CHARACTERISTICS OF YBaCuO MAGNETIC SHIELDS

M.J. Hurben, O.G. Symko
Department of Physics, University of Utah
Salt Lake City, Utah 84112

W.J. Yeh
Department of Physics, University of Idaho
Moscow, Idaho 83843

S. Kulkarni
AVX Corporation
Myrtle Beach, SC 29577

M. Novak
Department of Physics
University Federal of Rio de Janeiro
Fondao, Rio de Janeiro, Brasil

Abstract

Magnetic shielding properties of YBaCuO tubes have been studied at temperatures of 77 K and 4 K. Shielding effectiveness was determined by measuring the magnetic field inside the tube in the presence of external magnetic fields. A high degree of shielding was achieved up to a critical external field which is determined by the critical current density of the material. Typically this critical field is 23 Oe at 77 K extending up to 105 Oe at 4 K. Tubes made with material containing 10% silver exhibited much stronger flux pinning behavior when the external magnetic field started to penetrate the tubes. The tubes studied here were effective in shielding a rf biased SQUID for operation at 77 K.

Introduction

The quest for higher sensitivity superconducting devices brings with it a need for effective shielding of such devices. Superconducting shields are very well suited for such applications and their effectiveness has been demonstrated with regular superconducting materials at temperatures near T_c and lower, especially for SQUID devices[1]. Shielding occurs because magnetic flux through a circuit is constant when the resistance of the circuit is zero and because superconducting materials exhibit diamagnetism with $B = 0$ well inside the superconductor. Such shields are part of the instrumentation used with SQUID devices, superconducting electronics, all sorts of detectors, high energy physics, and even constant magnetic field generators. Usually the shielding factor is defined as the ratio of the magnetic field inside the shield at its center to the applied field. For high T_c devices, operating up to T_c, effective shielding is crucial and hence high T_c shields are necessary to cover similar temperature ranges. High T_c materials, especially in bulk samples, tend to have a variety of defects which limit the current densities and hence their shielding effectiveness. We present here a study of high T_c shields and some of their limitations.

Manuscript received September 24, 1990

Experimental Details

Two types of shields were investigated here, regular $YBa_2Cu_3O_7$ tubes, and $YBaCuO_7$ + Ag tubes. The tubes ranged from 5 cm to 23 cm in length, with an od of 1.2 cm and an id of 0.96 cm. They were made from high purity powders of $BaCO_3$, CuO, and Y_2O_3; the mixture was ball milled for 24 h. The resulting slurry was dried at room temperature, calcined at 930 °C for 45 h, wet ball milled again for 24 h, and then an isostatic pressing technique was used to obtain green ceramic tubes. They were fired at 960 °C for 12 h in air and slowly cooled in the furnace, followed by an anneal in an oxygen atmosphere for 18 h at 850 °C.

Tubes were also made with Ag. After the superconductor powder of YbACuO was formed, silver powder 3 μm size was added; the amount of silver was 10%. The binder was then added. It was pressed and fired. The reason for the silver addition was to try to stabilize fluxon motion.

To determine the shielding characteristics of each tube, the internal magnetic field H_I was measured as a function of applied field H_A at liquid nitrogen temperature as well as at 4 K. The magnetic field detector was a Hewlett-Packard Fluxgate magnetometer, model 4288R, with a sensitivity of better than 10^{-5} G, and a Hall (Ohio Semitronics, Inc., HR 66) probe for the higher fields. Measurements were taken after zero-field cooling of the tube. Fig. 1 shows the basic experimental set-up for studying the shielding effectiveness.

Results

As an external magnetic field was applied axially to the shield, a persistent current was induced in the tube to keep the interior flux constant. Such current increased with H_A until the critical current of the tube was reached. At this point, H_A was the largest magnetic field that could be effectively shielded before flux started to penetrate into the interior of the tube. Further increases in H_A caused the internal magnetic field H_I to change, with partial shielding of the interior by induced currents. Fig. 2 shows the shielding characteristics of an YBaCuO shield at 77 K and 4 K. As the critical current increases, the critical magnetic field for flux entry is also increased.

