Temperature dependencies of g-factors in $GdBa_2Cu_3O_{6+x}$ crystal.

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Received November 22, 1997
Accepted December 11, 1997

Magnetic Resonance in Solids
Electronic Journal

Volume **1**
No. **3, 1997**

Abstract

The temperature dependencies of the g - factors in $GdBa_2Cu_3O_{6+x}$ crystal are successfully explained using the suggestion that the big macroscopic magnetization of the samples due to the high concentration of Gd^{3+} ions (100 %) is responsible for the ESR signal. The difference of the temperature behavior of g-factors on the 35 GHz and 9.3 GHz is due to a different fraction of the penetration depth of the field in the superconductor.

PACS : 74.25.Jb; 74.72.Bk

Keywords : high-T_c superconductors, EPR

Selected for publication by Programme Committee of youth scientific school "Actual problems of a magnetic resonance and its applications: Magnetic resonance in high T_c materials", Kazan, November 20-22, 1997

In present communication the trying was undertaken to explain the unusual behavior of the ESR spectra in high-T_c superconductor $GdBa_2Cu_3O_{6+x}$ that were observed by Baranov and Badalyan [1]. In spite of a big attention attracted by those results [2], their origin is still puzzled for high-T_c community. In papers [1]-[3] was noted that the g-factors of the ESR line depend strongly on the temperature and their dependencies are different at X- and Q-bands.

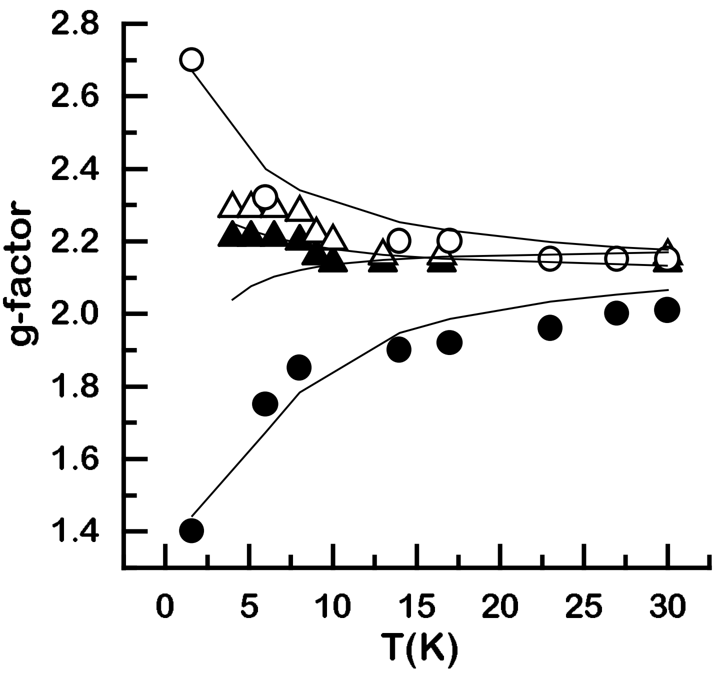

Figure 1: The temperature dependencies of the g-factors in $GdBa_2Cu_3O_{6+x}$. Circles Q-band; triangles X-band; open circles and triangles correspond magnetic field is parallel to c - axes; filled circles and triangles, correspond magnetic field is perpendicular to c - axes. The calculated g - factors is presented by straight line.

In Fig. 1 is shown the g-factor temperature dependencies for $GdBa_2Cu_3O_{6+x}$ crystal [2]. Circles represent Q-band; triangles represent X-band; open circles and triangles correspond magnetic field is parallel to c - axes; filled circles and triangles, correspond magnetic field is perpendicular to c - axes. The samples have been heated up to 500-800^{0}C and then rapidly quenched to 300 or 77K by dropping into water or liquid nitrogen. The magnetic resonance signal appears below 40K and its intensity increases more rapidly that it would be expected according to the Curie law. The signal intensity corresponds the concentration of the spins more than 10^{20}. It is natural to connect this fact with appearance in the sample the new metastable copper-oxygen clusters or magnetic polarons.

Here we suggest the present ESR signal is directly related to macroscopic magnetization. And the sample shape influences on the resonance field B_0 [4, 5, 6]. In experiments [1]- [3] the samples are the thin plates. In this case, the conditions for the resonance fields at the operating frequency $\omega_0/2\pi$ are [5], $\omega_0 = \gamma(B_0 + 4\pi M)$ and $\left(\frac{\omega_0}{\gamma}\right)^2 = B_0(B_0 - 4\pi M)$, where γ is the gyromagnetic ratio and the M are the magnetizations at the respective resonance fields B_0 for the applied magnetic field parallel and perpendicular to the c axis respectively.

