Josephson Plasma in Ru- and Fe-cuprates

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Abstract

The Josephson plasma in RuSr$_2$GdCu$_2$O$_8$ and FeSr$_2$YCu$_2$O$_y$ is measured by the sphere resonance method. For ferromagnetic RuSr$_2$GdCu$_2$O$_8$, the plasma is observed in a very low-frequency region (around 8.5 cm$^{-1}$ at $T \ll T_c$), which represents a large reduction in the Josephson coupling at ferromagnetic RuO$_2$ block layers. For non-ferromagnetic FeSr$_2$YCu$_2$O$_y$, the plasma frequency increases to 31 cm$^{-1}$, which is comparable to that of lightly-doped Ba$_2$YCu$_3$O$_{6+\delta}$. The temperature dependence of the plasma does not shift to zero frequencies (i.e. $j_c = 0$) at low temperatures, indicating that there is no transition from the 0-phase to the $\pi$-phase in these compounds.

Key words: Josephson plasma; RuSr$_2$GdCu$_2$O$_8$; FeSr$_2$YCu$_2$O$_y$; $\pi$-phase

1. Introduction

Recently, there have been many studies of RuSr$_2$GdCu$_2$O$_8$ that investigated the coexistence of superconductivity and ferromagnetism in the material[1,2]. It has been predicted that the $\pi$-phase, which has a superconducting order parameter that changes the phase by $\pi$ between two adjacent superconducting CuO$_2$ layers, is realized in the compound at low temperatures since the node at the ferromagnetic RuO$_2$ layer greatly reduces the pair breaking effects[3–5]. One possible way to observe the 0-$\pi$ phase transition is to measure the temperature dependence of the maximum critical current $j_c$, since $j_c$ achieves its maximum value and decreases to zero at the transition line due to the decoupling of the junctions, and increases again in the $\pi$-phase region[5,6]. Otherwise, we can measure the Josephson plasma frequency $\omega_p$, since $j_c$ and $\omega_p$ are related through the relation $\omega_p^2 = 8\pi^2 cdj_c/\epsilon_0\Phi_0$, where $d$ and $\epsilon_0$ are the width and dielectric constant of the insulating layer. It is also interesting to investigate the plasma of FeSr$_2$YCu$_2$O$_y$, which is isostructural to RuSr$_2$GdCu$_2$O$_8$ and contains magnetic Fe ions, although ferromagnetism has not been confirmed[7].

Here, the Josephson plasma of RuSr$_2$GdCu$_2$O$_8$ and FeSr$_2$YCu$_2$O$_y$ is studied by the sphere resonance method. The method is the established way to determine the Josephson plasma frequency from the ceramics [2,8,9], and seems to be the only way to investigate the 0-$\pi$ phase transition since growth of single crystals of these compounds has not been achieved.

2. Experimental

The ceramic samples were synthesized by the conventional solid-state reaction of oxides and carbonates. After repeated sintering and regrinding, annealing was performed at 1065°C for 150 hr at 1 atm O$_2$ for RuSr$_2$GdCu$_2$O$_8$ and at 350°C for 85 hr at 370 atm O$_2$ for FeSr$_2$YCu$_2$O$_y$. A furnace for hot isostatic pressing (HIP) was used for the high-oxygen-pressure annealing. While a magnetic transition was observed at $T_M = 133$ K for RuSr$_2$GdCu$_2$O$_8$, no obvious magnetic transition was observed for FeSr$_2$YCu$_2$O$_y$. The resistivity showed $T_{\text{onset}} = 53$ K and $T_{\text{zero}} = 34$ K for RuSr$_2$GdCu$_2$O$_8$, $T_{\text{onset}} = 60$ K and $T_{\text{zero}} = 34$ K for FeSr$_2$YCu$_2$O$_y$. The powder X-ray diffraction indi-
cated a single phase for both samples. The transmission spectra of the powder sample were measured using a Fourier transform interferometer combined with a Si bolometer.

3. Results and discussion

Figure 1 shows the difference between the absorption coefficients of the superconducting and normal states for RuSr$_2$GdCu$_2$O$_8$. Below $T_{\text{c onset}}$, the Josephson plasma peak appears and the oscillator strength increases as the temperature decreases. The peak is very broad and it is impossible to determine the peak frequency, while it becomes rather narrow below $T_{\text{c zero}}$. The peak is around 8.5 cm$^{-1}$ at 10 K. The peak frequency is very low compared with that of the plasma of YBa$_2$Cu$_3$O$_7$ above 100 cm$^{-1}$, which has a similar crystal structure and a similar doping level (optimum to overdoped region), and shows a strong reduction in Josephson coupling at the ferromagnetic RuO$_2$ block layers. It is also noted that the peak oscillator strength is considerably weaker than that of the other non-magnetic cuprates. The peak does not move to zero frequencies with decreasing temperature, which indicates that there is no 0-π transition in this compound.

Figure 2 shows the difference between the absorption coefficients of the superconducting and normal states for FeSr$_2$YCu$_2$O$_y$ ceramics. The Josephson plasma peak appears below $T_{\text{c onset}}$, and it shifts to higher frequencies and the oscillator strength increases as the temperature decreases, which is commonly observed in other non-magnetic cuprates. It is around 31 cm$^{-1}$ at 10 K. The peak position is comparable to that around 30 cm$^{-1}$ of underdoped YBa$_2$Cu$_3$O$_{6.85}$, which is at a similar doping level, and suggests that the FeO$_2$ insulating layer is magnetically inactive. The temperature dependence of the peak does not exhibit the 0-π transition. These features are typical of non-magnetic cuprates.

Although all the features of the plasma for FeSr$_2$YCu$_2$O$_y$ are typical for non-magnetic cuprates, some anomalies are seen with RuSr$_2$GdCu$_2$O$_8$. The most prominent anomaly is the constant behavior of the peak frequency as the temperature decreases. The theoretical calculation of (superconductor/(ferro)magnetic/superconductor-···) -type Josephson-coupled multilayers predicts that $\omega_p$ decreases slightly at low temperatures from the monotonic increase as the exchange energy increases from zero, and the decrease becomes large as the exchange energy increases to the 0-π transition line[5]. The observed constant behavior of $\omega_p$ suggests that the exchange energy, while it is not zero for the sample, is small and insufficient to induce the 0-π phase transition.

References