0018-9464/91/0300-1874$01.00 © 1991 IEEE

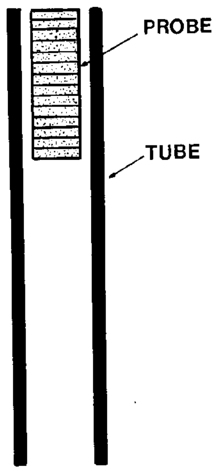

Fig. 1. Basic set-up for measuring shielding effectiveness.

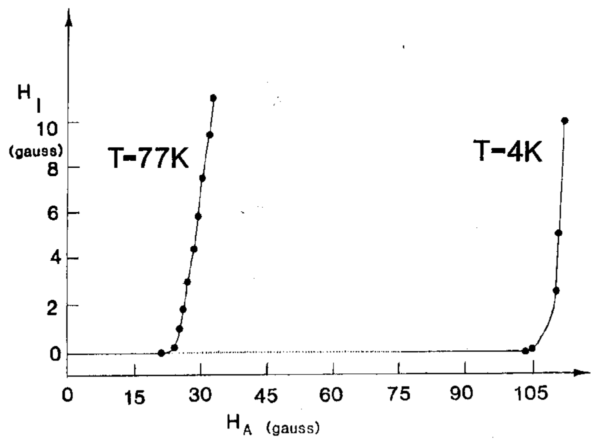

Fig. 2. Shielding characteristics of YBCO tube showing inside magnetic field as a function of applied field.

With such a shield a high T_c SQUID[2], rf biased, showed a limiting noise level of 6×10^{-4} $\phi_0/\sqrt{Hz}$ at 77 K. The shield was 10 cm long.

Measurements were repeated with YBaCuO shields containing 10% silver. Although the critical current did not improve, the flux penetration behavior was quite different from the YBaCuO shield. This is shown in Fig. 3 at a temperature of 77 K. The steps correspond to small changes in H_A. Flux penetration does not occur as easily in the YBaCuO + Ag tube as in the YBaCuO one.

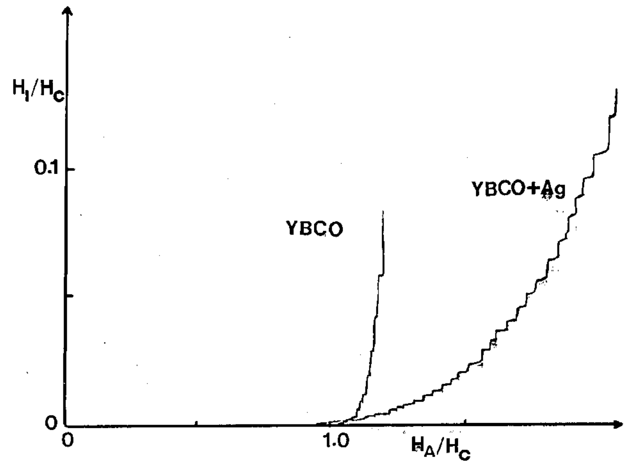

Fig. 3. Comparison of shielding by YBCO tube and YBCO + Ag (10%) tube.

Conclusions

We have shown that effective shielding using high T_c superconducting shields can be achieved up to critical magnetic fields of 10-100 Gauss. Shielding effectiveness is demonstrated with a rf-biased high T_c SQUID, of the fracture type. A typical SQUID output with a high T_c shield at 77 K, is shown in Fig. 4.

