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Influence of long-term exposure of high-density direct current on the current carrying ability of 2G HTSC tapes based on the REBCO

Svetlana Veselova, Maxim Osipov, Alexandr Starikovskii, Irina Anishenko, Sergey Pokrovskii, Dmitriy Abin, Igor Rudnev

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe sh. 31, 115409 Moscow, Russia
SVVeselova@mephi.ru

Abstract. In this work, the phenomena of electromigration in samples of HTSC tapes of the 2nd generation was investigated. Samples of $\text{REBa}_2\text{Cu}_3\text{O}_{7-x}$ (REBCO, where RE is a rare earth element) were used in the form of a copper-plated tape. A superconducting bridge was preliminarily formed on the surface of the tape by the method of chemical etching (to decrease the total value of critical current). The sample was exposed by a direct current of $I = 0.9I_c$. The duration of exposure was up to 350 hours. The value of the current density in the area of the bridge was $J = 1.38 \times 10^{10} \text{ A/m}^2$. The measurements were carried out at liquid nitrogen temperature (77 K). The influence of the electric current flow on the value of the sample critical current is controlled at the selected time intervals. The experiment showed high stability of the tape under the specified conditions.

1. Introduction

During operation, high-temperature superconducting materials are exposed to high-density current loads in the superconducting state (up to 100 MA / cm^2). Superconductors are exposed to even greater supercritical pulsed current loads that occur in current-limiting and switching modes when the pulsed transport current significantly exceeds through superconducting elements of the critical current [1]. Long-term and high-density pulsed current loads can lead to deterioration of superconducting properties, namely the critical current and critical temperature values [2]. Testing elements of this system under conditions that simulate real operating conditions is one of the ways to determine the reliability of the system. Since the systems can work for years, it is necessary to apply accelerated testing. Usually, special techniques are used to estimate the real life-time of the material. The accelerating factor is increased current density (relative to operating conditions) in them. At the same time, there is evidence of the presence of electromigration (EM) processes in oxide cuprates in 2G HTS when the similar electric current density occurs [3,4]. Previously, studies were conducted at 200°C for 860 hours [3], which led to the degradation of YBCO thin films, but in real life, superconducting materials are used at cryogenic temperatures, which was not reflected in this work. Works on pulsed action on a superconducting bridge [4] at various temperatures (in the range up to 50K) and current densities up to $35 \times 10^{10} \text{ A/m}^2$ were also presented. As a result, it was found that there is a temperature range in which the superconducting critical current can exceed the electromigration current. This mode can be detrimental to devices. According to the impact result, all existing methods can be divided into two groups: destructive and non-destructive. However, there are no unambiguous methods that allow us to take into account the peculiarities of the EM process in each specific case. Due to the complexity of the physical processes that occur in HTS during EM tests, most of the methods belong to the first group, since it is much easier to control the moment of superconductor failure than to establish a connection between degradation processes and its failure [5-7]. Superconducting composites are not subject to problems of atomic migration mainly because there is no momentum transfer between charge carriers (Cooper pairs) and the atomic lattice. Besides, in superconductors with a low critical temperature, the critical current density J_c is significantly lower than the required current density J_{EM} to start the movement of atoms. However, the cuprate superconductors situation is different. On the one hand, the diffusion barrier of atoms may be



relatively weak for certain atoms, such as oxygen in REBCO (where RE is a rare earth element), hence reducing J_{EM} . On the other hand, these connections can withstand high current densities, sometimes exceeding J_{EM} . In [5], critical J_{EM} values of the order of 25-35 A/m² (for the temperature of liquid nitrogen) are presented. This process can cause permanent damage to the material at low temperatures. Until now, this phenomenon has been largely ignored. Therefore, the problem that is solved in this work, namely, the study of non-destructive high-performance and reliable methods for predicting the electromigration resistance, is relevant. An increase in the current density can lead to a local rise in temperature, and the result is the occurrence of quenches. This situation may affect the processes of oxygen diffusion in the cuprate and the deterioration of the sample properties [8]. This article is devoted to the study of the prolonged effect of the current density $J=1.38 \times 10^{10}$ A/m² on the HTSC of the 2nd generation REBCO-based films.

