Effect of gap suppression on the *ab*-plane conductance spectrum of a normal-metal–$d_{a^2-b^2}$-wave-superconductor junction

P. Pairor* and S. Nilmoung
School of Physics, Institute of Science, Suranaree University of Technology, Nakhon Ratchasima, Thailand
(Received 5 June 2004; revised manuscript received 18 August 2004; published 15 November 2004)

We study the effect of gap suppression near the surface on the conductance spectra of normal metal-{100} and {110} $d_{a^2-b^2}$-wave superconductor junctions using the scattering method. We find that for {100} junctions the positions of the maxima of the spectra are not always at the gap maximum of the bulk. The positions depend on the degree of the gap suppression at the interface. For {110} junctions, we find that the width of zero-bias conductance peaks (ZBCPs) in the spectra depends on the magnitude of the gap function at the interface of the junction. The ZBCP is absent when the gap function is totally suppressed at the interface. We also find that the shape of the spectra depends on the slope of the order parameter at the interface.

DOI: 10.1103/PhysRevB.70.184509 PACS number(s): 74.50.+r, 74.25.Fy, 74.20.Rp, 74.70.Dd

I. INTRODUCTION

The anisotropy and phase change of $d_{a^2-b^2}$-wave symmetry can result in pair breaking and thus suppression of the order parameter near the surface. The degree of the suppression depends strongly on the surface orientation.[1] Interpreting the results of the experiments that are sensitive to the surface properties must then be done in a very careful fashion. Tunneling spectroscopy is among these experiments. The conductance spectrum of a normal metal-$d_{a^2-b^2}$-wave superconductor junction does not always resemble the bulk density of states of the superconductor, as it does for isotropic *s*-wave superconductors. Instead, it is proportional to the local density of states and, therefore, depends very strongly on the junction orientation. From the calculation in Refs. 2 and 3 for *ab*-plane junctions away from {100} interface orientations of a $d_{a^2-b^2}$-wave superconductor, the conductance spectra should contain zero-bias conductance peaks (ZBCPs), which indicate the formation of zero-energy surface-bound states. These bound states result from the scattering of quasiparticles at an interface to a new state with an order parameter of opposite sign, as it is a signature of the $d_{a^2-b^2}$-wave order parameter.[4,5] ZBCPs have been observed in many tunneling experiments of high-temperature superconductors.[6–18] However, in some *ab*-plane tunneling experiments ZBCPs do not always show up (see, for example, Refs. 19–23).

In all the surfaces away from {100} surfaces of $d_{a^2-b^2}$-wave superconductors, the outgoing and incoming quasiparticles experience the order parameter of opposite signs. Assuming no distortion of the order parameter, the existence of zero energy surface bound states is therefore predicted to occur in such surfaces.[5] However, the assumption that the order parameter is not distorted is not always right. Even for smooth surfaces the $d_{a^2-b^2}$-wave order parameter can be suppressed due to pair breaking.[1] The degree of suppression depends on the surface orientation, i.e., at {110} surfaces the suppression is complete, but there is no suppression at {100} surfaces.[1] Surface roughness is predicted to also play a role in the suppression of the order parameter. It causes some suppression in {100} surfaces and destroys the total suppression in {110} surfaces.[24–28]

In this paper, we investigate the effect of the suppression of the order parameter on the tunneling spectra of $d_{a^2-b^2}$-wave superconductors using the Blonder-Tinkham-Klapwijk formalism,[29] in which one finds the tunneling conductance from the quasiparticle transmission coefficients at the interface. We find that the degree of the suppression affects the position of maxima of the conductance spectra of junctions with {100} interface. Because the conductance spectra of {100} junctions are normally interpreted to be the density of states of the bulk, this would affect the determination of the measured gap maximum. We find that the maximum of the spectra appear at voltage corresponding to the value of the magnitude of the order parameter at the interface. Therefore with any suppression at all, the maxima will appear at an energy smaller than the maximum value of the parameter in the bulk. This result is similar to that from the studies done on the dependence of the surface density of states and/or conductance on surface roughness.[25,27,28] For {110} junctions, we find that the width of ZBCP depends on the magnitude of the order parameter at the interface. If the order parameter is completely suppressed, then the conductance spectra do not contain ZBCPs. This result is different from that found in the previous studies,[1,25,27,28] which obtain the differential conductance from the local density of states.

In Sec. II, we briefly describe the model used to represent the junction and method used to calculate tunneling conductance. We then present our results and discussion on {100} and {110} junctions in Sec. III. In Sec. IV, we summarize and comment on possible implications for the interpretation of tunneling experiments.

II. MODEL AND METHOD

We represent our normal metal-superconductor junction with an infinite system, half of which is a normal metal and the other half is a superconductor (see Fig. 1). The junction insulating barrier is represented by a delta function potential with strength *H*. In our treatment, we ignore the effect of the real Fermi surface. We assume our system is quasi-two-dimensional and use the continuous model to obtain the Fermi surface. The real Fermi surface would provide extra

