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ELECTROMAGNETIC WAVE ABSORPTION IN HIGH-Tc SUPERCONDUCTORS AND ITS APPLICATION

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Abstract

The experimental study of the electromagnetic wave absorption of high-Tc superconductors subjected to small magnetic fields has been extended to a wide frequency range. The results obtained show an almost frequency independent behaviour in the 4 MHz - 20 GHz region. The measurement technique for the high frequency regime was developed in such a way that the sensitivity increased so much that the sample under investigation could be used as a very sensitive magnetic field detector, too.

Introduction

Since the discovery of the high-T_C superconductors, there has been investigation carried out on the microwave absorption of these type of materials. They were mainly made by the well-known electron spin resonance equipment (ESR). One of the results of these experiments was a sharp maximum in the derivative of the absorption vs. magnetic field in the low field region as it is shown in Fig. 1.

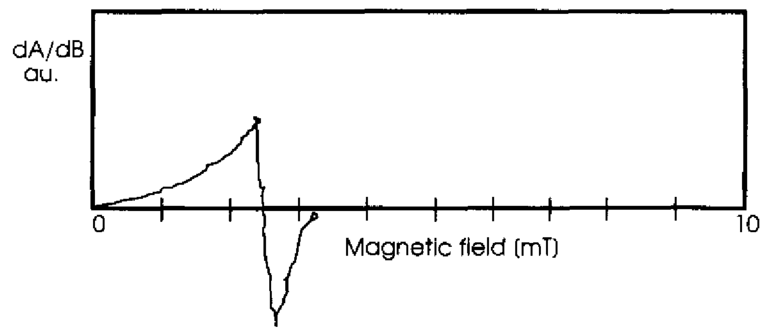

Fig. 1.

An abrupt change can be seen in the slope of the curve and even in its sign. This motivated us to extend the investigation of the absorption dependence on the magnetic field in a broad frequency range.

The ESR equipment contains a microwave cavity resonator in which the superconducting samples under investigation can be inserted. The applied DC magnetic field is modulated by a relatively small AC field. The reflected signal through a microwave bridge and a lock-in amplifier what was tuned to the modulator frequency has been detected. In this way the derivative of the absorption vs. magnetic field at a given frequency in the function of applied field can be measured. In most of the cases the ESR machines work at 10 GHz frequency.

Measurement

To broaden the frequency range in addition to the cavity we used a tuneable RF resonance circuit which could be tuned in the 4 - 40 MHz range. Using a similar measuring arrangement the derivative of the absorption vs. magnetic field for an YBCO sample is shown in Fig. 2. The right side of the curve has shown the response starting the measurement from zero field and the left side has shown the behaviour when first a 10 mT magnetic field was applied. The maximum of the effect in the function of magnetic field is shown in Fig. 3. while the resistivity vs. temperature is displayed in Fig. 4. whereas the curves were measured in the 0 - 1 mT range. It can be seen that the maximum change in the absorption derivative occurs at critical temperatures of the samples in question. Besides this method gives the possibility to measure the critical temperature without contact problems providing high accuracy at the same time. The absorption was frequency independent with the same character as it was known from the microwave experiments.

In order to make the measurement more direct and sensitive we constructed the resonator from the superconductor under investigation itself. This resonator circuit could be fabricated easily for the microwave region. One of the most simple designs of this type of microwave device is the ring resonator as it is shown in Fig. 4. The ground plane of the resonator was made of the same material as the conductor pattern. The substrate material had to be selected in such a way that its dielectric loss was low enough as not to dominate the measured response. Two substrate materials, the yttrium stabilized zirconia (YSZ) and the magnesium oxide single crystal (MgO) were selected. The YBCO thick films screen printed onto MgO substrate

