Abrikosov vortices depinning in high-Tc 3d-anisotropic superconductor with nanoscale defect structure

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INTRODUCTION

For new HTS materials, such as cuprates RE-Ba-Cu-O (RE – is the rare-earth element: Y, Gd, Nd), MgB_2 compound, and some of ferropnictides, the critical current density J_c reaches values of order mega-amperes per cm^2 . E.g. in cuprate thin films and coatings produced now by use of modern technologies J_c value at liquid nitrogen temperature (78K) amounts to $10^6 \div 10^7 A/cm^2$ [1]. Nevertheless, the intensive hard work still continues in many laboratories over the world in order to improve and reduce the price of HTS lengthy conductor fabrication technology, and also to increase the J_c(78K) value as well as to reduce its dependence on magnetic field and thickness of HTS layer [2,3]

METHODS

We study a series of pulse laser deposited (PLD) $YBa_2Cu_3O_{7-x}$ (YBCO) deposited on sapphire substrates. The films under study possess a different defect nano-structure (and thickness), namely: (a) - pristine YBCO; (b) -YBCO films with implanted $BaZrO_3$ (BZO) nano-particles; (c) - YBCO/Y_2O_3 multilayer films.The $J_c(T,B)$ dependencies for these were obtained from direct transport as well as from magnetic measurements. We have studied $J_c(B)$ dependencies for pristine YBCO, YBCO(BZO) and YBCO/Y_2O_3 multilayer films in applied perpendicular magnetic field and compared these results in order to get the more precise understanding the role of nanostructure defects of different nature and dimensionality on current-carrying abilities of HTS films (see Fig.1 and 2).

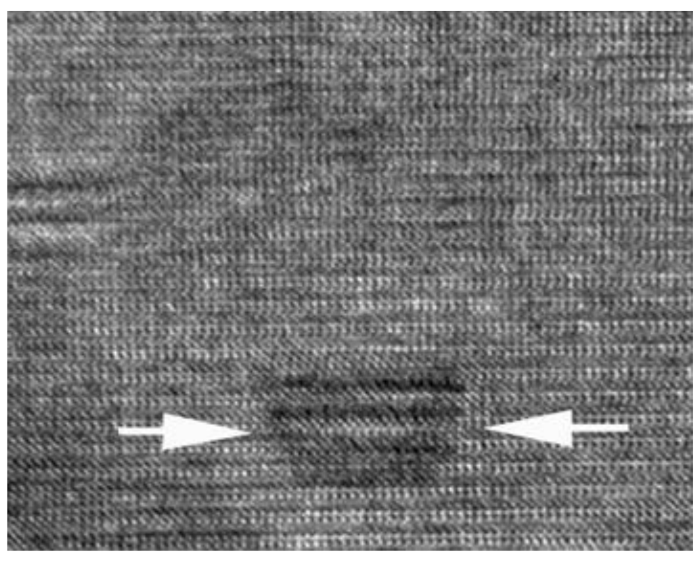

Fig. 1. Nanoparticles $BaZrO_3$ – "nanopancakes" R=3-10 nm

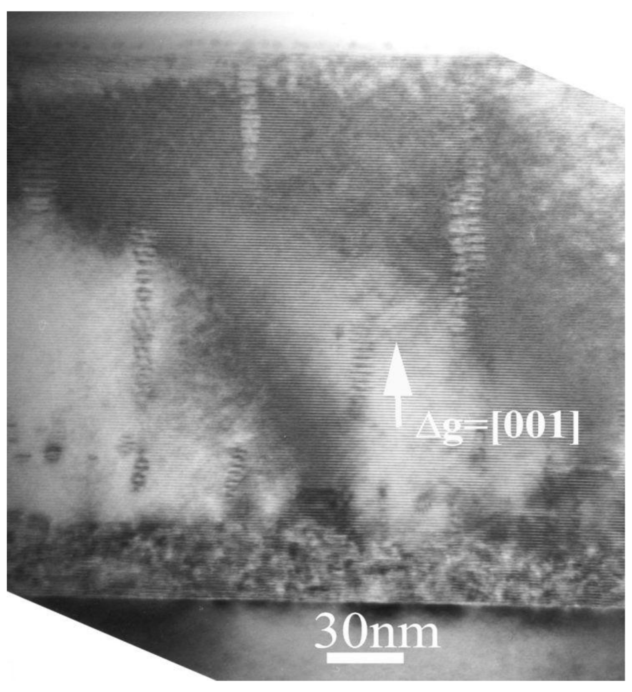

Fig. 2. Self-organization of BZO -nanoparticles in columns - "nanorods"

RESULTS

Magnetic field dependencies of the critical current density J_c(B, 78K) for YBCO, YBCO(BZO) and YBCO/Y_2O_3 multilayer films under study, determined by dynamic magnetic susceptibility method, are presented in Fig.3 Enhancement of J_c value in YBCO(BZO) films comparatively to that in pristine YBCO films is due to additional pinning of Abrikosov vortices by BZO nanorods splayed around the c-axis as well as randomly distributed small planar nano-particles - 'nanopancakes' [2, 3].

