

# SUPERCONDUCTIVITY AND MAGNETIC STUDIES OF BULK Y123/BaCuO<sub>2</sub> COMPOSITE

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*Abstract.* In this paper we present the results of the study of ceramic composite Y123/BaCuO<sub>2</sub> obtained in one-step procedure, which appears to lead to material possessing both superconducting and magnetic properties at low temperatures. By applying *scanning electron microscopy* (SEM), *energy-dispersive X-ray spectroscopy* (EDX), spectrophotometry for oxygen index evaluation and AC and DC magnetization measurements we managed to show that if the nominal starting composition is 1:3:4 (Y:Ba:Cu) one can obtain two phase composite with 62wt% of superconducting YBCO with high critical temperature equal to 92.6 K and 38wt% of magnetic BaCuO<sub>2</sub>. Stability of obtained composite in alkaline solution is superior over pure Y123 material which is important for practical application in the manufacture of batteries.

*Key words:* One-step procedure sintering, Y123/ BaCuO<sub>2</sub> composites, high-temperature ceramic superconductors and ferromagnetic.

## 1. INTRODUCTION

The term “high-temperature superconductor” has been used interchangeably with “cuprate” superconductor for compounds such as yttrium barium copper oxide (YBCO). Since the discovery in 1987 of high-temperature super conductance by Chu and Wu [1] up to today, the cuprate ceramics have been the subject of scientific interest, including both their preparation and application. The YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub> (Y123) system is one of the most thoroughly investigated superconducting systems as it is easy to prepare and finds many practical applications.

It is proved that stoichiometric  $\text{YBa}_2\text{Cu}_3\text{O}_x$  (Y123) is very stable in alkaline medium and may be successfully used as a basic electrolyte in alkaline batteries, improving their cyclic operation capabilities [2]. Over the years, the research efforts have been predominantly aimed at finding techniques increasing the transition temperature,  $T_c$ . Along these lines, the researchers have created many different YBCO-family compounds in order to obtain a  $T_c$  higher than that of Y123 (92 K), such as Y124 with  $T_c = 80$  K [3], and Y247 with a  $T_c$  varying from 30 K to 95 K depending on the oxygen content [4, 5]. Relatively recently (in 2009), Aliabadi, Farshchi and Akhavan [6] and Taviana [7] found a new Y-based high-temperature superconductor in Y-Ba-Cu-O (Y-358) that becomes superconducting above 100 K.

The crystal structure of the YBCO-family compounds is described as a distorted, oxygen deficient, multi-layered perovskite structure. Due to the oxygen deficiency, the coordination number of copper ions is reduced from six (octahedrons) in perovskite to five (square pyramids) and four (flat squares). The square pyramids are oriented so as to form Cu-O planes perpendicular to the  $c$  axis, while the flat squares form Cu-O chains along the  $b$  axis. Depending on the oxygen content ( $x \approx 0.1-0.3$ ), these chains have a limited length. The YBCO superconductor properties are strongly affected by the peculiarities of its structure. Generally, it is known that the CuO chains influence the superconducting carriers' concentration in the  $\text{CuO}_2$  planes [8, 9]. Moreover, the  $T_c$  value depends on the number of holes in the  $\text{CuO}_2$  planes. According to Udomsamuthirum *et al.* [10], there exists a relation between the number of  $\text{CuO}_2$  planes and the number of Ba atoms, and the number of CuO chains and the number of Y atoms. This dependence is applicable to different superconductors in the YBCO family (Y1 2 3, Y3 5 8, Y5 8 13, Y3 8 11, Y13 20 33).

The relation between the purity of the superconducting phase of an YBCO system and its superconducting properties has also been extensively studied. It has been shown that the presence of  $\text{BaCuO}_2$  as a secondary phase worsens the superconducting properties of the Y123 materials [11–13], while the effect of impurities on the properties of superconducting ceramics with other rare earths RE-123 (RE = rare earth ion) is negligible [14]. In contrast, an investigation of the influence of adding  $\text{Ba-CuO}_{2-\delta}$  to the Gd-Ba-Cu-O superconducting system demonstrated an improvement in its superconducting properties [15]. On the other hand barium cuprate has also been classified as one of the few copper oxides exhibiting ferromagnetic interactions that can affect the transition width of the  $\rho - T$  curves during  $T_c$  measurements [16, 17]. According to the examples given above an investigation of the possibility for existing of superconductivity (Y123) and ferromagnetism ( $\text{BaCuO}_2$ ) in polycrystalline composite materials was made. In this study we investigate a new ceramic composite (Y123/  $\text{Ba-CuO}_2$ ) in a one-step procedure by using solid state synthesis with the starting stoichiometry of 1:3:4(Y:Ba:Cu) which exhibits superconducting as well as ferromagnetic properties before and after the alkaline treatment. The latter seems to be important

in the preparing of batteries. Furthermore, the influence on the oxygen content, polycrystalline microstructure, and superconducting and magnetic properties of the ceramic composite material were also investigated.

