Design and performance of a space based high temperature superconductivity experiment

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We describe an experiment aimed at testing the long term survivability of high temperature superconductors (HTSCs) in space. The experiment consists of a thin YBCO film integrated with a cryocooler. The experiment was launched into orbit aboard the TECHSAT II satellite in July 1998. Since then, the superconducting film was tested periodically, and has shown little or no degradation of its properties. Our experiment should provide the basic long term survivability data needed for advanced applications of HTSC in space, in the field of satellite communications. © *1999 American Institute of Physics.* [S0003-6951(99)03335-5]

One of the most obvious applications of high temperature superconductors (HTSCs) is in the field of satellite communications. Given the large demand for communication satellites aimed at providing global coverage of cellular communications, internet, etc., it is very important to develop more efficient devices which can provide low loss, narrow-band filters needed to minimize interference between the various communication channels without the need to pay too much in weight and volume. The first program to demonstrate operation of HTSC components in space was initiated by Nisenoff and co-workers at NRL as early as 1988, within the framework of the high temperature superconductivity space experiment (HTSSE). This program was divided into two phases, the first of which, HTSSE-I, was supposed to check the survivability of relatively simple HTS devices in space.[1] The second phase, HTSSE-II, was designed to test actual subsystems and cryocoolers.[2] The launch of the first phase of this experiment was unsuccessful, and its successor, HTSSE-II, was launched in February 1999. The experiments are supposed to come online later this year. Thus, the fundamental question regarding future applications of HTS to satellite communications, that of long term survivability of HTSC in space, remains to be answered. Specifically, one has to determine how the material behaves under prolonged exposure to radiation, vacuum, and repeated thermal cycling combined. Our experiment attempts to answer this question as well as that relating to the combination of a HTS device with a cryocooler.

The scope of the present experiment was defined to a large extent by limitations imposed by the satellite itself. TECHSAT II is a microsatellite designed and built at the Technion Space Institute specifically for testing new technologies.[3] It has the shape of a cube, 45 cm on a side, and weighs 48 kg. A significant part of its internal volume is taken by the stabilizing hardware, namely a flywheel, and by the electronics crate. However, the largest limitation to the design of on-board experiments comes from the power budget. The power source of the satellite are solar cells, which coat four of the six faces of the cube. There are no external solar panels. The fifth face, pointing away from the earth is the cold panel. Our experiment is mounted on that panel. The last panel, facing the earth, houses the communication antenna, a video camera, and some of the other experiments. Because the surface area covered by the solar panels is small, the total power generated is only 25 W. About 8 W are dedicated to housekeeping, i.e., computer control, telemetry, and stabilizers. This leaves 17 W for all experiments on board, which means that these cannot be operated simultaneously.

The cryocooler used in this experiment, K-508,[4] was chosen mainly for its low power consumption of 12 W. It has a nominal cooling power of 0.5 W at 77 K. The limited power budget of the satellite needs to be shared between all the experiments on board. Consequently, our experiment can be operated only for a short period of time, typically less than 1 h. The cryocooler must therefore cool down below T_c within this time interval. This in turn restricts the thermal mass of the experiment. In our case, the total mass attached to the cold finger was about 5 g, which resulted in a cooldown time of approximately 15 min during terrestrial testing.

The superconducting device itself consists of a 300 nm thick epitaxial *c*-axis oriented YBCO thin film. The film was grown by laser ablation deposition on a $10\times10\,\mathrm{mm}^2$ (100) MgO substrate, and patterned into a microbridge 40 nm wide and 500 nm long. The contact pads were coated by Au, also deposited by laser ablation and annealed at 600 °C in an O_2 atmosphere for 30 min. Initially, the device had a T_c of 90 K, and J_c of $10^6\,\mathrm{A/cm}^2$ at 84 K. A schematic view of the experiment is shown in the inset of Fig. 1. The device is thermally attached to an Al block containing a diode thermometer using Ag loaded epoxy. The Al block is glued to the surface of the cold finger using the same method. The whole assembly was sealed within a housing machined from 1266 Stycast epoxy. Epoxy was chosen instead of a metal enclosure to reduce the thermal mass, and facilitate a hermetically sealed enclosure. It was important to keep the film hermeti-

