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# Investigations of the Defects Influence on I-V Curves of HTc Superconductors

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INVESTIGATIONSOFTHEDEFECTSINFLUENCEONI-VCURVESOFHTCSUPERCONDUCTORS

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# Investigations of the Defects Influence on I-V Curves of HTc Superconductors

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*Abstract-* Analysis of the influence of defects, created in irradiation process at nuclear accelerators or during mechanical and heat treatment of superconducting tapes in the technological process, on the current-voltage characteristics of superconducting multi-layered materials is given. New approach taking into account inter-layers interaction is proposed and results of calculations presented, which are in accordance with experiment. The magnetic field dependence of the critical current is theoretically deduced, which relation is useful then for analysis of the dynamical anomalies of the current-voltage characteristics in HTc superconductors. New solution of the magnetic diffusion equation into HTc superconductors is proposed, which predicts results concerning dynamical anomalies being in agreement with experimental data.

## I. Introduction

High temperature oxide superconductors are multi -layered materials, therefore their subtle structure is very sensitive to existence of nano-sized defects. Topic of nano-defects created by irradiation concerns especially superconductors used in the nuclear reactors [1], constructed by applying the superconducting windings as for instance it has the place in CERN and JINR in Dubna [2-3]. Neutron irradiation will appear also in the constructed ITER reactor and will influence therefore the current-voltage characteristics of using here superconducting wires and then critical current, which makes this problem very actual. The work of the HTc superconducting cables transporting current, which subject is close to the Author's scientific interests, is influenced too by the microscopic interaction of the defects with the magnetic vortices, what indicates also on relevance of this phenomenon. The multi-layered structure of HTc superconductors plays here additionally important function, what will be shown in this paper.

## II. Model Presentation

Neutron irradiation created defects influence strongly properties of low dimensional superconductors, such as layered HTc materials but also they are important for low temperature superconductors of an A15 type crystal structure. Destruction of linear chains of transition metals by fast neutron or heavy ions irradiation is presented in Fig. 1, showing elementary cell of an A15 type superconductor. Materials crystalizing in this structure, as Nb3Sn are used continuously in the techn-ology of the superconducting wires and really their superconducting properties, especially critical temper-ature is sensitive to heavy ions irradiation. From other side critical temperature of 3-dimensional type of conductivity NbTi materials is only slightly affected by punctual, irradiation induced defects.

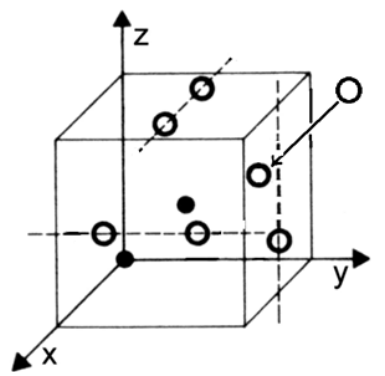


*Figure 1 :* Crystal structure of Nb3Sn A15 type superconductor, with shown linear chains of (O) transition metals, (•) positions of Sn atoms. The irradiation caused damage of the linear chain is also presented

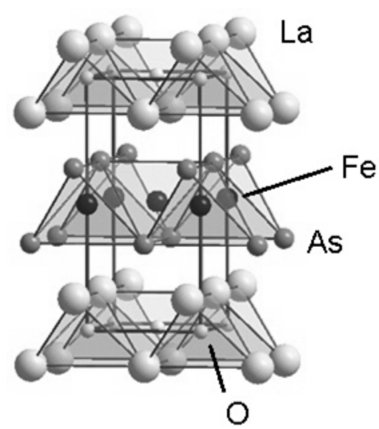


*Figure 2 :* Crystal structure of HTc iron superconductor LaFeAsO of the critical temperature above 40K

The multi-layered structure of HTc supercon-ductors is shown in Fig. 2 for LaFeAsO material, while Fig. 3 presents such multi-layered structure for YBaCuO and BiSrCaCuO composition with $CuO_2$ planes responsible for superconductivity.

