Analysis of technology methods and study of properties of high-temperature superconducting ceramics based on YTTIRIUM

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1 Introduction

The development of high-temperature superconducting (HTSC) ceramics is very topical. The international scientific community has reached a temperature slightly higher than the temperature of liquid nitrogen (77 K) for the critical temperature of the superconducting transition \( T_c \). If results above this value are achieved, it will be possible to use HTSC materials in various industries in electronics, electrical engineering, transport, and other areas of the economy. Therefore, research was developed in the fundamental direction and the applied aspect [1]. The key problem was the development of technologies that make it possible to manufacture the required products from such fragile ceramic materials as complex cuprates: wires and cables, inductors, cavity resonators, etc. In many cases of "low-voltage" applications (electronics, sensors), the use of film technologies for fabricating structures based on HTSC films proved effective. However, for "high-current" applications (energy, transport, accelerator technology, etc.).
2 Objects and methods of research

\[ \frac{1}{2} Y_2O_3 + 2BaO_2 + 3Cu + nO_2 \rightarrow YBa_2Cu_3O_{7+x} + Q, \]

\[ Y_2O_3 + BaCO_3 \rightarrow 2BaO_2 + O_2 \]

2 Objects and methods of research

\[ YBa_2Cu_3O_{7+x} \] is synthesized using all the reagents or one of them in the form of UDP. It was shown that when the synthesis temperature of the HTSC phase 1 decreases, and sintering of the formed grains of the HTSC phase is prevented, undesirable at the stage of successive chemical and structural transformations of synthesis (SES) from a powder. The use of UDP as an oxidizer, the degree of compaction of the initial charge, the use of an additional oxidizer, the possibility of controlling the combustion temperature (which determines the self-propagation of the reaction in the charge) due to the high stored energy of ultrafine particles.

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The formation of the compound \( YBa_2Cu_3O_{7+x} \) at the boundary of the reagents due to their surface activity, defectiveness of the substance of submicron copper particles (having the maximum stoichiometric content in the composition 1 with the use of UDP Cu, the synthesis temperature decreases to 920 °C within 10 min by introducing an additional oxidizer, the degree of compaction of the initial charge. The second series consisted of the same samples, but the conditions for measuring the ADAP curves differed.

The synthesis of the superconducting orthorhombic phase \( YBa_2Cu_3O_{7+x} \) is a diffusion process. An analysis of its flow and characteristics. Synthesis of the superconducting orthorhombic phase \( YBa_2Cu_3O_{7+x} \) showed that when the synthesis temperature of the HTSC phase \( 2 \) decreases, and sintering of the formed grains of the HTSC phase is prevented, undesirable at the stage of successive chemical and structural transformations of synthesis (SES) from a powder.

Among many well-known methods for synthesizing components, among all possible by the reaction:

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The survey was conducted in a temperature range of 900 ... 970 °C, which determines the self-propagation of the reaction in the charge. The use of UDP as an oxidizer, the degree of compaction of the initial charge, the use of an additional oxidizer, the possibility of controlling the combustion temperature (which determines the self-propagation of the reaction in the charge) due to the high stored energy of ultrafine particles.

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carried out under cryostatting (77...300 K). The third series of samples was prepared using the nitrate technology ($T_c = 85$ K) under a pressing pressure of $3\, N/\, sm^2$. The fourth series of samples was a pressing of yttrium-barium cuprite powder (TU48-0531-375-97) at a pressing pressure of $6.4\, N/\, sm^2$. The fifth series of samples was irradiated by HEB at the Tonus accelerator at the Tomsk Polytechnic University with the following parameters: energy $1.3\, MeV$; current density $j = 1.2\, kA/\, sm^2$, pulse duration $\tau = 50\, ns$. The ADAP curves were measured on a setup with a conditional resolution of $1\, mrad$ and a NaJ positron source with an activity of $7\, mCi$. Temperature measurements were carried out in an annihilation chamber, in a vacuum in the temperature range (77–300) K, which made it possible to carry out measurements in the region of the critical temperature of the HTSC $T_s$. Each spectrum was measured for $16 ÷ 18\, hours$, and the total score under the curve was $(1.5 – 6) \cdot 10^6$ counts. The positron lifetime (PLR) was measured on a fast-fast coincidence spectrometer with a time resolution of $225\, ps$ (width at half height). After subtracting the annihilation lifetime in the source substrate from the spectrum $\tau_1 = 150\, ps, \tau_2 = 450\, ps$, the spectrum was decomposed into two components. A helium cryostat was used, which allowed changing the temperature from 10 to 300 K. The temperature stability was no worse than $0.5\, K$.

Phase $1-2-3$, unreacted $Y_4Ba_3O_9$, $BaCuO_2$, as well as a small amount of orthorhombic phase $1-2-3$. The content of the HTSC phase $C$ increased to $40\%$ after annealing at $950\, ^oC$ for 2 h and to $50 – 60\%$ after annealing at $950\, ^oC$ for 6 h [1, 5].

For the study, samples were made in the form of tablets with a diameter of $11.2\, mm$, pressed under pressure, by two methods: statistical mode and when exposed to ultrasound. The USW intensity was set by the output voltage of the US generator $U_{USW} = 50.75$ and $100\, V$, which corresponded to the amplitudes of the mold wall oscillations $A_{USW} = 5.10$ and $15\, \mu m$ at a frequency of $21.5\, kHz$. The samples were baked for $48\, hours$ at different temperatures for different samples: for samples based on UDP-copper at a temperature of: $890\, ^oC$, and for samples based on standard reagents at a temperature of $950\, ^oC$. The results of the research can be found in Fig. 1.