## 2. EXPERIMENTAL PROCEDURE

A bulk ceramic composite Y123/ BaCuO<sub>2</sub> was synthesized by a solid-state reaction with starting stoichiometry of 1:3:4(Y:Ba:Cu). The reagents were Y<sub>2</sub>O<sub>3</sub>, BaCO<sub>3</sub> and CuO with analytical grade purity and were mixed by grinding in an agate mortar. The resulting mixture was calcined at 900 °C in a flowing oxygen atmosphere for 21 h. The calcined powders were reground and sintered again at 940 °C for 21 h with additional annealing at 450 °C in an oxygen atmosphere for 2 h. Further, the powders obtained were reground and then pressed into pellets. The bulk samples were sintered at 940 °C in a flowing oxygen atmosphere for 21 h and annealed at 450 °C in an oxygen atmosphere for 21 h.

The pellets of the sintered ceramics (10 mm diameter, 2 mm thickness) were soaked in an alkaline solution (7M KOH) for 24, 48, 72 or 96 hours. After the exposure, the samples were removed from the liquid, dried at room temperature and examined. Since the properties of all samples varied practically negligibly with the exposure period, further in the paper results for the longest soaking time in the alkaline solution (96 hours) are only presented and discussed.

## 3. EXPERIMENTAL METHODS

The X-ray diffraction patterns of the superconducting powder samples were obtained within the range 5.3 to 80°2θ at a constant step of 0.02°2θ on a Bruker D8 Advance Diffractometer with Cu Kα radiation and a LynxEye Detector. The phase identification was performed by the Diffracplus EVA program using the ICDD-PDF2 (2014) Database. The mean crystallite size was determined by the Topas-4.2 software package using the fundamental parameters peak shape description including appropriate corrections for the instrumental broadening and diffractometer geometry [18].

The microstructure of the samples was studied by means of a Zeiss EVO MA-15 scanning electron microscope (SEM) with a LaB6 cathode on the polished cross-section of the samples. The chemical composition was determined by X-ray microanalysis using energy dispersive spectroscopy (EDS) on an Oxford

Instruments INCA Energy system. The qualitative and quantitative analyses were carried out at an accelerating voltage of 20 kV.

The non-stoichiometric oxygen coefficient ( $\delta$ ) and the total oxygen content ( $y$ ) were determined by a spectrophotometric method based on the formation of an  $I_3^-$ -starch compound [19–21]: 1.5–2.0 mg of a bulk sample Y123/ BaCuO<sub>2</sub>, powdered and homogenized previously, were dissolved in a HCl and KI solution under inert atmosphere and the iodine liberated was bound with starch in a blue colored compound [19, 20]. A blank sample passing through all stages of the dissolution process was prepared along with the sample dissolution. Three measuring flasks were prepared [19] and their absorbance was measured in a differential mode; the non-stoichiometric oxygen coefficient  $\delta$  was obtained as the ratio of two absorptions according to the equations, as follow: Equation (1) for Y123 [21] and Equation (2) for Y123/ BaCuO<sub>2</sub>, respectively.

$$\delta = (A^5_{\text{Gly}})/(A^2_{\text{without Gly}}) \quad (1)$$

$$\delta = 1.33 (A^5_{\text{Gly}})/(A^2_{\text{without Gly}}) \quad (2)$$

The magnetic measurements were performed using a Quantum Design PPMS (Physical Property Measurement System) instrument and an Oxford Design 7000 Susceptometer. A five-segment hysteresis loop at 10 K up to 9 T, and the real and imaginary part of the differential complex magnetization in an AC magnetic field with an amplitude of 5 Oe and a frequency of 3333 Hz in the temperature interval 10–100 K, were measured for both samples (as-synthesized and electrolyte-treated). The DC magnetization was also measured in an increasing DC magnetic field up to 3 T at three different temperatures (10, 80 and 100 K) of the as synthesized sample. The curves zero field cooled-field cooled (ZFC-FC) *vs.* temperature were obtained at 100 Oe DC magnetization in the temperature range 10-210-10 K by the following procedure: 1) Cooling the sample down to 10 K without a magnetic field; 2) applying a 100 Oe DC magnetic field at a temperature of 10 K; 3) measuring the DC magnetization as raising the temperature from 10 to 210 K at 100 Oe – ZFC curve; 4) measuring the DC magnetization as decreasing the temperature from 210 to 10 K at a 100 Oe DC magnetic field – FC curve. The differential magnetization was additionally measured at four different frequencies (1, 3, 5 and 7 kHz) with amplitude of the AC magnetic field of 10 Oe. At the frequency of 1 kHz an amplitude of 10 Oe of the AC magnetic field, the AC magnetization was measured in two cases: with and without an additional DC magnetic field, namely, a DC magnetic field of 100 Oe was applied parallel to the AC magnetic field after ZFC to 2.2 K.

