NASA/TM-1998-208717

Assembly and Integration of Superconductive Measurement Circuits for a Spaceflight Experiment

Stephanie A. Wise, Purnell Hopson, Jr., and Johnny C. Mau
Langley Research Center, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

September 1998

n the following:

for AeroSpace Information (CASI)
l Drive
21076-1320
)0

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161-2171
(703) 487-4650

Available fro

NASA Cente
7121 Standar
Hanover, MI
(301) 621-03

ABSTRACT

Hybrid microelectronics containing both conventional electronic components and high-temperature superconductive films have been designed, fabricated, and tested. The devices operate from room temperature to 75K and perform d.c. four-probe resistance measurements on six superconductive specimens resident on each circuit. Four of these hybrid circuits were incorporated into the Materials In Devices As Superconductors (MIDAS) spaceflight experiment and evaluated over a 90-day period on the Mir space station. Prior to launch, comprehensive testing of the flight circuits was performed to determine the effects of thermal cycling, vibration loads, and long-term operation on circuit performance. This report describes the fabrication and assembly procedures used to produce the hybrid circuits, the techniques used to integrate the circuits into the MIDAS hardware system, and the results of pre-flight evaluations which verified circuit functionality.

INTRODUCTION

High-temperature superconductors have been proposed for use in several spacecraft systems due to their unique electrical, magnetic, and thermal properties (refs. 1-3). In each instance, the replacement of existing materials with high-temperature superconductors would either significantly increase the performance capability of the spacecraft instrument or substantially reduce the payload size and weight, thereby reducing launch costs. Furthermore, several spacecraft already employ cryogenic refrigeration systems, providing an operational environment well-suited for the use of superconductive devices.

Thick films of high-temperature superconductive materials have been fabricated using conventional manufacturing processes such as screen printing. These films have been deposited onto polycrystalline ceramic substrates such as Al_2O_3 and ZrO_2 and have been found to exhibit critical current density, J_c, values up to 100 A/cm^2 (refs. 4-8). Although the J_c properties of these films are lower than those of preferentially-oriented thin films of the same materials, the thick films do exhibit sufficient performance characteristics for many aerospace applications (refs. 1 and 3).

Thin film superconductors have been produced using several vacuum deposition processes including sputtering (ref. 9), laser ablation (ref. 10), and vapor deposition (ref. 11). These materials are typically deposited onto single crystal substrates such as (100) $SrTiO_3$ and (100) $LaAlO_3$, which have lattice constants similar to that of $YBa_2Cu_3O_{7-x}$. The similarity of the lattice constants allows the growth of superconductive films with the c-axis perpendicular to the substrate. Because of the preferred orientation of the films, these materials have been reported to exhibit J_c values in excess of 10^6 A/cm^2 (ref. 12).

To demonstrate the feasibility of using high-temperature superconductors in spacecraft systems, films of the $YBa_2Cu_3O_{7-x}$ material were integrated with conventional circuitry to produce active microelectronics packages. These hybrid circuits were designed to operate at cryogenic temperatures and enable the performance properties of six superconductive films incorporated into each circuit to be determined. Although specifically designed to perform electrical measurements, the processes and procedures used to fabricate and assemble the circuits could be applied to produce devices for many spacecraft applications.

To alleviate concerns regarding the survivability of superconductive devices under launch vibrations and their long-term performance in a microgravity environment, four hybrid circuits were integrated into the Materials In Devices As Superconductors (MIDAS) spaceflight experiment and tested on orbit. The MIDAS experiment was launched on Space Transportation System mission 79 (STS-79) in September of 1996, transferred to the Priroda module of the Mir space station, and operated for 90 days prior to its return to Earth on STS-81 in January of 1997. This report describes the fabrication and assembly procedures used to produce the hybrid circuits for the MIDAS experiment, the techniques used to integrate the circuits with the MIDAS hardware system, and the results of pre-flight evaluations of circuit performance.

