HIGH T_c RF-BIASED SQUID

C.H. Harmston, O.G. Symko, W.J. Yeh, and D.J. Zheng,
Dept. of Physics, University of Utah, Salt Lake City, Utah 84112,
and
S.K. Kulkarni,
Ceramatec, Salt Lake City, Utah 84115

Abstract

Results are presented on the behavior of a simple rf-biased SQUID made out of $YBa_2Cu_3O_7$. It consists of a fractured ceramic pellet stuck together at room temperature. This simple device is shielded by a high T_c tube and it shows the characteristic flux quantization behavior up to 77K. At 4.2K its magnetic flux resolution is less than $2 \times 10^{-4}\phi_o/\sqrt{Hz}$ and it shows sensitivity degradation as the temperature is raised.

Introduction

One of the exciting possibilities of the new high T_c superconductors is the application to devices and electronics at 77K and even higher temperatures. Here we present one such application, an rf-biased SQUID shielded by a high T_c superconducting tube. The early attempts[1] in this field showed some SQUID behavior in bulk material. Subsequently, a dc SQUID was fabricated[2] using thin films of YBaCuO where the weak links were made to be 17 μm wide; it was operated in the temperature range of 4.2K to 68K. Meanwhile, a fracture technique[3,4] was applied to making a Josephson junction[5] and simple point-contact-like SQUIDS, where the weak link was made at approximately 4K using a special mount. This type of SQUID was rf-biased and it operated[6] up to 81K, using μ-metal shielding. We show here the development of a point contact SQUID fabricated at room temperature and operating over a temperature range of 4.2K to 77K; it uses a high T_c superconducting shield.

Experimental Details

The devices were fabricated from bars of YBaCuO. The ceramic material was prepared by conventional ceramic fabrication methods. The samples were pressed at 30,000 p.s.i. pressure and sintered at 960°C for 12 hours; they were then annealed in an oxygen atmosphere at 900°C and 700°C for 24 hours and then slowly cooled to room temperature. The bars were fractured into small parallelepipeds (5.6 mm × 5.3 mm × 7 mm). Each sample had a 0.6 mm diameter hole drilled through the center. The pellet was fractured, by hand, across the hole; the 2 pieces were fixed together with glue or epoxy (they can also be held together with small alligator clips). The rf coil for biasing, with approximately 25 turns of copper wire (0.127 mm diameter), was glued in the hole. Because μ-metal shielding was not adequate, we developed[7] a high T_c superconducting shield for this application. It consisted of a YBaCuO tube, 6 cm long, 0.9 cm i.d., with a wall thickness of 1 mm. The SQUID sensor was located in the middle of the shield and the entire unit was cooled in an old standard rf SQUID probe used with adjustable point contact devices. Figure 1 shows the arrangement.

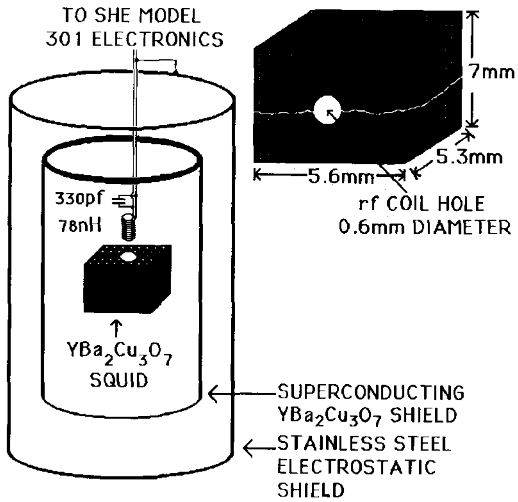

Figure 1 – Experimental arrangement for the high T_c rf SQUID. The upper right shows an enlarged view of the device.

At first, the entire unit was cooled to 4.2K and then it was slowly warmed up in the helium vapors, the temperature being monitored by a chromel-constantin thermocouple. With improved techniques of fabrication, we dipped the device directly into liquid nitrogen.

Results

Even though the experimental procedure for fabricating this device was very simple, we saw the characteristic flux triangles at the output of the SQUID electronics. Figure 2 shows the output of the peak detector as a function of an injected audio signal into the rf. bias coil with the SQUID at 4.2K and with a high T_c shield.

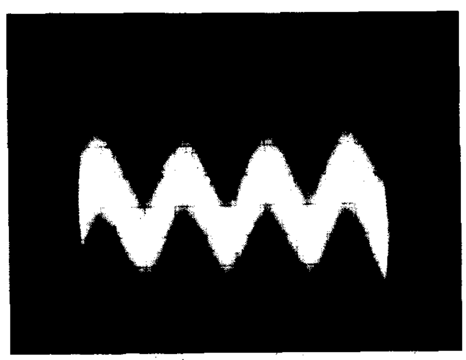

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Figure 2 – Rf detector output as a function of external flux for a SQUID operating at 4.2K.

