ISSN 1063-7842, Technical Physics, 2009, Vol. 54, No. 2, pp. 235–238. © Pleiades Publishing, Ltd., 2009.
Original Russian Text © G.N. Mikhailova, E.I. Demikhov, V.P. Aksenov, L.Kh. Antonova, L.D. Iskhakova, L.N. Zherikhina, E.A. Kostrov, S.V. Lavrishchev, V.S. Mikhailov, A.V. Troitskii, A.M. Tskhovrebov, 2009, published in Zhurnal Tekhnicheskoĭ Fiziki, 2009, Vol. 79, No. 2, pp. 72–75.

Long-Term Stability of Bi(2223) and Dy(123) Superconducting Tapes in the Direct Current Circuit

G. N. Mikhailova[a], E. I. Demikhov[b], V. P. Aksenov[a], L. Kh. Antonova[a], L. D. Iskhakova[c], L. N. Zherikhina[b], E. A. Kostrov[b], S. V. Lavrishchev[c], V. S. Mikhailov[a], A. V. Troitskii[a], and A. M. Tskhovrebov[b]

[a] *Prokhorov General Physics Institute, Russian Academy of Sciences, ul. Vavilova 38, Moscow, 119991 Russia*
e-mail: at@kapella.gpi.ru
[b] *Lebedev Physical Institute, Russian Academy of Sciences, Leninskii pr. 53, Moscow, 119991 Russia*
[c] *Fiber Optics Research Center, Russian Academy of Sciences, Leninskii pr. 53, Moscow, 119991 Russia*

Received February 13, 2008

Abstract—The stability of critical parameters T_c and I_c of commercial high-temperature superconducting wires upon long-term passage of transport current (about $0.7I_c$) in liquid nitrogen (77 K) is studied. Voltage–current characteristics $U(I)$, as well as the critical current and critical temperature, are investigated for the case of Bi(2223) hermetic multifilament wires and Dy(123) superconducting tapes covered by a thin Ag layer. In the former case, a considerable decrease in the critical current (by ~30%) and swelling of the wires after passage of the current for 323 h are observed. The same is true for a reference sample, which does not experience the action of current and stays in liquid nitrogen for 700 h. The decrease in the critical current in the Bi(2223) sample is likely to be associated with penetration of a liquid coolant into the composite conductor: evaporating and expanding as a result of heating, it severely deforms the material. The Dy(123) sample grown epitaxially demonstrates high stability of the critical current after it has experienced the action of current for 400 h and been kept in liquid nitrogen for 1000 h.

PACS numbers: 74.72.-h

DOI: 10.1134/S1063784209020121

INTRODUCTION

Progress in fabrication of long high-temperature superconducting wires opens new opportunities for producing high-current multiconductor cables, transformers, motors, and current limiters for the power industry. However, the long-term reliability and long-term stability of the parameters of superconducting wires need further investigation.

The proximity of the superconducting, structural, and magnetic transitions in cuprate high-temperature *d*-pairing superconductors causes their crystallochemical instability, which shows up in the process of synthesis and also under the action of external factors. It was found that long-term passage of direct current through ceramic high-temperature superconductors (HTSCs) leads to local changes in the phase composition in the range between room temperature and liquid helium one, which was accounted for by the electrostimulated diffusion of heavy ions and oxygen. This effect was found in thick Y(123), Bi(2212), and Bi(2223) ceramic films [1–4]. Degradation of the HTSC characteristics upon passage of current through tape conductors has recently been described in [5, 6].

Another effect that can deteriorate the properties of HTSC wires during operation is swelling [7], which may be observed at temperature cycling. This effect is associated with a liquid coolant penetrating into the superconductor: evaporating under heating, it causes a severe deformation of the material.

In this paper, we study the stability of critical properties T_c and I_c of Bi(2223) and Dy(123) HTSC wires upon long-term passage of transport current (about $0.7I_c$) in liquid nitrogen (77 K).

EXPERIMENTAL

The objects of investigation were hermetic Bi(2223) $(BiPb)_2Sr_2Ca_2Cu_3O_{10-x}$ multifilament wires (HTS Hermetic wires, American Superconductor Co., United States), so-called first-generation (*1-G*) wires. The superconductor was embedded in a silver matrix and laminated by brass to provide hermetic encapsulation and improve mechanical strength.

