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Nonlinear microwave response to magnetic modulation in BSCCO

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Abstract

We study magnetic field modulated microwave absorption in BiSrCaCuO single crystals. In addition to the well-known signal corresponding to the field-derivative of the thermally activated flux-flow resistivity, which appears close to T_c and *linearly* depends on the modulation level, we observe a new signal with a *nonlinear* dependence on the modulation field. This new signal (i) extends to low temperatures, (ii) appears only above some threshold modulation level, (iii) strongly depends on the magnitude and direction of the dc magnetic field, (iv) appears only in highly anisotropic superconductors. © 2000 Published by Elsevier Science B.V. All rights reserved.

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We report the microwave absorption induced by low-frequency ($1 < f < 100$ kHz) magnetic modulation (IMAMM) [1] in $Bi_2Sr_2CaCu_2O_x$ single crystals. The measurements were performed using a 10 GHz EPR spectrometer and a helium flow cryostat to sweep the temperature from above T_c to low temperatures. The IMAMM was measured as a function of temperature, magnetic field, crystal orientation and the amplitude and frequency of the magnetic modulation.

1. Results

Fig. 1a shows temperature dependence of the microwave absorption signal (NMAS) normalized by the modulation amplitude, for $B_{DC}||c$ and for different modulation levels B_{AC}. This signal corresponds to the magnetic field derivative of the thermally activated flux-flow (TAFF) resistivity, it appears close to T_c and almost does not depend on the modulation level (the curves for different B_{AC} overlay). Fig. 1b shows the NMAS for $B_{DC}||a$–b. Unlike the TAFF signal (Fig. 1a) this new signal strongly depends on the modulation level (the curves for different B_{AC} are distinctly different). This is more evident from the Fig. 2 which presents the NMAS for $B_{DC}||a$–b as a function of B_{AC}. Fig. 2 clearly demonstrates that the microwave absorption appears only above some threshold modulation level (especially 50 K curve), above which the normalized signal increases almost linearly with the modulation with a tendency of saturation towards higher modulation levels. The nonlinear signal appears not only at $B_{DC}||a$–b but is observed also at other orientations as well (see Fig. 1 inset) although it shifts to lower temperatures and its magnitude decreases when the magnetic field is rotated from $B_{DC}||a$–b towards $B||c$. It is even observed at $B||c$. Its dependence on the DC magnetic field at constant temperature $70\,K < T < 80\,K$ and fixed B_{AC} is close to exponential: $I = \exp(H/H_0)$ with H_0 varying between 0.008 and 0.017 T for different crystals. The intensity as well as the shape does not depend on the

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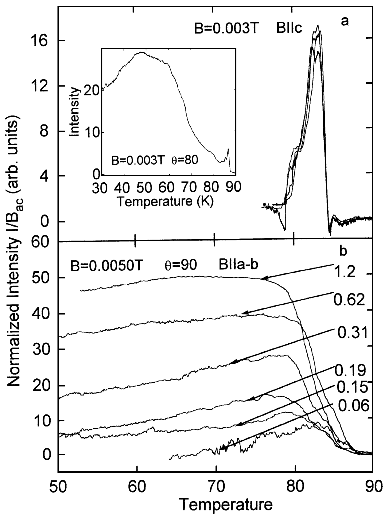

Fig. 1. Microwave absorption for BSCCO crystal (a) for $B||c$ and (b) for $B||a$–b for different modulation levels in mT peak to peak. (shown as numbers in (b). Similar modulation levels are used in (a). The inset shows the absorption signal for the DC field orientation 10° away from a–b plane where both the TAFF and the nonlinear signals are observed.

modulation frequency 1 kHz $< f <$ 100 kHz. The non linear signal decays much slower with decreasing temperature in BSCCO crystals with larger anisotropy constant; it is not observed in crystals with low anisotropy constant such as YBaCuO.

2. Discussion

While the linear (TAFF) modulation signal is generally attributed to the microwave dissipation by vortices moving *inside* the potential well of the pinning potential we attribute this new nonlinear signal to the microwave dissipation by vortices moving *out* of the potential well when the modulation field exceeds some threshold corresponding to the critical current at modulation frequency. Therefore the TAFF signal is linear with B_{AC} (Fig. 1a).

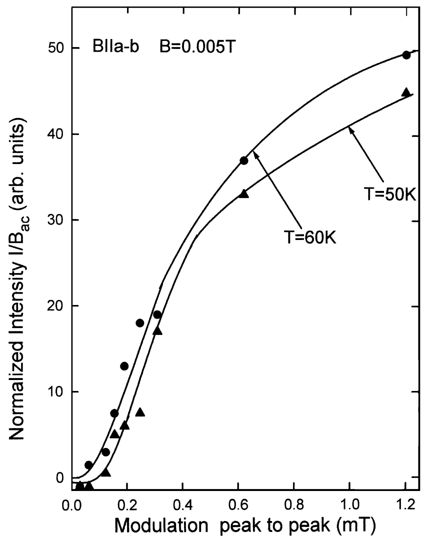

Fig. 2. Normalized intensity of microwave absorption as a function of modulation for temperatures of 50 and 60 K.

The linear increase of the normalized absorption signal on the modulation level above the threshold (Fig. 2) is expected for this process. It also agrees with the tendency towards saturation above a certain modulation level as the total number of vortices is constant for a given DC magnetic field. The exponential decrease of the nonlinear signal with DC magnetic field is well known for critical current and originates from the field dependence of the pinning potential. The independence on the modulation frequency is due to the fact that (i) below 100 kHz the AC field penetrates almost the whole sample and (ii) the time response is sufficiently fast. The non linear signal appears only in highly anisotropic compounds since the threshold modulation level is low there due to the strong dependence of the pinning potential on anisotropy.

References

[1] D. Shaltiel et al., Physica C 315 (1999) 23.