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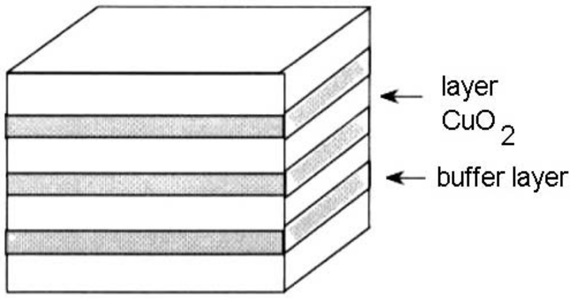


*Figure 3 :* Schematic structure of the multi-layered HTc superconductor with shown $CuO_2$ planes in YBaCuO or BiSrCaCuO compound

This structure is very sensitive therefore to the nano-defects appearance and on the other hand to the interplane interaction. Model of the capturing interaction has been elaborated for 2D layered HTc superconductors, in which pancake shape vortices are formed. Change of the free energy of the Ginzburg-Landau type has been analysed for an arrangement of the vortices captured on the regularly ordered nano-defects, acting as the pinning centers, in the function of vortex deflection from initial, equilibrium position. Shift of the vortex from this position causes an increase in the normal energy of the system. The energy barrier arises, which is function of the vortex displacement, according to the notation of Fig. 4 given by:

$$\Delta U_2(x) = \frac{\mu_o H_c^{\ 2} l d x}{2} \qquad (1)$$

for $x<x_c$, where $x_c$ is any critical distance, dependent on ratio $d/2\xi$. In opposite case appears relation:

$$\Delta U_3(x) = \frac{\mu_o H_c^{\ 2} l \xi^2}{2}\left[\arcsin\frac{x}{\xi} - \frac{\pi}{2} + \arcsin\frac{d}{2\xi} + \frac{x}{\xi}\sqrt{1-\left(\frac{x}{\xi}\right)^2} + \frac{d}{2\xi}\sqrt{1-\left(\frac{d}{2\xi}\right)^2}\right] \qquad (2)$$

$H_c$ denotes in Eqs. 1-2 thermodynamic critical magnetic field, $\mu_0$ is magnetic permeability, while parameter x shown in Fig. 4 describes the deflection of the vortex core against the pinning center formed by the nano-defect of the width $d$. $\xi$ is coherence length and describes the radius of the core of the vortex, while $l$ is the thickness of the pancake type vortex, equal to the thickness of the superconducting layer in oxide HTc superconductor. In the paper has been considered an initial captured vortex position on the depth of the coherence length inside the pinning center, which is favorable from the point of view of the shielding current

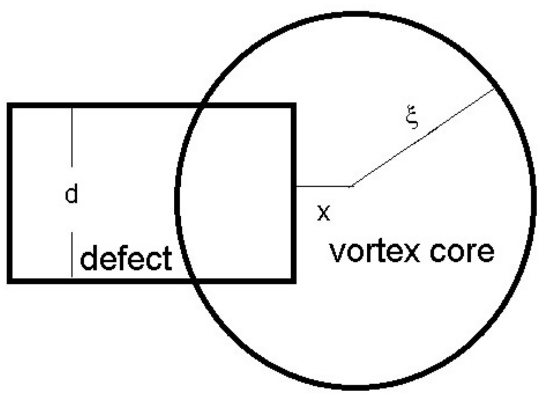


*Figure 4 :* Schematic view of the vortex captured on the depth (ξ - x) inside the nano-defect

distribution, however other configurations can be also regarded. While taking into account the Lorentz forces as well as elasticity energy of the vortex lattice expressed by the coefficient $\alpha$ an energy barrier height $\Delta U$ is received in the current representation as follows:

$$\Delta U = \frac{\mu_0 H_c^2 l \xi^2}{2}\left[-\arcsin\ i + \arcsin\frac{d}{2\xi} + \frac{d}{2\xi}\sqrt{1-\left(\frac{d}{2\xi}\right)^2} - i\sqrt{1-i^2}\right] + \alpha\xi^2\sqrt{1-i^2}\left(\sqrt{1-i^2}-2\right) \qquad (3)$$

Tilting of the potential energy wells is caused by the current flow of the reduced density $i = j/j_c$, where $j_c$ is received in the present model critical current density, expressing the transition between flux creep and flux flow states. $S$ in Eq. 4 denotes the defect cross-section, while $a$ lattice constant of regularly arranged defects:

$$j_c = \frac{\mu_0 H_c^2}{\pi\xi\ B}\cdot\frac{S(1-S/a^2)}{a^2} \qquad (4)$$

In the present paper interaction between the neighboring superconducting planes shown in Fig. 3

has been taken into account. Results of preliminary calculations of the influence of number of interacting planes on the current-voltage characteristics, performed inserting the scaling coefficient, connected with shielding effects in individual planes, is shown in Fig. 5. Above described model predicts too the magnetic field dependence of the current-voltage characteristics of the HTc superconductors. The results of calculations are shown in Fig. 6 and are in qualitative agreement with the experimental data measured on $Bi_2Sr_2Ca_2Cu_3O_x$ superconductor at liquid nitrogen temperature in external magnetic field, presented in Fig. 7.

