VARIATIONS OF ELECTRIC PROPERTIES OF $YBa_2Cu_3O_{7-x}$ AT LOW-TEMPERATURE (30 K) REACTOR NEUTRON IRRADIATION

B. A. Borisov, V. A. Chekanov, R. F. Konopleva, A. K. Pustovoit, B. L. Oksengendler[1)]

[1)] *Nuclear Physics Institute, Uzbek Academy of Sciences, Tashkent 702132, Uzbekistan*

The interest to studies of the effect of irradiation on a new class of superconducting materials (HTSC) is due to both a possibility of modification of their properties (primarily, an increase of critical current) and their possible use under conditions of intense irradiation (mainly in controlled fusion machines). Irradiation at low temperatures (< 77 K) not only reproduces conditions approaching those of practical operation, but also permits one to investigate the process of defect formation with less interference from defect diffusion, as well as to separate the radiation-induced processes from thermal ones.

A number of publications [1 - 5] report on the effect of low temperature (≈20 K) neutron irradiation on the HTSC. They showed the properties of the HTSC materials under conditions of low temperature irradiation to vary in a complex and poorly understood way. It was thus of interest to investigate the modification of the properties of the HTSC materials in the course of neutron irradiation in a specially designed low-temperature loop (LL) on the WWR-M PNPI reactor [6].

Samples of the HTSC ceramics $YBa_2Cu_3O_{6.9}$ with T_c(onset)= 92 K and transition width $\Delta T \simeq 1$ K were loaded into the lowtemperature reactor channel and maintained in a flow of helium with $T = 18$ K. The neutron flux density was 10^{13} n/cm^{2}s for fast ($E > 1$ MeV) and $7 \cdot 10^{13}$ n/cm^{2}s for thermal neutrons. By properly controlling the helium flow rate through the LL in the reactor core, one could vary the irradiation temperature in the range $20 \div 300$ K. This possibility was used to study the temperature dependences of conductivity in the course of irradiation. For this purpose the LL was heated periodically for short times (≈30 min) to $T = 110$ K. The absence of radiation defect annealing during such a heating was checked by comparing the SC transition curves in the upward and downward transits.

Temperature measurements under conditions of considerable (≈1 W/g for Fe) radiation-induced energy release and temperature pickup degradation require a high accuracy. Using high thermal conductivity gas under turbulent flow conditions and checking the radiation induced change of the pickup sensitivity against platinum thermometers placed outside the irradiation zone provided an absolute accuracy of temperature measurement of ≈0.2 K, and a relative accuracy of ≈0.02 K. Such accuracy permits reliable measurement of T_c variations at low F where these variations are small.

The results of such measurements are as follows. For $F < 10^{18}$ n/cm^2, the T_c increases monotonically with increasing F from the initial value (92.3 ± 0.15) K up to (95 ± 0.3) K. For $F < 10^{18}$ n/cm^2 the T_c drops linearly with increasing F with a rate $dT_c/dF = -2.5 \cdot 10^{-18}$ K·cm^{2}n. The resistivity in the normal state increases strictly linearly with $d\rho/dF = 6 \cdot 10^{-23}$ Ohm·cm^{3}n, exhibiting a slight minimum at low F.

Our analysis of the possibility of modification of the HTSC properties under neutron irradiation has shown, in particular, that the main and sufficiently efficient mechanism operating under such conditions is the creation of defects in the oxygen subsystem under elastic scattering of fast neutrons [7]. It is presently established that in the known HTSC it is the oxygen subsystem connected with copper that determines the carrier type involved, the

character and magnitude of the conductivity in the normal state and the value of T_c. For $YBa_2Cu_3O_{7-x}$ the oxygen ordering in the $Cu1$–O plane, namely, the location of oxygen vacancies in position $O5$, and of oxygen atoms in $O4$, results in an increase of T_c and a decrease of ρ.

Thus the radiation-induced variations of T_c and of r_{100} should be related with variations in the oxygen subsystem, the increase of T_c and a decrease of ρ at low F being connected with oxygen ordering, apparently, in the $Cu1$–O plane, and the degradation at high F being connected with its disordering.

The model based on the formation of radiation-induced defects of two types, namely, stable (s) and metastable (m), characterized by the formation rates λ_s and λ_m, and (radiation-thermal) annealing rates $1/\tau_s$ and $1/\tau_m$, accordingly, provides an explanation for the nonmonotonic dependence $T_c(F)$ [8]. The kinetics of the total number of vacancies created under irradiation

$$n_v = n_c + n_m \simeq \lambda_m\tau_m + \left(n_m^0 - \lambda_m\tau_m\right) exp(-t/\tau_m) + \lambda_s\tau_s\left[1 - \exp\left(-t/\tau_s\right)\right] \qquad (1)$$

has a minimum at sufficiently high initial metastability $n_m^0 > \lambda_m\tau_m$. The presence of the minimum can be attributed to the fact that in the initial stage of irradiation the radiation annealing of metastable defects dominates over the formation of new defects.

Using the approximation [9] for the transition to T_c

$$T_c = 1.14\langle\omega\rangle \exp[-1/VN(E_F)], \qquad (2)$$

where ω is a quantity near by the Debye frequency (10^{13} s^{-1}), $N(E_F)$ is the density of states on the Fermi surface, V is the pairing potential, and taking into account that the vacancy formation in the oxygen sublattice reduces $N(E_F)$, we come to the following dose dependence of T_c

$$T_c(F) = T_c^0 \exp[-1/N(E_F) \cdot V \cdot d(\ln(N(E_F)))/dx \cdot \Omega n_v(F)] \qquad (3)$$

(Ω is the primitive cell volume), which has a maximum corresponding to the minimum of $n_v(F)$. The value of $dN(E_F)/dx$ can be readily obtained from [10]. A comparison with the experimental curves yields the defect parameters: $\tau \approx 10^3$–10^4 sec, $\tau_s/\tau_m \approx 10$, $n_m^0 \approx 10^{18}$ cm.

In this case the metastable defects are apparently oxygen atoms in position $O5$, whose initial concentration, in accordance with the above estimate, is 0.02% of the concentration of oxygen in position $O4$.

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