Scientific Research of the Institute of Mathematics and Computer Science, 2(10) 2011, 237-242

# DETERMINATION OF CURRENT CHARACTERISTICS OF 2G HTSC

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**Abstract.** This paper presents the results of investigations of a state-of-the art high-temperature ceramic superconducting tape of the SF 12050 series. The study focuses on the current and voltage characteristics, examination of the microstructure and analysis of the chemical composition in superconducting tapes of the SF series. In order to measure the current parameters, a measuring system was designed to investigate sections of the tapes at the temperature of liquid nitrogen. The system is powered with a direct current of parameters I = 0÷580 A and U = 0÷8 V. Measurements of the critical current were taken by means of determination of the decline in voltage along the measurement section for the tape with an accuracy of 1nV. Analysis of the chemical composition was carried out by using a scanning microscope which features a chemical composition microanalyser EDX. The paper presents microscopic images which are a result of the examination of the structures by means of a light microscope and scanning microscope. The method of preparation of the superconducting tapes for soldering and the method the selecting of solder were also presented.

## Introduction

Superconductivity means a state of matter when a superconducting material, below critical temperature $T_K$ conducts electricity at zero resistance. Resistivity at room temperature (20°C) amounts to, respectively, for metals: Ag 1.62 $10^{-8}$ Ωm, for semiconductors e.g. n-type silicon: 8.7 · $10^{-4}$ Ωm, for insulators e.g. glass: $10^{10}$÷$10^{14}$ Ωm [1, 2].

For some materials, the transition into a superconducting state is possible at higher pressures. Superconductors include a variety of chemical elements, chemical compounds, metal alloys, ceramics or organic compounds. Superconducting properties at low temperatures are demonstrated by e.g. carbon in the form of carbon nanotubes or doped fullerenes [3].

The pioneer in the domain of superconductivity was Heinke Kamerlingh-Onnes, who was the first to obtain liquid helium. This breakthrough lead to the discovery of the relationships between the electrical current in metals and temperature.

While testing the purest from the then available elements i.e. mercury, he found that instead of a smooth decline in electrical resistance with a reduction in temperature, at a temperature of ca. 4 K, resistance rapidly decreases to zero and, below this temperature, mercury does not show electrical resistance [4].

Apart from zero resistance, type-I superconductors emit a magnetic field from their interior (Meissner effect), whereas in type-II superconductors, in the magnetic fields within the range of $<Bc_1, Bc_2>$, the magnetic field penetrates the superconductor and the occurrence of a mixed state is observed. For a magnetic field higher than $Bc_2$, superconductivity is destroyed.

Scientists worldwide have investigated a variety of different materials, searching for superconductors with even better functional parameters such as: critical current $J_C$, critical field $H_C$ or critical temperature $T_C$ [5]. A record critical temperature of 254 K was observed for the superconductor $(TlBa)Ba_2Ca_2Cu_7O_{13+}$. The most recognized superconducting materials include superconductors based on Bi - $Bi_2Sr_2CaCu_2O_9$ (BSCCO) with a $T_C$ of ca. 110 K, and $YBa_2Cu_3O_7$ (YBCO) with a $T_C$ of ca. 90 K [3]. They are used for the mass manufacturing of a variety of elements, e.g. rings, tapes and pipes with comparable properties [4, 6-8].

Until 2006, it had been assumed that cupric compounds are the only high-temperature superconductors. In 2006, Hideo Hosono discovered the first compound which created the second type of high-temperature superconductors: Fe-pnictides. These materials typically undergo structural transitions [9-13].

## 1. Research methods and material

The investigations were carried out for high-temperature superconducting tape 2G HTSC ($2^{nd}$ Generation High Temperature Superconductors) of the SF 12050 series (SF means superconductors with iron taking part in the appearance of superconducting phases, whereas 12050 means width of 12 mm and thickness of 0.5 mm). The tapes are delivered with the manufacturer's specifications, which contain information about the following parameters: critical current $I_C$ at the temperature of liquid nitrogen (77 K, in a uniform field), minimal value 240 A ±10%, tape width 12 mm, tape thickness 0.055 mm, thickness of silver coating 2 μm ±0.5 μm, base material: alloy of Ni and Mo and alloying elements, commercially sold as Hastelloy, base material magnetic properties: non-magnetic, resistivity of the base material: 125 μΩcm. Commercial sections of the tape are up to 1000 m long. In order to carry out the investigations, a 10-metre long tape section was purchased.

A measurement system was developed in order to determine the values of critical currents. Exceeding critical current causes the material to switch back from the superconductivity state to a normal state. The system allows for long-term loading of the tape with a current exceeding critical levels, which leads to the destruction of superconducting materials. Further investigations will attempt to characterize the mechanism of destroying HTSC. The current circuit was composed of a three--phase current supply with a maximal direct output current intensity of 580 A (current accuracy reaching 0.5 A) and output voltage within the range of 0÷8 V.

For the empirical current-voltage characteristics, the best mathematical functions describing them were determined.

