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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Recently, physical phenomena originating from the spin-orbit interaction in crystals have been intensively studied. The spin-orbit interaction comes from relativistic theory, and it has been known to affect various physical properties of electronic states and band structure in solids, and it is a key concept in the active field of spintronics, leading to unique transport properties such as spin field-effect transistor, Edelstein effect and persistent spin helix. Furthermore, various unique spin structures have been found in the interfaces and surfaces of Rashba systems and topological insulators, for example, an out-plane spin distribution and peculiar band splitting in the surface of Tl/Si and Bi/Si crystals due to low symmetries, unusual spin texture in a multilayer of Rashba bilayers with opposite Rashba spin-orbit interaction, topologically-protected gapless interface states between two topological insulators with opposite sign of the spin-orbit interaction and a phase transition between a topological insulator and an insulator phases in a multilayer of a topological insulator and an insulator. These unique states originate from symmetry and topology of systems with modulating the sign of the spin-orbit interaction, and hence we expect that the sign of the spin-orbit interaction gives a wide variety of symmetry and topology, to the system leading to unique states and intriguing phenomena.

In this thesis, we investigate these unique spin states and theoretically design novel states in the surfaces and multilayers focusing on its symmetry and topology by modulating the sign of the spin-orbit interaction. We aim to have unique band structure and novel spin states which appear only in such nanostructure. Firstly, we construct effective tight-binding models from symmetry of the systems for surface states in the Tl/Si and the Bi/Si having non-Rashba spin splitting around the K point. Our results from the effective Hamiltonian qualitatively agree with experimental results in terms of the band structure and the spin texture. Using the effective models, we find bound states at junctions between two surface regions with opposite signs of the spin-orbit interaction in the Bi/Si and in the Tl/Si systems. We investigate their spin properties from a viewpoint of symmetry. As a result, the spin directions of the bound states in the Bi/Si system are out-of-plane due to the mirror and time-reversal symmetries. We also discuss possibilities for realization in materials. Secondly, we consider a multilayer, consisting of alternating layers of two types of topological insulators and a normal insulator. We modulate the signs of the velocities of the surface Dirac cones of topological insulator layers alternately. We find a new phase diagram having topological nodal-line semimetal phase, which is absent in the simplest multilayer of a topological insulator and a normal insulator. This topological nodal-line semimetal phase has a nodal line, and it is protected by an internal symmetry and Kramers theorem. Interestingly, by breaking inversion symmetry, there appears a nodal surface in our multilayer. Additionally, we investigate the origin of the topological nodal-line semimetal phase by adding a warping term to change the symmetry of the system. We show that such multilayers exhibit various topological semimetal phases including a Dirac-node semimetal, a nodal-line semimetal and a nodal-line semimetal phases. In addition, the nodal surfaces are topologically characterized as zeros of the Pfaffian of a product between the Hamiltonian and a constant matrix, in other words, the nodal surfaces are characterized by the Z_2 topological number. Finally, we also find peculiar surface states in a multilayer of topological insulators, and it is similar to the bound states in the zigzag edge of the graphene ribbon. We analyze the surface states using effective models and investigate the mechanism for their emergence. We show these unique band structures come from interplay between symmetries and topology, and these states can be

realized by designing symmetries and topology of the nanostructures.

Thus we have shown that non-Rashba effects due to the low symmetries of systems give rise new spin properties which are absent in conventional Rashba systems, and they have much room for further research because such non-Rashba effects exist not only in the Tl/Si but also in the transition metal dichalcogenide monolayers. Furthermore, our study on the multilayer has shown new possibilities for realizing these unique states, for example, Dirac semimetal and nodal-line semimetal phases, from a new viewpoint: the sign of the spin-orbit interaction. Such novel topological nodal semimetal phases including a nodal-surface semimetal phase in spinful systems will help us to discover new spin transport phenomena.