EXPERIMENTAL PROCEDURE

Hybrid Circuit Assembly

The $YBa_2Cu_3O_{7-x}$ superconductive material used for thick film deposition was synthesized by the solid-state reaction of Y_2O_3, $BaCO_3$, and CuO. After synthesis, the powder was ball-milled in acetone to produce an average particle size of 12 µm. A thick-film printing paste was prepared by blending the $YBa_2Cu_3O_{7-x}$ powder with an organic carrier vehicle using a solids content of 75 per cent by weight. The paste was then screen printed onto polycrystalline yttria-stabilized zirconia (YSZ) substrates using a 200-mesh screen patterned by photolithography. The printed films were dried at 200°C and then sintered for 60 minutes at 950°C in air. During cooling, an oxygen atmosphere was introduced into the furnace, and the films were annealed at 600°C for six hours to allow the oxygen content of the films to equilibrate. The details regarding the sintering of the $YBa_2Cu_3O_{7-x}$ superconductive films have been reported elsewhere (ref. 7).

For each hybrid circuit, six superconductive films of dimensions 1.02 x 0.10 cm were deposited onto a 2.54- x 2.54- x 0.10-cm YSZ substrate and sintered as previously described. Gold conductive paths for connection to the measurement circuitry and four silver electrical contacts per superconductive film were then deposited using electron-beam evaporation. A photograph showing a typical YSZ substrate containing six superconductive films and a substrate with both superconductive films and gold conductive paths is provided in Figure 1.

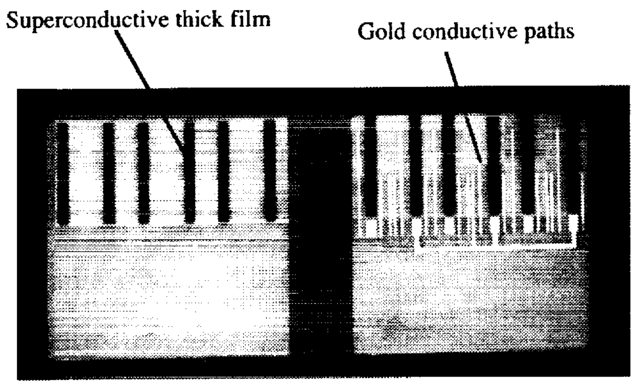


Figure 1. Photograph showing a typical YSZ substrate containing six superconductive films (left) and a substrate with both superconductive films and gold conductive paths (right). Substrate dimensions are 2.54 x 2.54 cm.

Next, a measurement circuit was designed to perform d.c. four-probe resistance measurements on the superconductive films. The measurement circuit was fabricated on a 2.54- x 1.27- x 0.10-cm alumina substrate using conventional multilayer thick-film processing. Each circuit contained three surface-mounted electronic components, namely two 8x2 multiplexers and one amplifier. One of the multiplexers was used to direct applied current from an external current source to the outer two contacts of each superconductive film under test, and the other multiplexer was used to direct the voltage signals generated across the inner two contacts to the external data storage system. Prior to leaving the hybrid circuit, the generated voltages were amplified by a factor of ten using the on-board amplifier. Additionally, a Platinum Resistance Thermometer (PRT) temperature sensor was located near the active components to monitor the extent of self-heating of the electronics during operation.

The measurement circuit was prepared using eight printed layers, including two gold conductive layers, two gold via fills, three dielectric layers, and one solderable platinum-gold layer. The gold conductive layers provided the necessary conductive paths for directing current and voltage signals to and from the superconductive films. The dielectric layers were used to separate the conductive layers with via fills appropriately connecting electrical paths, thus producing a multilayer circuit with a reduced surface area. Finally, platinum-gold was used to produce solderable connections for off-circuit wiring. Figure 2 shows the circuit after printing and firing of (a) the initial gold layer, (b) two dielectric layers, (c) the associated via fills, (d) the second conductive layer, (e) the platinum-gold layer, and (f) the final dielectric layer.

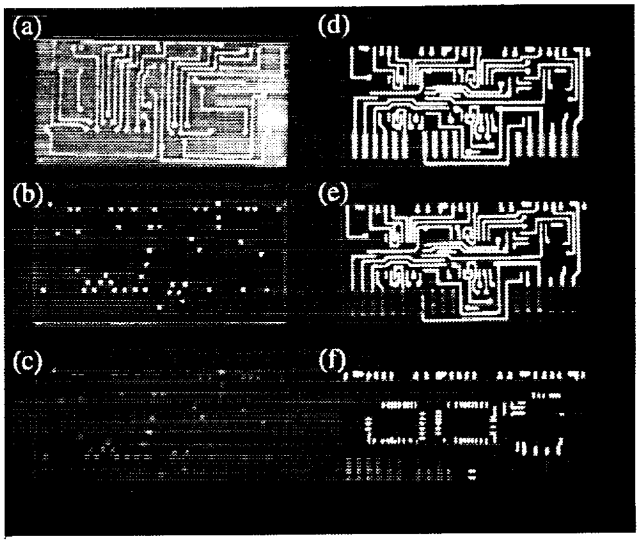


Figure 2. Measurement circuit after printing and firing of (a) the initial gold layer, (b) two dielectric layers, (c) the associated via fills, (d) the second conductive layer, (e) the platinum-gold layer, and (f) the final dielectric layer. Each substrate has dimensions of 2.54 x 1.27 cm.