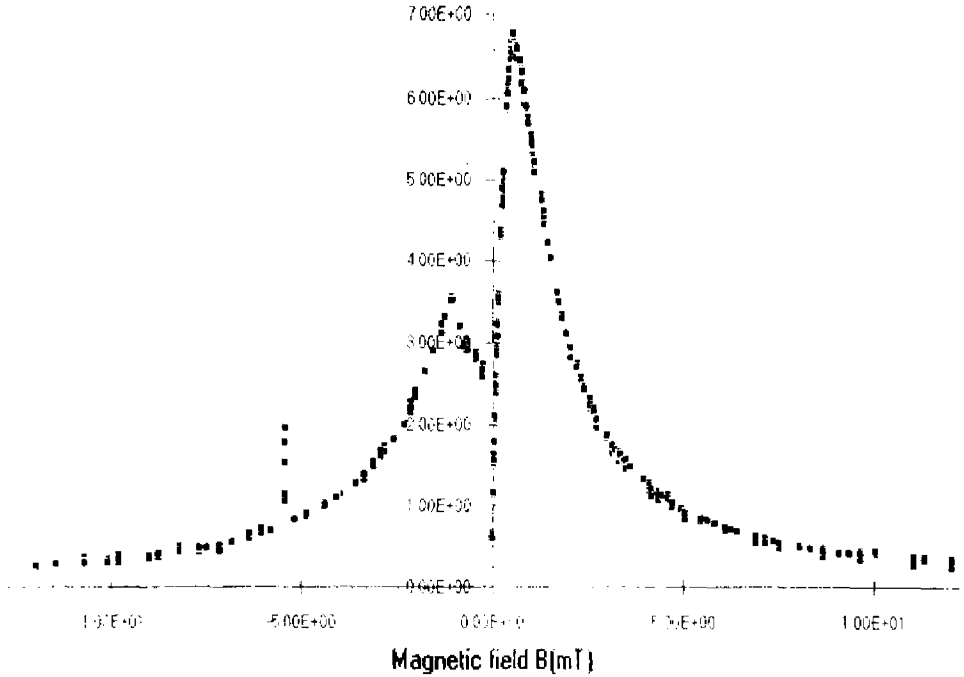

Fig. 2.

The derivative of the absorption in the function of the magnetic field of an YBCO sample in the 4-40 MHz range.

were degraded by the substrate/film interaction on a degree that the critical temperature of the film was over 10 K worse than the one on the YSZ substrate, however the microwave property of the MgO (ε, $\tan\delta$) were better than that of the YSZ, therefore the resonators were fabricated on both of the substrate materials.

For comparisons high quality resonators were made of screen printed $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ as well.

Identical ring resonators were made of gold on the same substrate materials to compare their microwave properties at temperatures in question.

The diameter of the ring can be calculated by the

$$D_0 = n \frac{\lambda_{RN}}{\Pi}, \qquad (1.)$$

equation [1.], where $\mathbf{D_0}$ is the diameter of the ring, $\boldsymbol{\lambda_{RN}}$ is wavelength, **n** is the harmonic mode.

