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Proximity effect induced by Kondo interaction in a network composed of YBCO and spin density wave

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A R T I C L E I N F O

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The possibility of the proximity effect mediated by Kondo interaction in YBCO embedded in system of diluted magnetic spin ordering has been studied. An YBCO sample is selected in which both metal to insulator transition and superconducting state exist in the different ranges of temperature. The intergranular network of the bulk Y-123 has been modified by the inclusion of $YMnO_3$ which has a well defined magnetic structure depending on temperature. The current–voltage measurements have been carried out in pure Y-123 at several temperatures. At the same set of temperatures the current–voltage curves in presence of $YMnO_3$ have been studied. The role of the diluted spin magnetic ordering in tuning proximity effect and conduction property in binary systems is associated with reduced coherence length in the normal region.

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1. Introduction

Proximity effect in superconducting networks is an important aspect to understand the relation between the vortex pinning and current density. Conduction currents in an anisotropic superconductor along different crystallographic axes can be tuned by different ways using the idea of the proximity effect. The presence of an inclusion in the intergranular networks makes superconducting systems more complex. Several studies were carried out earlier to understand the physical properties of the binary systems composed of high-T_c superconductors (HTS) and other materials. The conduction current along any direction becomes strongly modified in the presence of any magnetic intergranular networks. The intergranular networks form the normal part of a superconductor–normal-superconductor (SNS) junctions which are randomly oriented with respect to a crystallographic axis of a superconductor. According to De Gennes formulations, we know that the critical current through an SNS junction can be expressed by using the following equation [1,2],

$$I_c = (\pi/2eR_n)\left(\Delta_{\mathrm{i}}^2/kT_c\right)(d/\xi_{\mathrm{N}})\mathrm{e}_{\mathrm{N}}^{-\mathrm{d}/\xi}$$

Here Δ_{i} is the energy gap of the superconductor, d is the thickness of the normal region, ξ_{N} is the coherence length in the normal region and R_n is the resistance of the junction in the normal state. Any secondary magnetic phase present in the contact of the superconducting grains therefore will be able to affect critical current drastically through changes in R_n [3].

Suppression of the superconductivity by any type of magnetic ordering is associated with the understanding of the origin of superconductivity. Both internal and external magnetic ordering with respect to the origin of superconducting pairs are crucial. If the normal region in the SNS junction has a specific magnetic ordering the normal state conduction, transition temperature, pairing mechanism and critical current density will be highly affected. Bulaevskii et al. suggested that in granular superconductor grains are connected by two types of conducting channels. In one of two channels current is associated with the spin flipping in the intergranular region [4]. Several works are carried out in determining the nature of the tunneling current in granular superconductors. Furthermore, even though there are numerous works on how superconducting order parameter penetrates in ferromagnet, very little is known how homogeneous magnetic order parameter penetrates in superconductor [5]. It will not be unjustified to mention that very little has been understood how an inhomogeneous magnetization related order parameter penetrates to affect superconductivity and vice versa. Our present study addresses the idea of interaction between the superconducting order parameter of YBCO and the intergranular region consisting of a random distribution of magnetic spin ordering. We have used hexagonal $YMnO_3$ in which Mn^{3+} with $S = 2$ generate a magnetic ordering in the form of a triangular lattice [6]. Conventional spin waves including different spin structures therefore are present arising out of magnetic ordering in the intergranular regions over a wide range of temperature

