

論文 / 著書情報
Article / Book Information

題目(和文)	量子ネットワークノードに向けたダイヤモンド中の鉛 - 空孔センター
Title(English)	Lead-vacancy centers in diamond for quantum network nodes
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出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第12703号, 授与年月日:2024年3月26日, 学位の種別:課程博士, 審査員:岩崎 孝之,山田 明,波多野 睦子,小寺 哲夫,荒井 慧悟,岩本 敏
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Tokyo Institute of Technology, Report number:甲第12703号, Conferred date:2024/3/26, Degree Type:Course doctor, Examiner:,,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

論文要約

THESIS ABSTRACT

系・コース
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Department of Graduate major in

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Student's Name

電気電子
電気電子

系
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申請学位（専攻分 博士
野）:

Academic Degree Requested

審査員主査:

Chief Examiner

Doctor of (工学)

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Lead-vacancy centers in diamond for quantum network nodes

(量子ネットワークノードに向けたダイヤモンド中の鉛-空孔センター)

The rapid development of quantum information technology will greatly shape our future lifestyle. To achieve long-distance quantum bits (qubits) transmission, there is a great demand for quantum nodes in quantum network. Compared to other solid-state quantum emitters, such as quantum dots and defects in SiC, color centers in diamond serve as prospective quantum nodes in quantum network, owing to their relatively long spin coherence time and efficient quantum light-matter interface. Although two-photon interference and quantum entanglement based on the nitrogen-vacancy (NV) center have been reported thus far, the low fraction of emission into the zero-phonon-line (ZPL) and weak resistance to external noise pose challenges for further application in quantum network. Alternatively, inversion-symmetric negatively-charged group-IV vacancy centers demonstrate large fluorescence concentrations in their ZPLs and high robustness against external noise. Nevertheless, their spin coherence times are limited by phonon-mediated transitions within the ground states. Since the ground state splitting becomes larger with increasing atomic number, the heaviest group-IV vacancy center, the lead-vacancy (PbV) center, is expected to obtain superior spin properties at an elevated temperature. Therefore, the purpose of this study is to determine the emission properties of the PbV center, to evaluate the potential for a long spin coherence time, and to observe the transform limited photon emission from the PbV center. The summary of this thesis is listed as follows.

Chapter 1 begins with the comprehensive introduction of the quantum network and considerable candidates for quantum nodes. By comparing the performance in the field of quantum network, the vital role of the PbV center can be emphasized, which clearly demonstrates the value of this study.

Chapter 2 describes the basic properties of the PbV center in diamond and the current situation of the researches on the PbV centers. The lattice structure and the electronic structure of the PbV center are discussed according to other group-IV vacancy centers. The electron phonon interaction in the D_{3d} symmetric structure is discussed. We discuss the disagreement on the ZPLs in previous studies due to the great difficulty in the fabrication of high-quality PbV center in diamond.

Chapter 3 provides the basic information of the sample fabrication and the experiment setup. We introduce the high-pressure and high temperature annealing to produce the high-quality PbV center in the diamond lattice. The experimental methods and experiment setup in our research are summarized here.

Chapter 4 introduces the clear spectroscopic investigation of the PbV center in diamond and determination of its ZPLs for the first time. We recorded the photoluminescence spectra at varying temperature from room temperature to 6 K. Two intense emission peaks at 550 and 554 nm were observed from both high-dose and low dose samples, with a large splitting of approximately 3900 GHz, which are thought to correspond to the ZPLs of the PbV center. With increasing temperature, the emission linewidth took a cubic broadening as same as other group-IV vacancy centers. We achieved the polarization measurements on a single lead-related emitter. The nearly orthogonal polarization of the two emission peaks strongly indicates that these two peaks are related to the ZPLs of the D_{3d} symmetric PbV center. The large ground state splitting significantly suppressed the phonon-mediated transition. Based on the calculation of phonon absorption rate, a millisecond-level spin coherence time could be expected at ~ 9 K for the PbV center in diamond. Chapter 5 reports the transform-limited photon emission from the PbV centers in diamond. Photoluminescence excitation measurements revealed stable fluorescence with a linewidth of 39 MHz at 6 K, close to the transform-limit estimated from the lifetime measurement. The statistical analysis on multiple PbV centers indicated that the coherent optical emission is commonly obtained from the PbV centers fabricated. The emission stability and charge state conversion under resonant excitation were discussed. The split spin-conserving transitions under external magnetic field proved the $1/2$ -spin configuration and gave rise to possible optical spin manipulation.

Chapter 6 presents the detailed investigation on a phonon relaxation model to interpret the linewidth broadening in the group-IV vacancy centers. The high phonon emission rate in the PbV center was reported to be responsible for the significant difference of the linewidth between the C- and D-transitions. The model also successfully predicted the strong temperature robustness of coherent photon emission from the PbV center: the nearly transform-limited linewidth was observed even over 10 K, which is higher than other color centers in diamond. The physical analysis in this work was applicable to other group-IV color centers and would become important in the community.

Chapter 7 outlines summary we have achieved on the PbV center and the promising prospect for the quantum network. Our work has demonstrated that the PbV centers in diamond cater to key requirements for quantum nodes in quantum network application. The further study on their charge state, spin properties, and quantum control pave the way to the realization of remote quantum entanglement among the PbV centers in diamond.