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Degradation and Restoration of Superconducting Parameters of HTS Tapes under Mechanical Loads and Heat Treatment

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Abstract

As it is known, the current-carrying properties of HTS tapes are structurally sensitive parameters, and largely depend on the grain size, morphology, texture, presence of pinning centers and others. These structural parameters may be changed by shock loading actions.

The report presents the results of research of varying intensity shock loads effects from 0.35 to 100 J/cm^2 on the structure and characteristics of superconducting Bi-2223 tapes. A strong degradation of the critical current J_c and critical temperature T_c were shown for tapes exposed by strikes with a specific energy higher than 5 J/cm^2. The structural changes in the superconducting interlayers exposed by shock loads are researched. Subsequent thermal treatment at the temperatures from 825^{o}C up to 840°C for 5-10 hours leads to the restoration of the superconducting characteristics. The superconducting transition after annealing becomes sharper, and the values of T_c on 4-5 K higher than for samples in the initial state. The critical current increases monotonically with increasing of annealing time.

Keywords: Superconductivity, HTS tapes, mechanical impacts, morphology, critical current

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1. INTRODUCTION

Firstly shock waves with pressure 10^{11} Pa were used to increase the current-carrying capacity of commercial composite YBCO (123) HTS tape in the works [1, 2]. The implementation of sub micro second shock-wave effect was achieved by using high cumulative interaction of plasma jets with a solid target. The mechanism of action is based on the fact of formation of point defects - vacancies and interstitials (collective Frenkel pairs) at the front of shock waves when they pass through the metal and semiconductor materials [3]. At the same time the concentration of vacancies arising after impact

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of the plasma jet can be many times greater than the concentration of thermal vacancies in the initial material [3]. On the basis of the open effect (formation of point defects in the metallic and semiconductor materials at the front of shock waves for niobium-based alloys) effect of laser influence at the superconducting transition temperature (T_c) was studied [4, 5]. These experiments showed a marked effect of shock waves influence at the critical temperature T_c. The observed effect is due to the acceleration of diffusion processes arising from the shock waves pass, excess of thermodynamic equilibrium defects and the appearance of dislocation loops. The results of these studies suggest that the shock waves of high power will cause significant changes in the superconducting characteristics and HTS structure of tapes both by creating a more equilibrium structure-phase states, and due to the formation of dislocation loops deployment and vacancy voids that may play a role of effective pinning centers.

In recent years an increasing interest is connected not only with the use of shock waves (SW) generated by plasma pulses, but also with metered mechanical shocks [4-10]. Interest in this research is growing because of the possibility to use this method for improvement the critical current of ready commercial tapes.

The purpose of this work is to study the influence of mechanical shock with energy (from 0.5 to 100 J/cm^2) and the heat treatment in the range 830-840°C at the value of the frozen magnetic field, the critical temperature T_c, the critical current in the magnetic field 2-9 T and microstructure of superconducting layers.

2. MATERIALS AND EXPERIMENTAL METHODS

Investigations were carried out on the commercial multilayer composite tapes, which are consist of a silver matrix with $(BiPb)_2Sr_2Ca_2Cu_3O_{10+x}$layers. The samples had the following dimensions: thickness - 0.2 mm, width - 4 mm, length - 35-40mm. On the special installations tapes were subjected by mechanical shocks with different energy (from 0.5 to 100 J/cm^2). At the first installation the shock striker with weight 0.71 kg dropped vertically in the pipe from different height: 4.3 cm, 12 cm, 30 cm and 45 cm, the square of strikes was equal to 0.6 cm^2. The energy of strikes was 0.5, 1.38, 3.3 and 5.16 J/cm^2.

On the second installation the strikes on the surface of the tape applied by loads of the special form with mass – 0.5 and 0.8 kg from the height - 0.3 m. After each strike the tape moved a step from 0.4 to 1.2 mm. Area of strike overlapping was about 0.1 mm. The dimensions of the striker were greater than the width of the tape. The area of mechanical shocks was $\sim$ 1.6 mm^2. Specific mechanical energy of impact was varied from 15 to 100 J/cm^2.

