УДК 538. 945

EFFECT OF HIGH ENERGY RADIATION ON CRITICAL PARAMETERS OF SUPERCONDUCTING CERAMICS $YBa_2Cu_3O_7$

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Critical temperature (T_c) and critical current density (j_c) of high temperature superconducting (HTSC) ceramics $YBa_2Cu_3O_7$ were measured as functions of dose from $5x10^3$ Gy to $3x10^8$Gy. Samples were irradiated at room temperature by protons with energies 0.66 and 8.09 GeV and by ^{12}C with energy 3.65 GeV/nucleon. Radiation degradation of critical parameters j_c and T_c of HTSC-ceramics is stronger than in the NbTi alloy based superconductors and is obviously connected with the formation of disordered regions, leading to the electron localization and to the infractions of Josephson contacts between ceramics grains.

The investigation has been performed at the Laboratory of High Energies, JINR.

Влияние излучений высокой энергии на критические параметры сверхпроводящей керамики $YBa_2Cu_3O_7$

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Измерены зависимости критической температуры (T_c) и плотности критического тока (j_c) высокотемпературной сверхпроводящей (ВТСП) керамики $YBa_2Cu_3O_7$ от дозы в диапазоне $5 \cdot 10^3$ $3 \cdot 10^8$ Гр. Облучение проведено при комнатной температуре протонами с энергией 0,66 и 8,09 ГэВ и ядрами ^{12}C с энергией 3,65 ГэВ/нуклон. Радиационная деградация критических параметров j_c и T_c ВТСП-керамики сильнее, чем у сверхпроводников на основе NbTi сплава, и связана, по-видимому, с образованием разупорядоченных областей, приводящих к локализации электронов и нарушению джозефсоновских контактов между гранулами.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Samples and Conditions of Irradiation

Single-phase samples of $YBa_2Cu_3O_7$ ceramics were prepared as described in ref.(1) and had dimensions not exceeding 1x4x15 mm.

Such sample size was determined mainly by ceramics mechanical strength, by the construction of current and potential contacts, and by the cross section of extracted beam from a synchrophasotron and phasotron of JINR in the region of irradiation.

Samples were irradiated at room temperature directly by protons with energy E_p = 660 MeV and ^{12}C nuclei with energy E = = 3.65 GeV/nucleon, and also by protons with energy E_p = 8.09 GeV through a copper target. Dose fractions after the samples successive irradiations (D) are presented in the table.

At D $\lesssim 10^5$ Gy the doses were determined both directly, using the coloured film dosimeters (12), and by fluence (ϕ) of the beam through the samples. At D $\gtrsim 10^5$ Gy the doses were determined by the fluence only (taking into account nuclear interactions) by measuring the activation from the $^{27}Al(p,3p3n)^{22}Na$ reaction of the aluminium foils the samples were rapped in. Transition coefficients from ϕ to D are:

$$K_p\,(E_p = 0.66\ \text{GeV}) = 2.9 \times 10^{-10}\ \text{Gy} \cdot \text{sm}^2\,;$$

$$K_{^{12}C}\,(E = 3.65\ \text{GeV/nuc}) = 17 \times 10^{-10}\ \text{Gy} \cdot \text{sm}^2\,.$$

In all cases the dose determination error did not exceed 20%. Following ref. (3), for the protons with E_p = 0.66 GeV the number of displacements per atom was calculated as $C_d = 6.4 \times 10^{-21}$ per unit fluence.

Effect of Irradiation on j_c and T_c

Measurements of the volt-ampere characteristics (VAC) and resistance of samples R(T) after each irradiation fraction were carried out independently on three different apparatuses by using the standard 4 contact method. As a rule, with increasing dose the regular growth of specific resistance was observed at room temperature.

The relative change in critical current density caused by a dose $j_c(D)/j_{c0}(D)$ for all the irradiated samples of $YBa_2Cu_3O_7$ ceramics (3) and for the NbTi alloy based superconductors (1 and 2) is shown in fig. 1. Data on samples, primarily different in quality and specific resistance under normal conditions and then irradiated by protons, are in good enough agreement and lie on a common curve (3). At irradiation with heavy charged particles (in our case carbon nuclei) the degradation curve shifts to the region of smaller doses. It should be

