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MEASUREMENTS OF THE LONDON PENETRATION DEPTH IN $YBa_2Cu_3O_x$ BY MEANS OF MUON SPIN ROTATION (μSR)

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Abstract: Muon spin rotation (μSR) measurements on a high-quality sintered $YBa_2Cu_3O_x$ sample [$x = 6.970(1)$] were performed in order to get an accurate value of the London penetration depth λ. The results are consistent with the two-fluid model and yield the effective penetration depth $\lambda(0) = 1550(100)\AA$.

1. INTRODUCTION

An accurate measurement of the London penetration depth λ is of great importance to understand more about the mechanisms of high-T_c superconductivity. For s-wave superconductors, the temperature dependence of λ is generally given by the two-fluid model : $\lambda(T) = \lambda(0)[1-(T/T_c)^4]^{-1/2}$. The μSR technique provides a sensitiv probe (the muon) of the local magnetic field distribution $p(B)$ in a superconductor. Assuming that a perfect triangular vortex lattice is formed in the sample, it is possible to calculate the magnetic penetration depth λ by means of

$$\lambda^4 = 0.00371\Phi_0^2/ < \Delta B^2 >, \quad (1)$$

where $< \Delta B^2 >$ is the second moment of $p(B)$ [1]. Note that this equation is only valid in high magnetic fields, where $< \Delta B^2 >$ is independent of the applied field.

2. EXPERIMENTS AND RESULTS

μSR experiments were performed on a high-quality sintered sample of $YBa_2Cu_3O_x$ [$x = 6.970(1)$] at the Paul Scherrer Institut (PSI) using low momentum muons (29 MeV/c). Magnetization measurements of the sample exhibit a very sharp transition at $T_c = 89.5(5)$ K with a width of 8 K (10 - 90%) and a Meissner fraction of approximately 60% in a field of 1.42 mT. To keep the background as low as possible, the sample with a diameter of 14.5 mm and a thickness of 3.5 mm was mounted on an Fe_2O_3 target holder, using a beam spot of only 4 mm in diameter. With this experimental setup, about 95% of all the muons stopped in the superconductor. To make sure that the applied field was high enough to use Eq. (1), a field scan between 5 mT and 350 mT was performed (Fig. 1) . Every single data point of this scan was obtained after field-cooling (FC) the sample to 10 K. The μSR time spectra were analysed by assuming a Gaussian relaxation function $exp(-\sigma^2 t^2)$, which corresponds to a Gaussian distribution $p(B)$. The second moment of $p(B)$ can be determined by means of the equation $< \Delta B^2 >= 2\sigma^2/\gamma_\mu^2$, where γ_μ is the gyromagnetic ratio of the muon. As shown in Fig. 1, the depolarization rate σ is constant above 150 mT, indicating that flux pinning effects are negligible at large fields. As a consequence, a field-cooled temperature scan was performed in a magnetic field of 350 mT.

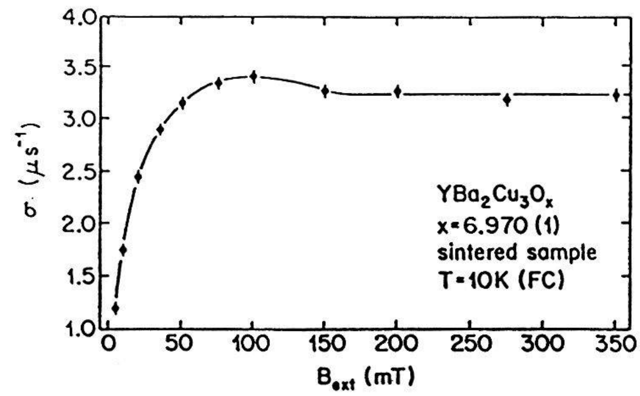

Figure 1: Depolarization rate σ as a function of the external field B_{ext} at 10 K (FC). The line is a guide to the eye.

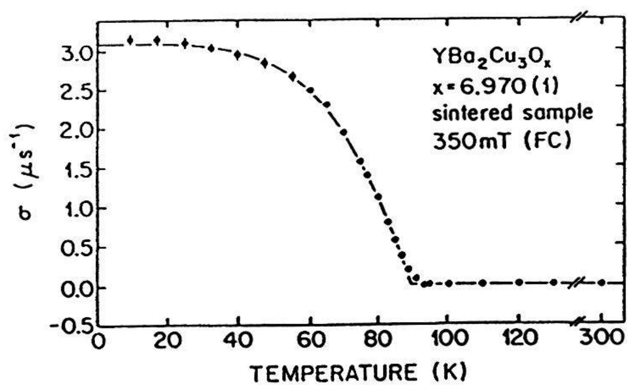

Figure 2: Depolarization rate σ as a function of temperature in a field of 350 mT (FC). The line is a fit to the data using the temperature dependence given by the two-fluid model.

The temperature dependence of λ for sintered $YBa_2Cu_3O_x$ is well described by the conventional two-fluid model, as shown by the solid line in Fig. 2. A complete analysis of this data (with a model-independent determination of $< \Delta B^2 >$ [1]) yields an effective penetration depth $\lambda(0) = 1550(100)$ Å, where the estimated error is mainly due to systematic effects. The value of λ for a sintered sample is an average over all orientations. However, Barford et al. [2] have shown, that λ_{ab} can be extracted from this average, if the fraction λ_c/λ_{ab} is of the order of 5 or larger. In this case, the average value λ is 1.23 times bigger than λ_{ab}. μSR-investigations on a c-axis- oriented polycrystal [3], torque [4] and dc-magnetization [5] measurements indicate that the anisotropy is of the right order of magnitude for $YBa_2Cu_3O_x$. Thus, the calculated value of λ_{ab} is 1300(100) Å.

In conclusion, measurements of the local field distribution in a high-quality ceramic sample have been performed. The temperature dependence of the depolarization rate $\sigma \propto \lambda^{-2}$ was found to be in excellent agreement with the behavior observed for an ordinary s-wave superconductor, yielding an effective penetration depth $\lambda = 1550(100)$ Å.

3. REFERENCES

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