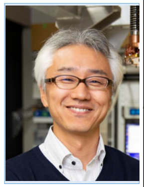
【Grant-in-Aid for Scientific Research (S)】

Creation of innovative quantum repeater technology for semiconductor spin qubits based on photon-spin quantum state conversion



Principal Investigator	Osaka University, Institute of Scientific and Industrial Research, Professor OIWA Akira　　　　Researcher Number:10321902
Project Information	Project Number : 23H05458　　　　Project Period (FY) : 2023-2027 Keywords : Photon-spin quantum interface, quantum dot, spin qubit, quantum repeaters

Purpose and Background of the Research

●Outline of the Research

In recent years, the studies on quantum information technologies, which are expected to bring revolutionary changes to our society, such as quantum computers and quantum cryptography based on the principles of quantum mechanics, have been very actively promoted by global information companies, universities and research institutes worldwide. To bring such quantum information to our daily uses in future, a quantum networks, like the current Internet, is indispensable. The quantum networks need long-distance quantum communications, being under studied in various qubits such as diamond NV centers and cold atoms. However, there is still no definitive physical system that can realize quantum repeaters.

Semiconductor spin qubits, which use the magnetic properties (spin) of electron or hole confined in a semiconductor microstructure, are the strong candidate for quantum computers because of their high affinity with semiconductor integrated circuit processes. Since an important feature of semiconductors is the functionalities of optical devices, we believe that semiconductor spin qubits are also promising for quantum communications, and we develop technologies to convert quantum information between semiconductor spin qubits and photons for quantum repeaters, which is indispensable for quantum networks. The goal of this research is to establish principles and technologies to significantly improve the quantum state conversion from photon polarization to spin to realize quantum repeaters, and to achieve innovative performance. Specifically, we will focus on germanium quantum dots that operate directly at a telecom wavelength and improve the performance of high-efficiency conversion by using photonic nanocavities and quantum memory functionality, as well as to develop a new quantum light source for quantum repeaters using spin qubits.

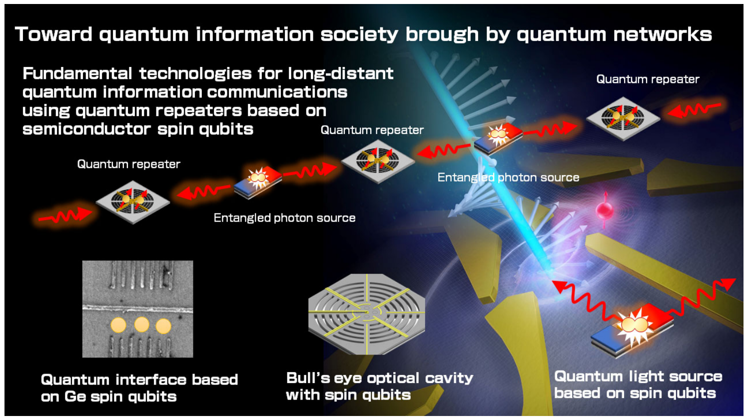


Figure 1. Schematics of our proposed quantum repeater system and project overview

In our proposed quantum repeater system (Fig.1), entangled photons from quantum entangled photon sources are delivered to a repeater, then are converted to spin, and Bell measurement is performed, thereby extending the communication distance of quantum. In this study, we conduct highly original research on a photon-spin quantum interface and a spin quantum state emitter using spin qubits.

●Ge quantum dot-Bull's eye cavity quantum interface

Quantum interface, which converts quantum information from photons to spins and has a memory and quantum processors, is a core element for quantum repeater. In this study, we will challenge to realize a quantum interface with Ge hole spin qubits, whose operating wavelength is consistent with the telecom wavelength. The direct operation at a telecom wavelength is a significant feature compared to other candidates for quantum repeaters. We will establish the basic principle of photon-hole spin quantum state conversion in a Ge quantum dot and will tackle to significantly enhance the conversion efficiency by a Bull's-eye optical cavity.

●Spin quantum state emitting devices

Quantum light sources are extremely important for quantum communications and photonic quantum computers. Conventionally, nonlinear optical materials and self-assembled quantum dots have been established, and quantum light sources using gate-controlled quantum dots, a platform of spin qubits has not been reported. A highly electrically tunable quantum light sources would provide innovative technologies such as on-demand quantum light sources and entangled photon sources. In this study, we challenge to realize a spin quantum state light emitting device by combining gate-controlled quantum dots and a planer LED structure.

Expected Research Achievements

●Photon-spin quantum interface in germanium quantum dots

We will demonstrate and establish the quantum state conversion from a photon polarization state to a hole spin state in Ge quantum dots, at a telecom wavelength. Furthermore, the use of Ge can add superior functionalities, such as high-speed spin manipulation through a strong spin-orbit interaction, extension of hole spin coherence time by isotope enrichment, and a single nuclear spin memory.

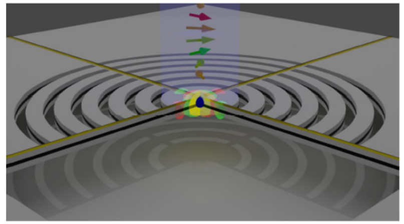


Figure 3. Bull's eye optical cavity

●Highly efficient quantum interface using Ge hole spin qubit Bull's-eye cavity

As an innovative quantum interface for quantum repeater, we will design and develop a Bull's eye cavity that operates at a telecom wavelength (Fig.2), and by introducing Ge hole quantum dots into the cavity, a significant increase in photon-hole spin conversion efficiency. For this purpose, a Germanium-On-Insulator substrate with a Ge quantum well stacked on SiO2 will be realized. Furthermore, for Bell measurements, 2D Ge quantum dot array with a charge sensor will be implemented in the Bull's eye cavity.

●Spin quantum state emitting devices

We study novel quantum light sources that converts quantum states from a spin to a photon polarization. Gate-controlled quantum dots are incorporated into a planer LED structure (Fig. 3). A single photon and an entangled photon source will be investigated.

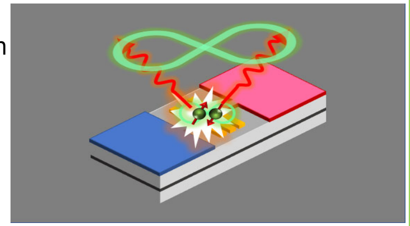


Figure 4. Spin quantum state emitting device

Homepage Address, etc.	https://www.sanken.osaka-u.ac.jp/labs/qse/indexEN.html