After the mechanical strikes tapes were annealed in a muffle furnace in air at 830-835°C for 5-30 hours. Cooling of the samples to 300 K was carried out with the oven. The temperature stability in the annealing process was ± 4°C.

Microstructure of the tapes was investigated by optical and scanning electron microscope EVA-40 Zeiss Company. The elemental composition of the ceramic layers in Bi-2223 tapes examined with a scanning microscope JSM-35 with the Link prefix. X-ray analysis of the HTS layers was carried out on Ultima IV Rigaku diffractometer.

The picture of the frozen magnetic field in HTS tapes was studied by scanning Hall magnetometry [11].

The temperature of the superconducting transition (T_c) measured by the 4-probe method in the temperature range 78 - 115 K. Measurements of the temperature dependence R(T) were performed in the original state, after the application of mechanical shocks, and after heat treatment. The potential probes are soldered to the surface of tapes by indium along the edges of mechanical shock zone (10-12mm). The value of measuring current was equal to 3, 10 and 30 mA, the current frequency - 9 Hz.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The influence of strikes leads to the marked thinning of the tapes in the strike zone. The degree of deformation can be varied from 0.1% to 15% or more and depend on the shock energy. After strikes with energy greater than 5 J/cm^2 appreciable disorders were observed in the cross section of the superconducting tapes, in the superconducting layers and silver matrix. The length of step between the strikes has a marked effect on the surface relief of the tapes. At fig.1. regular longitudinal stripes in the strike zone are observed. An increase of the step of tape movement from 0.4 to 0.6 mm leads to the marked increase in the number of longitudinal stripes on the surface of the tape. Further increase of the step (to 0.8 - 1.2 mm) leads to the complete disappearance of the stripes.

The results of measurements of the frozen magnetic field in the tape after application of the single mechanical shock with an energy - 0.5 J/cm^2 demostrated a sharp decrease of magnetic field in the strike zone (close to zero) (2a). Subsequent annealing at 835°C for 4 hours, restored the value of the frozen field (2b).

The results of microstructure researches in the cross section in the initial state and after exposure by mechanical shock with different energies showed marked differences in size, shape of HTS layers and silver sheath. In the initial tapes irregularly arranged ceramic layers, pores, cracks and silver layers with different thickness are observed. The presence of these defects is the structural reason of decrease of the

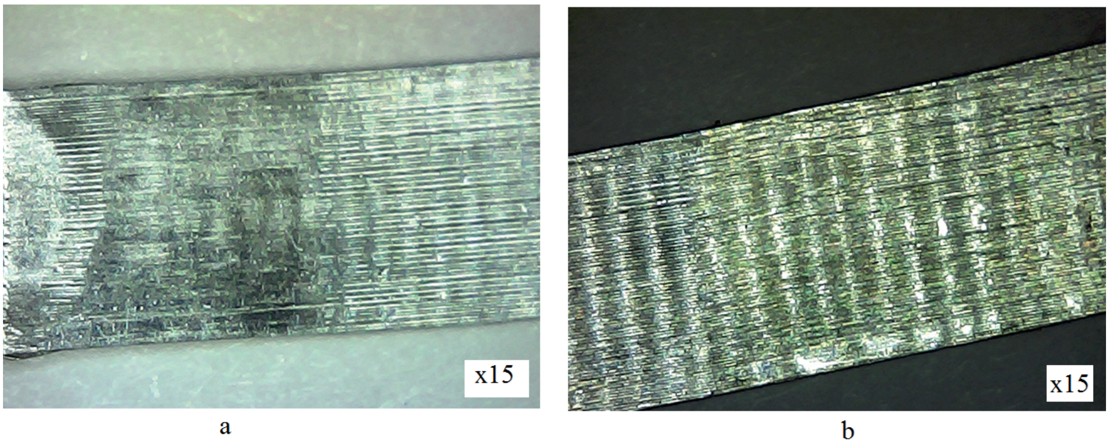

Figure 1: The relief of Bi-2223 tape surface after applying the mechanical shocks with the energy 0.1 J/cm^2, the step of displacement a- 0.4 mm, b- 0.6 mm.