2. Experimental details

To carry out an experiment, we used the samples of the 2nd generation HTS tape SuperOx based on REBCO with dimensions of 40 mm×4 mm. The tape has a thickness of 0.2 microns. The substrate is made of Hastelloy C276 alloy with a thickness of 60 to 100 microns, buffer layers Al_2O_3 , Y_2O_3 , IBAD-MgO, LaMnO_3 with a total thickness of about 150 nm, and a superconducting layer CeO_2 : RE and REBCO of about 1 microns. It was deposited by PLD (pulsed laser deposition). The sample is coated with a layer of copper on both sides. The initial critical current of the tape was 155A. After creating a 1.5 mm wide bridge (figure 1) obtained by chemical etching, the critical current was 23A. This I_c value was less than expected one, that may be caused by excessive influence of chemical etchants not only on silver and copper but on HTS layer too. The layers of silver and copper were preserved on the bridge.

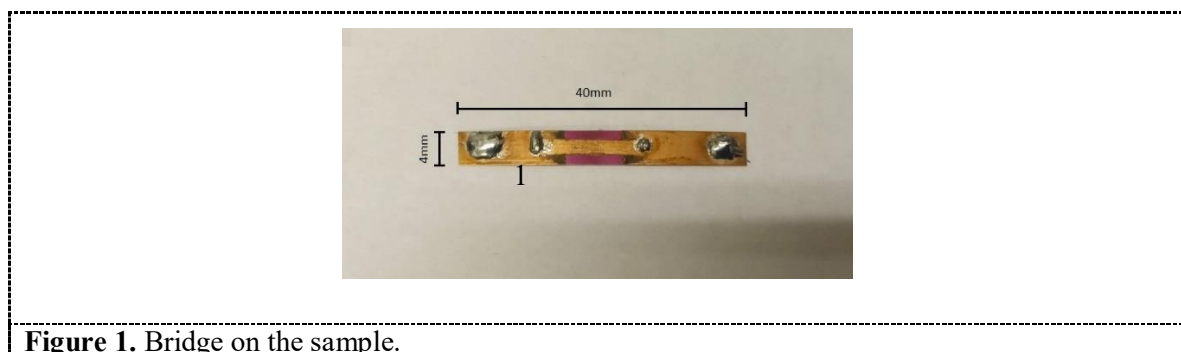


Figure 1. Bridge on the sample.

The photo of the experimental setup is shown in figure 2. In the Dewar vessel (1) an insert (2) was placed, on which the sample was attached so that it was always in liquid nitrogen. During the entire experiment (about 350 hours), the composite was not subjected to thawing and was at a cryogenic temperature. Next, the current leads (3) connected to the current source were connected to the insert (4).

