μSR study on multi-layered $HgBa_2Ca_4Cu_5O_y$ (Hg-1245) superconductor

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Abstract

We have carried out zero-field muon spin relaxation (ZF-μSR) measurements in multi-layered $HgBa_2Ca_4Cu_5O_y$ (Hg-1245) superconductor with T_c of 108K. The variation of ZF-μSR time spectra from Gaussian-type to exponential-type behavior was observed with decreasing temperature below 60K and the muon precessions were also observed below 45K. These results indicate the appearance of a static magnetic order of Cu moments at muon sites below T_c. It revealed that the magnetism(most likely to be antiferromagnetism) coexisted with superconductivity in Hg-1245

Key words: μSR; Hg-1245, coexistence of antiferromagnetism and superconductivity

1. Introduction

It is well known that electric and magnetic properties in high-T_c cuprate superconductors are strongly dependent on the carrier concentration in CuO_2 planes. In case of mono- and bi-layered compound, doped hole carrier distributed homogeneously to CuO_2 planes. Multi-layered high-T_c cuprate superconductors which include three or more CuO_2 planes have crystallographically inequivalent CuO_2 planes in the unit cell, that is, outer planes (OP) with a five oxygen coordination and inner planes (IP) with a four oxygen coordination. It is known that dope carriers are not distribute homogeneously among the CuO_2 planes in the multi-layered high-T_c cuprate superconductors. $HgBa_2Ca_4Cu_5O_y$(Hg-1245) superconductor is the fifth member compound in the homologous series of mercury system and has two OP's and three IP's.

Recently, Kotegawa et al. carried out ^{63}Cu-NMR measurement of Hg-1245[1]. They found that OP's were in a slightly underdoped state and IP's were in a fairly underdoped one from the results of Knight shift(K) measurement. The tempeature dependence of K and spin lattice relaxation rate($1/T_1$) in OP showed anormalous behavior below 60 K. However, both signals of the K and $1/T_1$ for the IP could not be detected below 150 K because of the low carrier concentration in IP. It seems that the disappearance of these signals was caused by antiferromagnetic order of Cu spins in IP's. In order to study magnetic properties below T_c, we have performed muon-spin-relaxation(μSR) measurements on Hg-1245 samples.

2. Experimental

The Hg-1245 sample for this measurement was synthesized using high pressure technique. The sample was characterized by X-ray diffraction measurements.

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Nearly single phase samples, including a small amounts of non-magnetic impurity phases such as CaO, were obtained at 1020-1050˚C under pressure of 4.5 GPa. The values of Tc in these samples determined from the temperature dependence of the resistivity and the magnetization were around 108K. The zero field (ZF) and longitudinal field (LF) μSR measurements were carried out at the KEK-MSL in Japan, using spin-polarized pulsed surface muon beam with a momentum of 27 MeV/c between 10 K and 150 K.

3. Results and discussion

We have carried out the ZF-μSR measurements above and below T_c. Figure 1 shows time spectra of Hg-1245 sample at 150 K, 50 K, 45 K and 4 K. The time spectrum at 150 K is well expressed by Gaussian-type function. Similar behaviors were also observed in the ZF-μSR time spectra above 60 K. It indicates that no significant magnetic effect exists at the muon sites except for randomly distributed nuclear dipolar fields in this temperature range.

On the other hand, with decreasing the temperature below 60 K, the depolarization behavior gradually changed from a Gaussian-type to an exponential-type with a loss of initial asymmetry. Moreover, the muon spin precession was also observed below 45 K. These variations of μ spin relaxation functions $G_z(t)$ imply the appearance of an additional magnetic effect, originating from dynamical or static magnetic correlations between Cu spins. It is similar to the behavior observed in the heavily under-doped state or the so-called "1/8 anomaly" state[2,3]. In order to make clear that whether the magnetic internal field is caused by dynamical or static below 60 K, we carried out LF-μSR measurements up to 1 kG at 50 K. The fast-relaxing component was found to decouple completely by about 500 G and the average field is estimated around 200 G. This means that the magnetic correlation between Cu spins is attributed to the static internal fields. Since the coherent precession of muon spins was not observed in the temperature range between 60 K and 45 K, it is considered that this static internal field is caused by inhomogeneously distributed Cu spins.

As seen in Figure 1, the component of muon spin precession was observed below 45K. This oscillation in the $G_z(t)$ under zero applied field demonstrate that the sample is in magnetically long range ordered state. It suggests that the some part of positive muons implanted into Hg-1245 sample feel a homogeneous internal field. Comparing with NMR results, the magnetic order of Cu spins in Hg-1245 is caused in IP's due to their low carrier concentration and it is most likely to be antiferromagnetic state.

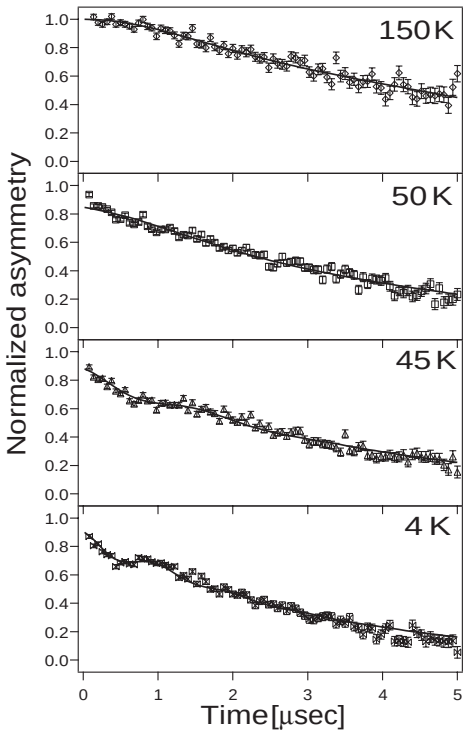

Fig. 1. Zero-field μSR time spectra of Hg-1245 at 150 K, 50 K, 45 K, and 4 K.

4. Conclusion

ZF- and LF-μSR measurements have carried out to study magnetic properties of Hg-1245. We have observed the change of μ spin relaxation functions $G_z(t)$ from Gaussian type to exponential type below 60 K, indicating the magnetic order of Cu spins. Our results provide the evidence of the existence of superconductivity and antiferromagnetism in Hg-1245 below 60 K.

Acknowledgements

We are grateful to S. Shiota(Tanaka Kikinzoku K.K) for supporting our experiments. This work has been supported by Core Research for Evolution Science and Technology (CREST)

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