The surface-mounted components were attached to the measurement circuit, wire bonded, and glob-topped. Figure 3 shows a typical circuit after integration of the electronic components. Three additional PRT temperature sensors were then integrated in the same manner near the superconductive film specimens on the YSZ substrate to permit localized temperature measurement of the films during operation. To complete the hybrid circuit, the alumina substrate was adhesively bonded to the YSZ substrate, and the gold conductive paths to the superconductive films were electrically connected with wire bonds. For these connections, redundant wire bonds were used to ensure reliability. Figure 4 shows a typical, fully-integrated superconductive circuit. A magnified image showing the gold wire bonds connecting the conductive paths from the YSZ and alumina substrates is provided in Figure 5.

Circuit Operation

During operation of the hybrid circuit, the resistance of each superconductive film was measured at temperatures

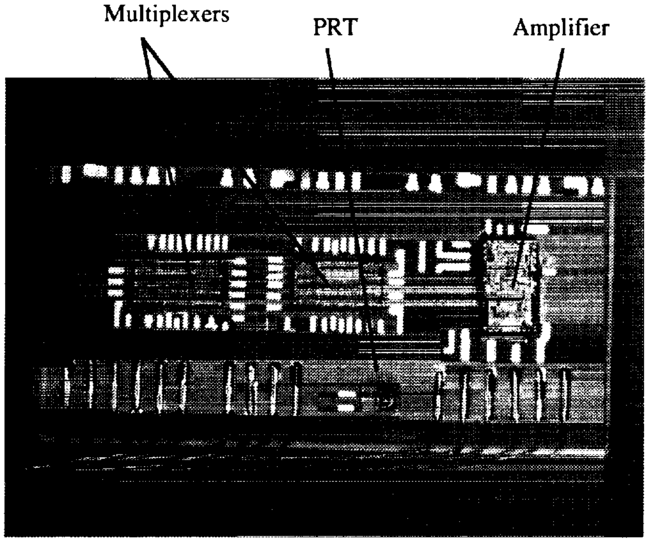


Figure 3. Typical measurement circuit after attachment of electronic components and off-circuit wiring, before wire bonding and glob-topping of the electronic components.

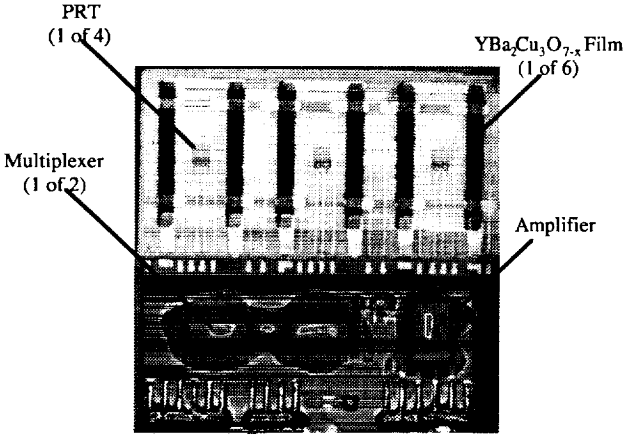


Figure 4. Fully-integrated hybrid circuit containing six superconductive thick films. Dimensions are 2.54 x 2.54 cm.