Fig. 1. Density of compacts $\rho_p$ depending on intensity of ultrasonic waves and pressing pressure ($P$) UDP HTSC: 1) 746 MPa; 2) 907 MPa; 3) 1069 MPa; and charging from standard reagents: 4) 746 MPa; 5) 907 MPa. Values of the Meissner effect, which correlates with the content of the HTSC phase in the samples, depend on the charge pressing pressure before SHS initiation. Our studies have shown that the formation of texture during sintering of $1-2-3$ ceramics from the synthesized UDP HTSC proceeds optimally at a pressure of uniaxial dry pressing above $300\, MPa$, a duration of pressing under such a load of more than $10\, h$ and a sintering temperature of $950 - 975\, ^oC$ [1, 5].
3 Electrophysical properties of HTSC ceramics and developed products

Table 1. Electrophysical properties of samples of HTSC ceramics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ρc (Ω·cm)</td>
<td>9.6…6.2</td>
<td>10…20</td>
<td>9.5…5.3</td>
</tr>
<tr>
<td>Tc (K)</td>
<td>95…85</td>
<td>90…75</td>
<td>90…75</td>
</tr>
<tr>
<td>ΔTc (K)</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>jс (A/cm²)</td>
<td>920</td>
<td>150</td>
<td>250</td>
</tr>
<tr>
<td>Q1</td>
<td>150</td>
<td>241</td>
<td>241</td>
</tr>
<tr>
<td>Q2</td>
<td>241</td>
<td>241</td>
<td>241</td>
</tr>
</tbody>
</table>

Where *dz* is the average grain size according to optical and scanning electron microscopy data; **jc** is the critical current density determined by the 4-probe method (77 K, 0 T); Q1 is the quality factor of polished ceramic samples at a frequency f = 3 GHz (2Δf = 20 MHz) at room temperature (in the numerator) and at 77 K (in the denominator), measured at the Laboratory of Microwave Radio Engineering MIREA O.M. Oleinik; Q2 is the quality factor of the same specimens, measured under the same conditions one year later, indicates the resistance of ceramics to degradation.

Tests of the same cylindrical samples as screens for electromagnetic fields were carried out at the SPTI at TSU.
Curves of superconducting transition for HTSC ceramics fabricated using UDP Cu: 1) dry static pressing, sintering at 920°C and 950°C, respectively (measurements of $T_c$ were carried out at FLNP JINR by V.N. Polushkin); 2) Ultrasonic pressing, sintering at 950°C (measurements of $T_c$ were carried out at LSHFHR MIREA by A.A. Bush).

The screening factor at $T=77$ K at a frequency of 10 kHz was $k>100$. The hysteresis of the field-voltage characteristic (VFC) of the HTSC screen at 77 K, in contrast to the constant at 300 K, also indicates the diamagnetic properties of the product under study (current through the sample $I_{cm}=1.3$ mA; $f=10$ kHz). The sensitivity of a superconducting quantum interference sensor (SQUID) is characterized by the parameter $\beta$:

$$\beta = 2 \cdot L \cdot \frac{I_c}{\Phi_0}$$

which is usually a hole with a diameter of 0.5...1.0 mm; $I_c$ is the critical current through the Josephson junction (JC); $\Phi_0=2.07 \times 10^{-15}$ V is the magnetic flux quantum. For HTSC squids, the values $\beta=1...2$ are realistically achievable. Therefore, the value of $I_c=1...10$ mA.

For HTSC ceramics, the values of the critical current density $j_c = \frac{l_c}{s} = 10 ... 10^3$ A/sm$^2$ should be within 0.1...100 $\mu$A/µm$^2$.

To form a DP in HTSC ceramics from grains of the specified sizes, we used the methods of solid-phase synthesis and dry pressing described above to manufacture ceramic HTSC SQUID-Zimmermann type. DP was formed in an HTSC tablet between two holes during the formation and sintering of a dense textured HTSC ceramic with a density of 5.7 – 6.0 g/cm$^3$ with grain sizes in the texture plane of 10 – 20 µm. Then, by mechanical scribing under control under an optical microscope and subsequent heat treatment in an oxygen environment, the critical current density $j_c$ can be determined by the average grain size of HTSC ceramics. This condition determines the average grain size of HTSC ceramics.
flow, the required DP thickness of ~10 μm was achieved. The sensitivity of SQUIDs to an external magnetic field reached values of $1...2 \mu V/\Phi_0$.

4 Conclusions

Under natural conditions, SHS of both a bulk charge of composition 1-2-3 and compacts does not lead to the formation of an HTSC phase, the synthesis of which requires additional annealing at $950^\circ\text{C}$.

The initiation of SHS in the air by an electric pulse from the surface of the compacts of the investigated geometry is observed only for a charge with UDP Cu; the use of coarsely dispersed copper, in this case, does not provide the necessary thermal effect of the reaction.

For the formation of an HTSC phase by the SHS method, reagents of a grade no worse than "analytical grade" (primarily, the $\text{Ba}_2\text{O}_3$ oxidizer) are required.

References