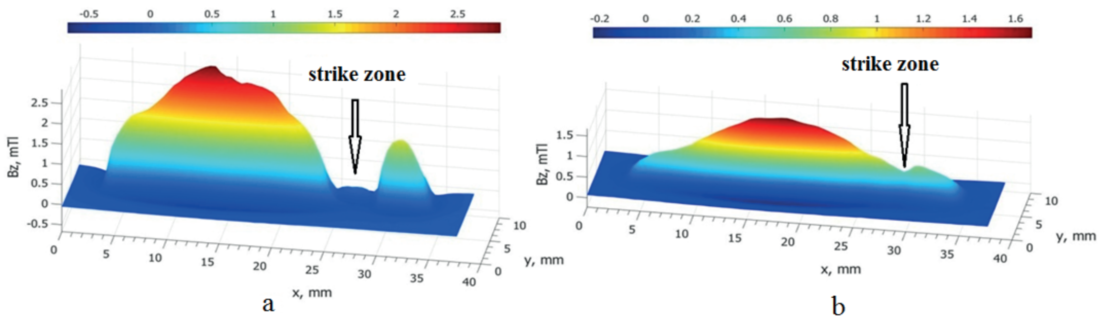

Figure 2: The value of the frozen magnetic field in the Bi-2223 tapes after single mechanical shock impact with energy of 1.4 J/cm^2 (a) and the subsequent heat treatment at 835°C for 4 hours (b). The arrow marks - the spots of the strike.

critical current and the magnetic field. After exposure by high intensity mechanical shocks (greater than 20 J/cm^2), there was an increase of the number of gaps in the ceramic and silver layers. The thickness of the tapes in the strike zone decreased and the degree of deformation reached 5-15%. During the studying in the surface layers and in the structure of original HTS and processed HTS (after removal of silver from the surface of the tape) (Fig. 3) a significant difference in the density was esteblished. After the shock impact and heat treatment HTS grains have became larger and more densely packed (fig. 3. c, d).

The temperature of superconducting transition (T_c) is less sensitive to defects in the structure after impact shock pulses. On fig. 4. the dependence of the resistance from temperature R (T) for the tape in the initial state and after influence with energy 15 J/cm^2 and annealing at 835°C for 5 hours are presented. It can be seen that the superconducting transition in the original sample is wider (from 102K to 108K). After strikes the width of the transition significantly expanded and T_c decreases. In the sample which was subjected by shocks and heat treatment, superconducting transition