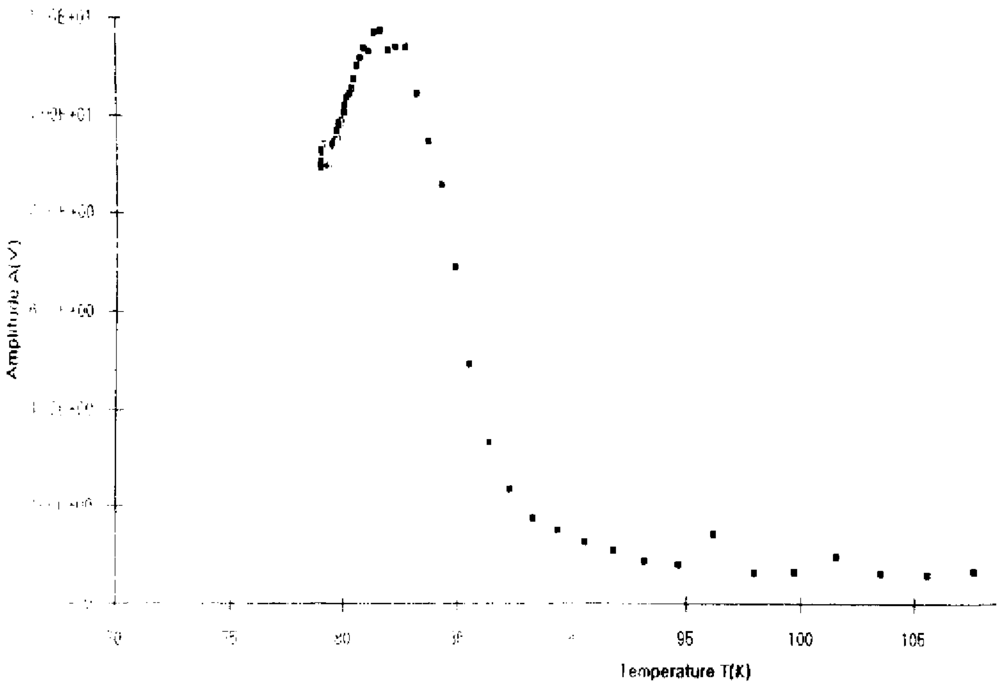

Fig. 3.

The maximum absorption as a function of the magnetic field for the same YBCO sample

The resonators to be measured were inserted into a closed cycle refrigerator which could vary the temperature in 20 - 300 K range.

The resonator sample was mounted in an aluminium sample holder as it is shown in Fig. 5. and connected to the HP Network Analyzer (HP 8410 C) via coaxial cable. The network analyzer worked in the 2-18.6 GHz frequency range. For the experiments at 77 K a vacuum tight aluminium box was immersed into liquid nitrogen with the connection of coaxial cable as in the case of the refrigerator. The sample preparation and measurement arrangement described more detailed elsewhere [2.].

The magnetic field was generated by a simple coil, oriented perpendicularly to the surface of the specimen.

