Doppler shift of zero energy Andreev bound state

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Abstract

The influence of a magnetic field H on the zero bias conductance peak (ZBCP) due to zero energy Andreev bound state (ZES) in normal metal / unconventional superconductor is studied. For p-wave junctions, ZBCP does not split into two by H, while ZBCP splits for d-wave. This unique property originates from the fact that for p-wave superconductors, perpendicularly injected quasiparticle form ZES, which contribute most dominantly on the tunneling conductance.

Key words: p-wave; Doppler shift; Andreev bound state; Tunneling effect

1. Introduction

Nowadays, tunneling spectroscopy in unconventional superconudctor is an fasicating field in solid state physics. The formation of zero energy Andreev bound states (ZES) at surfaces [1,2] or interfaces [3] of unconventional superconductors is receiving increasing attention. This state, which is created by injected and reflected quasiparticle's feeling different signs of the pair potential, can play an important role in determining the pairing symmetry of anisotropic superconductors. The detection of the ZES is reflected as an observation of a zero-bias conductance peak (ZBCP) in tunneling conductance, which is generally considered as a clear signature of anisotropic pairing [4–9]. The ZBCP is observed in various superconductors having anisotropic pairing symmetry, such as the cuprates [5,10–12]. Sr_2RuO_4 [13,14], and UBe_{13} [15].

Since the existence of ZES is a universal phenomena expected for unconventional superconductors having pair potential that changes sign on the Fermi surface, difficulty may arise in determining the pairing symmetry only from conventional tunneling spectroscopy.

In order to overcome this difficulty, we require some *in situ* way of probing the symmetry from the tunneling spectroscopy. We propse that a promising way is to use a tunneling spectroscopy in the presence of a magnetic field [16].

2. Result

We calculate tunneling conductance in normal metal / unconventional superconductor junctions by solving Bogoliubov-de Gennes (BdG) equation using quasiclassical approximation as in our previous theory [3,17,19]. As regards the triplet pairing cases, we assume that Cooper pairs are formed by electrons having antiparallel spins, but an extension to more general cases including parallel spin pairing or non-unitary cases [8,9] is straightforward. Now, we consider the case where a specularly reflecting surface or interface run along the y-direction. The insulator located at the interface between normal metal and d-wave superconductor is expressed by delta function model $H\delta(x)$. The magnetic field is applied parallel to the z axis, so that the vector potential can be chosen as $\mathbf{A}(\mathbf{r}) =$

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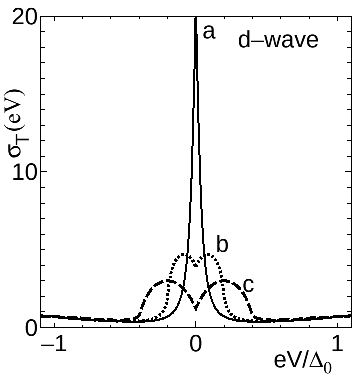

Fig. 1. The normalized tunneling conductance $\sigma_T(eV)$ in the $d_{x^2-y^2}$-wave state with (110) oriented surface. Z=5. a: $H=0$, b $H=0.2H_0$, and c: $H=0.4H_0$.

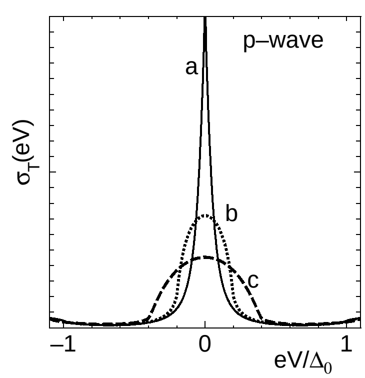

Fig. 2. The normalized tunneling conductance $\sigma_T(eV)$ in the p_x-wave state with (100) oriented surface. Z=5. a: $H=0$, b $H=0.2H_0$, and c: $H=0.4H_0$.

$(0, A_y(x), 0)$. The pair potential depends only on x since the system is homogeneous along the y-direction. Since we are now considering the situation where the coherence length of the pair potential ξ is much smaller than the penetration depth of the magnetic field λ, we can ignore the spatial dependence of $A_y(x)$ in the following calculations. We assume $A_y(x) = A_0 = -H\lambda$, where H is the applied magnetic field.

For $d_{x^2-y^2}$-wave junction, it has been shown that screening currents shift the ZES spectrum (Doppler shift) and lead to a splitting of ZBCP [21,20,17,18]. By contrast, we have shown that for p-wave cases, ZBCP does not split into two in the presence of a magnetic field since the most dominant contribution to tunneling conductance is given by perpendicular injection [22], where the energy shift of the quasiparticles does not occur at all due to the odd parity of the pair potential.

In this paper, we have shown that the tunneling spectroscopy in the presence of magnetic field is a promising method to distinguish between d-wave and p-wave superconductor where both of these show ZBCP without magnetic field.

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