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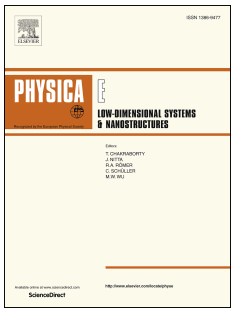


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# Manipulatable Andreev reflection due to the interplay between the DIII-class topological and $s$-wave superconductors

Xiao-Qi Wang[1], Guang-Yu Yi[1],* Yu Han[2], Cui Jiang[3], and Wei-Jiang Gong[1]†
*1. College of Sciences, Northeastern University, Shenyang 110819, China*
*2. Physics Department, Liaoning University, Shenyang 110036, China*
*3. Basic Department, Shenyang Institute of Engineering, Shenyang 110136, China*
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We construct one mesoscopic circuit in which one quantum dot couples to one DIII-class topological superconductor and one $s$-wave superconductor, in addition to its connection with the metallic lead. And then, the Andreev reflection current in the metallic lead is evaluated. It is found that the two kinds of superconductors drive the Andreev reflection in the constructive manner. Next as finite superconducting phase difference is taken into account, the Andreev reflection oscillates in period $\frac{\pi}{2}$, and it can be suppressed in the low-energy region if the superconducting phase difference is $(n+\frac{1}{2})\frac{\pi}{2}$ ($n \in Integer$). Such a result is almost independent of the increase of the intradot Coulomb interaction. Therefore, this structure can assist to realize the manipulation of the Andreev reflection. Also, the result in this work provides useful information for understanding the property of the DIII-class topological superconductor.

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## I. INTRODUCTION

Search for the bound states of exotic non-Abelian quasiparticles has been one focus of both theoretical and experimental studies in the field of condensed matter physics, due to its fundamental physics and potential applications in topological quantum computation[1–4]. Lots of reports showed that the bound states of Majorana fermion, i.e., the Majorana bound states (MBSs), can be realized by fabricating the topological superconductors (TSs)[5–7]. Moreover, in a new type of TSs with time-reversal symmetry, i.e., the DIII-class TSs[8–12], the zero modes appear in pairs due to Kramers's theorem[13–15], differently from the Majorana zero mode in the D-class TS. Accordingly, at each end of time-reversal-invariant TS wires, paired MBSs, i.e., Majorana doublet, will come into being which are protected by the time-reversal symmetry[16, 17]. It has been demonstrated that Majorana doublet is able to induce new physics mechanisms and promising applications. One important result is that its contributed Josephson effect exhibits the parity-dependent period and oscillation manner[18, 19]. In view of such a fact, researchers have studied proposals to realize the DIII-class TS wires using the proximity effects of $d$-wave, $p$-wave, $s$-wave, or conventional $s$-wave superconductors for realizing its application in future[20–25].

It is certain that for understanding the characteristics of one TS, its contribution to the Andreev reflection in the metal-TS system is one important aspect[26–28], in addition to the Josephson effect[29–32]. During the past years, various structures formed by the coupling between the metal and D-class TS have been built to investigate the Andreev reflection behaviors. Moreover, quantum dots (QDs) are usually embedded in these systems to analyze the interplay between the electronic and Majorana bound states, and a variety of interesting results have been observed. For instance, in the T-shaped double QDs coupled to the MBS, the Andreev conductance spectrum presents a well-defined insulating band in the low-bias region[33]. In a MBS-embedded Fano setup, the Fano effect becomes more complicated and determined by the structural parameters[34]. When the QD eneters the Kondo regime, some important phenomena are induced due to the interaction between the Kondo effect and the Andreev reflection [35–40]. It has been shown that in the structure where the MBS couples to the metal via a one Kondo QD, the system flows to a new fixed point controlled by the Majorana-induced coupling in addition to the Kondo fixed point, which is characterized by the correlations between the QD and the fermion parity of the TS and metal[36].

In view of the above researches, one can anticipate that the Andreev reflection driven by the Majorana doublet will be interesting. In fact, such a topic has received attention, and the Andreev-reflection result has been proposed to detect the Majorana doublet[41]. Moreover, it has been observed that in the Andreev reflection structure with Majorana doublet, the Kondo correlations occur between the localized state in the QD and two continuum states simultaneously, i.e., the continuum state in the metal and the continuum Andreev reflection state between the metal and TS[42]. This means that the Majorana doublet plays the different role in driving the Andreev reflection, compared with the MBS in the D-class TS and $s$-wave superconductor[43].

*Electronic address: yiguangyu@mail.neu.edu.cn
†Electronic address: gwj@mail.neu.edu.cn