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1. Introduction

Excitation by high-frequency electromagnetic field has been extensively used to investigate its interaction with the vortex system in superconductors as it gives information related to surface properties [1]. In particular it has been used to investigate Josephson vortices (JV) due to their very low viscosity compared to the viscosity of pancake vortices (PV) that is orders of magnitude larger. Most experiments are performed when only a DC magnetic field is applied [2]. Recently, the microwave dissipation in high anisotropy $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) single crystals was investigated by the so called ‘‘Induced Microwave Dissipation by AC Magnetic Field’’ (IMDACMF) technique, where microwave losses are measured as a function of temperature, DC magnetic field, AC magnetic field, and orientation [4]. Strong microwave dissipation is observed in contrast to the much weaker dissipation without application of the AC magnetic field [2]. AC induced microwave dissipation was not observed in low anisotropy YBCO [3]. To confirm that high anisotropy is necessary to observe AC induced microwave dissipation we have investigated tri-layered $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ (Bi2223) single crystals using the IMDACMF technique and compare the results with those observed in the bi-layered Bi2212 compound. Using the sine-Gordon equation we show that the quite similar microwave dissipation found in both compounds originates from the dynamic interaction of the AC field with the Josephson vortices.

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2. Experimental details and results

The IMDACMF experimental method is performed in a conventional CW electron-spin-resonance spectrometer as described elsewhere [3]. The superconducting crystal is exposed to the magnetic microwave field parallel to the *a–b* plane and to a collinear DC and AC field also parallel to the *a–b* plane but perpendicular to the microwave field. The reflected microwave power is fed into a diode and the resulting AC signal is fed to a lock-in detector that gives the signal intensity and the phase with respect to the external AC phase.

Fig. 1a and b show the signal intensity as a function of DC magnetic field, at 20 K for an AC magnetic field of 0.1 mT peak to peak (p to p) for the Bi2223 and Bi2212 crystals, respectively. Both crystals exhibit a bell-shape signal with an elongated decrease of the intensity at higher fields. This decrease fits an exponential decay which is stronger in Bi2212 than in Bi2223. The signal phase measured with respect to the phase of the external AC field is around −180° in both samples. No signal was detected for magnetic fields parallel to the *c*-axis. Such a microwave-dissipation pattern is observed in both compounds for temperatures below 85 K. It implies that the mechanisms of the interaction with the AC field are the same in Bi2212 and in Bi2223 in this temperature range. Only an anomalous behaviour of the signal intensity in Bi2223 from T_c down to 85 K indicates a different interaction at higher temperatures, and possibly a phase transition at 85 K.

3. Theory and discussion

The strong intensity signals observed for magnetic fields parallel to the planes where only JV are formed in contrast to zero intensity signals observed for magnetic fields perpendicular to the planes where only PV are formed, implies

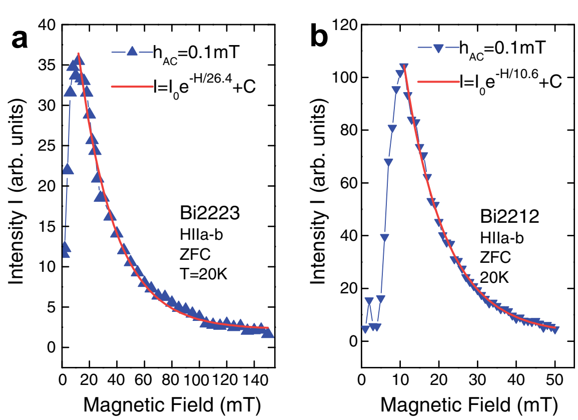

Fig. 1. Intensity as a function of DC field for a low AC field of 0.1 mT at 20 K for Bi2223 and Bi2212. The exponential decay shown as solid fit curve is stronger for Bi2212.

that the origin of the microwave dissipation results from the interaction of the AC field with JV but not with PV vortices. The AC field induces motion of the JV in and out of the superconductor where they interact with the microwave that resides within the microwave skin depth. It indicates a dynamic interaction that should be distinguished from the static interaction observed without the presence of the AC field [2]. In both compounds under consideration the response of the microwave dissipation as a function of DC field at low AC magnetic fields, shows a similar behaviour below 85 K with an exponential decrease on the high-field wing; hence, both can be described by the dynamic interaction.

As far as the microwave in these measurements is only the carrier of the observed signal the AC field is essential to the observed microwave dissipation. In order to calculate the energy absorption in a superconducting plate subjected to the slowly varying external magnetic field parallel to the layers within a quasi-static approximation one has to find the static solution with constant field and to replace it by the time-dependent field. The theoretical analysis is based on the Lawrence–Doniach Hamiltonian [5] for layered superconductors. The Hamiltonian can be mapped onto the sine-Gordon equation, which carries solitons, i.e. JV. The analysis shows that the AC magnetic field governs the dissipative dynamics of the JV created by the DC magnetic field. The interaction of the driven by the AC field JV with the microwaves is responsible for a large power absorption in the layered superconductors. The power of the microwaves absorption has the form:

$$P_J = P_0 \exp\left(-\frac{h}{h_{\mathrm{ch}}}\right).$$

Here h and h_{ch} denote the dimensionless external static field and a certain characteristic field for the soliton dynamics, respectively. This dependence is in excellent agreement with the experimental results presented in Fig. 1 confirming the interaction of the AC field with JV solitons.

The dependence of the intensity as a function of DC field for larger AC field >0.3 mT in Bi2212 has been reported elsewhere [4]. It shows an entirely different behaviour that consists of a high intensity peak at low DC field and a lower intensity peak at higher fields. Similar behaviour is observed in the Bi2223 compound. It implies again that the mechanism of interaction as function of DC field in both high anisotropy compound is the same. To understand this behaviour at higher AC field in detail further theoretical effort is necessary. In conclusion we show that the dissipation of the microwave in the layered superconductors Bi2223 and Bi2212 has universal features as a function on the external DC magnetic field. It results from the dynamic interaction of the microwave with JV moved by the AC field, which can be well described in terms of the sine-Gordon equation.

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References

[1] M.W. Coffey, J.R. Clem, Phys. Rev. Lett. 67 (1991) 386.
[2] H. Enriquez, N. Bontemps, A.A. Zhukov, et al., Phys. Rev. B 63 (2001) 144525.
[3] D. Shaltiel, J. Low Temp. Phys. 130 (2003) 383.
[4] D. Shaltiel, T. Tamegai, Physica C 406 (2004) 505.
[5] A.E. Koshelev, Phys. Rev. B 68 (2003) 094520.