LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although portions of this report are not reproducible, it is being made available in microfiche to facilitate the availability of those parts of the document which are legible.

3

CONF-870118--4

LA-UR -89-2142

Received by OSTI

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--89-2142

DE89 014291

TITLE ANOMALOUS TEMPERATURE DEPENDENCE OF Cu NMR LINE WIDTH AND MAGNETIZATION IN $YBa_2Cu_3O_{7-\delta}$

AUTHOR(S) Masashi Takigawa, Chris P. Hammel, Robert H. Heffner, Zachary Fisk, Joe D. Thompson, and Martin Maley

SUBMITTED TO Materials and Mechanisms of Superconductivity

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

MASTER

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ANOMALOUS TEMPERATURE DEPENDENCE OF Cu NMR LINE WIDTH AND MAGNETIZATION IN $YBa_2Cu_3O_{7-\delta}$

M. TAKIGAWA, P. C. HANDEL, R. H. HEFFNER, Z. FISK, J. D. THOMPSON and M. MALEY

Los Alamos National Laboratory, Los Alamos, New Mexico 87545, U.S.A.

We report an anomalous temperature dependence of the magnetization and the NMR line width at the planar Cu(2) and oxygen sites in the mixed state of aligned $YBa_2Cu_3O_{7-\delta}$ powder at relatively high field ($\gtrsim$ 30 kOe), where hysteresis of the magnetization due to flux pinning is not important. Both the magnetization and the NMR line width at all sites show a steep increase at low temperature. We found a much larger line width at Cu(2) sites than at oxygen sites when the magnetic field is applied perpendicular to the c-axis, indicating a very microscopic local field modulation.

In this paper we report an anomalous temperature dependence of the planar Cu NMR line width in the superconducting mixed state of aligned powder of $YBa_2Cu_3O_{7-\delta}$ ($T_c \approx$ 93 K), which seems to be closely related to the peculiar temperature dependence of the bulk magnetization found at relatively high field ($\gtrsim$ 30 kOe). In order to compare Cu and O NMR line widths, we used the same ^{17}O enriched sample that was used for ^{17}O Knight shift measurements.[1] The powder was imbedded in epoxy and cured in a 42 kOe magnetic field to achieve alignment of the c-axis along the field.

Fig. 1 shows the ^{63}Cu central transition NMR spectra at the planar Cu(2) sites with the magnetic field applied perpendicular to the c-axis at several temperatures. These spectra were obtained at a fixed NMR frequency by sweeping (increasing) the magnetic field. The peak position is shifting to higher field, corresponding to a decrease of the Knight shift, as the temperature drops. This result agrees with our previous results.[2] The full width at half maximum (ΔH) is increasing below T_c, indicating an inhomogeneous distribution of the local field.

Generally there are three sources for the NMR line broadening in the mixed state. First, the vortex lattice produces a distribution of the local field whose second moment is given as[3] $\langle \delta H^2 \rangle^{1/2} = \Psi_o / \lambda_L^2 (16\pi^3)^{1/2}$ in the field range $H_{c1} \ll H \ll H_{c2}$, where Ψ_o is the flux quantum and λ_L is the penetration depth. Second, the demagnetizing field is different from grain to grain and not uniform in a single grain. The equilibrium magnetization in the same field range can be expressed[4]

$$4\pi M_e = H_{c1} \frac{\ln (H_{c2}/B)}{\ln \kappa} = \frac{\Psi_o}{4\pi\lambda_L^2} \ln(H_{c2}/B) , \quad (1)$$

where κ is the Ginzburg-Landau parameter. $4\pi M_e$

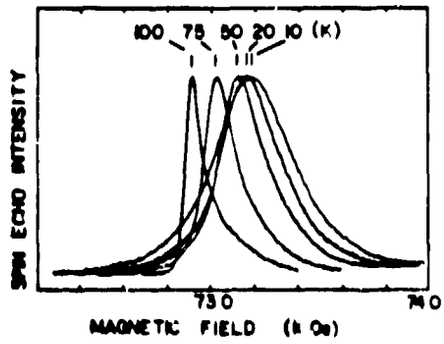

Figure 1. ^{63}Cu NMR spectra at the Cu(2) sites at different temperatures with magnetic field applied perpendicular to the c-axis. The peak positions are indicated by vertical bars.