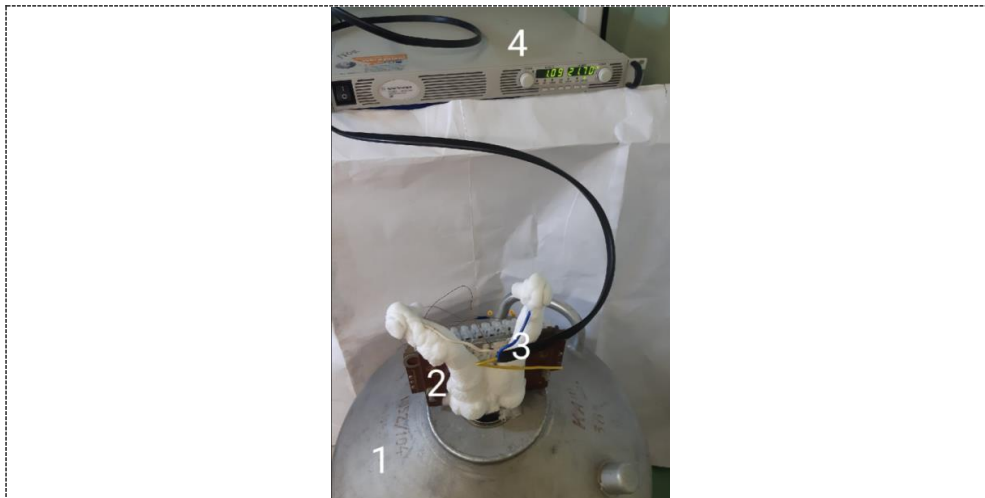


Figure 2. Experimental setup: 1 - Dewar vessel, 2 - sample insert, 3 - current leads, 4 - current source.

The volt-ampere characteristic was measured using a four-probe method. Since composite HTS tapes have an unsymmetrical structure relative to the substrate, potential and current wires were soldered on the superconductor side. The total time spent by superconducting tapes in liquid nitrogen was about 670 hours, of which under the influence of a current equal to $0.9I_c=20.7\text{A}$ and current density was $J=1.38\times 10^{10}\text{A/m}^2$ (1) more than 350 hours.

$$J=I/S=20.7/(1.5\times 10^{-9})=1.38\times 10^{10} [\text{A/m}^2], \quad (1)$$

where J - the current density on the sample, I - the current through the cross-section of the superconductor with area S . Control samples were used for the purity of the experiment. One of them was at room temperature and was not exposed to cryogenic temperatures and electric current. The second sample was attached to the insert and was in the same Dewar vessel as the test sample, but was not exposed to electric current. At this stage of research, the current-voltage characteristics (CVC) of the control samples were not removed, because the experimental setup continues to work (an important condition is the permanent location of the test tape at the temperature of liquid nitrogen).

3. Results and discussion

As a result of the experiment, it was found that the critical parameters of the superconducting composite were not subject to degradation after being in liquid nitrogen for 670 hours and under the influence of high current density for 350 hours. All values are within the margin of error. There is no tendency to deterioration in the properties of the parameters (figure 3). Figure 4 shows a dependence of the critical current values on the measurement time.