#### 4. RESULTS AND DISCUSSION

##### XRD ANALYSIS

The X-ray diffraction patterns of the synthesized samples (Y123/ BaCuO<sub>2</sub>) showed the presence of 62 wt % superconductive 123YBCO and 38 wt % of BaCuO<sub>2</sub> phase, Figure 1. A similar proportion between the superconducting and non-superconducting phases was also found by Chainok *et al.* [22]. The refined unit cell parameters were  $a = 3.8226(3) \text{ \AA}$ ;  $b = 3.8913(3) \text{ \AA}$ ;  $c = 11.6586(1) \text{ \AA}$  for YBCO (SG: *Pmmm*) and  $a = 18.333(2) \text{ \AA}$  for BaCuO<sub>2</sub> (SG: *Im-3m*). After the treatment by the alkaline solution, all peaks remained and the unit cell parameters were  $a = 3.8225(3) \text{ \AA}$ ;  $b = 3.8912(3) \text{ \AA}$ ;  $c = 11.661(1) \text{ \AA}$  for YBCO (SG: *Pmmm*) and  $a = 18.328(2) \text{ \AA}$  for BaCuO<sub>2</sub> (SG: *Im-3m*). The percentages of the two phases were 66 wt % for the superconductive 123YBCO and 34 wt% for BaCuO<sub>2</sub>.

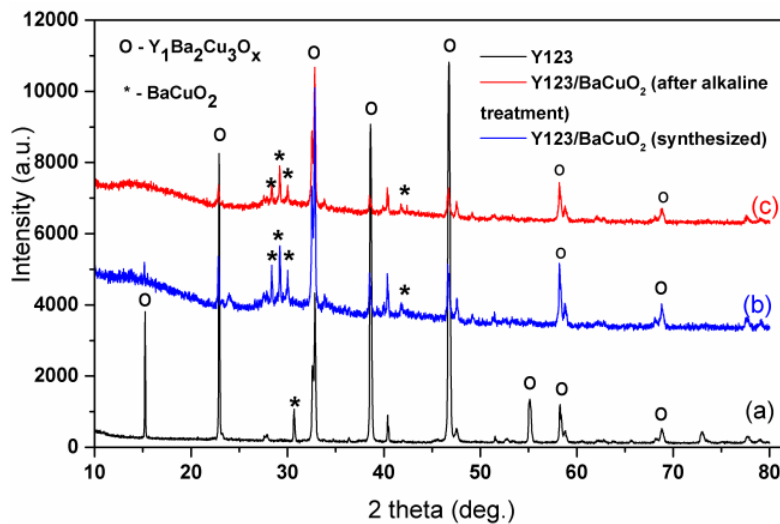


Fig. 1 – Powder X-ray diffraction patterns of Y123/ BaCuO<sub>2</sub> samples – as synthesized and after alkaline treatment.

##### SEM AND EDX ANALYSIS

Figure 2 presents SEM images of a synthesized Y123/ BaCuO<sub>2</sub> sample and the same after alkaline treatment (\*Y123/ BaCuO<sub>2</sub>). The grain boundaries and micro-cracks are visible in both images. The sample prepared had a typical polycrystalline structure with relatively large main grains (5–10  $\mu\text{m}$ ).