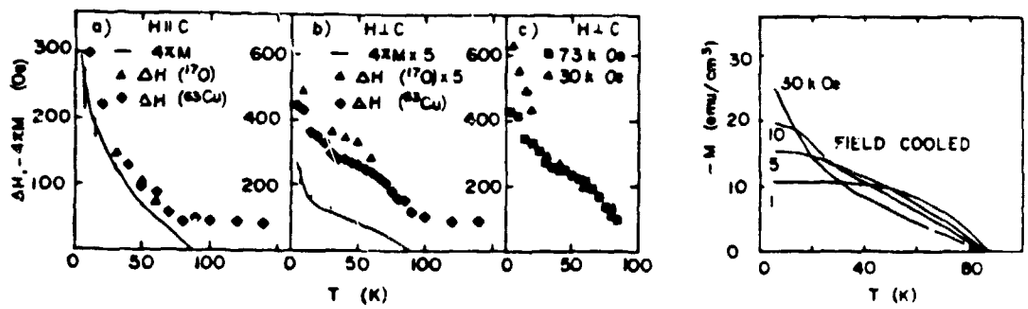

Figure 2. a), b): Temperature dependence of $4\pi M$ (warming at 50 kOe after zero field cooling to 5K), ΔH at Cu(2) and oxygen sites for two field directions. ΔH was measured at 73 kOe for Cu(2) and 69 kOe for oxygen. Vertical bars show hysteresis of $4\pi M$ at 45 kOe. c) Temperature dependence of ΔH_{sup} at Cu(2) sites at different fields. d) Temperature and field dependence of magnetization measured with increasing temperature.

has the same temperature dependence as $\langle \delta H \rangle^{1/2}$ and is larger by a factor $\sqrt{\pi}\ \ln(H_{c2}/B)$. Third, when the external field is swept, vortex density gradients caused by flux pinning produce field a distribution. However, this effect is expected to be small in the present case because the hysteresis of the magnetization is small at high field ($\gtrsim$ 40 kOe). These general considerations lead to the prediction that NMR line widths due to shielding currents will be the same at all sites and have the same temperature dependence and similar magnitude as $4\pi M_e$.

Fig. 2 a) and b) show the temperature dependences of $4\pi M$ and ΔH at the Cu(2) and oxygen sites for two field directions. ΔH for oxygen is obtained from the central transition spectra in which inequivalent oxygen sites are not resolved below about 70 K. We wish to point out several anomalous features of these data:

1) The magnetization at 50 kOe shows a steep increase at low temperatures ($\lesssim$ 20 K) for both field directions. This is very peculiar since a much weaker temperature dependence is expected from eq. (1). This is observed only at high field ($\gtrsim$10 kOe) as shown in Fig. 2 d). The hysteresis of M is quite small at such fields (Fig. 2 a) and b)). Therefore, the rapid low temperature increase of M must be characteristic of the thermal equilibrium magnetization.

2) For H ∥ c, ΔH at both Cu(2) and oxygen sites show similar temperature dependences and magnitudes as $4\pi M$. Most surprisingly, ΔH at Cu(2) sites for H⊥c is larger than that for H ∥ c and is almost an order of magnitude larger than $4\pi M$ and ΔH at oxygen sites, indicating a huge microscopic field distribution within an interatomic distance. However, the temperature dependence is similar to that of the magnetization.

3) ΔH at Cu(2) starts to increase at T_c, clearly indicating that the line broadening is related to superconductivity. In Fig. 2 c), we plot the temperature dependence of ΔH_{sup}, the field distribution due to supercurrents obtained from the relation $\Delta H^2 = \Delta H_{norm}^{\ 2} + \Delta H_{sup}^{\ 2}$, where ΔH_{norm} is the line width at 100 K. ΔH_{sup} decreases with increasing field below 30 K. This field dependence is again consistent with that of the magnetization and cannot be accounted for by magnetic impurities or quadrupolar effects.

REFERENCES

1. M.Takigawa et al., to be published.
2. M.Takigawa et al., Phys. Rev. B39 (1989) 7371.
3. P. Pincus et al., Phys. Lett. 13 (1964) 21.
4. M.Tinkham, Introduction to Superconductivity (McGraw-Hill, NY, 1975) p. 154.