The magnetization of the single crystal $GdBa_2Cu_3O_{6+x}$ contains two terms: the first is the magnetization of the Gd^{3+} ions and the second is the magnetization of the copper-oxygen clusters [7, 8, 9, 10]. The copper-oxygen cluster with S=2 has been used for the fitting of the low temperature ESR signal intensity in $YBa_2Cu_3O_{6.25}$ and it deviation from Curie law [11]. The temperature dependence of the magnetization has been calculated as follows:

$$M = -\frac{Ng\beta H}{V} \frac{\sum_{i=-S}^{S} m_i \exp(-\frac{\varepsilon_i}{kT})}{\sum_{i=-S}^{S} \exp(-\frac{\varepsilon_i}{kT})} \qquad (1)$$

where N - is a number of spins, V - is a sample volume, ε_i are the energy level, m_i - are the projections of the magnetic moment on the chosen direction.

The spin Hamiltonian for the Gd^{3+} ion (S=7/2) can be written:

$$H = b_2^0 O_2^0 + b_4^0 O_4^0 + b_4^4 O_4^4 + g\beta B_0 S \qquad (2)$$

The crystal field parameters are $b_2^0 = -18000MHz, b_4^0 = -180MHz, b_4^4 = 600MHz$ [12]. The effective g-values of Gd^{3+} is 2.17 and was measured in the samples with temperature below 100 K [13].

Among all possible copper-oxygen clusters the most stable has $S = 2$. It energy spectrum is described by spin-Hamiltonian [14]:

$$H = DS_z^2 + g\beta B_0 S \qquad (3)$$

where $D = 0.08meV, g_{||} = 2.25, g_{\perp} = 2.05$ [11].

I interpreted the experimental data using formulas (2), (3) and taking into account that single crystals $GdBa_2Cu_3O_{6+x}$ are the II-type superconductors and the magnetic field penetrates into the sample by vortexes [15]. The fraction of the normal phase in the sample is proportional $\xi^2 n\lambda$, where ξ - a coherence length, n - a vortexes density and λ is a penetration depth.

Let me consider now the ratio of the normal phase fractions in the case of the parallel and perpendicular sample orientations in the Q-band experiments. The values $\xi_{||} = 4A$, $\xi_{\perp} = 12A$ are taken from [16], and $\lambda_{||} = 3\mu m$, $\lambda_{\perp} = 0.6\mu m$ are from [17]. For the temperature $T = 1.6K$ the magnetic resonance fields in Q-band for the parallel and perpendicular orientations equal $B_{||}(Q) \sim 18000 \cdot Oe$, $B_{\perp}(Q) \sim 9000 \cdot Oe$ respectively. Therefore, the ratio of the normal phase fractions is near 1 that means the ratio of the spin concentration N/V in the expression for the magnetization is constant for the parallel orientation the same as for the perpendicular. The situation is changed drastically in the case of the analysis of the experimental results in the X-band. The vortexes density decreases because $B_{||}(X) \sim 3000 \cdot Oe$, $B_{\perp}(X) \sim 3000 \cdot Oe$. In comparison to Q - band the normal phase fraction for the parallel orientation decreases six times at the same time as for the perpendicular orientation the fraction decreases three times only. Consequently, the same fall is for the spin concentration N/V that gives the contribution to the macroscopic magnetization M.

The calculated temperature dependencies of g - factors is presented in Fig., straight line. The effective gyromagnetic ratios of the magnetic polaron is accepted to be equal $\left(\frac{\gamma h}{\beta}\right)_{||} = 2.17$, $\left(\frac{\gamma h}{\beta}\right)_{\perp} = 2.1$. The Gd^{3+} ions concentration is $56 \cdot 10^{20}$, and copper-oxygen clusters - $31 \cdot 10^{20}$ (Q-band). As one can see, the calculated results well agree with experimental data [1]-[3].

In conclusion, the results of the present work can be formulated as follows:

i. The temperature dependencies of the g - factors observed in [1]- [3] can be successfully explained using the suggestion that the big macroscopic magnetization of the samples due to the high concentration of Gd^{3+} ions (100

ii. The difference of the temperature behavior of g-factors on the 35 GHz and 9.3 GHz is due to a different fraction of the penetration depth of the field in the superconductor.

I am grateful to Dr. I. N. Kurkin to bring my attention on the role of the demagnetization factors and paper [4]. This work was supported by ISSEP "Soros graduate students " program (Grant No. a97-2593).

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