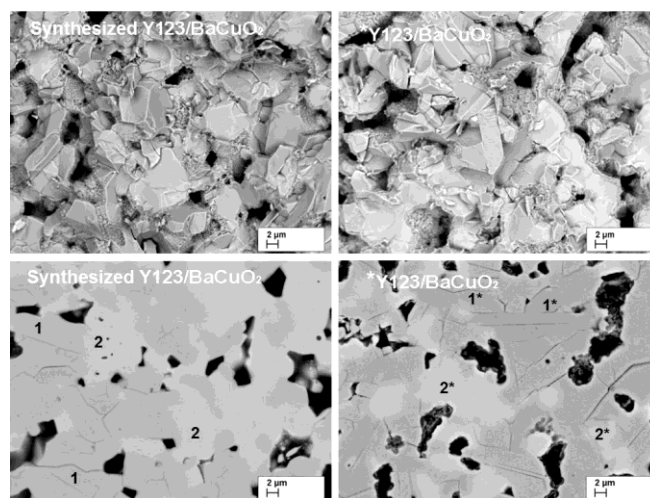


Fig. 2 – SEM images of an as-synthesized sample Y123/ BaCuO<sub>2</sub> (a) and an \*Y123/ BaCuO<sub>2</sub> (b) sample after alkaline treatment.

From the EDX data presented in Tables 1 and 2, one can conclude that stoichiometric 1:2:3 phases were present.

Table 1

Distribution of the elements in an as-synthesized sample Y123/ BaCuO<sub>2</sub>

Phase Compound	Elements content, at %				Phase Content, %
	Y	Ba	Cu	O	
Y <sub>1</sub> Ba <sub>2</sub> Cu <sub>3</sub> O <sub>z</sub> Point 1 (crystal)	7.85	15.51	22.04	54.60	62
BaCuO <sub>2</sub> Point 2	–	23.94	24.52	51.54	38

The white zones observed (marked by 2 in Fig. 2) confirmed the appearance of the BaCuO<sub>2</sub> phase, as established by the X-ray phase analysis. In the same zones, the ratio of Ba:Cu was nearly 1:1, which was confirmed by the EDX analysis (Table 1 and Table 2).

Table 2

Distribution of the elements in a sample after alkaline treatment \*Y123/ BaCuO<sub>2</sub>

Phase Compound	Elements content, at%				Phase Content, %
	Y	Ba	Cu	O	
Y <sub>1</sub> Ba <sub>2</sub> Cu <sub>3</sub> O <sub>z</sub> Point 1* (crystal)	7.74	15.87	21.52	54.87	64
BaCuO <sub>2</sub> Point 2	–	23.24	23.31	53.45	35

It is well known that the presence of the BaCuO<sub>2</sub> phase simultaneously with the main 123 phase results in a low-melting eutectic [23, 24]. The last statement could be the result of the preparation process. During the sintering at 900–950 °C, the connectivity between the grains was improved, and a better sintering was achieved. As a result, the porosity of the samples decreased, too. The same characteristics were established using the microstructure analysis and chemical components of the \*Y123/ BaCuO<sub>2</sub> sample after the alkaline treatment (Fig. 2b and Table 2). The distribution maps of the different elements in Fig. 3 showed that Y was distributed homogeneously in the samples, which proved its presence inside the grains, while barium was irregularly distributed. In the separate zones (lighter colored), the ratio of Ba:Cu was nearly 1:1, which confirmed the appearance of the BaCuO<sub>2</sub> phase, as established by the X-ray phase analysis (Fig. 1) and confirmed by the EDX results presented in Table 1 and Table 2.

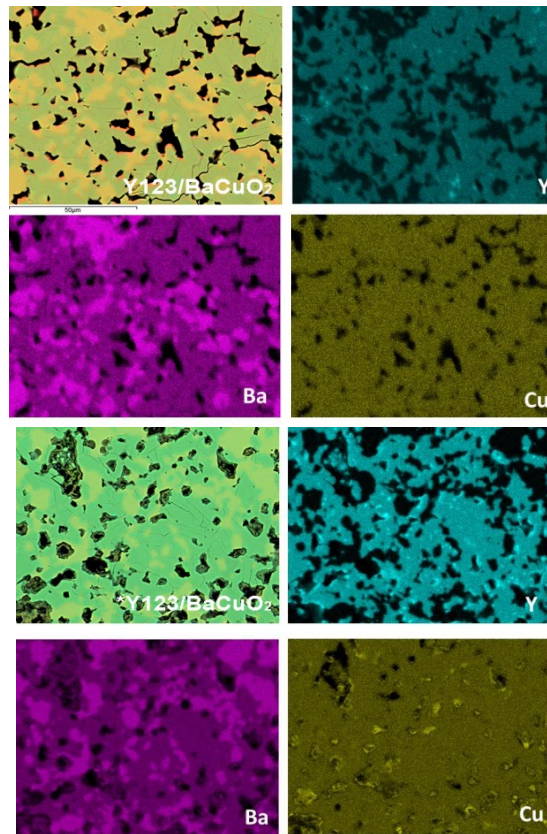


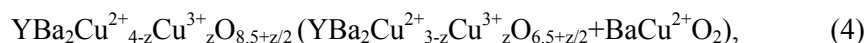
Fig. 3 – Scanning electron image of an as-synthesized (Y123/ BaCuO<sub>2</sub>) sample – top and after alkaline treatment \*(Y123/ BaCuO<sub>2</sub>) – bottom, showing the distribution maps of the different elements.

