recently, large energy losses in soft magnetic inductor cores in high-frequency (~MHz) operation restrict the reduction of energy loss in power electronic systems. Imaging the energy loss and understanding its mechanism is essential. In this study, a widefield and wide-frequency-range (DC-20 kHz, 300kHz- 2MHz) magnetic field imaging system was developed. The magnetization response of a soft magnetic CoFeB-$SiO_2$ thin film, developed for high-frequency inductors and exhibiting uniaxial magnetic anisotropy, was imaged. In DC measurements, around the film edge, the easy and hard axes directions exhibited different responses to the external magnetic field. The observed responses were consistent with the ones observed by Magneto-Optical Kerr Effect (MOKE) microscopy. Moreover, discontinuous magnetization along domain walls was detected, which is challenging to observe in the MOKE measurement. In AC measurements, this study proposed a novel measurement protocol, 'Qubit frequency track (Qurack)' track to image an AC field up to 20 kHz. In this protocol, microwave frequency modulation tracks qubit frequency oscillation. Quantum heterodyne imaging was demonstrated to be effective for the simultaneous imaging of the amplitude and phase of AC magnetic fields beyond the MHz range. A frequency-dependent magnetic response up to 2.3 MHz was imaged. The CoFeB-$SiO_2$ thin film exhibited almost zero phase delay up to 2.3 MHz, implying the energy loss was almost zero. Moreover, the energy loss depended on the anisotropy of the thin film: when the thin film was driven along the easy axis, the phase delayed as frequency increased, implying the loss increased. Diamond quantum sensors can help evaluate magnetic materials and design power electronics.

Further development of this research will advance life science and realize carbon neutrality.


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。
Note : Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1copy of 800 Words (English).