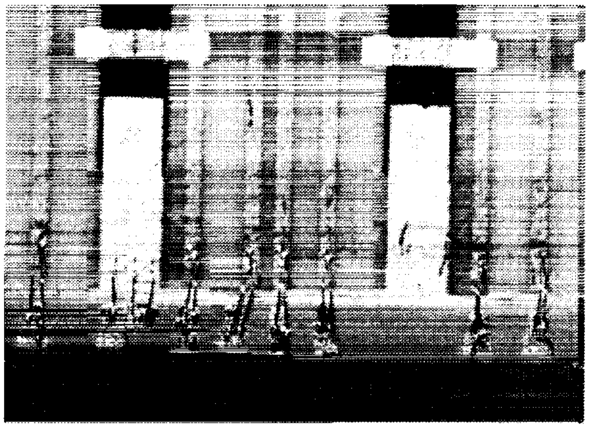


Figure 5. Magnified image of the redundant gold wire bonds connecting the alumina and YSZ substrates.

ranging from 75 to 250K using an applied current of 0.1 mA. From these data, the temperature at which the films became superconductive, or the critical transition temperature, T_c, was determined. Additionally, the critical current density, J_c, of each specimen was determined at periodic intervals at a constant temperature of 75K. The J_c was measured by applying currents from 0 to 15.9 mA to each superconductive film using a current increment of 0.1 mA. For both measurements, the films were considered superconductive when the voltage generated across the inner two electrical contacts was less than 0.01 mV.

Integration and Testing

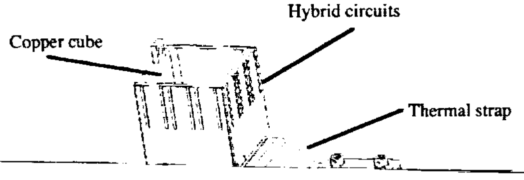
Four measurement circuits were selected for spaceflight including circuits containing both thin- and thick-film superconductive specimens. Two circuits contained $YBa_2Cu_3O_{7-x}$ thick films produced by NASA Langley Research Center (LaRC) in the manner previously described. One circuit contained specimens supplied by the Moscow Institute of Electronic Equipment (MIEE), including three $YBa_2Cu_3O_{7-x}$ thin films and three $Bi_2Sr_2Ca_2Cu_3O_x$ thin films produced by sputter deposition. The final circuit contained six $YBa_2Cu_3O_{7-x}$ thin films supplied by Eaton Corporation in cooperation with Los Alamos National Laboratory (LANL). The Eaton/LANL films were deposited using an ion-beam-assisted deposition (IBAD) technique.

The four circuits were bonded to the primary surfaces of a hollow copper cube and mounted inside a vacuum chamber for integration into the MIDAS experiment. A cryocooler was used to control the circuit temperature, and the cold finger extended into the vacuum chamber. To avoid damaging the cryocooler cold finger during high vibration events such as launch, the cube was mounted on a titanium structural support and thermally connected to the cryocooler cold finger via a copper strap. Figure 6 shows a schematic of the cube and support structure used to integrate the hybrid circuits into the MIDAS hardware. The vacuum chamber was evacuated prior to spaceflight, and an ion pump was used to maintain the necessary vacuum level for optimum cryocooler performance. To reduce water vapor and other contaminants and to promote a low vacuum pressure, the entire system was heated at temperatures up to 75°C for 72 hours while evacuating the chamber.

Once the vacuum chamber was evacuated, a series of vibration, thermal, and electrical tests were performed to qualify the MIDAS hardware for spaceflight. Vibration tests were performed to ensure that the loads experienced during launch would not damage either the circuits or the system hardware. Thermal tests were performed to verify that variations in the ambient spacecraft temperature would not affect the ability of the hardware to appropriately control the circuit temperature. Finally, electrical tests were conducted to demonstrate that the cooling capacity of the cryocooler was not compromised if the input voltage to

vibrational loads to 16g, and near-continuous

ground under flight-like



circuit to be fabricated on a single crystal.

Additionally, both the superconductive films and the measurement circuitry were separately evaluated prior to combining the substrates to produce the hybrid devices. The adhesive used to bond the substrates together could not be

tests indicate that durable superconductive devices can be successfully designed, fabricated, and integrated into complex hardware systems such as those required for spacecraft instruments.

REFERENCES

1. Romanofsky, Robert R.; and Sokoloski, Marty M.: Prospects and Progress of High Tc Superconductivity for Space Applications. *Advances in Materials Science and Applications of High Temperature Superconductors*, L.H. Bennett, Y. Flom, and K. Moorjani, eds., NASA-CP3100, 1991, pp. 477-486.

2. Brasunas, J.; Lakew, B.; and Lee, C.: High-Temperature-Superconducting Magnetic Susceptibility Bolometer. *J.Appl.Phys.*, vol. 71, no. 7, 1992, pp. 3639-3641.

