Microwave Josephson absorption of high-temperature superconductors

J. Niewolski [a], A. Kołodziejczyk [a], T. Zając [a], W. M. Woch [a], Z. Tarnawski [a], K. Przybylski [b], T. Brylewski [b], G. Gritzner [c], M. Enengl [c], W. König [c], O. Heiml [c]

[a] *University of Mining and Metallurgy, Faculty of Physics and Nuclear Technique, 30-059 Cracow, Poland*
[b] *University of Mining and Metallurgy, Faculty of Material Engineering and Ceramics, 30-059 Cracow, Poland*
[c] *Kepler Universität, Institut für Chemische Technologie Anorganischer Stoffe, A-4040 Linz, Austria*

Abstract

Magnetic field dependence of the Direct (DMA) and the Magnetically Modulated (MMMA) Microwave Absorption of a number of Y-, Bi- and Tl- based high-temperature superconductors were measured at 4.2 K and 77 K by X-band microwave spectrometer. Correlation between value of the Low Field Maximum (LFM) of the absorption and the inter-grain critical currents of Josephson junctions was found. Results were analyzed and compared to theoretical models of microwave absorption available in the literature yielding good agreement.

Key words: microwave magnetoabsorption; Josephson junctions; critical currents

1. Introduction

The MMMA in superconducting state of high–temperature superconductors (HTS)was observed in very low applied magnetic field with the so-called LFM in magnetic field of a few mT due to existence of natural inter-grain Josephson junctions in those systems [1–10]. The microwave absorption was measured mostly by the standard microwave spectrometers yielding the record of the first derivative of the absorption as a function of magnetic field [1–3,5]. Only a few results of measurements of DMA without applying of the modulation field were presented up to now [5–7] because intensity of the effect is very small. However, the comparison of the DMA results with theoretical relations is more rational because the MMMA signal contains also contribution coming from the modulation field.

A few theoretical models were proposed to explain the phenomenon. They assume that Josephson junctions form the rf- or dc-SQUID or Resistively Shunted Josephson Junctions (RSJJ) system which absorbs the microwave power [7,9,10]. Our motivation was to measure both MMMA and DMA as a function of magnetic field and temperature because DMA may be directly compared to the available theoretical models.

2. Experimental results and their analysis

The samples of $YBa_2Cu_3O_{7-\delta}$ were prepared by the standard procedure and the chemical sol-gel method [11]. The samples of $Bi_{1.85}Pb_{0.35}Sr_{1.9}Ca_{2.05}Cu_3O_{\sim 10}$ (Bi(2223)), $Tl_{0.6}Pb_{0.5}Sr_{1.8}Ba_{0.2}CaCu_3O_{\sim 10}$ (Tl(1223)), and series of Tl(1223) with Bi, F and U, were synthetized by various methods (standard mixed oxide, co-precipitation and gel methods) [12].

Superconducting transition temperature T_c as well as the intergrain critical current densities J_{cJ} were determined from *ac*-susceptibility measurements in our previous paper [13]. The MMMA and DMA were measured by X-band (9.5 GHz) spectrometer at temperatures 4.2 K, 66 K and 77 K and in magnetic field from zero to 1 T (see Fig. 1). The special microwave bridge was build up to measure the very low DMA signal [8].

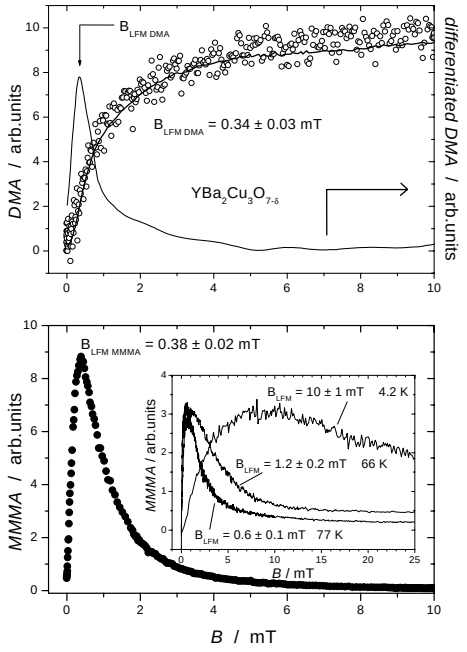

Fig. 1. Typical DMA signal and its numerical derivative (upper panel) and MMMA signal (lower panel) at 77 K.

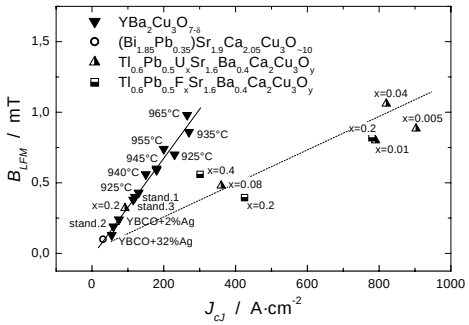

Fig. 2. Correlations between B_{LFM} and J_{cJ} at 77 K. The sintering temperatures of sol-gel samples, the 2% Ag and 32% Ag for Y-Ag composites and 1, 2 and 3 standard Y- samples are indicated.

The virgin curve of DMA was smoothed to compute the derivation and to compare it to the MMMA. $B_{LFM,DMA}$ and $B_{LFM,MMMA}$ are the values of magnetic field at which the characteristic LFM of DMA and MMMA appear, respectively. The values of B_{LFM} were chosen as a quantity well characterizing the microwave absorption processes. The $B_{LFM,MMMA}$ and $B_{LFM,DMA}$ as a function of J_{cJ} at 77 K show linear correlations (see Fig. 2). The typical histeresis loops of MMMA and the irreversibility fields, B_{irrJ}, *vs* maximum swept field exhibiting two-step behavior (see Fig. 3)were ascribed to a two step mechanism of microwave absorption; first in the system of week Josephson junctions and next onto the grain surface [8].

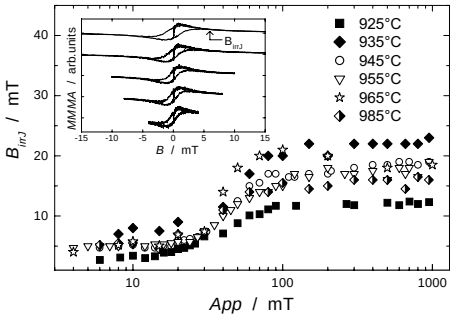

Fig. 3. The irreversibility field as a function of maximum applied field at 77 K for $YBa_2Cu_3O_{7-\delta}$ sol–gel specimens. Insert: Hysteresis loops of MMMA for $YBa_2Cu_3O_{7-\delta}$ 965°C at 77 K.

Three theoretical models: RSJJ [10], rf-SQUID and dc-SQUID [9] were quantitatively compared with experimental data of virgin curve of DMA. The best agreement was achieved for the RSJJ model [8].

3. Conclusions

The intergrain microstructure and critical currents determine the microwave absorption of HTS. The plot of B_{LFM} *vs* J_{cJ} at 77 K shows linear dependence (*cf.* Fig. 2). The RSJJ model describes the microwave absorption of HTS in sufficiently good way.

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