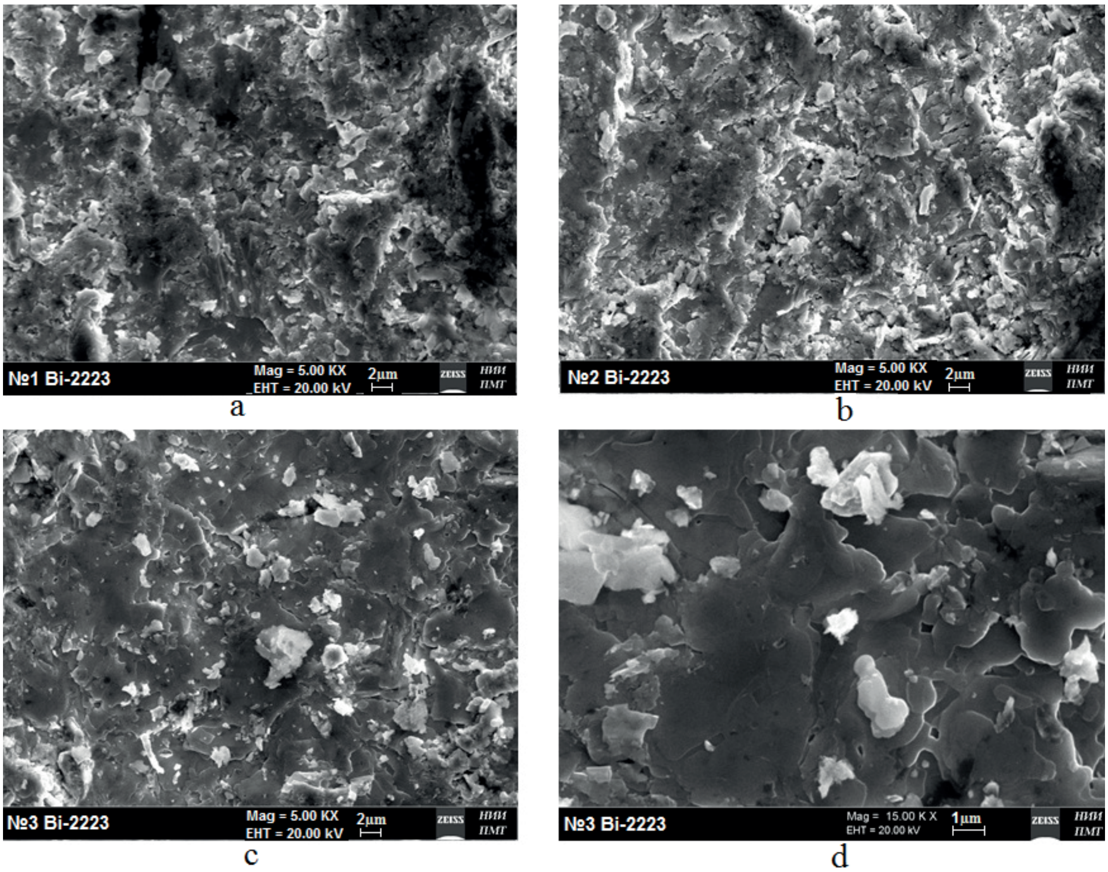

Figure 3: The microstructure of HTS surface layers in the initial state (a), after the application of mechanical shock (b), after heat treatment at 835°C for 5 hours (c, d). .

becomes sharper (106 - 107 K). In the middle of the transition T_c increases and reaches 4-5 K (Fig. 4).

The dependence of the critical current from magnetic filed for the samples subjected by shocks of different energy (5.16 and 0.5 J/cm^2) and subsequent annealing at the temperature 835°C for 5 hours are shown in Fig.5. On the samples of tapes after impact with energy 0.5 J/cm^2 in the parallel magnetic field the critical current is 110 A, and in the field 6T the critical current reaches 140 A (curve 1). The results indicate a high current-carrying capacity of these tapes in the magnetic fields from 7 to 10 T. With decreasing magnetic field below 5T the critical current should increase manifold. It can be seen from the direction of the curve 1. However, measurements of critical currents in the magnetic fields in the range (0-5.0 T) at this stage was not carried out because of the lack more powerful source of direct current.

With an increase of impact energy to 5.16 A/cm^2, the critical current (curve 2) significantly decreases. Thus, it is clear that the impact energy is an important factor affecting at the current carrying capacity of Bi-HTS tapes, including in high magnetic fields.

