Abstract of Doctoral Dissertation

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Title of Doctoral Dissertation

Charge Redistribution Near the Surfaces of Superconductors
(超伝導体における表面電荷)

At the surfaces of d-wave superconductors cut along certain directions, multiple Andreev reflection leads to a sign change in the pair potential and to the formation of zero energy bound states. Several theoretical studies have predicted the appearance of these mid-gap surface states. Their signatures have also been observed in experiments. The appearance of zero energy surface bound states has become a defining characteristic of d-wave superconductivity. The presence of surfaces in d-wave superconductors is expected to be accompanied by the appearance of certain forces responsible for charge redistribution in superconductors. However, before this time, the electrodynamic implications of these surface effects have not been considered from a fully microscopic point of view.

In this thesis, we have carried out a microscopic study on the accumulation of charge near the surface of a *d*-wave superconductor cut along the [110] direction, due to the pair potential gradient (PPG) force which originates from the spatial variation of the pair potential near the surface, and another force due to the pressure difference between the normal and superconducting regions arising from the slope of the density of states (SDOS) in the normal states at the Fermi level. To this end, we used the augmented quasiclassical equations, with the PPG force and SDOS pressure terms as first-order quantum corrections in terms of the quasiclassical parameter. We have also used a Fermi surface model appropriate for cuprate superconductors.

Our numerical results on surface charging in a *d*-wave paired superconductor indicate that despite the absence of supercurrents, electric charge spontaneously accumulates around the surface of the superconductor cut along the [110] plane. In addition, the charging effect due to the SDOS pressure dominates over that due to the PPG force for all the realistic electron-fillings n=0.8, 0.9 and 1.15 at all temperatures. Furthermore, for the electron-doped system with filling n = 1.15, the PPG force and the SDOS pressure contributions have the same negative signs, which gives a larger total surface charge compared to the hole-doped systems. We therefore remark that both the sign and amount of the surface charge depends greatly on the Fermi-surface curvature. Within the model considered in this study, zero energy bound states appear at the surface and this is consistent with previous theoretical predictions as well as experimental observations.

Furthermore, we have calculated the deviations in the local density of states (LDOS) within the augmented quasiclassical theory from the standard Eilenberger solutions. Locally large particle-hole asymmetry appears in the LDOS deviations

around the surface, which is a qualitative evidence of electric charging. Although the connection between particle-hole asymmetry in the LDOS and the existence of electric charging in the vortex state of type-II superconductors has been suggested, we have shown the appearance of this asymmetry in the LDOS deviations around the nodal surface of a *d*-wave superconductor, due to contributions from the PPG and the SDOS pressure. We remark that the particle-hole asymmetry is a qualitative evidence of the [110] surface electric charging in the model d-wave superconductor and it may be observed in experiments.

This thesis is organized as follows.
In Sect. 2, we derive the augmented quasiclassical equations of superconductivity in the Matsubara formalism, with the force terms which are responsible for charging, following earlier works.
In Sect. 3, we apply the augmented quasiclassical equations to perform a microscopic study on the spontaneous charge redistribution near the surface of a *d*-wave superconductor cut along the [110] direction. We also calculate the local density of states within the augmented quasiclassical theory.
In Sect. 4, we give give a general summary of the content of this thesis and our conclusion.