## EVALUATION OF THE OXYGEN CONTENT BY SPECTROPHOTOMETRY

In our previous studies spectrophotometric methods for determination of the oxygen content in single phase cuprate ceramics were developed. It has been established that the results for non-stoichiometric oxygen content obtained by the spectrophotometric methods are accurate and precise. The oxygen content of the Y123 samples before and after the treatment with KOH was also examined in [21]. The data showed that the alkaline treatment of the Y123 samples does not change the oxygen content and its superconducting properties. In this work, modification of the spectrophotometric method (based on measuring of the absorbance of  $I_3^-$  – starch compound [19, 20]) was applied in order to evaluate the oxygen content in a non-monophasic composite material: Y123/ BaCuO<sub>2</sub>. The method does not require either calibration or precise measurement of the sample's mass [19, 20]. The oxygen content  $y$  and the  $\delta$  coefficient were calculated from the molar ratio of Cu (III) and the total copper content using the sum of the oxidation numbers of



and



where  $\delta = z / 2$ .

After mathematical transformations of the formulae for  $\delta$  and calculating  $y$  of an Y123 bulk sample (Eq. (3)), the method cited was used to calculate (Eq. (4)) the coefficient of the active oxygen  $\delta$ , as well as the total oxygen content in Y123/ BaCuO<sub>2</sub> before and after alkaline treatment. The values of the oxygen content and the  $\delta$  coefficient for Y123 and Y123/ BaCuO<sub>2</sub> are presented in Table 3. Each result is the mean value of at least three parallel determinations. The standard deviation is in the limits of  $\pm 0.0015$ . The oxygen content could also be obtained by non-destructive semi-quantitative methods, such as Raman and X-ray spectrometry, as a mathematical relation “oxygen content – physical parameter” exists [20]. Such a mathematical relation between the  $c$ -axis unit cell parameter (determined from powder diffraction patterns) and the  $y$  oxygen coefficient (determined by the destructive methods) has been derived for Y123 [25]. The values of the refined  $c$ -axis unit cell parameter for Y123 phase from the composite material are also listed in Table 3.

Using the known equation  $y = 75.250 - 5.856c$  [25], we calculated the  $y$  coefficients values for both Y123 and for the Y123 phase from Y123/BaCuO<sub>2</sub> sample (Table 3). We also performed a comparative analysis of the oxygen content in the Y123 bulk sample and in the Y123 phase. The difference between the results



for  $y$  obtained by the spectrophotometric and the XRD methods was not significant; the mean  $y$  value of the two methods was calculated and is presented in Table 3. One can see that the superconducting properties (total oxygen content  $y$  and  $\delta$  coefficient) of the 123 phase in the Y123/ BaCuO<sub>2</sub> bulk sample are the same as these of a single-phase Y123 superconductor. Furthermore, the values of  $y$  of the samples before and after treatment are within the limits of the random error.

Table 3

Values of the  $c$ -axis of the cell and the  $y$  and  $\delta$  oxygen coefficient before and after treatment by KOH

Sample	Spectrophotometric method		XRD-method		mean value of $y$
	oxygen coef. $\delta^*$	oxygen coef. $y$	$c$ unit cell param.	oxygen coef. $y$	
YBa <sub>2</sub> Cu <sub>3</sub> O <sub><math>y</math></sub> (Y123) Before treatment [21]	0.450	6.950	11.676(5)	6.875	6.912
Y123/ BaCuO <sub>2</sub> Before treatment	0.417	6.917	11.6586(13)	6.846	6.881
YBa <sub>2</sub> Cu <sub>3</sub> O <sub><math>y</math></sub> (Y123) After treatment [21]	0.458	6.958	11.672(5)	6.899	6.928
Y123/ BaCuO <sub>2</sub> After treatment	0.432	6.932	11.6614(10)	6.846	6.889

\* The confidence interval with  $P = 0.95$  for each sample is  $\pm 0.006$ .

#### MAGNETIC MEASUREMENTS

The complex magnetic moments for an AC magnetic field (ACM) for both (as-synthesized and alkaline-treated Y123/ BaCuO<sub>2</sub>) samples did not show any significant difference, except for the low-temperature region, where the real component of the susceptibility of the alkaline-treated Y123/ BaCuO<sub>2</sub> sample (Fig. 4a) was lower.