In another series of experiments, the samples were Dy(123) $(DyBa_2Cu_3O_{7-x})$ superconducting tapes (THEVA, Germany), which are categorized as second-generation (*2-G*) wires. $DyBa_2Cu_3O_{7-x}$ superconductor was deposited by electron-beam epitaxy on a Has-

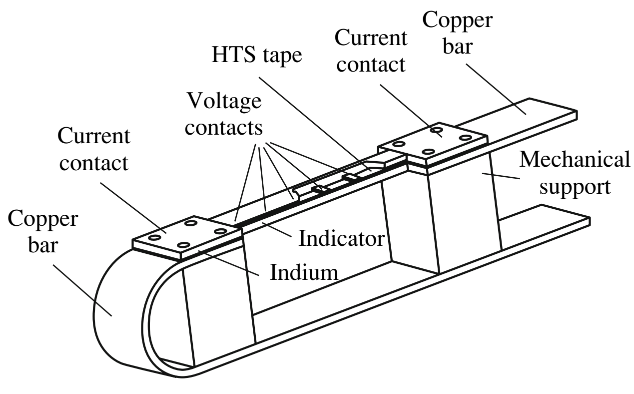

Fig. 1. Fixation scheme of the HTSC-tape sample.

telloy substrate with a MgO sublayer and covered by a thin (350 nm) silver layer.

The structure and chemical composition of the samples were studied under a JEOL JSM 5910-LV scanning electron microscope equipped with an INCA platform (Oxford Instruments) for energy dispersive X-ray analysis. Before analysis, the samples were polished. To characterize changes in the structure and chemical composition, we compared the images of the samples taken under the conditions when the contrast was due to the difference in chemical composition and to the difference in surface relief. To illustrate the chemical composition distribution over the sample, we constructed maps of the elements.

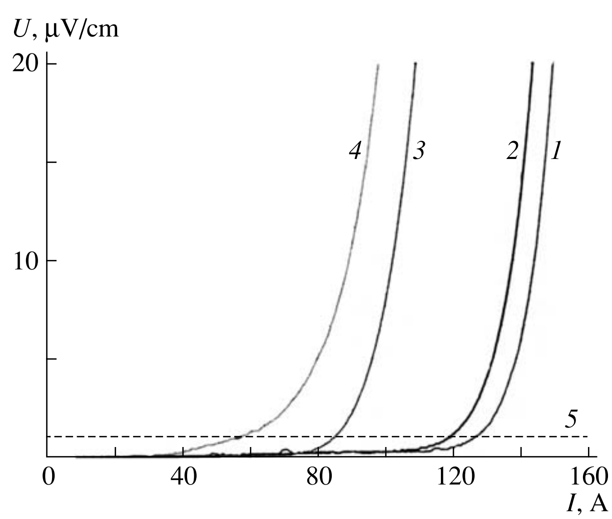

Fig. 2. Voltage–current characteristics $U(I)$ for the experimental (B1) and reference (B2) Bi(2223) tapes: (*1*) initial $U(I)$ for sample B1, $I_c = 126$ A; (*2*) initial $U(I)$ for sample B2, $I_c = 119$ A; (*3*) $U(I)$ for sample B1 upon passing the current for 323 h, $I_c = 85$ A; (*4*) $U(I)$ for sample B2 after the completion of the experiment, $I_c = 55$ A (sample B2 was placed in liquid nitrogen for 700 h without passage of current); and (*5*) criterion for finding the critical current value, 1 μV/cm.

We will use the following designations: B1 is the Bi(2223) sample through which current passes, B2 is the reference one (without current), B0 is the initial sample, and D1 and D2 are Dy(123), samples.

Bi(2223) 1-G Tape

A rectilinear sample of Bi(2223) tapes measuring $108 \times 4 \times 0.4$ mm had critical parameters $T_c = 110$ K and $I_c = 126$ A. The scheme of sample fixing is shown in Fig. 1. It was placed in a cryostat with liquid nitrogen to investigate the effect of long-term passage of transport current. We used pressed current contacts with an intermediate indium layer. Voltage contacts allowed us to control the superconducting state of the sample. Reference sample B2 made of the same wire and having the same size as sample B1 was also placed in the cryostat. A transport current of 85 ± 2 A was passed through sample B1, and $U(I)$ characteristics were periodically recorded. The total time for which the current passed through wire B1 was 323 h. The values of $U(I)$ and I_c remained constant within initial 100 h. Eventually, the critical current decreased considerably, from 126 to 85 A (Fig. 2; curve *1*, *3*). Upon heating, sample B1 swelled up: its thickness increased from 0.4 to 0.7 mm. It should be emphasized that samples B1 and B2 were kept in liquid nitrogen for about 700 h (the current was switched on in the daytime only).