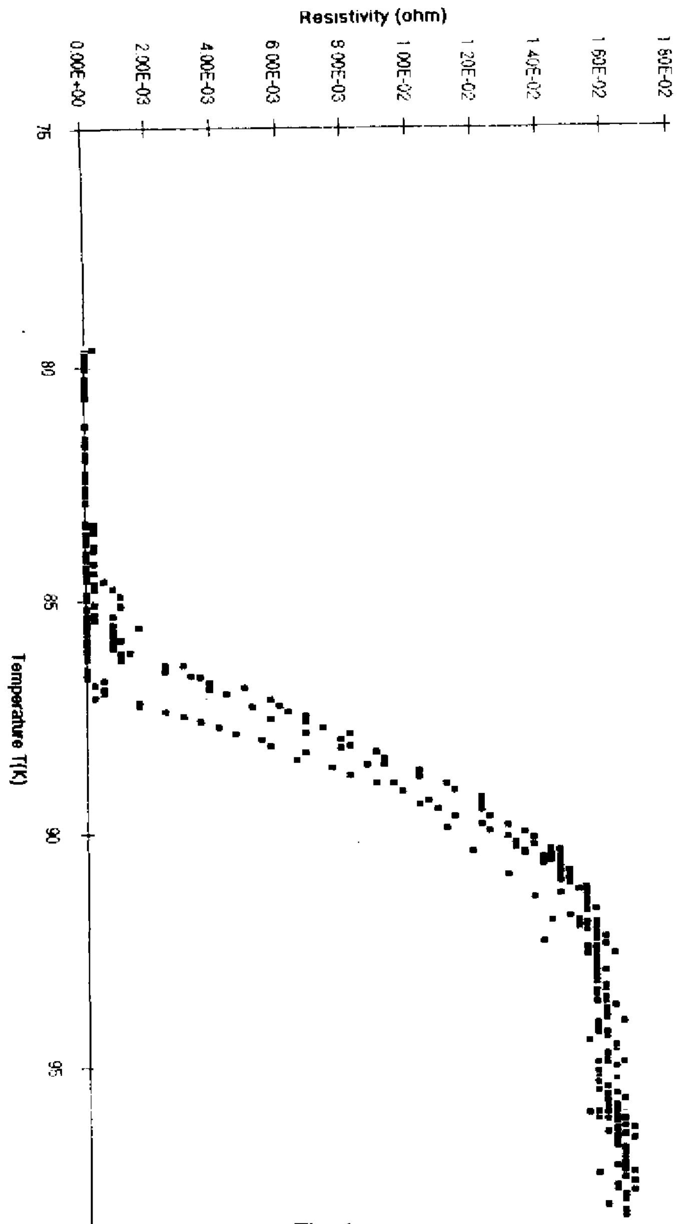

Fig. 4.

The resistivity vs. temperature for the YBCO sample

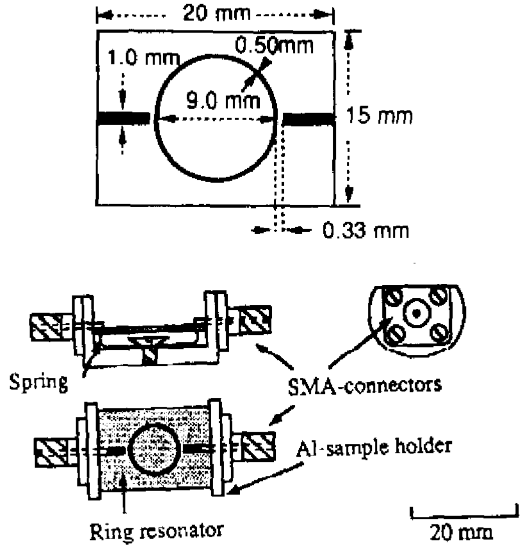

Fig. 5.

The layout and the mounting arrangement of the ring resonator

The superconducting parameters of the sample under investigation in the microwave region are listed in Table 1.

Sample and substrate material	T_c [K]	I_c [K]	Critical current density (77 K) [A/cm^2]
YBCO/YSZ 1	87	32.9	408
YBCO/YSZ 2	85.5	3.36	33.9
YBCO/MgO 1	76.8	0.043	0.42
YBCO/MgO 2	76.5	12.9 (70 K)	125 (70 K)
BSCCO/MgO 1	101	14.9	354
BSCCO/MgO 2	102	24.3	481

Table 1.

Results

The measured values for the YBCO samples shown in Fig. 6. we can see that the maximum change in the quality factor (82000) could be achieved at 50 K for YSZ substrate. For this maximum change 1 mT magnetic field would have been applied. In all of the other cases somewhat higher magnetic field was needed and the maximum changes were less. (1.1 - 11 mT for the maximum change.)

The resonators on MgO substrates gave worse result as the YSZ ones.

As an example the reflected power vs. frequency at different magnetic flux densities and the quality factor in the function of magnetic field at the most sensitive point measured for the YBCO/YSZ 1 sample at the resonant frequency 14.927 GHz is shown in Fig. 7.

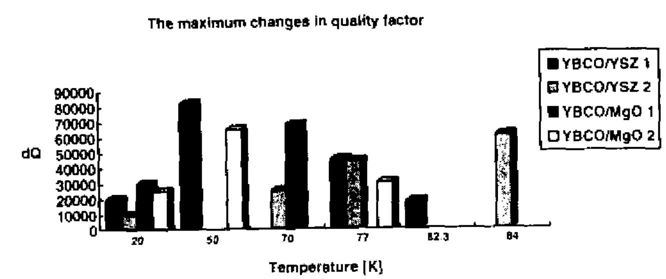

Fig. 6.