Table

Doses at successive irradiation of HTSC-ceramics $YBa_2Cu_3O_7$, Gy

N	Sample code and symbol of experimental points in figs. 1 and 2		Type of radiation and energy of particles						Sum of dose
			p, E_p=8.09 GeV irradiation through target	p, E_p=8.09 GeV irradiation through target	^{12}C, $E_{^{12}C}$=3.65 GeV/n	p, E_p=0.66 GeV	^{12}C, $E_{^{12}C}$=3.65 GeV/n	p, E_p=0.66GeV	
			1	2	3	4	5	6	*
1	M1	⊕	$5.2\cdot10^4$	$4.8\cdot10^4$	-	$3.5\cdot10^5$	-	-	$4.6\cdot10^5$
2	M2	⟠	-	-	$5\cdot10^3$	-	$1.3\cdot10^4$	-	$1.8\cdot10^4$
3	D1	□	10^5	$4.8\cdot10^4$	$2.6\cdot10^3$	$3\cdot10^6$	$3.5\cdot10^4$	-	$3.2\cdot10^6$
4	D2	⊽	-	10^4	$8\cdot10^2$	-	-	$3.5\cdot10^5$	$3.6\cdot10^5$
5	D3	◊	-	$3\cdot10^4$	$8\cdot10^3$	-	-	-	$3.8\cdot10^4$
6	D6	◊	-	-	-	$2.2\cdot10^5$	-	$1.7\cdot10^8$	$1.7\cdot10^8$
7	D8	○	-	-	$6\cdot10^4$	-	$3.4\cdot10^4$	-	$9.4\cdot10^4$
8	D10	▽	-	-	-	$1.5\cdot10^7$	-	$2.9\cdot10^8$	$3.1\cdot10^8$
9	D11	△	-	-	-	$4.4\cdot10^5$	$2.8\cdot10^4$	-	$4.7\cdot10^5$
10	B1	◧	-	$1.6\cdot10^4$	$2\cdot10^2$	-	$3\cdot10^4$	-	$4.6\cdot10^4$
11	B2	⊗	-	$8\cdot10^4$	$1.5\cdot10^3$	$5\cdot10^6$	$1.5\cdot10^4$	$1.6\cdot10^8$	$1.6\cdot10^8$
12	B3	●	-	-	-	$3\cdot10^4$	$3.5\cdot10^4$	$4.4\cdot10^5$	$5\cdot10^5$
13	B4	▲	-	-	-	$1.5\cdot10^4$	-	$2\cdot10^8$	$2\cdot10^8$
14	B5	◩	-	-	-	$2\cdot10^4$	$3.2\cdot10^4$	-	$5.2\cdot10^4$

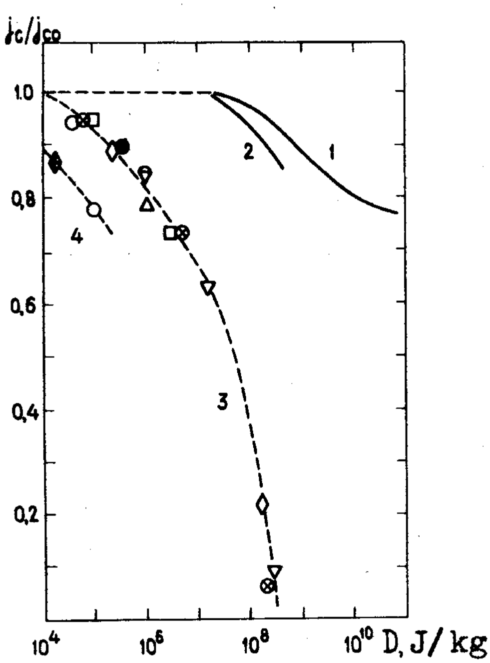

Fig. 1. Dependence $j_c(D)/j_{co}(D)$ for the low temperature NbTi superconductors irradiated by reactor neutrons (1) and protons with energy 30 GeV (2), and for the HTSC-ceramics $YBa_2Cu_3O_7$ irradiated by protons with energy 0.66 and 8.09 GeV (3) or nuclei ^{12}C with energy 3.65 GeV/nucleon (4). Denotions are indicated in the table.

noted that the irradiation under similar conditions of a monocrystal of a $YBa_2Cu_3O_7$ compound investigated in work (4) has increased j_c by 2-3 times, while the reported here HTSC-ceramics are by 1-2 orders of magnitude less radioresistant than the NbTi superconductors, which are also sensitive to the type of irradiation at equal doses.

Figure 2 shows the dependence of the relative critical temperature of the given HTSC ceramics on the doses $T_c(D)/T_{co}(D)$ in comparison with the results on irradiation of Chevrel phases and A-15 structures (6). Data on different samples lie also on a common curve and are in agreement with earlier data (7,8). The observed in work (4)

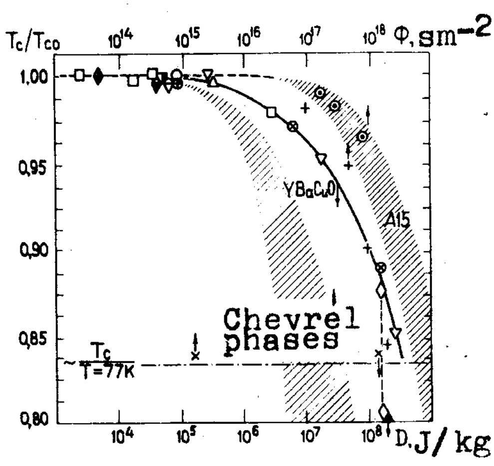

Fig. 2. Dependence $T_c(D)/T_{co}(D)$ for the HTSC-ceramics $YBa_2Cu_3O_7$ under irradiation: a) by protons and ^{12}C nuclei (solid curve with experimental points on it, symbols being explained in the table; b) by neutrons with E_n > 0.1 MeV (the data on single-phase ceramics (+) and monocrystal (O) are given); c) by α-particles with $E_α$ =6.1 MeV (the results are obtained with a film 1-2 μm thick (∇)).

degradation of T_c at irradiation of a monocrystal $YBa_2Cu_3O_7$ by fast neutrons is as yet difficult to explain.

Conclusions

Under irradiation the disorder regions seem to arise in a $YBa_2Cu_3O_7$ compound. Spontaneous recombination of initially knocked out atoms due to thermally activated (in track) zones of disorder in a crystal with a dielectric layer allows the use of the dose dependence of critical parameters in place of the dependence on the number of displacements per atom.

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Received on Jule 22, 1988.