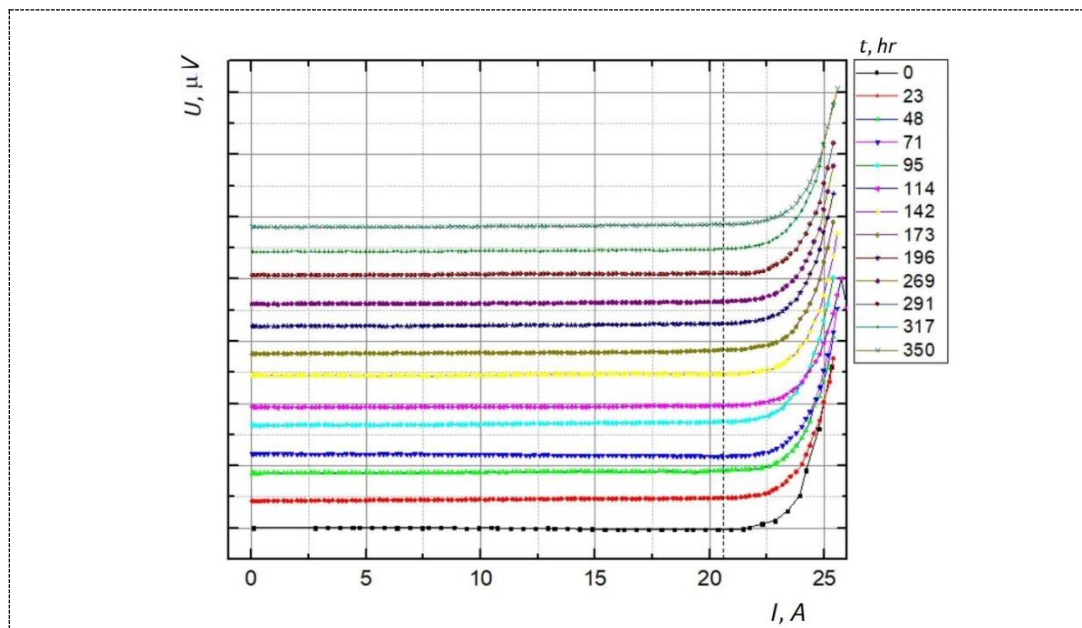


Figure 3. CVC at all stages of measurement. The current-voltage characteristics are shifted along the ordinate axis for easy analysis. The dotted line corresponds to the value of the transmitted current $I=20.7$ A.

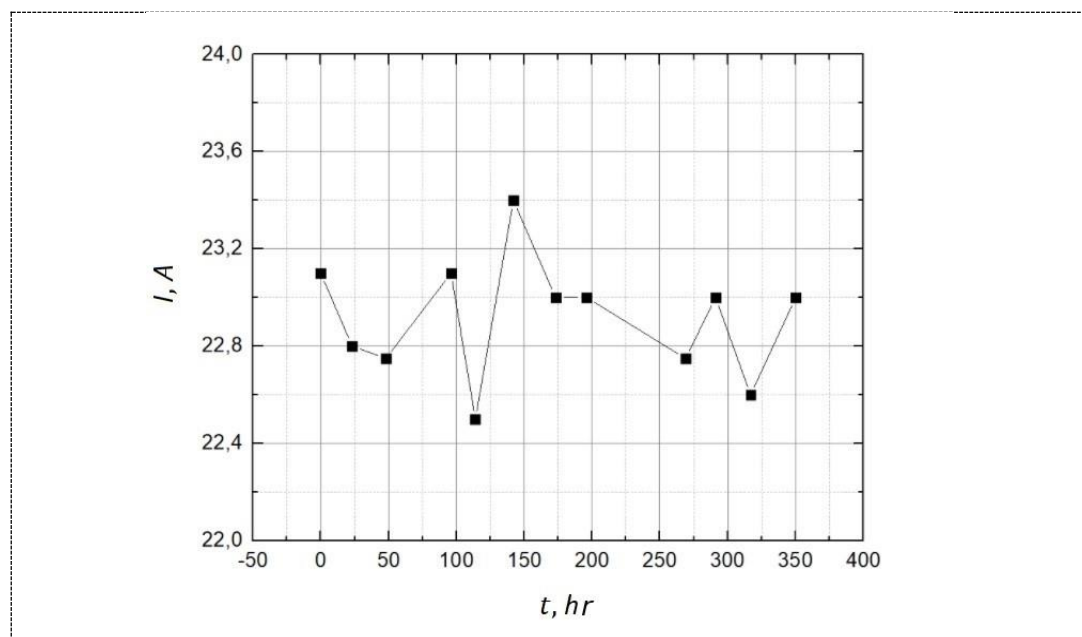


Figure 4. A plot of the dependence of the critical current on time.

Thus, it can be observed that the current density of electromigration was not achieved in this experiment. Some studies are showing that the process of oxygen diffusion in superconducting cuprates takes place if all the conditions are met [9,10].

4. Conclusions

In this work, the dependence of the critical current on time for HTS tapes of the 2nd generation is obtained. A bridge was formed on the surface of the tape by chemical etching, and the sample critical current was 23A. It was shown that for long-term (350 h) exposure to a current of $0.9I_c$, the critical current remains within (22.9 ± 0.5) A. The error of 2.2% is comparable to the random error of this experiment. Thus, it was shown that the current density $J = 1.38 \times 10^{10} \text{ A/m}^2$ is not sufficient for the occurrence of oxygen diffusion in the superconducting layer of a REBCO-based composite, even under prolonged exposure. When the experiment is completed, the sample will be examined by Hall microscopy and magneto-optic microscopy. And the results will be compared with two control samples. It is possible to conduct additional studies with higher current densities and pulse action.

Acknowledgments

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