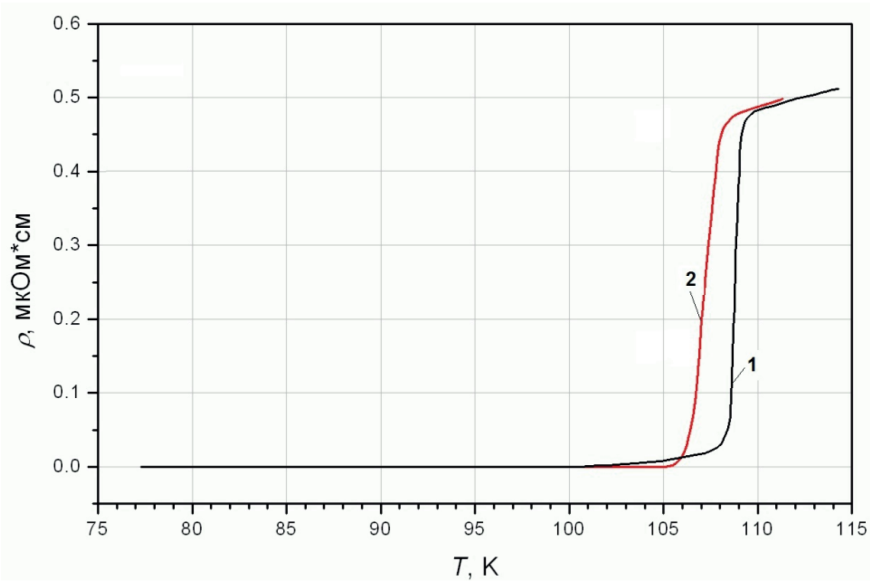

Figure 4: The dependence R(T) for a Bi-HTS tape in the initial state (1) and after the application of mechanical shock and subsequent annealing at 835°C for 5 hours (2).

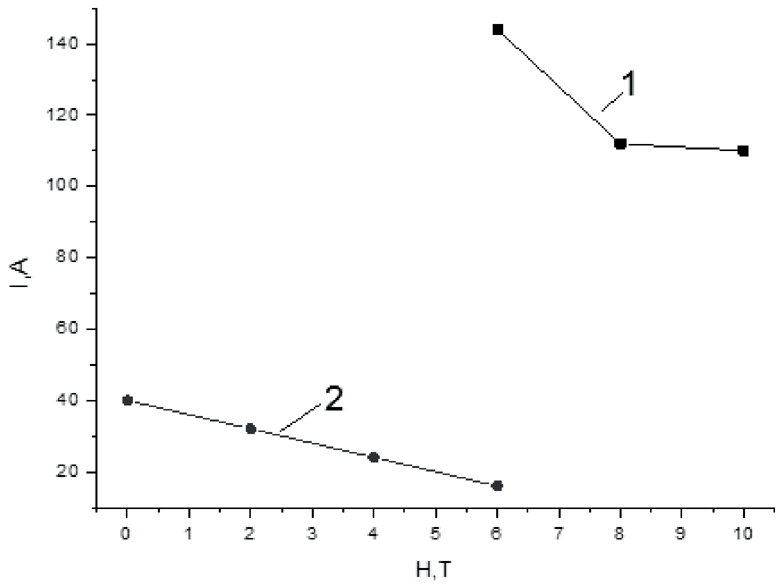

Figure 5: The dependence of the critical current from magnetic filed for superconducting Bi-2223 tapes treated by mechanical strikes with energy 0.5 J/cm^2 - curve 1 and 5.16 J/cm^2 - curve 2), (II magnetic field T = 4,2K).

4. CONCLUSIONS

1. The limit values of mechanical shocks energy at the surface of the Bi-HTSC tapes in which superconductivity in the strike zone is maintained are established.

2. The possibility of full recovery of the superconducting properties of HTS tapes (T_c, frozen magnetic field, the critical current I_c) after exposure by mechanical shock

pulses with energy density from 0.5 to 1.5 J/cm^2 and heat treatment at the temperature 835°C were researched. With increasing shocks energy it is necessary to use longer annealing to restore the superconducting properties.

3. After applying mechanical shocks with optimal energy and thermal treatment of HTS layers structure becomes more homogeneous and dense.

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