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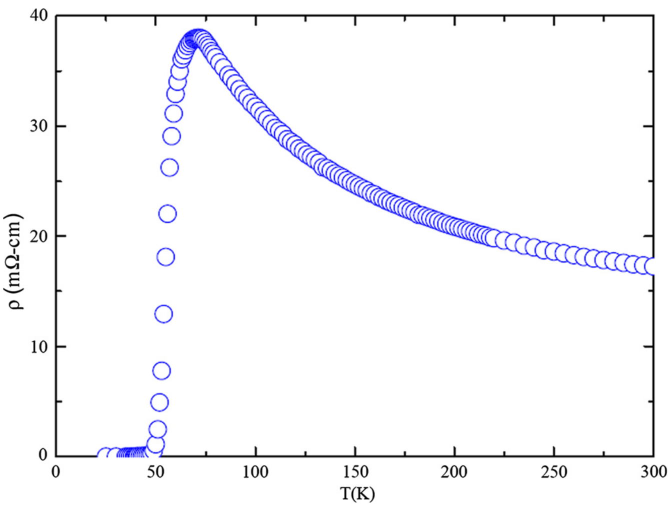

Fig. 1. Resistivity as a function of temperature in $YBa_2Cu_3O_{7-\delta}$.

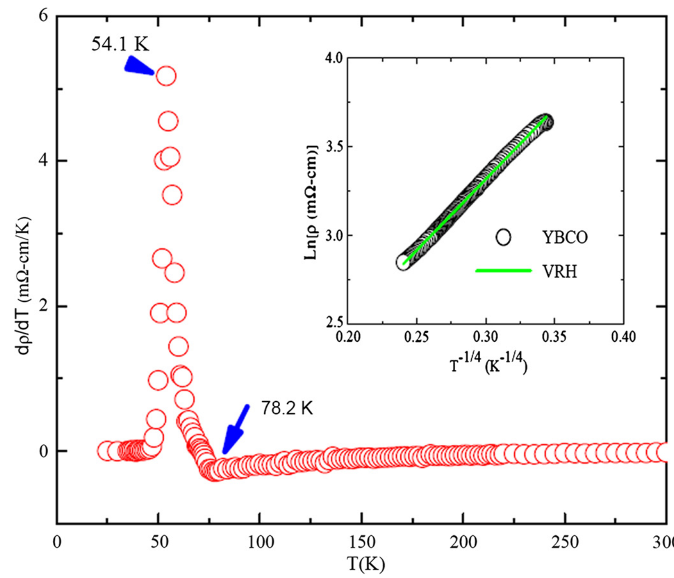

Fig. 2. Variation of $\mathrm{d}\rho/\mathrm{d}T$ with temperature in $YBa_2Cu_3O_{7-\delta}$. Inset shows the plot of $\mathrm{Ln}(\rho)$ with $T^{-1/4}$ in $YBa_2Cu_3O_{7-\delta}$ in the normal state region, $T = 300$ K to 71.5 K. The solid line represents a fitting following three dimensional variable range hopping (VRH) conduction.

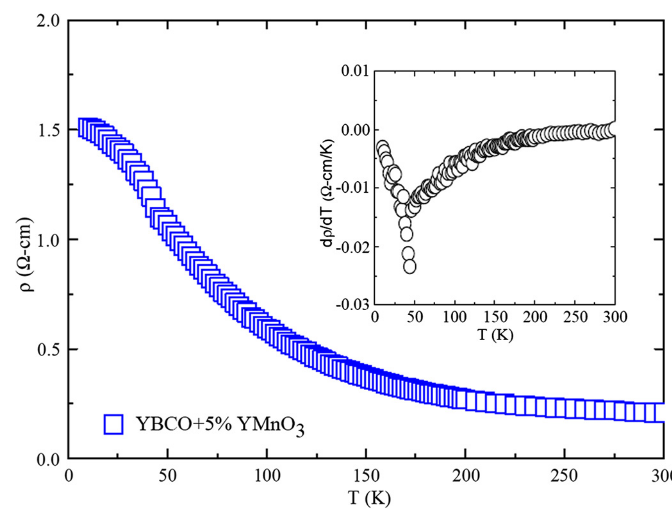

Fig. 3. Resistivity as a function of T of network composed of $YBa_2Cu_3O_{7-\delta}$ and $YMnO_3$. Inset shows the variation of $\mathrm{d}\rho/\mathrm{d}T$ with temperature for the same.