This may be related with the better ordering of the alkaline-treated Y123/ BaCuO<sub>2</sub>'s crystalline structure (see XRD) and the improved surface quality (after alkaline treatment – see SEM). At the same time, there was no difference in the samples' critical superconducting temperatures ( $T_c = 92.6$  K). The as-synthesized

Y123/ BaCuO<sub>2</sub> sample possessed a slightly stronger DC magnetic moment than the alkaline-treated sample at 10 K (Fig. 4b).

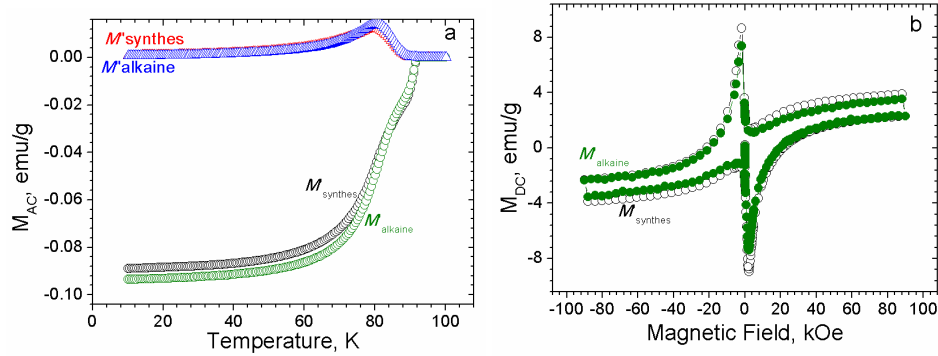


Fig. 4 – Real  $M'$  and imaginary  $M''$  parts of the complex magnetization a) and hysteresis loop at 10 K up to 9 T b) for as-synthesized and alkaline-treated samples.

It is interesting to note the unusual form of the hysteresis loop at 10 K. At lower magnetic fields up to  $H_1 = 2.3$  kOe, corresponding to the initial maximum of the diamagnetic moment  $M_{\text{dia-max}}$ , the magnetic field was completely screened. This field value, being the same in both samples, is in agreement with the value measured earlier for pure single-phase Y123, prepared by standard solid-state synthesis [2]. Above this field, the sample was in a mixed state up to a field where the DC magnetization went through zero and became positive. Further, the positive DC magnetization increased nonlinearly, which is characteristic for the existence of a magnetic component. Such a type of asymmetrical hysteresis has been observed earlier [26, 27] in superconducting/ferromagnetic composite materials. The points at which the ferromagnetic moment compensated the superconducting diamagnetic moment  $H_{\text{comp}}$  ( $M = 0$ ) were 21.5 kOe and 19.7 kOe for the as-deposited and alkaline-treated samples, respectively, and was in the same range as the results obtained for BPSCCO/LPMO samples [26]. The magnetic behavior at comparatively higher DC magnetic fields ( $> 20$  kOe) could be due to the presence of the second BaCuO<sub>2</sub> phase (38 mass % and 35 mass % for as-synthesized and alkaline-treated samples, respectively) in the samples (see XRD). The BaCuO<sub>2+ $\delta$</sub>  phase has a complex magnetic behavior depending on the stoichiometry (value of  $\delta$ ,  $\delta < 1$ ) and temperature range [28–32]. It could be ferromagnetic (FM), paramagnetic (PM) or antiferromagnetic (AFM) depending on the value of  $\delta$  and on the temperature. The parental unit cell of the BaCuO<sub>2+ $\delta$</sub>  compound is bcc oxocuprate with a lattice parameter  $a = 18.28$  Å and could be considered as constructed of three types of Cu clusters: two Cu<sub>18</sub>O<sub>24</sub> spherical clusters; eight Cu<sub>6</sub>O<sub>12</sub> ring clusters; and six CuO<sub>4</sub> lone units [28–32]. As the Cu units alone are mainly in a paramagnetic PM state, the Cu<sub>18</sub> and Cu<sub>6</sub> clusters could be FM or AFM

ordered, with the combined effective magnetic moment, giving rise to a complex magnetic behavior. In the BaCuO<sub>2</sub> compound, the FM order is replaced by an AFM one below 15 K [28, 29], while in BaCuO<sub>2.14</sub> there no long-range magnetic order, so that a PM order is observed [28, 29]. In some studies of BaCuO<sub>2.1</sub>, FM to AFM transition at 12 K [31] has been reported. All these investigations demonstrated the complex magnetic nature of the BaCuO<sub>2+δ</sub> compound, so that an even more complicated situation should be expected in our samples with YBCO (Y123) islands surrounded by a BaCuO<sub>2+δ</sub> phase.