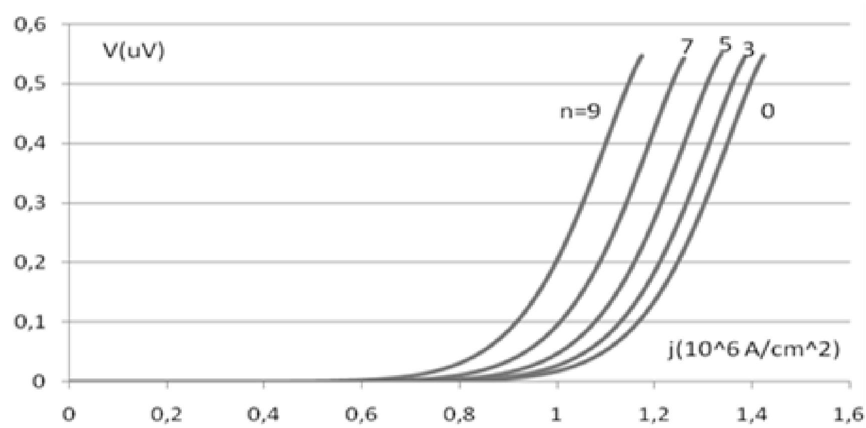


*Figure 5 :* Influence of the number of interacting planes ($n$) in HTc multilayered superconductor on the current-voltage characteristics of the irradiation defected sample n=0, 1, 3, 7, 9.

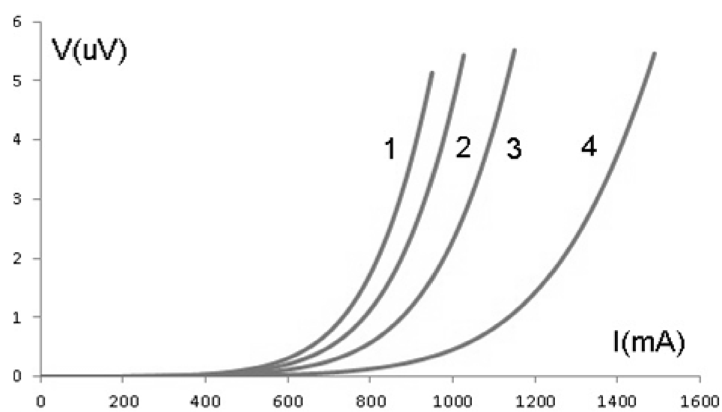


*Figure 6 :* Theoretically calculated current-voltage characteristics of HTc superconductor in static magnetic field: (1) B=35 mT, (2) 33 mT, (3) 30 mT, (4) 24 mT

Experimental magnetic field dependence of the critical current for that sample is shown in Fig. 8 and really confirms significant influence of magnetic induction on this parameter, as predicts theoretically Eq. 4.

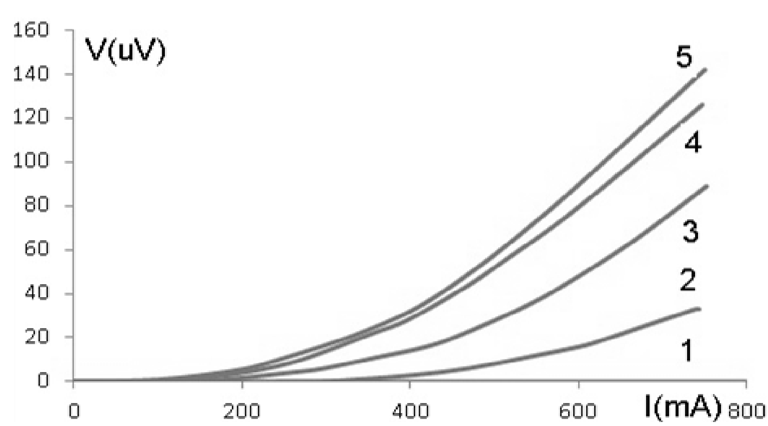


*Figure 7 :* Experimental current-voltage characteristics for $Bi_2Sr_2Ca_2Cu_3O_x$ superconductor in liquid nitrogen temperature for various magnetic fields: (1) B=0, (2) 13,5 mT, (3) 24 mT, (4) 33 mT, (5) 35 mT.

Figure 8 presents the experimental critical current dependence on the magnetic induction in the liquid nitrogen temperature basing on experimental data of Fig. 7.