The voltage measurement circuit was equipped with a very sensitive digital nanovoltmeter manufactured by Keithley Instruments Inc. With a measurement accuracy of 1 nV. The current-based investigations of superconducting tapes were performed at the temperature of liquid nitrogen in a cryostat. In order to solder clamps and terminals, a mixture of fusible tin, Wood's alloy (with melting point of 66÷72°C), rosin and flux was used. The soldering temperature was approximately 100°C.

## 2. Results and discussion

One of the most important parameters which characterize materials that demonstrate superconducting properties is critical current $I_C$. Exceeding the critical value of current causes the return of a superconductor to its normal state although the temperature in the circuit is maintained within the range of superconductivity. If a current exceeding the value of Ic passes through the circuit for a certain time, permanent damage to the superconducting tape occurs. Figure 1 presents the current-voltage characteristic for superconducting tape of the second generation, SF 12050 series.

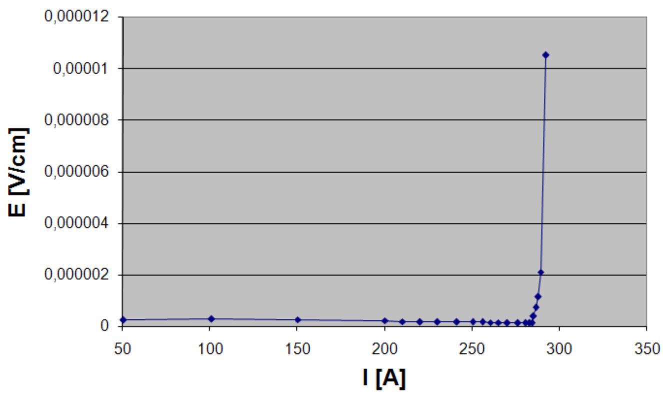


Fig. 1. Current-voltage characteristics for superconducting tape of SF 12050 series determined at temperature of liquid nitrogen

The current-voltage characteristics for the SF12050 tapes are described as a function of $y = y_0 + A_1 \exp(x/t_1)$, where $A_1 = 3.5960 \cdot 10^{-30}$, $y_0 = -9.12613 \cdot 10^{-4}$ and $t_1 = 3.21438$.

In order to compare the differences which occur in the current-voltage characteristics and critical current $I_C$, the current-voltage characteristics were determined for two additionally selected tapes in differing in their chemical composition and structure. Tapes SF 12050 and SF 4050 differing in width (SF 12050: 12 mm; SF 4050: 4 mm). A bismuth high-temperature superconducting tape was also the subject of investigations: it was marked as Bi2223 (BSCCO; $Bi_2Sr_2CaCu_2O_9$) and differed in its structure and composition. The current-voltage characteristics for the bismuth tapes were prepared in the Institute of Low Temperatures and Structural Research at the Polish Academy of Science in Wroclaw, Poland, whereas for the tapes of the SF 4050 and SF 12050 series, the characteristics were prepared in the Faculty of Materials Processing Technology and Applied Physics at the Czestochowa University of Technology.

As results from the characteristics presented in Figures 2 and 3, the highest critical current of $I_C$ = 272 A among the investigated tapes can be observed for the tape of the SF 12050 series. The critical currents for the bismuth tape and SF 4050 tape were similar and amounted to nearly 120 A.

The current-voltage characteristics for the SF4050 tapes were described as a function of $y = A \exp (B x)$, where $A = 1.9836 \cdot 10^{-5}$ and $B = 0.15219$.

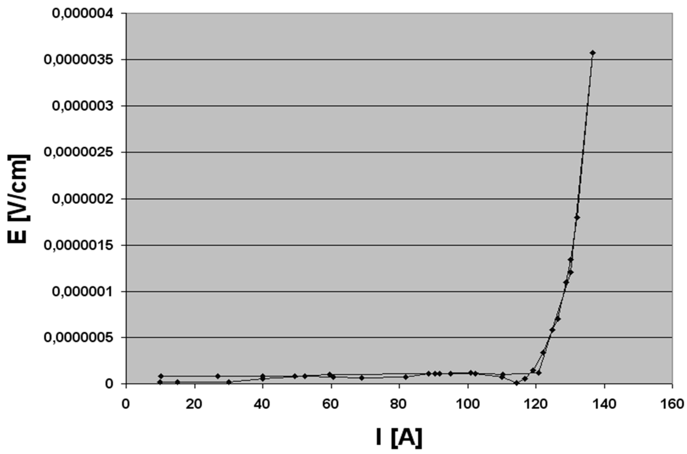


Fig. 2. Current and voltage characteristic for superconducting tape of SF 4050 series at temperature of liquid nitrogen

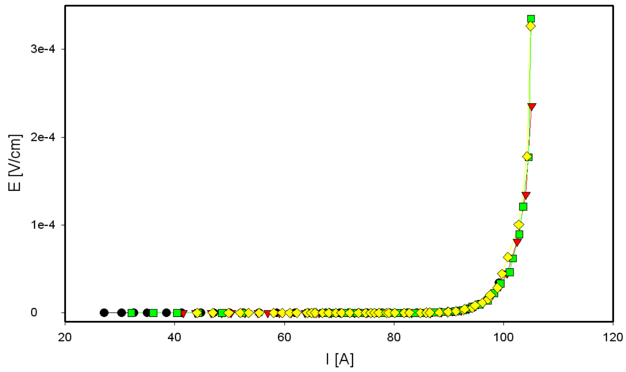


Fig. 3. Current and voltage characteristic for superconducting tape of YBCO Superpower at temperature of liquid nitrogen

The current-voltage characteristics for the YBCO tapes were described as a function of y = A exp (B x), where A = 1.20371 · $10^{-10}$ and B = 0.43719.