Recently, the same unexpected magnetic behavior has been observed in the Y-Ba-Cu-O superconductor with additional BaCuO<sub>2</sub> as a secondary phase [33, 34]. It has also been suggested that the magnetic behaviour of the Y-Ba-Cu-O superconductor could be explained by the existence of secondary BaCuO<sub>2</sub> phase.

We also measured the DC magnetization of the as-synthesized sample in a DC magnetic field increasing up to 3 T at three different temperatures (10, 80 and 100 K). The magnetic field  $H_1$ , which corresponded to the maximum diamagnetic DC magnetization ( $M_{\text{dia-max}}$ ), as well as the magnetic field at which the DC magnetization changed its sign  $H_{\text{comp}}$ , decreased with the temperature. The non-linear dependence of the positive DC magnetization at 10 K was replaced by a linear one at 80 K, Figure 5a. Above the critical temperature of 100 K, a paramagnetic dependence took place, which is in agreement with the results of Yamamoto *et al.* [29]. They observed that a FM order in Cu<sub>6</sub> clusters for BaCuO<sub>2.00</sub> compound arose below 100 K and was replaced by an AFM order below 15 K.

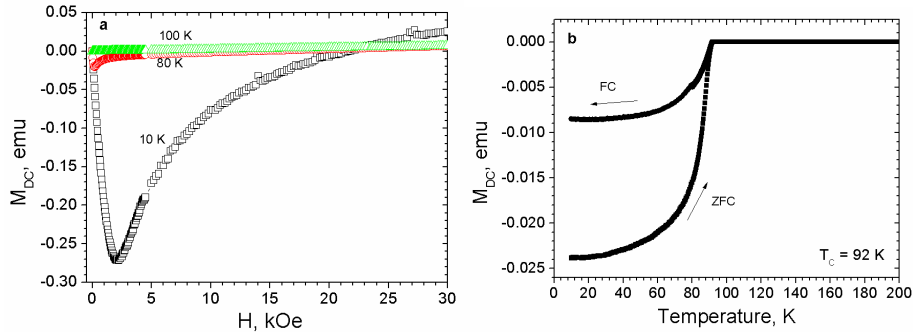


Fig. 5 – DC magnetization vs. magnetic field at different temperatures a) and ZFC-FC magnetization vs. temperature at 100 Oe DC magnetic fields b) for as-synthesized Y123 sample.

A critical temperature of 92 K was also obtained from the ZFC-FC measurements of the DC magnetization vs. temperature (Fig. 5b), which supported the results obtained from AC magnetization measurements (Fig. 3a).

The differential magnetization was additionally measured at four different frequencies (1, 3, 5 and 7 kHz) with an amplitude of the AC magnetic field of 10 Oe, Fig. 6. At the frequency of 1 kHz and an amplitude of 10 Oe of the AC

magnetic field, the AC magnetization was measured in two cases with and without an additional DC magnetic field (a DC magnetic field of 100 Oe was applied parallel to the AC magnetic field after ZFC to 2.2 K).

The temperature dependence of the real part of the differential magnetization  $\chi'(T)$  without a DC magnetic field exhibited a similar behavior for all applied frequencies (1–7 kHz). First, as the temperature was raised,  $\chi'$  increased slowly up to about 50–60 K. Next,  $\chi'$  increased faster up to about 85–90 K. The rise became very steep close to the SC transition.

