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Vortex penetrations in parallel-connected two stacks of intrinsic Josephson junctions

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Abstract

In mesoscopic stacks of intrinsic Josephson junctions (IJJs) in $Bi_2Sr_2CaCu_2O_{8+y}$ (Bi2212), the penetrations of individual vortices are detectable by the measurements of the transport properties, i.e., *c*-axis resistance or critical current. We have measured the *c*-axis resistance as a function of magnetic field in samples with two stacks of IJJs connected in parallel by Bi2212 itself to study any interaction of individual vortex penetrations into them. Since the superconducting loop containing two stacks of IJJs is the same geometry as that of superconducting quantum interference device (SQUID), we might expect a periodic resistance (or current) modulation as a function of magnetic field, whose period corresponds to the area in the loop. However, the results were just simple mixing of the resistive changes by the individual vortex penetrations into each of the stacks; behavior like SQUID has not been observed in present samples.

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Keywords: Bi2212; intrinsic Josephson junctions; vortex; SQUID

1. Introduction

$Bi_2Sr_2CaCu_2O_{8+y}$ (Bi2212) single crystals have a layered crystal structure that consists of alternate stackings of superconducting and insulating layers, i.e., intrinsic Josephson junctions (IJJs) [1]. While numerous efforts have

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been devoted to study the properties of single IJJ stack [1-3], a coupling of two stacks of IJJs connected by a superconducting loop, which is important for applications as a superconducting quantum interference device (SQUID), was investigated only in several experiments [4-9]. In earlier studies, magnetic properties of the critical currents (I_c) in an IJJ stack with a single hole at the center along the *ab* plane (the out-of-plane loop geometry), which is regarded as a SQUID made in IJJs, were theoretically studied [4], and experimentally tested in samples prepared by a three-dimensional fabrication technique using a focused ion beam (FIB) [5]. However, no clear magnetic modulation of I_c by the quantum interference was reported [5]. On the other hand, in the in-plane loop geometry fabricated by the double-side etching technique [10], whose schematic illustration is shown in Fig. 1(a), clear voltage modulations with applied magnetic field have successfully been observed [6-9].

Recently, penetrations of individual vortex lines into an IJJ stack in field parallel to the *c*-axis have been found in stacks with a very small in-plane area less than 2 μm^2 [11]. The same behaviors were reproduced in much larger stacks, also [12, 13]. Since there is no research studying an interaction of the individual vortex penetrations into two stacks connected by a single loop in the in-plane loop geometry, it is interesting to explore whether such an interaction exists. In this proceeding, we report on the penetrations of individual vortices into parallel-connected two IJJ stacks observed by the *c*-axis resistance (R_c) in magnetic field parallel to the *c*-axis. As a result, the vortex penetrations into each of the stacks were almost independent; a signature of interference effect was not detected in studied samples.

2. Experiments

High-quality single crystals of Bi2212 were grown by the traveling-solvent floating-zone method [14]. The double-side etching technique was employed to fabricate stacks of IJJs with superconducting electrodes on the top and bottom [6-10]. In milling processes, we used a FIB in addition to photolithography and Ar-ion milling. First of all, a trench with several micrometers in width was fabricated on a surface of a bulk single crystal using FIB, and the surface was then fixed on a MgO substrate with a polyimide adhesive. After cleaving another side of the crystal until the sample became slightly transparent on the position of the trench, Au was evaporated onto the fresh surface to form ohmic contacts and provide protection from the ion beams. A pattern of a wide single bar with terminals was formed on the Au covered surface by the pair of the photolithography and the Ar-ion milling. Then, the shapes of two IJJ stacks parallel-connected in the in-plane loop geometry (see Fig.1 (a)) were fabricated by FIB millings.

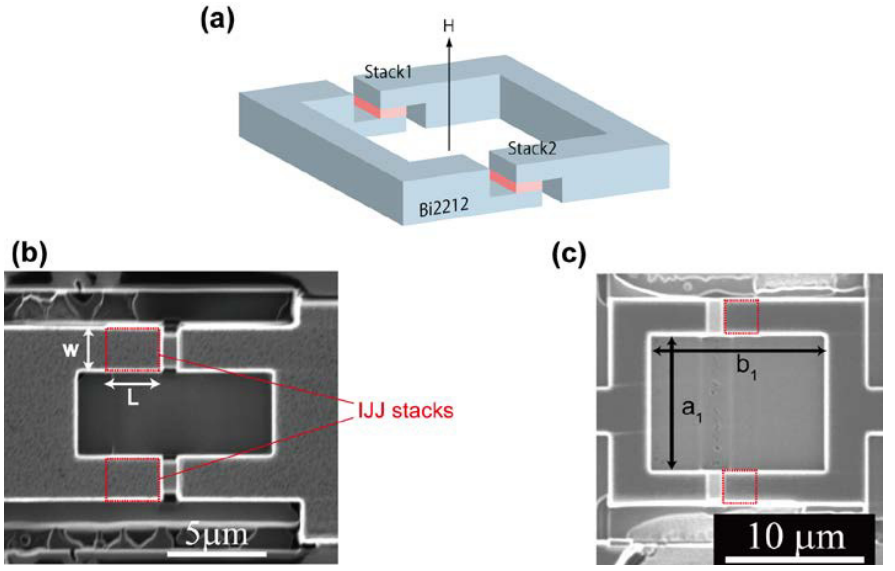

Fig. 1. (a) Schematic illustration of parallel-connected two IJJ-stacks in the in-plane loop geometry. (b, c) SIM images of sample A and B, respectively. The positions of IJJ stacks are surrounded by red squares. The definitions of the inner dimensions of rectangular Bi2212 loops are drawn in (c).