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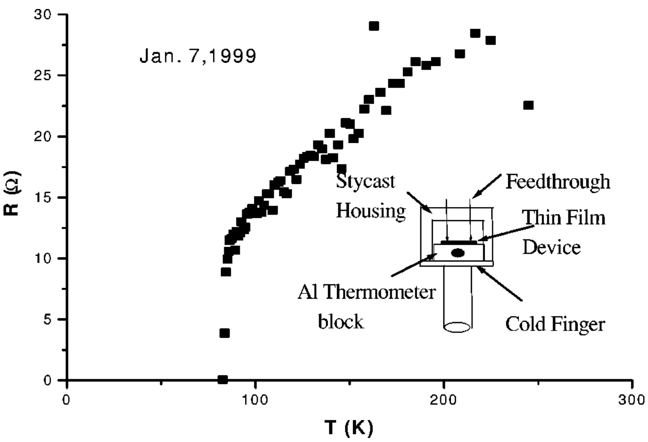

FIG. 1. A typical resistance temperature of the device as measured in orbit. The inset shows a schematic view of the experiment.

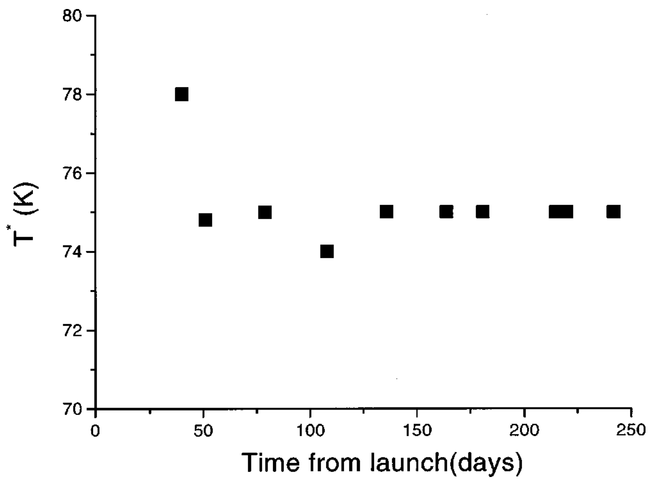

FIG. 3. The dependence of T^* on time since launch.

cally sealed to protect it from atmospheric humidity during the storage period prior to launch. The cold finger was surrounded by a single layer radiation shield made from Al.

To mimic the ambient conditions in orbit, the cryocooler with the device was operated inside a vacuum chamber under ambient pressures between 10^{-4} and 10^{-6} Torr. The heat produced by the cooler was ejected into a thermal sink at 300 K, which is the typical in orbit temperature of the cold panel of the satellite. In addition, the experiment was tested under 50 g shocks along the three axes. Delivery for integration took place in May 1997. After integration, the whole satellite was further subjected to standard acceptance tests. The launch itself took place over a year later, in July 1998.

The experiment is operated in orbit using a dedicated electronic package consisting of a swept current source and a voltmeter in a four terminal arrangement. An experimental run begins by first turning on the cooler. Then, during cooldown, a linear current ramp is initiated once every 30 s, for a maximum duration of 3 s, with a maximal current of 100 mA. The ramp is interrupted once the voltage across a microbridge reaches a preset value. From the time it takes to reach this interrupt, we calculate the resistance above T_c, and I_c below T_c. An I_c of 100 mA corresponds to $J_c \sim 10^6$ A/cm^2. All the parameters relevant to the operation of the experiment are programmable via telemetry from the ground station. For each temperature during cooldown, the data returned from the experiment includes the total time elapsed since the experiment was turned on, the temperature, and the duration of the current ramp. The experiment is terminated after the total allocated time has elapsed. Usually, this total time is 20–30 min. Initially, the data are stored by the on-board computer, and subsequently transmitted to the ground station while the satellite passes overhead. Communication with the satellite takes place twice a day, for 10 min each time.

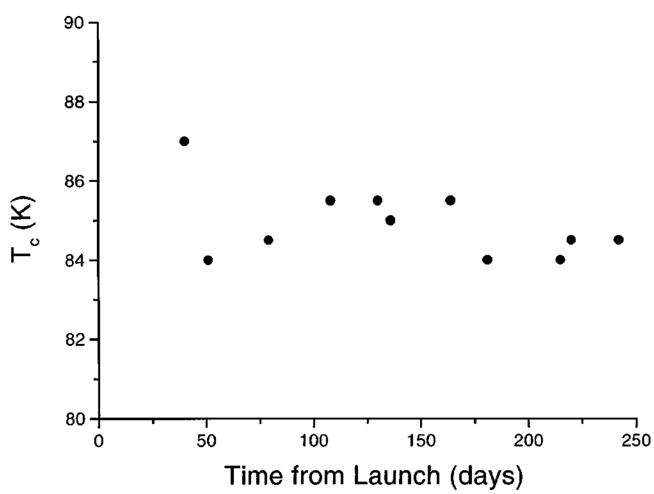

FIG. 2. The dependence of T_c on time since launch.