The $U(I)$ characteristics of reference sample B2 (kept in liquid nitrogen for 700 h without current) are shown in Fig. 2 (curves *2*, *4*). The critical current of this sample decreased from 119 to 55 A, and the sample also got thicker. The critical temperature of both (experimental and reference) samples remained constant, 110 K.

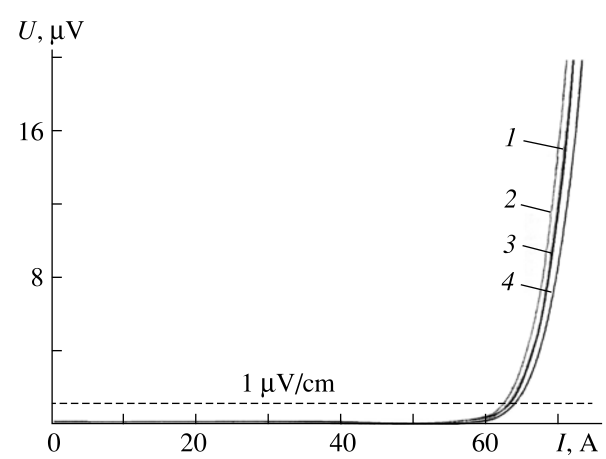

Fig. 3. Voltage–current characteristics $U(I)$ (*1*) before passing current and after passing a current of 44 A through Dy(123) tape D1 placed in liquid nitrogen (77 K) for (*2*) 100, (*3*) 200, and (*4*) 300 h. $I_c \approx 63$ A.

Results of chemical analysis (at %) of the Bi(2223) samples

Sample	Chemical element					
	Bi(±0.39)*	Pb(±0.37)	Ca(±0.1)	Sr(±0.23)	Cu(±0.23)	O(±0.32)
B0	10.16	0.89	10.26	10.77	15.37	2.545
B1	9.61	0.94	9.53	10.52	12.98	56.42
B1	10.05	0.95	9.57	11.27	13.84	54.31
B1	10.72	0.85	11.1	11.39	16.24	49.7
B1	10.22	0.8	10.43	11.18	14.7	52.67

* Bracketed values are errors in at %.

Dy(123) 2-G Tape

A rectilinear sample of Dy(123) tapes D1 measuring 108 × 4 × 0.1 mm had critical parameters I_c = 63 A and T_c = 90 K. The scheme of sample fixing is shown in Fig. 1. In this case, we also used current pressed contacts with an intermediate indium layer and reference sample D2 was also placed in the cryostat. A current of 44 A was passed through sample D1 for 300 h at 77 K. The $U(I)$ characteristics of Dy(123) sample D1 are shown in Fig. 3. After the experiment, no appreciable changes in the critical current, critical temperature, and geometrical sizes of both samples (D1 and D2) were observed. Then, the transport current in sample D1 was increased to 80 A (>I_c) and passed for 100 h at liquid nitrogen temperature. No changes in $U(I)$ and critical current in sample D1 were detected. Thus, passage of current through the Dy(123) *2-G* tapes for 400 and 1000 h in liquid nitrogen did not lead to appreciable changes in critical parameters I_c and T_c.

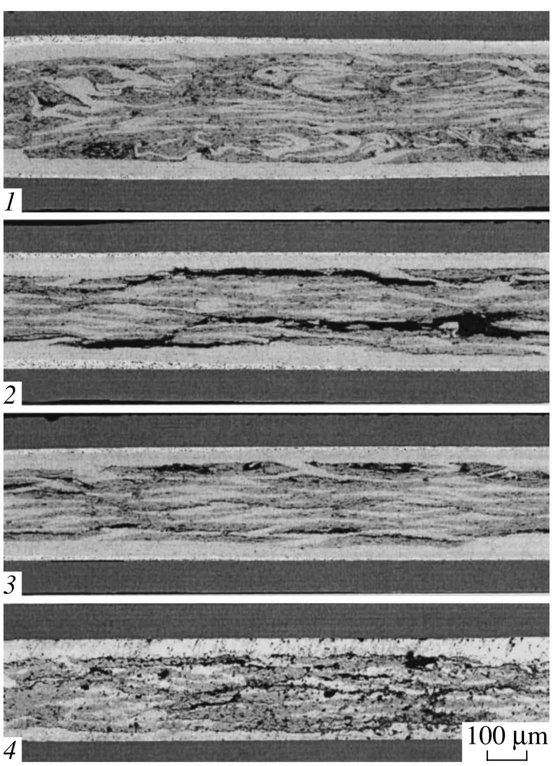

Fig. 4. SEM images of the cross sections of the Bi(2223) HTSC tape before and after passing transport current at 77 K.

