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Letter

A versatile cryostat and a mutual inductance coil for a.c. susceptibility measurements on high T_c superconductors

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Abstract

An inexpensive cryostat and a mutual inductance coil are described for a.c. susceptibility measurements on high temperature superconductors. A unique feature of the cryostat is that it can be operated from 77 K upwards, whereas conventional gas-flow-type cryostats reach a lowest temperature of about 90 K. Other advantages of the system are also presented.

1. Introduction

The discovery of new oxide superconducting materials continues to be very fascinating. A superconductor is characterized by the Meissner(-Ochsenfeld) effect, *i.e.* exclusion of the magnetic flux B and a loss of d.c. resistivity, well below the critical transition temperatures T_c. A SQUID magnetometer is ideally suitable for studying the Meissner(–Ochsenfeld) effect: however, it is very expensive. Several workers have used the a.c. inductance technique for determination of T_c etc. This technique is also relatively expensive because it needs a sophisticated variable-temperature cryostat. Mulay [1] and Mulay and Mulay [2] have reviewed several inductance techniques and associated cryostats. In addition, gas-flow-type cryostats have been described by Ziegenfuss [3], by Sena [4] and by Hockman *et al.* [5]. These cryostats work well between about 100 and 300 K. In this paper, we describe the construction of an inexpensive cryostat, which operates at even lower temperatures (77–200 K); this cryostat essentially utilizes the principle of the gas flow technique. Thus it provides in a simple manner a continuously variable temperature between 77 and 300 K, and above, when needed. The construction of a mutual inductance coil, suitable for use with this cryostat, is presented.

2. The cryostat

The cryostat was designed to meet the following important requirements: (1) maintenance of a constant temperature over the desired range; (2) a quick change-over from one sample to the next. The design of the simple cryostat and the coil assembly are shown in Fig. 1. A small glass Dewar

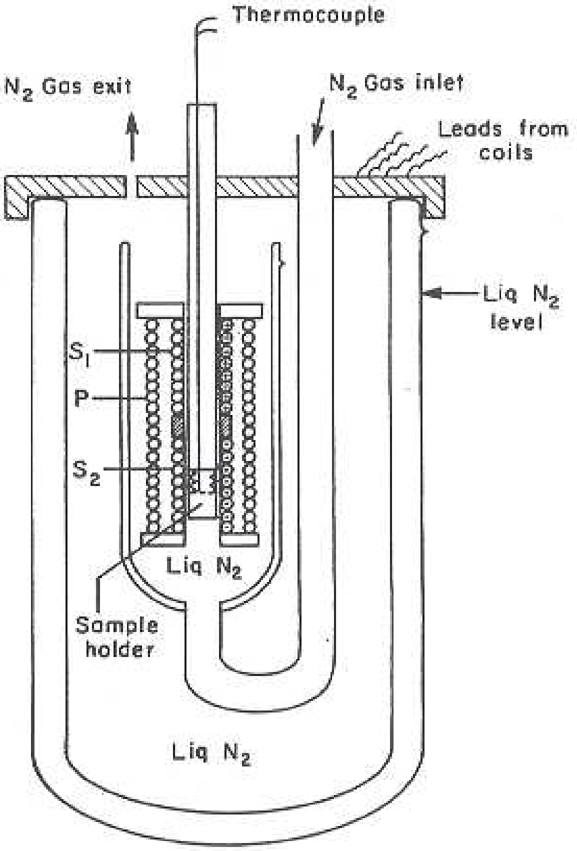

Fig. 1. Schematic diagram of the cryostat (77–300 K) and the inductance coil.

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flask (2.5 cm in inside diameter and 12.5 cm long) with a U-tube tail was placed in another larger Dewar flask. At the beginning of the operation the large Dewar flask was filled with liquid nitrogen so that the U-tube and about two-thirds of the small Dewar flask could be submerged; the small Dewar flask was also partially filled with liquid nitrogen. The sample was attached to a long plastic (Lucite) rod with a copper–constantan thermocouple. A tightly packed powdered sample was placed in a (diamagnetic) ultrapure copper holder and was attached to the bottom of the Lucite rod so that the sample occupied the same position in one of the secondary coils. Thus the sample could be changed quickly by removing the Lucite rod from the top lid of the large Dewar flask. Constant temperatures in the range 77–200 K were obtained by flowing nitrogen gas through a control valve, while keeping liquid nitrogen both inside the U-tube and in the large outer Dewar flask.

Starting at the lowest temperature (77 K) and warming up to 200 K the rate of evaporation of liquid nitrogen and warming up to 200 K could be controlled by regulating the flow of nitrogen gas. The nitrogen gas flow was kept at a very low level, especially at the start of the warming process, so as to maintain a constant temperature for a relatively long period. A small hole was provided in the tight lid of the large Dewar flask to allow the exit of the nitrogen gas, while maintaining a small positive pressure of the gas inside it; this feature prevented the condensation of moisture in the entire system.

Temperatures in the range 200–300 K could be obtained by flowing in cold vapors of nitrogen gas [3, 4]; temperatures above 300 K can obviously be obtained by flowing heated nitrogen gas. After an experiment was completed the temperature inside the small Dewar flask could be quickly brought down to 77 K by filling it with small quantities of liquid nitrogen. The system has proven to be very efficient.

3. Mutual inductance coil

The a.c. inductance method basically measures the change in mutual inductance between two secondary coils S_1 and S_2 (wound in opposition) and a primary coil P wound on top [1, 2]. The mutual inductance was made close to zero to obtain high sensitivity. The coil bobbin was made of thin silica glass tubes with plastic (polyvinyl chloride) disks glued at the ends. The inside diameter of the bobbin for the secondary coil was 0.7 cm and for the primary was 1.1 cm. The lengths of the primary and both of the secondary coils were 7.35 cm and 2.3 cm respectively. Several small holes were drilled in the end disks to allow a free flow of cold nitrogen vapor. The coils were wound almost perfectly by using 40 standard wire gauge insulated copper wire with $n_P = 238$ turns cm^{-1} and $n_S = 1043$ turns cm^{-1} for the primary and secondary coils. The layers of the secondary and primary coils were coated with GE varnish 7031, not only for good insulation but also to minimize any significant changes in the coil geometry with temperature.

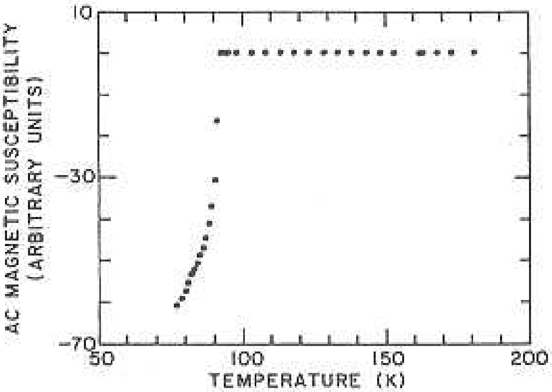

Fig. 2. A.c. susceptibility of the $YBa_2Cu_3O_{7-\delta}$ superconducting compound.

A typical result for a.c. susceptibility of $YBa_2Cu_3O_{7-\delta}$ is shown in Fig. 2. T_c was found to be 93 K for this sample which is in agreement with the resistivity measurement. The calibration of the coil, a brief description of the inductance bridge calibration procedures for absolute measurements of susceptibility etc. will be published separately.

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