[7,8]. In a system of $Nd_{1-x}Y_xMnO_3$ the ground state becomes a spin density wave (SDW) with the dilution of the ferromagnetically ordered moment of Nd^{3+} [9]. Current between two superconducting regions is expected to be affected due to the presence of the magnetic structure in the form of spin density wave originated by the spin distribution in $YMnO_3$. The idea of Kondo type interaction between the magnetic ordering and the superconducting order parameter has been used to understand the destruction of superconductivity [10]. In presence of such Kondo type interaction we have studied the modifications of the current–voltage (I–V) relation and explored the vortex depinning within the framework of Kosterlitz–Thouless transition [11].

2. Experimental

Following the usual standard solid state reaction YBCO bulk material has been synthesized. In another YBCO sample a small amount of 5 weight percentage of $YMnO_3$ in the intergranular region has been mixed uniformly. Bar shaped samples are used for the transport measurements down to 10 K. Resistivity as a function of temperature in both samples has been measured by using the four probe method with the help of a cryogenerator (Janis, USA) [12,13]. Keeping temperature constants the current–voltage (I–V) measurements have been carried out as well. Typically the minimum and maximum currents used for such measurement are 100 nA to 5 mA respectively.

3. Results and discussions

We have plotted the resistivity ρ of YBCO (S1) as a function of temperature T in Fig. 1. In Fig. 2 we have shown the variation of $\mathrm{d}\rho/\mathrm{d}T$ with T. Following the variations, we observe that the onset critical temperature T_c is 78.2 K. A clear upturn in the variation of resistivity has been observed. Normal state upturn has been compared with the three dimensional variable range hopping (VRH) conduction. In the inset of Fig. 2, we have shown $\mathrm{Ln}(\rho)$ as a function of $T^{-1/4}$ which is found to be linear. Therefore, the superconducting transition is followed by a hopping conduction in YBCO sample. The localization length ξ of the hopping conduction is extracted following the fitting of the normal state data as shown in the inset of Fig. 2. Using the slope $T_0^{1/4} = 8.02 \pm 0.27$ $\mathrm{K}^{1/4}$ of the $\mathrm{Ln}(\rho)$ versus $T^{-1/4}$ one can extract the localization length ξ from the following equation within the frame work of Mott type variable range hopping conduction, $\xi = [16/k_B N(\varepsilon_F) T_0]^{1/3}$, where $N(\varepsilon_F)$ is the density of states at the Fermi level [14]. Assuming $N(\varepsilon_F) = 6.61$ states/(eV $\mathrm{\AA}^3$) we obtain the localization length of YBCO, $\xi \sim 1.89$ Å [15].

In Fig. 3, we have plotted the variation of the resistivity as a function of temperature for a sample (S2) consisting of YBCO and $YMnO_3$ (5%). Firstly we observe a huge enhancement of the resistivity by 12 times in this compound with respect to that of the pure YBCO at 300 K. An upturn is also observed as the temperature is lowered. The variation of $\mathrm{d}\rho/\mathrm{d}T$ with T for the mixed sample S2 has been shown in the inset of Fig. 3. An increase in $\mathrm{d}\rho/\mathrm{d}T$ below $T \sim 44.8$ K is also observed indicating existence of competing orders [16]. In $YMnO_3$ the magnetic ordering originated due to the coupling of Mn spin becomes antiferromagnetic in nature below $T_m \sim 75.0$ K and the moments are saturated around 20.0 K [17].

We have used diluted $YMnO_3$ in the intergranular network of YBCO. The coupling of Mn spin in $YMnO_3$ plays a crucial role to modulate the superconducting property in the YBCO grains. In Fig. 4(a) and Fig. 4(b), we have shown the granular nature of sample S1 and S2 respectively. It reveals that the granularity remains typically unaltered even low concentration $YMnO_3$ is mixed the in-

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