3. Hooker, M.W.; Wise, S.A.; Selim, R.; Caton, R.; and Buoncristiani, A.M.: High-Tc Leads for Remote Sensing Applications. *Cryogenics*, vol. 34, 1994, pp. 119-122.

4. Tabuchi, Junji; and Utsumi, Kazuaki: Preparation of Y-Ba-Cu-O Thick Films with Preferred C-Axis Orientation by a Screen Printing Method. *Appl.Phys.Lett.*, vol. 53, no. 7, 1988, pp. 606-608.

5. Maeoka, Toshiaki; Okada, Hideya; Nagamori, Yoshitaka; Hirosue, Chiyoko; Kondo, Yoshimi; Yano, Shinobu; Inada, Hisako; Okamoto, Susumu; and Hayashi, Kunihiko: Fabrication of Screen-Printed High-Tc Superconducting Oxide Thick Films on YSZ Substrates. *International Symposium on New Developments in Applied Superconductivity*, Y. Murakami, ed., New Jersey: World Scientific, 1989, pp. 123-128.

6. Yoshiara, Kiichi; Kagata, Kenji; Hiroki, Tsutomo; and Nakahigashi, Kiyotaka: Multi-Layered Superconducting $YBa_2Cu_3O_y$ Thick Films on Y_2BaCuO_5 Substrate. *Advances in Superconductivity: Proceedings of the 1st International Symposium on Superconductivity*, K. Kitazawa and T. Ishiguro, eds., Springer-Verlag, 1989, pp. 319-324.

7. Hooker, Matthew W.; Wise, Stephanie A.; Hopson, Purnell, Jr.; Kruse, Nancy M.H.; and High, James W.: Optimization of $YBa_2Cu_3O_{7-x}$ Thick Films on Yttria-Stabilized Zirconia Substrates. *IEEE Trans. on Applied Superconductivity* , vol. 5, no. 2, 1995, pp. 1936-1938.

8. Hooker, Matthew W.: Preparation and Properties of High-T_c Bi-Pb-Sr-Ca-Cu-O Thick Film Superconductors on YSZ Substrates. NASA CR-4761, 1996.

9. Li, Y.H.; Leach, C.; Yupu, L.; Kilner, J.A.; Lacey, D.; Caplin, A.D.; and Somekh, R.E.: Microstructure and Electrical Properties of YBCO Thin Films.

Technique. *Jap.J.Appl.Phys.*, Part 1, vol. 33, no. 7A, 1994, pp. 4058-4065.

11. Desisto, W.J.; Henry, R.L.; Newman, H.S.; Osofsky, M.S.; Cestone, V.C.: Metalorganic Chemical Vapor Deposition of $YBa_2Cu_3O_{7-x}$ on $SrTiO_3$ and $LaAlO_3$. *J.Cryst.Growth*, vol. 128, nos.1-4, 1993, pp. 777-780.

12. Sheahan, Thomas P: *Introduction to High-Temperature Superconductivity*, New York: Plenum Press, 1994.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
September 1998

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Assembly and Integration of Superconductive Measurement Circuits for a Spaceflight Experiment

5. FUNDING NUMBERS
WU 956-17-00-01

6. AUTHOR(S)
Stephanie A. Wise, Purnell Hopson, Jr., and Johnny C. Mau

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-17775

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/TM-1998-208717

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category 76 Distribution: Standard
Availability: NASA CASI (301) 621-0390

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Hybrid microelectronics containing both conventional electronic components and high-temperature superconductive films have been designed, fabricated, and tested. The devices operate from room temperature to 75K and perform d.c. four-probe resistance measurements on six superconductive specimens resident on each circuit. Four of these hybrid circuits were incorporated into the Materials In Devices As Superconductors (MIDAS) spaceflight experiment and evaluated over a 90-day period on the Mir space station. Prior to launch, comprehensive testing of the flight circuits was performed to determine the effects of thermal cycling, vibration loads, and long-term operation on circuit performance. This report describes the fabrication and assembly procedures used to produce the hybrid circuits, the techniques used to integrate the circuits into the MIDAS hardware system, and the results of pre-flight evaluations which verified circuit functionality.

14. SUBJECT TERMS
Microelectronics, hybrids, spaceflight, superconductive circuitry, thick films, high-temperature superconductors

15. NUMBER OF PAGES
11

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z-39-18
298-102