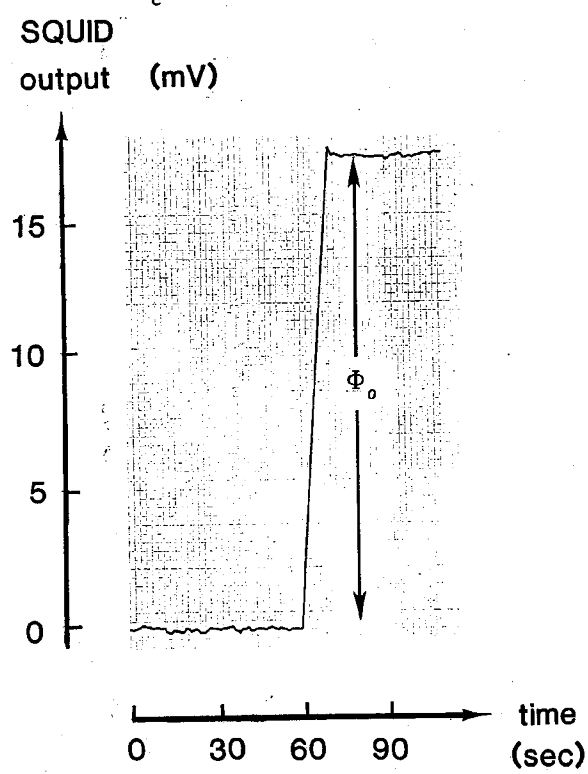

Fig. 4. Output of high T_c rf biased SQUID at 77 K shielded by YBCO tube.

As the current density of the tube is increased so is the critical field for flux entry. The relation between current density J_c and magnetic field H_A can be obtained from the critical state model, Kim's model[3], as

$$J_c(H_A + H_o) = \alpha_c \qquad (1)$$

where H_o and α_c are constants characteristic of the material. This expression leads to the relation between the internal magnetic field and the external one in the critical state; it is given by:

$$(H_I + H_o)^2 - (H_A + H_o)^2 = + \alpha_c k\, w \qquad (2)$$

where w is the wall thickness of the tube and k is a constant equal to (4 π/10) Oe cm/A.

The behavior of the YBCO + Ag shield can be interpreted as evidence for some flux pinning by the added silver[4], thus allowing less field penetration in the critical state.

We have shown that high T_c materials can be used in the fabrication of shields for superconducting devices; they operate very well at 77 K and they are adequate for shielding ambient stray magnetic fields which usually cause disturbances in the operation of a SQUID. In order to shield higher magnetic fields, the current density has to be raised by lowering the temperature below 77 K, or by improving the quality of the material used in fabricating the tube.

References

[1] B.S. Deaver and W. S. Goree, "Some Techniques for Sensitive Magnetic Measurements Using Superconducting Circuits and Magnetic Shields," Rev. of Sc. Instr. 38, 311 (1967).

[2] C.H. Harmston, O.G. Symko, W.J. Yeh, D.J. Zheng, and S. Kulkarni, "High T_c RF-Biased SQUID," IEEE Trans. on Magn. 25, 878 (1989).

[3] Y.B. Kim, "Magnetization and Critical Supercurrents," Phys. Rev. 129, 528 (1963).

[4] D. Pavuna, H. Berger, M. Affronte, J. Van der Maas, J.J. Capponi, M. Guillot, P. Lejay, and J.L. Tholence, "Electronic Properties and Critical Current Densities of Superconducting $(Y_1Ba_2Cu_3O_{6.9})_{1-x}Ag_x$ Compounds," Solid St. Com. 68, 535 (1988).

[5] E. Tjukanov, R.W. Cline, R. Krahn, M. Hayden, M.W. Reynolds, W.N. Hardy, J.F. Carolan, and R. C. Thompson, "Current Persistence and Magnetic Shielding Properties of $Y_1Ba_2Cu_3O_x$ Tubes," Phys. Rev. B 36, 7244 (1987).

[6] J.O. Willis, M.E. McHenry, M.P. Maley, and H. Steinberg, "Magnetic Shielding by Superconducting YBaCuO Hollow Cylinders," IEEE Trans. on Magn. 25, 2502 (1989).