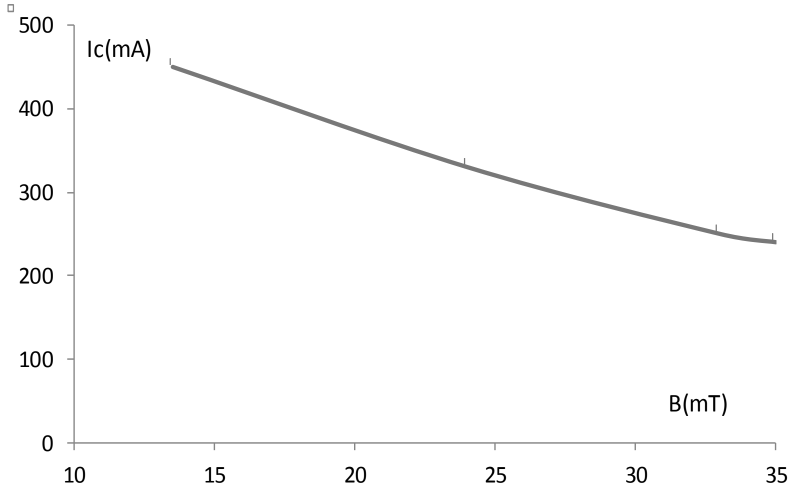


*Figure 8 :* Critical current magnetic field dependence for BiSrCaCuO ceramic superconductor in 77 K.

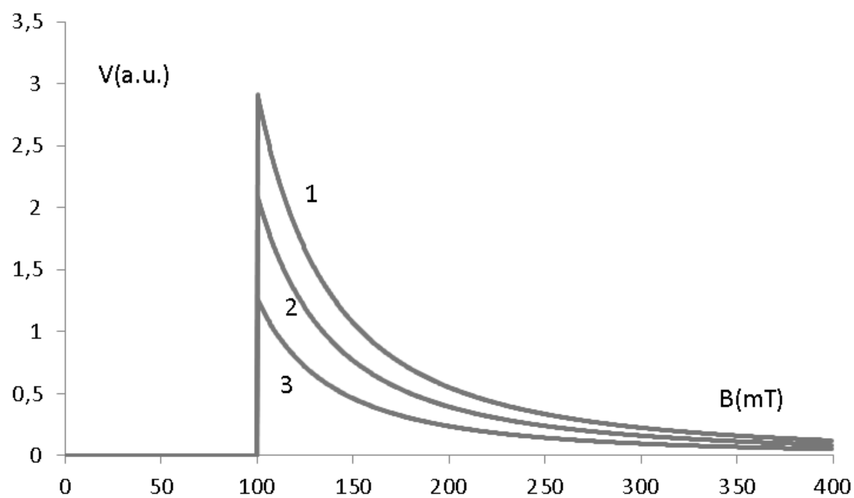


*Figure 9 :* Theoretically calculated dynamical anomalies of the current-voltage characteristics of HTc superconductor in slowly varying magnetic field 10 mT/s for transport current: (1) I=350 mA, (2) 250 mA, (3) 150 mA.

Elaborated model leading to the inverse magnetic field dependence of the critical current density given by Eq. 4 describes too, observed us experimentally dynamical anomalies of the current-voltage characteristics of the HTc superconductors, in slowly varying external magnetic field, which are also the subject of present investigations. New model of this phenomenon has been deduced basing on the solution of the magnetic diffusion equation. This new solution in the polynomial form, with additional constrains appropriate to description of superconductivity phenomenon, has been applied for analysis of the current-voltage characteristics in dynamically varying magnetic field. Some results of calculations are given in Fig. 9 and indicate on sensitivity of anomalies to the transport current, which makes them promising new tool for detecting current amplitude, as well as other electromagnetic quantities. Similar behavior has been measured us previously and shows the dependence of anomalies on such electromagnetic quantities as magnetic field sweep rate, current amplitude and frequency, temperature and generally superconducting sample quality.

## III. Conclusions

Performed investigations are devoted to the phenomenon of the transport current flow through the HTc ceramic, multi-layered superconductors with nano-defects, especially under point of view of analysis their current-voltage characteristics. This topic is related to the issue of applications of HTc superconductors in such electric devices as coils and cryocables, which are in the scope of author scientific interest. The relevance from the point of view of applied superconductivity, of the interaction of defects with pancake vortices is indicated, especially taking into account its influence on the critical current of HTc superconductors. The interplane interaction in these multilayered superconductors was investigated too in the paper and comparison of the theoretical model with experimental data is enclosed. It have been predicted theoretically dynamical anomalies of the current-voltage characterristics in varying magnetic field basing on new polynomial type solution of magnetic diffusion equation, which gives results in accordance with experimental data.

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