Josephson Plasma in Ru- and Fe-cuprates

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Abstract

The Josephson plasma in $RuSr_2GdCu_2O_8$ and $FeSr_2YCu_2O_y$ is measured by the sphere resonance method. For ferromagnetic $RuSr_2GdCu_2O_8$, 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 $FeSr_2YCu_2O_y$, the plasma frequency increases to 31 cm^{-1}, which is comparable to that of lightly-doped $Ba_2YCu_3O_{6+\delta}$. 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 π-phase in these compounds.

Key words: Josephson plasma; $RuSr_2GdCu_2O_8$; $FeSr_2YCu_2O_y$; π-phase

1. Introduction

Recently, there have been many studies of $RuSr_2GdCu_2O_8$ that investigated the coexistence of superconductivity and ferromagnetism in the material[1,2]. It has been predicted that the π-phase, which has a superconducting order parameter that changes the phase by π 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-π phase transition is to measure the temperature dependence of the maximum critical current j_c of intrinsic Josephson junctions, since j_c should show a unique temperature dependence; as the temperature decreases below T_c, 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 π-phase region[5,6]. Otherwise, we can measure the Josephson plasma frequency ω_p, since j_c and ω_p are related through the relation $\omega_p^2 = 8\pi^2 c d j_c/\epsilon_0 \Phi_0$, where d and ϵ_0 are the width and dielectric constant of the insulating layer. It is also interesting to investigate the plasma of $FeSr_2YCu_2O_y$, which is isostructual to $RuSr_2GdCu_2O_8$ and contains magnetic Fe ions, although ferromagnetism has not been confirmed[7].

Here, the Josephson plasma of $RuSr_2GdCu_2O_8$ and $FeSr_2YCu_2O_y$ 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-π 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 $RuSr_2GdCu_2O_8$ and at 350°C for 85 hr at 370 atm O_2 for $FeSr_2YCu_2O_y$. 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 $RuSr_2GdCu_2O_8$, no obvious magnetic transition was observed for $FeSr_2YCu_2O_y$. The resistivity showed $T_c^{onset} = 53$ K and $T_c^{zero} = 34$ K for $RuSr_2GdCu_2O_8$, $T_c^{onset} = 60$ K and $T_c^{zero} = 34$ K for $FeSr_2YCu_2O_y$. The powder X-ray diffraction indi-

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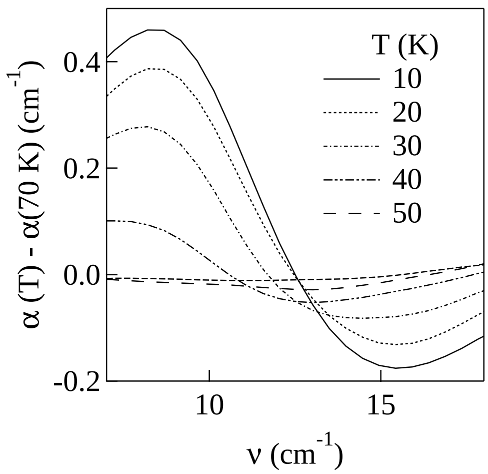

Fig. 1. Difference between α values in the superconducting and normal states for $RuSr_2GdCu_2O_8$.

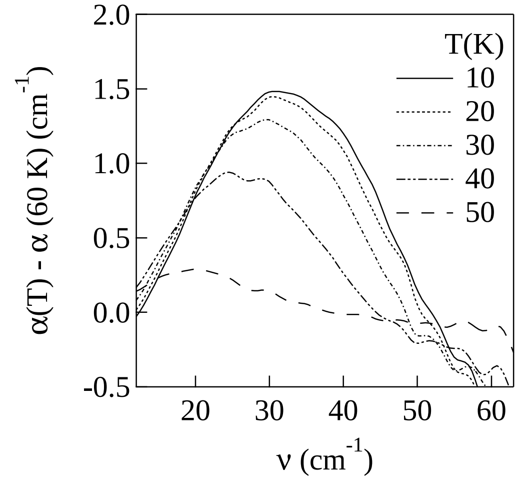

Fig. 2. Difference between α values in the superconducting and normal states for $FeSr_2YCu_2O_y$.

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 $RuSr_2GdCu_2O_8$ ceramics. Below $T_c^{\rm onset}$, 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 $T_c^{\rm zero}$. The peak is around 8.5 cm^{-1} at 10 K. The peak frequency is very low compared with that of the plasma of $YBa_2Cu_3O_{7-\delta}$ 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 $FeSr_2YCu_2O_y$ ceramics. The Josephson plasma peak appears below $T_c^{\rm onset}$, 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 $YBa_2Cu_3O_{6+\delta}$, 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 $FeSr_2YCu_2O_y$ are typical for non-magnetic cuprates, some anomalies are seen with $RuSr_2GdCu_2O_8$. The most prominent anomaly is the constant behavior of the peak frequency as the temperature decreases. The theoretical calculation of ($\cdots$superconductor/(ferro) magnetic/superconductor$\cdots$) -type Josephson-coupled multilayers predicts that ω_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 ω_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.

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