PCP8-1

Control of a single vortex in a stack of intrinsic Josephson junctions

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Penetrations of single vortices into a micron-sized single crystalline of $Bi_2Sr_2CaCu_2O_{8+y}$ (Bi2212) can be resolved in the c-axis resistance measurements using a stack of intrinsic Josephson junctions (IJJs) which are naturally contained in the crystal structure of Bi2212 [1-3]. We found that depending on field-sweep direction, an entry and exit of the first vortex into a stack of IJJs become irreversible below a certain temperature, normally ranging in 60 - 70 K. Probably, this behavior is related to the depinning transition that is confirmed in bulk crystals of Bi2212 as second order phase transition, since the boundary, where the irreversibility appears, in field-temperature (*H*-*T*) phase diagram locates at the position similar to the depinning-transition line. Employing this hysteretic vortex entry and exit, we have successfully demonstrated a vortex memory, in which both a vortex memory cell (a IJJs stack) and a control line are built in a flake of Bi2212.

Keywords: vortex memory, Bi2Sr2CaCu2O8+y, intrinsic Josephson junction, depinning

PCP8-2

Fabrications of Small and High-quality Intrinsic Josephson Junctions by Combinatorial Method of Ar-ion and Focused Ga-ion Etchings

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The fabrication of the small and high-quality intrinsic Josephson junctions (IJJs) is crucially important to study the macroscopic quantum tunneling and pseudogap phenomena occurring in high-T_c cuprate superconductors. The previous study on the fabrication of submicron $La_{2-x}Sr_xCuO_4$ (La214) IJJ stacks reported that argon ion etching after focused ion beam (FIB) etching was useful to control the thickness of IJJs [1]. In addition, the recent report of the transmission electron microscope (TEM) study on $Bi_2Sr_2CaCu_2O_y$ (Bi2212) IJJs suggested that the amorphous damage produced by the gallium ion etching was excellently removed by the argon ion etching [2]. Thus, the combination of both etching techniques is required to enhance the performance of small stacked IJJs.

Here, we present a study on the fabrication of Bi2212 IJJs by using the FIB etching and Ar-ion etching. First of all, we confirmed that the current-voltage (*I-V*) characteristics of small IJJs, which were sandwiched by two slits fabricated on the side wall of a microbridge, was never influenced by the direction of a Ga-ion beam in the FIB etchings processes. This shows a good agreement with our recent observation that the thickness of FIB damage is independent of the direction of the Ga ion beam [2]. We also found that Ar-ion etching after the FIB process is quite useful to enhance the performance of the *I-V* curves of IJJs. Furthermore, we succeeded in employing the double-side etching by the irradiation of Ar ions after the FIB microfabrication, by using the silicon substrate with a small square hole (50×50 μm^2). These results strongly support the importance of the combinatorial method of FIB and Ar-ion etchings for the fabrication of small and high-quality IJJs.

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Keywords: intrinsic Josephson junction, focused ion beam, Ar-ion etching

PCP8-3

Dynamics of Phase Switch in the Intrinsic Josephson Junctions Made of Bi2212 with Perfectly-stoichiometric Cation Compositions

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The intrinsic Josephson junctions (IJJs) of $Bi_2Sr_2CaCu_2O_y$ (Bi2212) cuprate superconductors have great advantage such as a perfectly smooth tunnel junction on an atomic scale and a high critical current density J_c. However, it is not necessarily enough to extract the underlying excellent properties of IJJs, because of a nonstoichiometry of cation compositions as well as oxygen nonstoichiometry in Bi2212 crystals. It is empirically known that the nonstoichimetry in cuprate superconductors induces inhomogeneity and constricts the superconducting transition temperature T_c and J_c. Here, we present a study on the phase switch in a small stack of IJJs with the cation compositions approaching to be perfectly stoichiometric, Bi:Sr:Ca:Cu=2:2:1:2. The previous magnetization measurements for the stoichiometric Bi2212 crystals suggested that the value of J_c in the vortex state was unexpectedly enhanced, implying the importance of the stoichiometric cation compositions [1].

We found that the switching current densities (~1.5×10^4A/cm^2) for the third phase switch (3rd SW), corresponding to the switch from the second branch to the third branch in the multiple-branched I-V curve, in the stoichiometric IJJs were 4 times larger than those for the conventional IJJs with the nominal compositions, Bi:Sr:Ca:Cu=2.1:1.9:1:2. In addition, it is found that an effective temperature T_{esc} for the phase escape is about 1.5 times larger than a bath temperature T_{bath} from 17 K to 35 K. This suggests that the cation stoichiometry enhances J_c so largely that the Josephson penetration depth becomes smaller than the lateral junction size [2]. Below 17 K, T_{esc} shows no temperature dependence, implying the occurrence of a classical-to-quantum crossover. This temperature is also about two times larger than that for the higher-order phase switches in the conventional IJJs [3]. These results clearly show that the cation stoichiometry in Bi2212 is quite important for the implementation of Josephson qubits utilizing IJJs at higher temperatures.

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Keywords: Bi-cuprate, intrinsic Josephson junctions, switching current distribution, macroscopic quantum tunneling

PCP8-4

Uncertainty analysis of the Boltzmann constant measured by Johnson noise thermometry using superconducting integrated circuit

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We report on our measurement of the Boltzmann constant by Johnson noise thermometry (JNT) using an integrated quantum voltage noise source (IQVNS) that is fully implemented with superconducting integrated circuit technology. The IQVNS generates calculable pseudo white noise voltages to calibrate the JNT system. The thermal noise of a sensing resistor placed at the temperature of the triple point of water was measured precisely by the IQVNS-based JNT. We accumulated data more than 429200 seconds in total (over 6 days) and used the Akaike information criterion to estimate the fitting frequency range for the quadratic model to calculate the Boltzmann constant. Upon the detailed evaluation of the uncertainty components, the experimentally obtained Boltzmann constant was $k = 1.3806436 \times 10^{-23}$ J/K with a relative combined uncertainty of 10.22×10^{-6}. The value of k is relatively -3.56×10^{-6} lower than the CODATA 2014 value.

Keywords: Boltzmann constant, Johnson noise, Superconducting electronics, pseudo random noise

PCP8-5

Spatiotemporal Dynamics and Collective Phenomena in a Driven Josephson Junction Network

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Spatiotemporal dynamics of phases of a current-driven Josephson junction network (JJN) in an external magnetic field is studied using a numerical simulation based on the resistively shunted junction model. We consider here a JJN which consists of a two-dimensional array of superconducting grains where each pair of the nearest-neighbor sites is connected by a Josephson junction. The array has some type of network structure with structural disorder. We focus on the spatiotemporal dynamics of the JJN with disorder in the presence of external currents with spatiotemporal modulation. The dynamics of the JJN shows complicated behaviors, and the dynamical properties depend on some controllable parameters of junctions and structure of the JJN. There exist synchronization phenomena and collective behaviors under certain conditions. Due to the effect of structural disorder, there also appear inhomogeneous behaviors in the current-driven dynamics. The complicated dynamics of the disordered JJN under spatiotemporal modulation effects are clarified in detail. The physical mechanisms that govern the synchronization dynamics and related spatiotemporal behavior of the JJN are discussed in comparison with another dynamical system.