Figure 3 shows the behavior of a similar SQUID at 77K in liquid nitrogen also with the same shield.

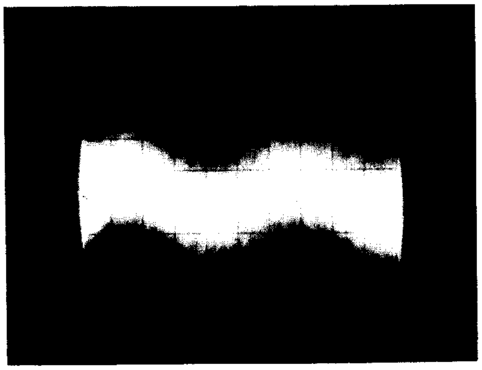

Figure 3 – Rf detector output as a function of external flux for a SQUID operating at 77K.

This was observed for a variety of samples whose critical current density at liquid N_2 ranged from 0.1 A/cm^2 to 50 A/cm^2. The SQUID could be locked in the feedback mode with a noise level less than $2 \times 10^{-4}\ \phi_o/\sqrt{H_z}$ at 4.2K. As the device and shield were warmed, the amplitude of the triangles would first increase and then degrade, or just degrade and eventually disappear above 77K.

The success yield of making a SQUID in the manner described above was over 70%. Thermal cycling did not seem to affect the performance and some SQUIDS were still working after a month. However, some of the SQUIDS did show degradations with time, possibly when there was insufficient glue or epoxy covering them.

The noise characteristics of a typical SQUID operating at 4.2K in the flux-locked mode is shown in Figure 4.

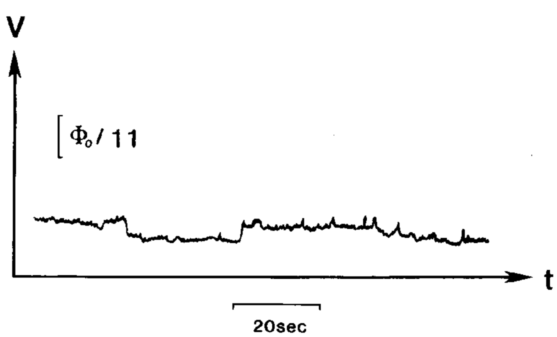

Figure 4 – Noise characteristics for a SQUID operating at 4.2K.

Its performance was no different from when the shield was replaced by a lead one; thus we conclude that our ceramic shield is adequate for this application. The jumps seen on the trace correspond to relative motion between the sensor and the shield, as they were wedged together with putty.

Discussion

We have presented a simple rf-biased SQUID which can operate over a wide range of temperatures. The characteristics displayed in Figures 2 and 3 show that there is a large amount of noise (this signal is before the noise reduction system of the electronics control). We attribute this noise to a series of parallel current loops satisfying the requirement that the SQUID inductance L be such that:

$$\phi_o = Li_c \qquad (1)$$

where i_c is the critical current through the weak barrier and ϕ_o is the flux quantum. They have slightly different periodicities and thus there is a distribution of phases leading to multiple SQUID triangles, hence to the observed noise. This is substantiated by the fact that we could not reduce the noise by decreasing the bandwidth with an external filter.

The ease of fabricating the devices described here is due to the fact that the material is granular and hence it has a low current density. This makes it easier to make a weak link which will satisfy equation 1 in these materials than in conventional metallic superconductors where the point contact has to be extremely fine. In view of this it is possible that the model[8,9] of a granular SQUID applies here; the current density is so low that equation 1 is easily satisfied for almost any point contact. Actually, our triangles in Figures 2 and 3 show some noise similarity with the noise characterization of reference 8. In that case it was due to the penetration of flux through the device film because the penetration depth was larger due to the granularity, while in ours it is due to the multiplicity of current paths satisfying equation 1.

In designing the present SQUID device it is important to realize that SQUID inductance L should be small so that its thermal flux noise $(kTL)^{1/2}$ is smaller than ϕ_o at liquid nitrogen temperature. For this reason we have made the center hole less than 1 mm in diameter.

We have presented a simple SQUID device which can be easily constructed at room temperature. The fracturing of the ceramic does not require low temperature mounts thus simplifying the device fabrication. Our unit is a self-contained instrument which has all high T_c materials for the device and the shield; it is capable of operation at liquid nitrogen, thus also simplifying the cryogenic requirements. Although the SQUID presented here does not show yet the ultimate sensitivity of some present day conventional superconductivity SQUIDS, its simplicity and cryogenic convenience make it already useful for a variety of applications including some biomagnetic experiments. By reducing the contact area between the two halves of the device, the number of current loops will be reduced thus decreasing the effective noise. The fact that there are 2 contacts for each current loop does not invalidate the quantization constraints for these loops, since the weaker contact will allow the penetration of flux quanta.

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