【Grant-in-Aid for Scientific Research (S)】

Charge control and creation of quantum network devices of group-IV vacancy centers in diamond

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Project Information	Project Number : 22H04962 Project Period (FY) : 2022-2026 Keywords : Diamond quantum emitters, Group-IV vacancy centers, Quantum network, Charge control

Purpose and Background of the Research

●Outline of the Research

Quantum network is a secure network transmitting quantum information. It is composed of quantum network nodes of senders, receivers, and quantum repeaters. Quantum emitters with superior optical and spin properties are required in the quantum network nodes to realize the quantum network. Defects with highly efficient optical transition and electron spin, formed in solid-state materials, are candidates for the quantum emitter. Group-IV vacancy centers in diamond[1] have great attention as a promising quantum emitter having both good optical and spin properties. Diamond is composed of carbon atoms of the lightest group-IV element and is a wide gap semiconductor with a large bandgap of 5.5 eV. Impurities introduced in diamond form quantum emitters with energy levels by binding with neighboring vacancies. Among them, a nitrogen-vacancy (NV) center is the most studied quantum emitter, but it has a low zero phonon line against the total fluorescence, which is utilized in the quantum network. In contrast, group-IV vacancy centers in diamond possess large zero phonon lines. Silicon-vacancy (SiV) and germanium-vacancy (GeV) centers have large zero phonon lines, while they need to be cooled down to milli-Kelvin temperatures in a dilution refrigerator to achieve a long spin coherence time. On the other hand, tin-vacancy (SnV) and lead-vacancy (PbV) centers with large spin-orbit interactions are expected to show a long spin coherence time at Kelvin temperatures by suppressing the effect of phonon[2,3]. In this project, we study SnV and PbV centers in diamond towards the quantum network.

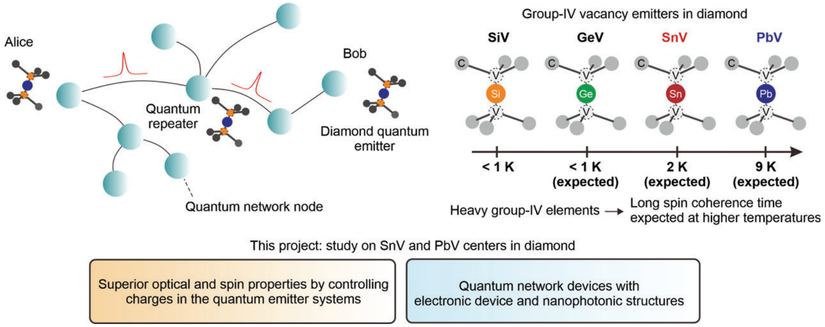

Figure 1. Quantum network and group-IV vacancy centers in diamond.

Optical properties, such as Fourier transform-limited linewidths and stable emission without spectral diffusion, and a long spin coherence time are required for the quantum network applications. It is important to understand and control the charge state of the system of the quantum emitters, which strongly influence the properties. Here, we develop methods to control the charge state of SnV and PbV centers and fabricate quantum network devices using the emitters.

The charge states of the quantum emitter itself and surrounding environment affect the properties of the quantum emitters. A resonant laser is used to optically excite the emitters. In this process, however, the charge state of the emitter changes. Additionally, the spectral diffusion occurs due to the charges of the nearby defects around the emitters. Furthermore, suppressing the magnetic noise from the defects and impurities is important to achieve a superior spin property. In this project, we perform the charge control of SnV and PbV centers from both experimental and theoretical methods.

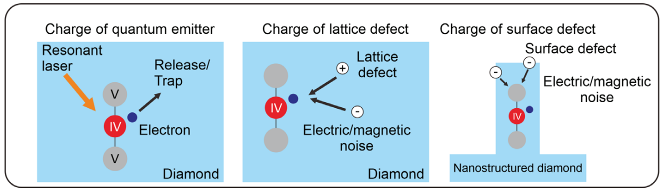

Figure 2. Charge of the system of quantum emitters.

Expected Research Achievements

●Charge control of quantum emitter systems

Mechanism analysis and control of the charge transition are performed. The detailed mechanism of the charge transition upon irradiation of both the resonant and non-resonant lasers are investigated for SnV and PbV centers. Theoretically, first-principles calculations based on time-dependent density functional theory is performed to analyze the transient responses in laser irradiation. Moreover, we control the formation and charge of the lattice and surface defects in diamond. The high-pressure and high-temperature anneal process is further developed to suppress the formation of the lattice defects.

●Spin characterization of quantum emitter

Spin coherence are disturbed by the magnetic noise from the lattice and surface defects. We investigate the magnetic noise in the system and characterize the spin properties of the quantum emitters. A pulse sequence, called dynamical decoupling, is utilized to characterize the spin state. We aim to realize long spin coherence times of the SnV and PbV centers. The superior spin property is expected at a higher temperature for PbV. Thus, we perform the measurements including clarification of its physical limits.

●Quantum network device and quantum interference

We fabricate quantum network devices with nanophotonic structures by developing diamond devices. The generation of indistinguishable photons from distant quantum emitters are required for the quantum network. Here, we measure quantum interference to observe the indistinguishability of photons from the quantum network devices.

●Expected effects

The quantum network devices developed in this project will lead to the generation of quantum entanglement and quantum repeaters for scalable quantum networks. Furthermore, the method of the charge state control studied in this project are expected be to useful for other solid-state quantum systems, and accelerate the development of quantum information and quantum sensing technologies.

Homepage Address, etc.	References 1. T. Iwasaki, Semiconductors and Semimetals 103, 237, 2020. 2. T. Iwasaki, Y. Miyamoto, T. Taniguchi, P. Siyushev, M. H. Metsch, F. Jelezko, M. Hatano, Phys. Rev. Lett. 119, 253601, 2017. 3. P. Wang, T. Taniguchi, Y. Miyamoto, M. Hatano, T. Iwasaki, ACS Photonics 8, 2947, 2021. Web: http://dia.pe.titech.ac.jp/