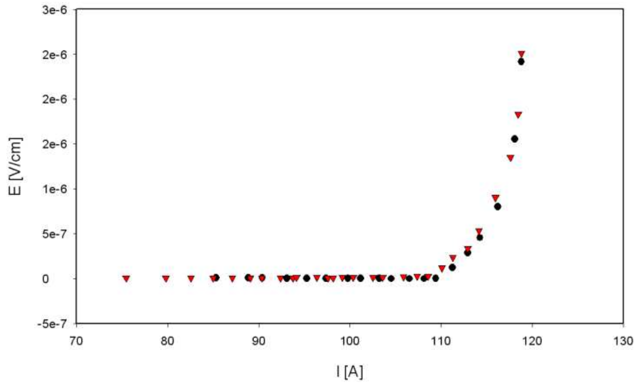


Fig. 4. Current and voltage characteristic for bismuth superconducting tape Bi2223-LIW2170B at temperature of liquid nitrogen

The current-voltage characteristics for the Bi2223 tapes were described as a function of y = A exp (B x), where A = 4.794 · $10^{-6}$ and B = 0.11784.

In Figures 3 and 4 the current-voltage characteristics of the chosen high temperature superconductors was presented. These determined characteristics show the differences between the values of the critical current.

## Conclusions

– Chemical composition and structure of high-temperature superconducting tapes considerably affect critical current $I_C$. Measurement for critical current for tape of SF12050 series amounted to 272 A, whereas this value for bismuth tape was ca. 120 A.
– Tape width considerably affects critical current values. The studied tapes SF12050 and SF 4050 show the same chemical composition but they differ in width. The difference in critical currents is considerable, but it is not directly proportional to tape width. For SF 12050 tape, $I_C$ amounts to 272 A, whereas in the case of tape SF 4050, the level of $I_C$ was 120 A.
– Knowing current-voltage characteristics of high-temperature tapes will allow for application of suitable current load which does not exceed the value of critical current.


## Acknowledgement

*In this paper are presented the results of research carried out under Grant MNiSW N N507 284636.*

## References

[1] Holliday D., Resnick R., Walker J., Podstawy fizyki, T. 3, WN PWN, Warszawa 2005.

[2] http://www.superconductors.org.

[3] Szota M., Superconducting materials, collective monographic, [in:] Materials Engineering Materials and Exploration Problems in Modern Materials Engineering, Czestochowa 2009, 94-114.

[4] Palka R., Monolityczne nadprzewodniki wysokotemperaturowe. Modele makroskopowe i zastosowania, Wydawnictwo Politechniki Szczecińskiej, Szczecin 2008.

[5] Juszczyk S., Gogolowicz M., Własności magnetyczne nadprzewodników wysokotemperaturowych, Wydawnictwo Uniwersytetu Śląskiego, Katowice 1993.

[6] Lebioda M., Pierścień nadprzewodzący w zewnętrznym polu magnetycznym, Przegląd Elektrotechniczny 2003, s. 616-618.

[7] Jimenez J., Chen Y., Xiong X., Xie Y., Zhang X., Rar A., Martchevskii M., Qiao Y., Knoll A., Lenseth K.P., Schmidt R.M., Herrin J., Hazelton D., Selvamanickam V., Recent Results in 2G HTS Wire Technology Development at Superpower, ICMC, Seul 2008 (21-25.07.2008).

[8] Selvamanickam V., Chen Y., Xiong X., Xie Y., Zhang X., Reeves J.L., Qiao Y., Rar A., Lenseth K.P., Schmidt R.M., DOE Wire & Applications Workshop, Panama City, FL (16-17.01.2007).

[9] Collins G.P., Żelazo bez oporów, Świat Nauki 2009, 48-55, 9(217).

[10] Kamichara Y., Watanabe T., Hirano M., Holono H., Iron Arsenic Superconductor $La[O_{1-x}F_x]FeAs$ (x = 0,05–0,12) with Tc = 26 K, Journal of the American Chemical Society 2008, 130, 11, 3296-3297.

[11] Zaanen J., Condensed Matter Physics; The Pnictide Code, Nature 2009, 457, 5460-547.

[12] Ma Y., Gao Z., Qi Y., Zhang X., Wang L., Zhang Z., Wang D., Fabrication and characterization of iron pnictide wires and bulk materials throught the powder-in-tube method, Physica C 2009, 469, 651-656.

[13] Qi Y., Zhang X., Gao Z., Zhang Z., Wang L., Wang D., Ma Y., Superconductivity of powder-in--tube $Sr_{0,6}K_{0,4}Fe_2As_2$ wires, Physica C 2009, 469, 717-720.