In Fig. 2, we show the values of T_c determined in orbit as a function of time since the launch. Figure 3 shows T^*, the temperature at which I_c of the device reaches 100 mA, the maximum current supplied by the current source. First, both T_c and T^* have deteriorated during the year long storage period before launch. Most probably, this resulted from an imperfect sealing of the device from the atmosphere. Additionally, there is a decrease in both quantities by about 2 K between the values recorded during the first run and the ones that follow. However, after that the value of T_c recorded in orbit remains constant within the scatter. The behavior of T^* is also similar. Since we are interested in failure analysis, it is important to reiterate that the conditions under which our experiment operates include repeated thermal cycling. These conditions are more stringent than required for a device which is operated continuously, such as a real communication circuit.

Let us turn now to the behavior of the cryocooler. In Fig. 4 we show T_{20}, the temperature recorded during each run after 20 min of operation. At first, there is a systematic increase of that temperature with time, while after several months T_{20} seems to saturate. This can mean one of two things: either the cooling power of the cryocooler is diminishing with time, or else the thermal contact between the thermometer–film block and the cold finger is deteriorating. One hint as to what is actually happening comes from the differences of T_c and I_c recorded between the first and all subsequent runs in orbit. The step-like decrease alludes to some loss of thermal contact resulting from thermal cycling of the device. The relatively significant decrease between the first and subsequent runs can be the result of a release of the stresses accumulated during launch. The other observation supporting this line of thought comes from the time depen-

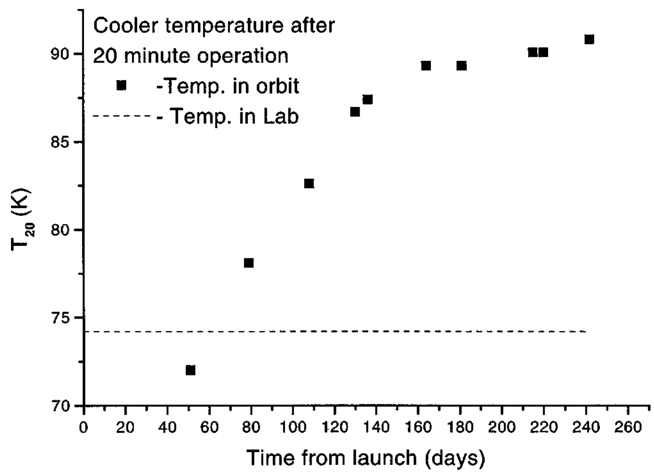

FIG. 4. Temperature reached by the experiment after 20 min of cooler operation, plotted vs time in orbit. The dashed line refers to the value measured during terrestrial testing.

dence of T_{20}. Were the decrease in the cooling power a result of a leak in the cooler, the continuous loss of working gas would result in a steady increase of the temperature reached after 20 min. However, a decrease of thermal contact resulting from the mismatch of thermal expansion coefficients between the cold finger (stainless steel) and the thermometer assembly (Al) would cause a deterioration which is self-limiting, since even if the silver loaded glue cracks, there is still a pressure contact exerted due to the force of the 0–80 in. bolts holding the assembly together. The same argument applies to the thermal contact between the thermometer assembly and the film. We therefore conclude that the initial decrease of T_c and of T^* is most probably due to a worsening thermal contact. However, the fact that after that the parameters of the device remain steady shows that there is no fundamental problem with the survivability of HTSC thin films in space.

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[1] J. C. Ritter, M. Nisenoff, G. Price, and S. A. Wolf, IEEE Trans. Magn. **27**, 2533 (1991).
[2] T. G. Kawecki, G. A. Golba, G. E. Price, V. S. Rose, and W. J. Meyers, IEEE Trans. Microwave Theory Tech. **44**, 1198 (1996), and references therein.
[3] M. Guelman, I. Flohr, F. Ortenberg, M. Shachar, A. Shirayev, A. Volfovsky, and R. Waller, Proceedings of the Second International Academy of Astronautics Symposium on Small Satellites for Earth Observation, Berlin, April 1999; see also website http://techsat.internet-zahav.net/
[4] The K-508 cryocooler is made by RICOR, LTD., Kibbutz Ein-Harod Ihud 18960, Israel.