論文 / 著書情報
Article / Book Information

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Title(English)	A Study on Device Technologies for Integration of Diamond Quantum Sensors
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Magnetometry is one of the key metrological techniques in contemporary society. It is widely applied in many fields such as life science, medicine, and mechatronics, among others; therefore, the spatial resolution, sensitivity, and dynamic range requirements differ from each other, no sensor can satisfy all fields. A nitrogen-vacancy (NV) center in diamond, which is the topic of this study, is one of the promising solid-state systems for quantum sensors due to its superior properties. Therefore, the NV center is being studied as a magnetometer with high sensitivity for a wide range of applications. Research on magnetometers based on the NV center is advancing, and a lot of effort has been devoted toward realizing highly sensitive magnetometers with the NV center. However, the measurement setup of magnetometers often includes an optical table with a size of more than 1 m, producing a large sensor system volume. This has become a bottleneck in the practical application of sensors. Therefore, it is of great importance to miniaturize and integrate sensor systems, as well as improve the sensitivity for practical applications of magnetometers with the NV center. Moreover, miniaturization of the sensor system will contribute to further expansion of the application field of high-sensitivity magnetometers with the NV center.

The electron spin states of the NV centers are often read out by detecting fluorescence emitted from the NV centers. However, the total photon detection efficiency, which determines the sensitivity of the sensor, is as low as a few percent because of a high refractive index of 2.4 of diamond and losses at optics. Instead of the optical detection, photoelectrical detection techniques have been proposed to detect the electron spin states of the NV centers as a spin-dependent photocurrent. These are crucial technologies not only to realize highly sensitive sensors but also to integrate sensor systems because it does not require optics such as photodetectors.

This study focused on device technologies as the basis for integrated sensor systems. Specifically, photoelectrical detection of the NV center was conducted. First, p–n junction devices for the photoelectrical detection of the NV centers were developed. A pseudo vertical p–n diode and lateral devices were fabricated. The pseudo vertical p–n diode showed relatively high leakage current. Investigation of current leakage sites by means of an electron-beam-induced current (EBIC) technique and conductive-atomic-force microscopy (C-AFM) revealed that characteristic defects observed on the surface of the device are leakage sites. On the other hand, there are no defect structure on the lateral devices observed by the optical microscopy, resulting in the low leakage current less than a detection limit of a measurement system. Ensemble NV centers were fabricated in the diamond lateral devices by nitrogen ion implantation and subsequent high temperature annealing. Photocurrent detection based on a two-photon ionization process was performed from NV centers in the lateral devices with laser illumination. Photoelectrically detected magnetic resonance measurements showed an electron spin resonance dip at 2.87 GHz, indicating that the spin-dependent component of the NV centers is included in the measured photocurrent. The DC magnetic sensitivity of the photoelectrical readout was estimated to be approximately 6 $\mu T/Hz^{-1/2}$. In photocurrent detection, the photocarriers generated from the NV centers are transported in diamond and then collected to the metal electrodes. To understand the photocarrier transport mechanism, the diffusion length of the optically generated carriers was estimated from the dependence of the photocurrent on the measurement position.

For large-area sensor processes, electronic devices (Schottky barrier diodes, SBDs) were fabricated on the heteroepitaxial diamond film grown onto the 3C-SiC/Si substrate and characterized. 3C-SiC/Si was selected as the substrate material because it enables production of large-size substrates with low cost and has high affinity to the conventional silicon processes. Fabricated SBDs exhibited a rectification ratio of over 10^8 in a voltage range of ±5 V, and high temperature operation at 500 K was achieved. A correlation between electrical properties of SBDs and crystal defects in heteroepitaxial diamond films was investigated. In a defect observation, it was found that there were two defects causing leakage current: linear pits, and nonepitaxial crystals. Suppression of these defects leads to improve feasibility as a substrate for integrated sensor systems for heteroepitaxial diamond films.

Since the device technologies studied in this dissertation are crucial elemental technologies to realize diamond quantum sensors for practical use in the future, these technologies pave the way for highly sensitive integrated quantum sensors.

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).