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学　位　論　文　内　容　の　要　旨

博士の専攻分野の名称　　博士（工学）　　氏名　李 在哲

学　位　論　文　題　名

Theoretical design for artificial spin-triplet superconductors
(スピン三重項超伝導体のデザインに関する理論的研究)

The proximity effect has been an important issue in the physics of superconductivity. In a normal-metal/superconductor (NS) junction, Cooper pairs penetrate from a superconductor into a normal metal, and modify its electromagnetic and thermal properties. Such effect is called proximity effect. For instance, a normal metal in an NS junction indicates large diamagnetic response to an external magnetic field and has the gapped energy spectra at the Fermi level. The degree of the proximity effect depends on the junction parameters such as the transparency of a junction interface and the degree of disorder in a normal metal. In addition, the symmetry of the pair potential in a superconductor is a key parameter that changes the proximity effect qualitatively. The symmetry of the pair potential is categorized into two classes: spin-singlet even-parity and spin-triplet odd-parity. Spin-singlet s-wave superconductivity occurs in many metallic superconductors. Superconductivity in high-Tc cuprates belongs to spin-singlet d-wave symmetry class. However, spin-triplet superconductors are very rare. At present, only several heavy-fermionic compounds are candidates of spin-triplet superconductors. However, the spin-triplet superconductivity in these materials has not yet been confirmed. Theoretical studies from 2002 to 2007 have suggested very unusual transport properties in NS junctions consisting of spin-triplet superconductors. For example, the differential conductance in a spin-triplet p-wave NS junction at zero-bias is quantized irrespective of the transparency at the junction interface and the degree of disorder in a normal metal. Such remarkable phenomenon is called anomalous proximity effect (APE). At that time, microscopic mechanisms of the APE were not clear at all. Therefore, the APE was considered as a phenomenon unique to spin-triplet superconductors. Phenomenologically, the APE was understood as an interference phenomenon between two phase coherent effects: the formation of Andreev bound states at the junction interface and the usual proximity effect in a normal metal. The former is realized when the pair potential is an odd function of wavenumber in the current direction. The latter is realized when the pair potential is an even function of wavenumber in the transverse direction to the current. Only spin-triplet p-wave pair potentials satisfy these conditions. To observe the anomalous proximity effect in experiments, prescriptions for synthesizing artificial spin-triplet superconductors by combining existing materials and existing technologies. In 2015-2016, several theoretical studies show that the quantized value of the conductance is described well by an invariant N which is called Atiyah-Singer index and represents the number of resonant transmission channels at zero energy in a normal metal. In these theories, chiral symmetry of Hamiltonian is a key property that explains stability of highly degenerate zero-energy states in a dirty normal metal.

In this thesis, we propose theoretical recipes for artificial spin-triplet superconductors. Spin-orbit interactions have been important items that realizes topologically nontrivial electronic in various mate-

rials such as topological insulators, topological semimetals, and topological superconductors. Specific properties in topological materials can be tuned by controlling types of spin-orbit interactions such as Rashba type, Dresselhaus type, and spin helix type. In this thesis, we consider spin-singlet d-wave superconductors with spin helix type spin-orbit interactions. In a spin-singlet d-wave superconductor, the Andreev bound states are present, but the proximity effect is absent. A spin helix type spin-orbit interaction enables the proximity effect in a normal metal. In another spin-singlet d-wave superconductor, the Andreev bound states are absent, but the proximity effect is present. Another specific spin helix type spin-orbit interaction enables the Andreev bound states at the junction interface. As a result of introducing spin helix type spin-orbit interactions, such artificial superconductor indicates the APE. Namely artificial spin-triplet superconductivity is realized in a spin-singlet superconductor with a spin-orbit interaction. These studies indicate that the APE is the unusual phenomenon of superconductors that have nontrivial Atiyah-Singer index.