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Josephson diode effect emergent from a coherent coupling of two Josephson junctions

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The superconducting devices with time-reversal and spatial-inversion symmetries broken have attracted much attention to emergent novel superconducting phenomena. Particularly, the superconducting diode effect which represents the direction-dependent superconducting transport has intensively been studied for future application in the dissipationless superconducting circuit components [1].

Recently, we have focused on the coherent coupling between two adjacent Josephson junctions [2]. As a result of the coupling, supercurrent flowing in one junction depends not only on a local phase difference of the junction but also on a nonlocal phase difference of the other junction. In this situation, the symmetries of one junction are easily broken by the nonlocal phase difference.

Here we discuss the Josephson diode effect in a Josephson junction coupled to the other adjacent junction fabricated from an Al/InAs quantum well. The adjacent junction is embedded in a superconducting ring to control the phase difference by the magnetic field. We measure the switching current of the junction in the positive and negative current directions and compare their absolute values as changing the magnetic field. Consequently, the positive switching current differs from that in the negative direction in a certain magnetic field region. This means that the observed Josephson diode effect is controlled by the nonlocal phase difference. Our result is an example of novel phenomena derived from the coherent coupling of two Josephson junctions and opens a new way to engineer novel superconducting functionalities.

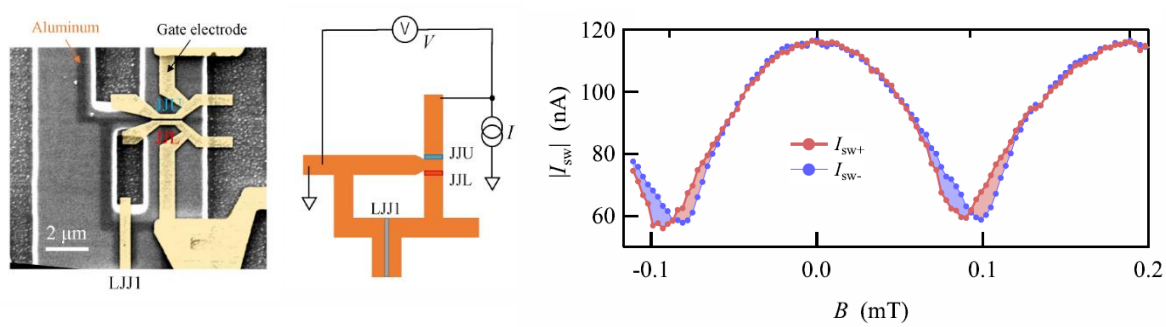

FIG. 1. Left: A scanning electron microscopic image of our device. Center: A schematic image of our device. Two junctions labeled by JJU and JJL are closely spaced.JJL is embedded in a loop. We measure the switching current of JJU. Right: Absolute value of the switching current in the positive (I_{sw+}) and negative (I_{sw-}) current directions. The magnetic field induces the diode effect.

[1] F. Ando, et al., Nature 584, 373 (2020), C. Baumgartner, et al., Nat. Nanotech. 17, 39 (2021).

[2] J.-D. Pillet, et al., Nano Lett. 19, 7138 (2019), S. Matsuo, et al., arXiv 2112.12960.