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

Broad Section D

Title of Project : Developments of reconfigurable quantum superconducting devices based on rotational spin current

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Keyword : spin current, spin-triple state, Josephson junction, multi-terminal spin injection

【Purpose and Background of the Research】

Superconductivity and ferromagnetism are representative phenomena in quantum condensed matter physics. The combination between two phenomena is promising approach for developing the innovative quantum devices. However, in general, the interplay between two phenomena deteriorates the superconducting properties because of the strong effective magnetic field from the ferromagnetic materials. Therefore, it is understood as exclusive phenomena for long decades. To overcome this intrinsic serious obstacle, here, we focus on a non-ferromagnetic normal conductor such as Cu and Ag.

Project leader developed various techniques for the efficient manipulation of the spin current. A highly efficient spin injection has been demonstrated by optimizing device geometry. As a result, it was clearly shown that the superconductor becomes an insulator for the pure spin current. Moreover, the state where the spin-polarized current and the cooper-pair current coexist can be realized in a nonmagnetic Cu layer in between the ferromagnetic metal and superconductor. Based on these unique techniques, in this project, we will develop spin-based superconducting devices, which make the innovation in quantum coherent devices.

【Research Methods】

First, we develop the formation technique of the triplet spin current by using the specially developed ferromagnet/non-ferromagnetic normal conductor / superconductor hybrid nano structures. By using time control of the multi-terminal spin injection technique using non-collinear spin injectors, we generate the rotational effective magnetic field in normal conductor, resulting in the transition from the singlet cooper pair to the triplet pair (Fig.1).

The developed spin-triplet state has entanglement property, which enables us to realize quantum bit. The spin entangled quantum state will be sensitively detected by an inverse spin Hall effect using a heavy metal, leading to the simple quantum-bit device. Moreover, by extending the multi-terminal spin injection technique, we will develop Josephson pi junction. Since the phase change due to the effective magnetic field can be adjusted by the spin injection, we are able to develop reconfigurable superconducting quantum devices.

【Expected Research Achievements and Scientific Significance】

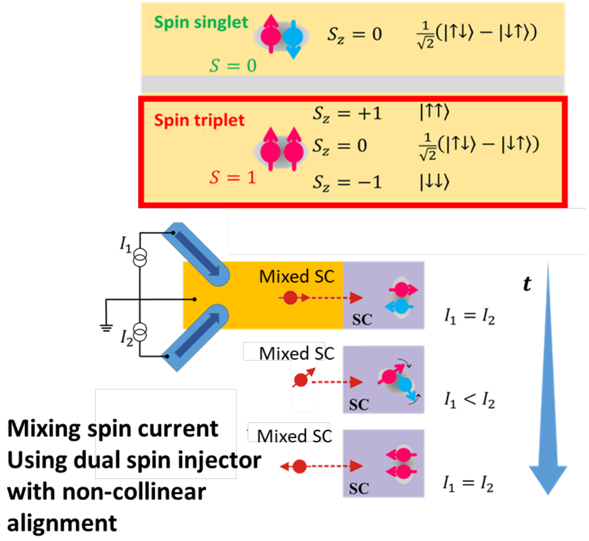

Fig. 1 Formation of spin-triplet copper pair using rotational spin current.

Superconductivity is one of the representative macroscopic quantum phenomena. Zero resistance and persistent current are excellent properties for recent nano electronics. In addition, nano-electronic device with ultra high speed operation and high performance quantum bit have also been demonstrated by using superconductors. On the other hand, in the field of spintronics, spin current plays an important role instead of the electric charge current. Development of the efficient spin injection is a key for a realization of high-performance spintronic devices. Therefore, if the super spin current can be realized, various advantage, which makes innovation both in spintronics and superconducting electronic, will be produced.

【Publications Relevant to the Project】

- S. Hu, X. Cui, T. Nomura, T. Min, and T. Kimura, Nonreciprocity of electrically excited thermal spin signals in CoFeAl-Cu-Py lateral spin valves, Phys. Rev. B 95, 100403(R) (2018)
- K. Ohnishi, Y. Ono, and T. Kimura, "Significant change of spin transport property in Cu/Nb bilayer due to superconducting transition." Sci. Rep. 4, 6260 (2014).

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