Anomalous superconducting effects in coherently-coupled Josephson junctions

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Recently nonreciprocal superconducting transport phenomena have intensively been studied. For example, the superconducting diode effect [1] where the positive and negative critical currents are different in the absolute value emerges in Josephson junctions of a normal conductor holding strong spin-orbit interactions under a strong magnetic field [2]. The superconducting diode effect is expected to realize rectifiers available in superconducting circuits.

In a Josephson junction made of a normal conductor sandwiched between two superconductors, Andreev bound states are formed in the normal conductor, which generates Josephson current. We are interested in the physics of hybridization of the Andreev bound states in the different Josephson junctions to design the nonreciprocal superconducting transport. When two Josephson junctions share a superconducting electrode, the Andreev bound states in the respective junctions are hybridized and form Andreev molecule states [3,4]. In such structures, the supercurrent in one of the junctions can be controlled by a phase difference of the other junction.

Recently we have experimentally studied superconducting transport in the device structures that two junctions share one short superconducting electrode, holding Andreev molecule states. We have observed the superconducting diode effect in one of the junctions by controlling the phase difference on the other junction [5]. In addition, we have fully evaluated a supercurrent in one of the junctions as a function of the phase differences on the two junctions [6]. As a result, we have succeeded in demonstration of the anomalous Josephson effect. These results reveal that the time-reversal and spatial-inversion symmetries of the junctions can be broken by the phase control of Andreev molecules, which is available to develop new superconducting functionality useful in superconducting circuits.

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