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

Developing Silicon Germanium Optical Spintronics

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Project Information	Project Number : 24H00034 Keywords : Semiconductor, Spintronics, SiGe, Quantum structure	Project Period (FY) : 2024-2028

Purpose and Background of the Research

●Outline of the Research

"Semiconductors" are involved in everything from electronic devices such as smartphones and personal computers to cutting-edge technologies such as artificial intelligence (AI), electric vehicles (EV), and quantum computer-related technologies. The development of AI technology in particular is beginning to create extremely serious issues that could lead to global environmental problems. According to data published by the LCS of JST (a national organization), the power consumption of data centers is estimated to expand by more than 2,500 times by 2050, compared to fiscal 2018. In general, "semiconductors" will account for approximately 60~80% of the power consumption of data centers. Therefore, the only way for Japan to achieve its goal of achieving a carbon-neutral society by 2050 is to make efforts to reduce the power consumption of these "semiconductors". The goal of this research is to establish the fundamental technology and basic science of "electron-spin-optical integrated semiconductor systems" as shown in Figure 1, based on the "room temperature semiconductor spintronics technology" that has been independently researched and developed by the Principal Investigator and Research Members for more than 10 years. Here, we focus on the semiconductor material system called silicon germanium (SiGe) to realize semiconductor optical spintronics devices on silicon (Si) semiconductor substrates with spintronics technologies.

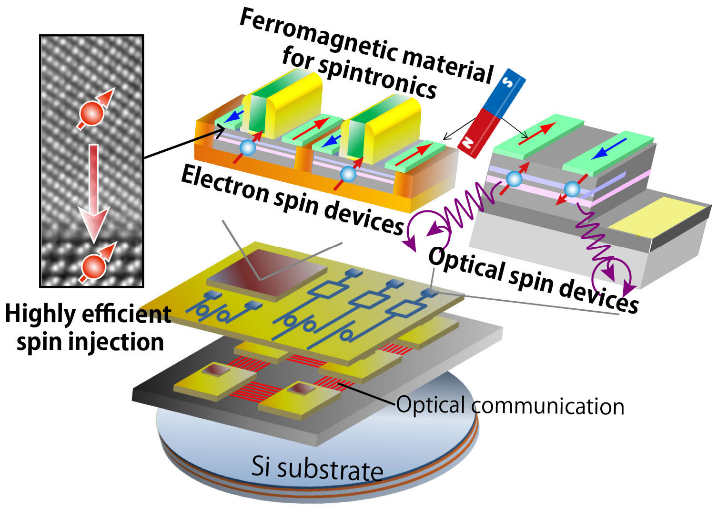

Figure 1: Schematic diagram of the research project (long-term perspective) and the optical spintronic device to be demonstrated in this research (right).

●Importance of this research and core technologies

The use of germanium (Ge), a semiconductor that is consistent with spintronics technology and can lead to optical devices that operate in the telecommunications wavelength band, is extremely promising. We are a world-class research team that has been working on the establishment of an academic foundation for Ge spintronics. We have already demonstrated an ultra-high quality junction of spintronics magnetic materials and Ge at the atomic layer level, as shown in Figure 1 (left), and have demonstrated a germanium "electron spin device" structure with non-volatile memory operation at room temperature (Figure 2). In this study, we will try to demonstrate "SiGe optical spin devices" by applying this technology and fusing it with various quantum structures made of SiGe (silicon germanium), which is an alloy of Ge and Si.

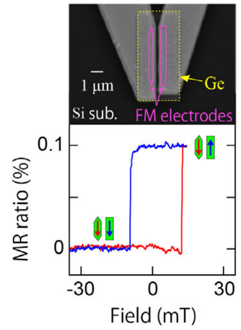

Figure 2: Room temperature nonvolatile memory effects in Ge electron spin devices.

Expected Research Achievements

● Theme 1 : Highly efficient spin injection into Ge/SiGe multiple quantum wells (MQWs) at room temperature

We will establish a technique to realize a high-quality SiGe layer on SiO_2 using a wafer-bonding process and demonstrate the so-called SiGe-on-Insulator (SGOI) structure. Furthermore, we will demonstrate Ge/SiGe multiple quantum well (MQW) structure on the SGOI and demonstrate room temperature and high efficiency spin injection into the MQW layer, thereby establishing a fundamental technology to realize optical spin devices.

● Theme 2 : Demonstration of spin LEDs using Ge/SiGe –MQWs

We will demonstrate a "circularly polarized spin LED" (Figure 3) that can simultaneously realize highly efficient room-temperature spin injection and emission in the telecommunication wavelength band using the technology to be constructed in Theme 1.

● Theme 3 : Construction of on-chip spin laser technology

Combining the technologies originally developed in Theme 1 and Theme 2, we will try to demonstrate spin lasers or perpendicularly resonant surface emitting spin lasers that incorporate an in-plane resonator structure. The important point is that a large current is likely to be required for circularly polarized laser oscillation at room temperature, but our high-efficiency, low-resistance spin injection technology is expected to be able to achieve a threshold current at nearly two orders of magnitude lower voltage than conventional technologies.

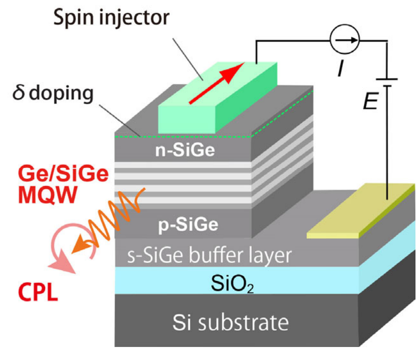

Figure 3 : Schematic diagram of a demonstration example for theme 2.

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