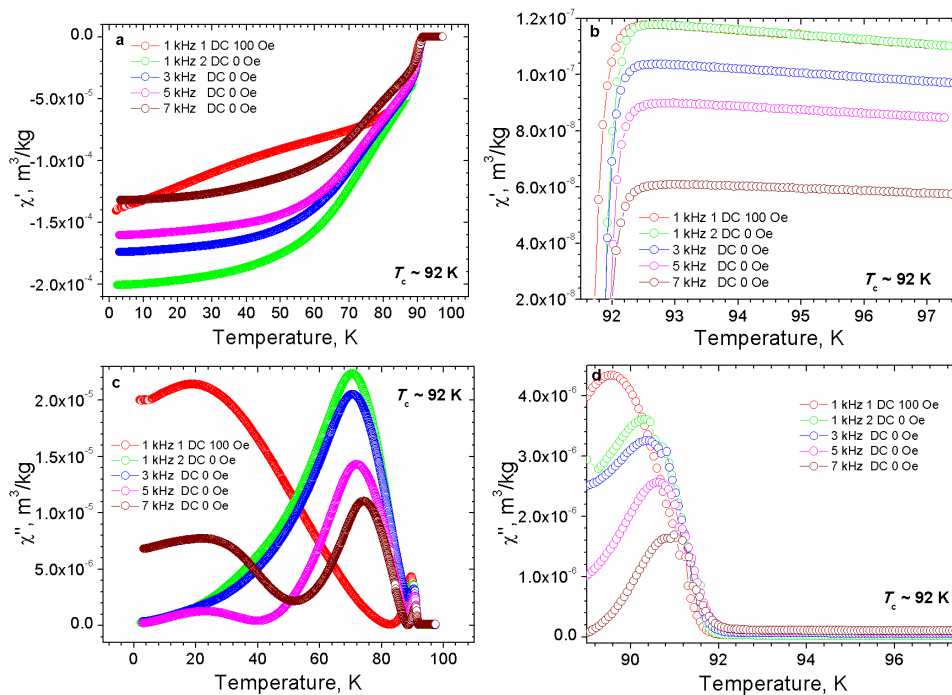


Fig. 6 – Differential AC magnetization of as-synthesized Y123/ BaCuO<sub>2</sub> sample vs. temperature: the real part of the AC magnetization for the whole temperature range (2–100 K); a) enlarged real part of the AC magnetization close to the critical temperature; b) the imaginary part of the AC magnetization for the whole temperature range (2–100 K); c) and enlarged imaginary part of the AC magnetization close to the critical temperature.

The presence of regions with different slopes could be due to both the polycrystalline nature (inter- and intra- grain currents) and the second phase (BaCuO<sub>2</sub>) in our samples. The application of additional ZFC DC field (100 Oe) lowered the AC magnetic moment and changed the shape of the curve (from convex to concave). The increasing of frequency led to a decrease of the magnetic moment in a superconducting state and to increase in a normal state. In a normal state, there existed a small positive moment ( $6 \times 10^{-8} - 1.2 \times 10^{-7} \text{ m}^3/\text{kg}$ ) with a linear

behavior of  $\chi'(T)$  and a negative slope of the curve. The imaginary part of the differential magnetization as a function of the temperature was strongly non-linear. At lower frequencies (up to 3 kHz), there were two maxima. At the higher frequencies (5 and 7 kHz), an additional maximum developed. The increasing of frequency resulted in a decrease of the imaginary part of the AC susceptibility and a decrease of the maxim's height their positions were shifted to the higher temperatures. The curve at 7 kHz and the curve at 1 kHz with an additional ZFC DC magnetic field of 100 Oe at a low temperature indicated higher magnetic susceptibilities.

## 5. CONCLUSION

A reproducible and well defined ceramic compound with nominal composition (Y123/BaCuO<sub>2</sub>) has been synthesized in one-step reaction. Our studies demonstrate composed that the sample is of two phases – Y123 and BaCuO<sub>2</sub> in a ratio of 2:1, respectively. The resulting composite material exhibits superconducting as well as magnetic properties. It is found that the oxygen content in the formula unit of the Y123 phase in the composite is 6.917, which is very close to the value of the referent single phase of the monophasic superconducting phase Y123, namely, 6.950. The composite Y123/BaCuO<sub>2</sub> possesses both ferromagnetic and diamagnetic properties with a superconducting transition temperature of 92.6 K. The data shows that the magnetic properties of the compound are due to presence of the composite material BaCuO<sub>2</sub>. Besides the superconducting properties, (typical for Y123), the Y123/BaCuO<sub>2</sub> composite exhibits some unusual magnetic properties due to the presence of the second phase – BaCuO<sub>2</sub>. Such types of composite materials represent a great interest from both fundamental and practical points of view. A high chemical resistance of the Y123/BaCuO<sub>2</sub> composite to an alkaline solution is observed and confirmed by structural and magnetic measurements. The study reveals that the Y123/BaCuO<sub>2</sub>-composite is remarkably stable and its superconducting properties remain unchanged after treatment in alkaline solutions. The substantial innovation in the synthesis of the composite material is the reduction of the quantity of “Y” by introducing of a second phase in the system. On the other hand, the superconducting and magnetic properties of the material are the same as the properties of the system Y123. We believe that the synthesized composite may be useful for practical application of “Y”-superconductors with an economic effect. Moreover, the material is resistant to alkaline treatment, which is important for practical application in the manufacture of batteries.

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