Evidence for spin density wave in the superconducting $YBa_2Cu_4O_8$

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Abstract

The torque curves of $YBa_2Cu_4O_8$ show the multiple peak effects when the field direction is scanned between the c and a axes. Especially, the position of the first peak, which appears at $\theta_{ca} \simeq 90 \pm 10^\circ$, is independent of T and H. However, the first peak does not appear when the field direction is scanned between the c and b axes. This strongly indicates that the first peak at $\theta_{ca} \simeq 90 \pm 10^\circ$ comes from the CuO double chains and/or the induced anisotropy in CuO_2 planes. We propose that the electronic spin modulation along the a axis with the long period of $20a_0$ is responsible for the appearance of the first peak in the superconducting states at temperatures below 40 K.

Key words: $YBa_2Cu_4O_8$; peak effect ; spin density wave ; underdope

1. Introduction

The $YBa_2Cu_4O_8$ crystal shows the several interesting features, i.e., a stoichiometric compound, no defects in oxygen sites, highly metallic CuO double-chains, the underdoped nature of electronic doping and cleanness with no twin boundaries. It is opened whether or not the CuO chains are helpful for the coherent nature along the c axis in the superconducting state. The band calculations of $YBa_2Cu_4O_8$ indicate that the Fermi surface tends to have the good nesting vectors [1]. Lang *et al.* [2] argued that the superconducting states consist of the mixture of the superconducting region and the quasi-gapped region. One wonders whether or not this is intrinsic to the various high-T_c cuprates. It is beneficial to investigate the cleanest underdoped $YBa_2Cu_4O_8$ for revealing the intrinsic nature of the underdoped regime.

In the present work, we have studied the superconducting mixed states of $YBa_2Cu_4O_8$ by means of the magnetic torque. A preliminary version of this work has been published elsewhere [3].

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2. Experimental

The $YBa_2Cu_4O_8$ single crystals were grown by a self-flux method under a high-pressure gas mixture of 80% Ar-20% O_2 [4]. The dc magnetization was measured using a SQUID magnetometer (Quantum Design MPMS-XL). The sample mass was estimated as 300 μg for YD#5 by the perfect diamagnetism and the demagnetization correction. The critical temperature T_c was 80 K. A torque magnetometer was built by using a split-type 6-T superconducting magnet [5]. The measurement system is fully computerized.

3. Results and Discussion

In Fig. 1, we show the torque curves of YD#5 at the various different temperatures in 60 kG. The sharp central peak at angles near 90 degrees is due to the intrinsic pinning. The second peaks are remarkable at higher angles from $\theta_{ca} = 90^\circ$ in the wider temperature range. If we summarize the second-peak data in the $H \cos\theta_{ca} - T$ diagram, The peaks reported by Zech *et*

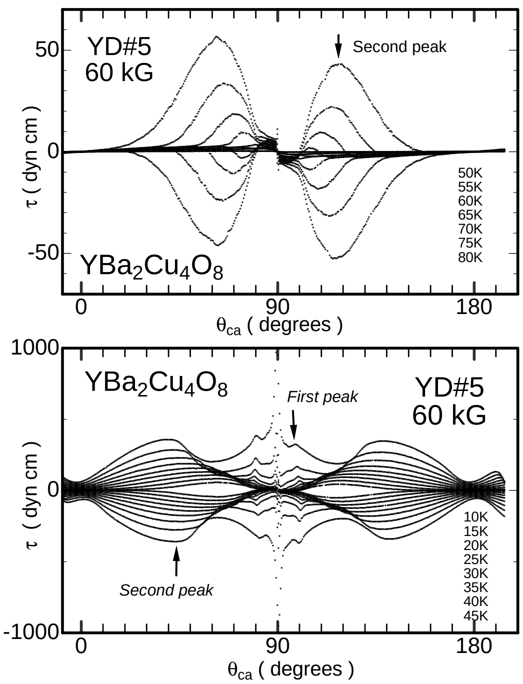

Fig. 1. The torque curves of $YBa_2Cu_4O_8$ as a function of θ_{ca} in 60 kG. The central peak, the first peak and the second peak can be seen.

al. [6] in 14 kG can be connected continuously to our second peaks. The second peak might be the precursor to the melting line in the lower fields. We notice that the first peaks are visible at $\theta_{ca} \simeq 90 \pm 10$ degrees only at temperatures below 40 K. This suggests that the vertical component $H \cos \theta_{ca}$ of the field $H = 60$ kG to the CuO_2 plane does not govern the origin of the first peak. We examined the torque curves as a function of θ_{cb}, but we could not see the first peaks at any temperature.

We consider the three possible candidates for explaining the first peak, i.e., (1) the phase transition from the tilted vortex lattice to the crossing lattice [7], (2) the nature of the double CuO chains, and (3) the some kind of pinning mechanism works. The anisotropy is not so high to take into account the crossing lattice. The CuO chains seem to be not fully superconducting [3]. A possible pinning center is a spin density wave along the a axis with a period of $\sim 20a$. This band structure seems to be consistent with the nesting between the two-dimensional bands [1].

In Fig. 2, we show a schematic diagram of a spin density wave with a long period of $\sim 20a_0$ along the a axis and the applied field. The vortex pinning benefits from the Zeeman energy between the spins and the vortex when $\theta_{ca} \simeq 90 \pm 10^\circ$. It is not certain whether a spin density wave is standing in the one-dimensional layers or in the two-dimensional layers.

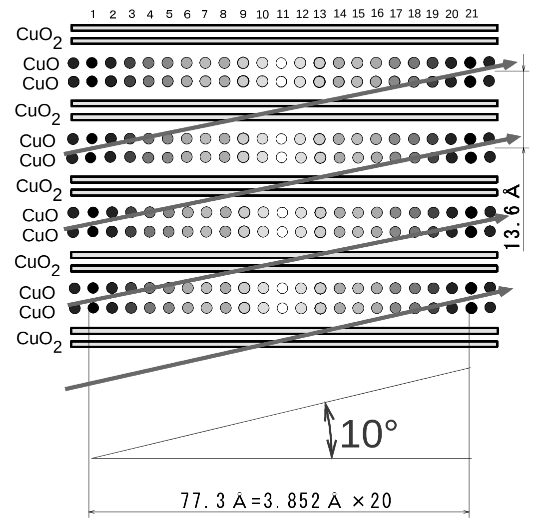

Fig. 2. Schematic diagram of a spin density wave along the a axis and the applied field. The Zeeman energy can be a source of the pinning potential at $\theta_{ca} \simeq 90 \pm 10^\circ$.

In conclusion, we have obtained evidence for the coexistence of the superconductivity and the spin density wave in $YBa_2Cu_4O_8$ at temperatures below 40 K. This might be a manifestation of the intrinsic property in the cleanest underdoped cuprate.

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