MICROANALYSIS OF Bi(2223) TAPES

Initial (B0), test (B1), and reference (B2) samples of Bi(2223) wires were studied under a scanning electron microscope equipped with an X-ray microanalyzer to reveal changes in the structure and phase composition of the superconductor. The averaged chemical composition of initial sample B0 is given in the table (first row). The data were averaged over five points taken arbitrarily. The next rows in the table show the elemental compositions in four parts of test sample B1. As is seen from the table, the amounts of cooper and calcium vary over the sample to a maximum extent.

The images of the cross sections of the Bi(2223) samples are shown in Fig. 4, where *1* is the image of initial sample B0; *2* and *3*, test sample B1; and *4*, reference sample B2. It is seen that, upon passage of the current, the silver (light areas) and HTSC (grey areas) layers change their positions and the number of defects (dark areas) grows. Analysis showed that defects are pores. The maps of elements plotted over an 60 × 60 μm area of initial sample B0 demonstrate a tendency to the formation of calcium- and copper-enriched microareas from 1 to 5 μm long. In test sample B1, changes in the composition are more pronounced. The composition of reference sample B0 is distributed more uniformly.

CONCLUSIONS

The investigation into the long-term stability of critical parameters I_c and T_c of Bi(2223) ($(BiPb)_2Sr_2Ca_2Cu_3O_{10-x}$) multifilament wires shows that, upon passing transport current for 323 h in liquid nitrogen, the critical current of sample B1 decreases from 126 to 85 A and the sample itself grows in size (swelling of the sample). The same changes are observed in reference sample B2, which is kept for 700 h in liquid nitrogen but is not subjected to the action of current. The value of T_c remains constant in both B1 and B2. X-ray spectrum microanalysis reveals micropores in B1 and B2 multifilament wires. To explain the reason for changes in the element distribution over the samples, further investigation is necessary.

It is conjectured that a reason for the decrease in the critical current and formation of micropores in the Bi(2223) tape may be a temperature-cycling-related effect known as swelling rather than electrostimulated ion diffusion. The wire swells when a liquid coolant penetrates into the composite conductor. Evaporating and expanding under heating, the coolant causes a severe deformation of the material and thereby leads to a decrease in the critical current.

Dy(123) ($DyBa_2Cu_3O_{7-x}$) superconducting tapes inserted in a dc circuit demonstrate good stability at 77 K for a long time (400 h).

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research, project no. 06-02-08205.

REFERENCES

1. Yu. A. Osip'yan, R. K. Nikolaev, N. S. Sidorov, V. S. Bobrov, and V. S. Tsoi, Pis'ma Zh. Éksp. Teor. Fiz. **47**, 257 (1988) [JETP Lett. **47**, 310 (1988)].
2. A. M. Prokhorov, Yu. M. Gufan, A. E. Krapivka, N. E. Lubnin, G. N. Mikhailova, E. G. Rudashevskii, A. S. Seferov, V. N. Sumarokov, V. A. Tarasenko, and A. G. Chistov, Dokl. Akad. Nauk SSSR **311**, 75 (1990) [Sov. Phys. Dokl. **35**, 252 (1990)].
3. G. N. Mikhailova, A. M. Prokhorov, L. Yu. Shchurova, and A. V. Troitskii, Physica C **409–410**, 692 (2004).
4. G. N. Mikhailova, A. M. Prokhorov, L. Yu. Shchurova, and A. V. Troitskii, Neorg. Mater. **36**, 969 (2000).
5. D. K. Bae, S. J. Lee, J. H. Bae, K. D. Sim, K. Y. Park, and T. K. Ko, IEEE Trans. Appl. Supercond. **13**, 2349 (2003).
6. X. Wang, S. Banda, H. Ueda, A. Ishiyama, Y. Iigiima, T. Saitoh, N. Kashima, M. Mori, T. Watanabe, S. Nagaya, T. Katoh, T. Machi, and Y. Shiohara, in *Proceedings of the 8th European Conference on Applied Superconductivity (EUCAS 2007), Brussels, 2007*, Vol. 0266-M1, p. 282.
7. F. Hornung, M. Klaser, and Th. Schneider, IEEE Trans. Appl. Sipercond. **17**, 3117 (2007).

Translated by M. Astrov