The maximum change in the quality factor for YBCO samples

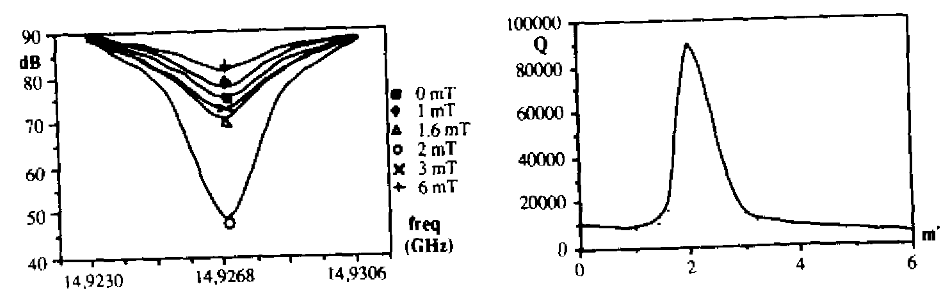

Fig. 7.

The influence of B on the reflected power (vs. frequency) and on the Q of the YBCO/YSZ 1 resonator at 50 K

The measurement of BSCCO/MgO ring resonators showed less sensitivity to the applied field at any temperature as it is shown in Fig. 8.

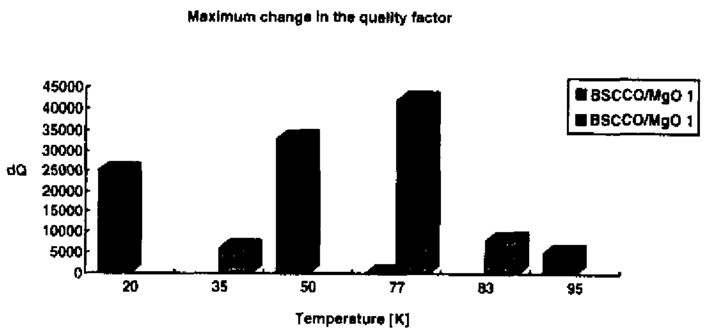

Fig. 8.

The field needed for the maximum changes varied from 0.5 to 19 mT.

For comparison the identical thick film ring resonators were made from special paste of gold material (ESL8880-H) dedicated for microwave application and their microwave properties in the same frequency range were measured. The Q-values of the gold ring resonators were ~2000 at room temperature and became even less at liquid nitrogen temperature. In comparison all of the superconducting ring resonators below the critical temperature had Q-value higher than that, mostly ~10 000 without external magnetic field, while under the influence of small magnetic field (0.5-2 mT) the quality factor could be increased up to 88 000 in the best case.

For explaining the effect we could suppose either a Josephson junction network formed by superconducting grains with lower Tc intergranular material in between or an effect of the magnetic field on creating pinning centers. In the first case, if an area enclosed by Josephson junctions would had resonant frequency near one of the resonators the Q will increase. The applied external magnetic field is just controlling this area in order to bring closer the resonant frequency of the Josephson chain to the resonator. By this way the ring resonator acts as a series of SQUIDs giving the sensitivity of this device for the magnetic field as the SQUIDs have. In the second case the increased number of the pinning centers causes a higher critical current and higher quality factor by this way. Consequently the further increase of the magnetic field deteriorates the superconductivity and reduces the Q.

Conclusion

Without any exact explanation of the effect described above we can draw certain conclusions.

The effect can be used in two ways. The first is as a microwave device to be controlled by small external magnetic field. It can provide a way modulation of microwave power for example. Secondly it gives a simple way of building very sensitive magnetic field sensor without the technical complexity of the SQUID devices.

The sensitivity what is much higher than that of the magnetically modulated resistance methods [3.] can be drawn from Fig. 6. is in the range of 10^{-9} T and it has good reproducibility. The further development of this device could result in a more sensitive and easily fabricated equipment - for example by the use of channel spark deposition technique [4.] - for detecting the magnetic field or the change in the field.

References

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