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Applications of High Transition Temperature Superconductors
at the Savannah River Site
(Annual Progress Report)

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Introduction

The second year of the research program has involved further evaluation of the applications of high transition temperature superconducting devices at the Savannah River Site and the fabrication of magnetic shields from high T_c materials that might be of use in programs at the site. In cooperation with AVX Corporation a satisfactory magnetic shield has been developed and the results of tests on it are included in this report. In addition, the results have been reported at two scientific meetings by the undergraduate students involved in the project. The improved version of a nitrogen temperature SQUID for applications such as those that might be encountered at the site has suffered some set backs in development. It has been possible to begin the initial studies with a high T_c device but some of the more detailed analysis has been restricted. The new device was received this month and will have an important impact on the outcome of the project by allowing for a more complete evaluation of a device that can be used in an industrial situation. The goals of the second year of the project are listed below and are addressed in this report.

Second Year Goals

1. Acquisition of research grade SQUID
2. Fabrication and Test of Magnetic Shields
3. Single Crystal Growth
4. Thermal Conductivity Studies on Single Crystal Samples with or without radiation exposure

Accomplishment of Goals

Acquisition of the Research SQUID System

A SQUID system manufactured by Conductus, Inc. was used for the initial characterization studies. A recently acquired research device is currently undergoing "beta" testing at South Carolina State. In this system the SQUID sensor is a ring of high transition temperature superconductor made of yttrium barium copper oxide ($\text{Y}_1\text{Ba}_2\text{Cu}_3\text{O}_7$, sometimes called YBCO or "1-2-3"). The present electronics system for this SQUID is designed for a device operating at liquid helium temperatures and therefore does not have the optimum $1/f$ noise circuitry that will be available within the next month. The present system is limited by these electronics to approximately 5 femtotesla. This is sufficient for the shielding measurements on the tubes but the shielding of the SQUID sensor must be improved before the magnetic properties of the single crystals can be studied in detail.

The initial evaluations of the SQUID performance in laboratory situations have established base lines for use of the systems. If the SQUID is configured as a second order gradiometer, all contributions (noise) from equipment and materials in the laboratory can be eliminated. There may be some complications when the more sensitive device is tested in field situations.

Fabrication of the Magnetic Shields by AVX

In conjunction with AVX Corporation, the initial devices were fabricated in the form of tubes of YBCO, nominally 16 cm long with an outer diameter of 1 cm. In this configuration the samples are ideal as electromagnetic shields for detectors. These tubes have transition temperatures above that of liquid nitrogen which means they are satisfactory for any detector that must be cooled to 77K or below.

With the original dimensions it was not possible to use the SQUID to determine the shielding provided by the tubes. In order to accomodate the SQUID and the sensor, AVX has prepared tubes with an

inner diameter of 22 mm with a wall thickness of 3 mm. It is possible to insert the SQUID directly into the tube and measure the shielding properties. The tubes were prepared both with and without a final annealing step in the process. As indicated in Figures 1 and 2, the transition temperature for both processes was above liquid nitrogen temperature even with the tubes in applied magnetic fields. Figure 3 is a diagram of the experimental setup used to study the shields. The DC perpendicular magnetic field was applied by a 4" electromagnetic located outside the cryostat. Parallel constant and time-varying fields were applied using a coil located in the cryostat with the axis of the tube along the axis of the coil. The results of these experiments, the extent of DC and AC field exclusion, are displayed in Figure 4. These results were reported at the U.S. Department of Energy's second Annual Historically Black Colleges and Universities/Private Sector/Energy Research and Development Technology Transfer Symposium in Birmingham, Alabama, April 1994. The earlier results of the shield study were reported at a National Science Foundation Undergraduate Research Meeting in Washington, D.C., October 1993.

Single Crystal Growth

Considerable progress has been made in this phase of the project. The studies are conducted on fully characterized monocrystalline samples of the high temperature superconductors $\text{Bi}_2\text{Sr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_x$ where $n = 1, 2, 3$, the "BiSCCO" compounds. These crystals were initially being grown and characterized at Clemson University, but the facilities for sample preparation at South Carolina State are now operational and samples are being grown at both universities. These samples are extremely difficult to work with due to their size, a typical sample will have a mass of less than 50 micrograms. During the course of the project it has become evident that additional information is needed regarding the growth processes for these single crystals. There are several parameters effecting the growth rate, size, and composition of the crystals. The work at SCSU has concentrated on the effects of slight amounts of dopants, especially aluminum, on the crystals. Figure 5 shows several areas on a substrate where crystals (whiskers) are

•Figure 1

• TRIAL I

○ TRIAL II

RESISTANCE VS. TEMPERATURE
FOR 79II BLANK TUBE
WITH APPLIED PERPENDICULAR MAGNETIC FIELD
(2-8-94)

FIELD = 50.5 V = 847 GAUSS

Figure 2

•

Figure 3

EXTENT OF D.C. AND A.C. FIELD EXCLUSION

Figure 5

growing. From Figure 6 it is evident from the composition of one of these whiskers that the aluminum in the substrate is either incorporated into the whisker or concentrated in the region at the base of the whisker. The mechanism of whisker growth and the effect of the dopant is not yet understood. Further studies are planned to investigate these areas.

Thermal Conductivity Studies on Single Crystal Samples

The design and fabrication of the components for the cryostat to measure the thermal conductivity of the samples have been completed. The initial measurements will be conducted on carefully characterized samples of 2213 phase material. The questions concerning the growth of the samples have delayed any significant measurements. It is planned that these measurements will be started by the first of June.

Major Accomplishment

The fabrication and analysis of a successful magnetic shield was one of the major goals of the program and, although there is still some work to be done, the results are satisfactory.

Problems Encountered

1. The electronics for the research SQUID need to be modified to reduce the noise factor at liquid nitrogen temperature.
2. Problems with understanding the growth processes involved with the single crystals have led to delays in studying the thermal conductivity of these samples.

Figure 6

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6/30/94

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