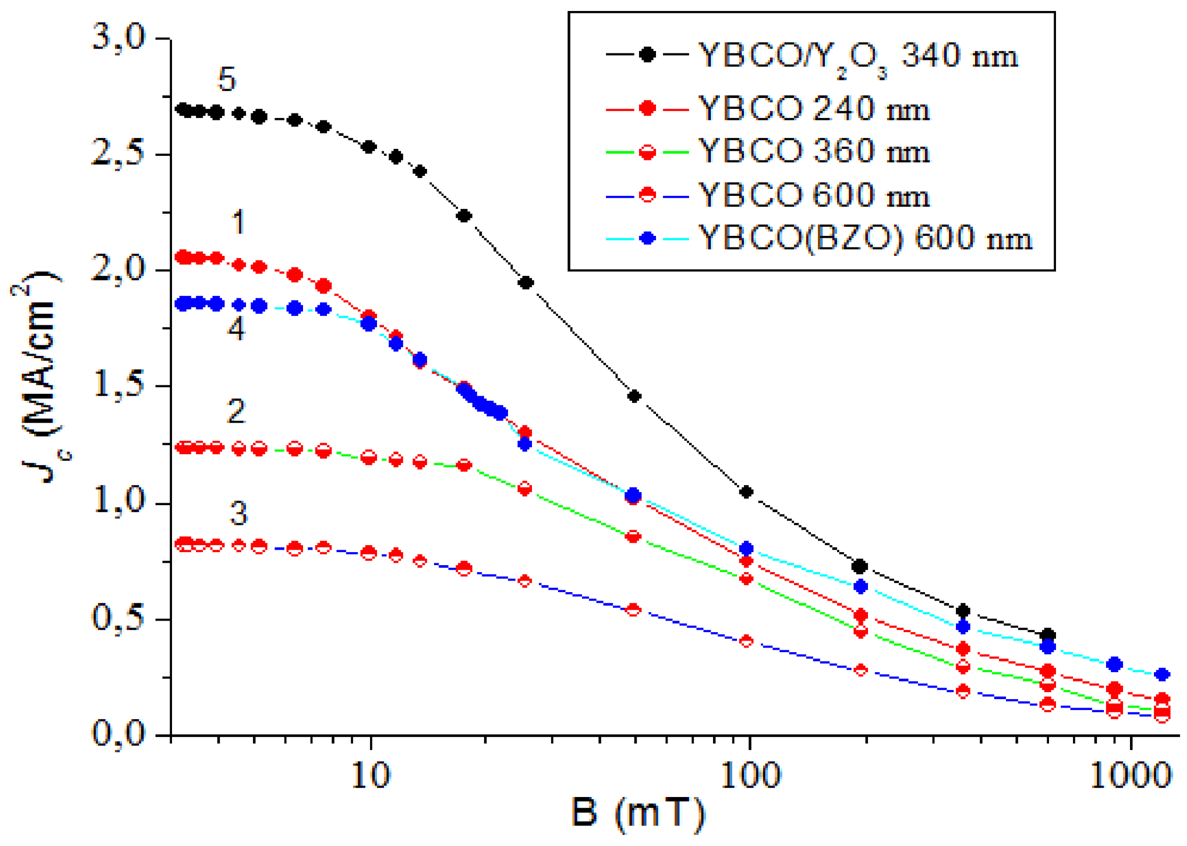

Fig.3. Magnetic field dependencies of J_c(B, 78K) for YBCO, YBCO(BZO)and YBCO/Y_2O_3 multilayer films.

The I-U curves for YBCO(BZO) films were measured using 90 µm wide bridges etched from 150 nm thick originally deposited films. These I-U curves are shown in Fig. 4 together with their first derivatives (differential resistance) $R(I) \equiv dU/dI$ in a duble-logarithmic scale. From this figure it's quite evident that $U(I)$ cannot be described by a power law with any exponent value. But instead, it's well described by a vortex-glass type law:

$$U(I) = A\exp\left[-\left(\frac{I_0}{I}\right)^{\mu}\right]$$

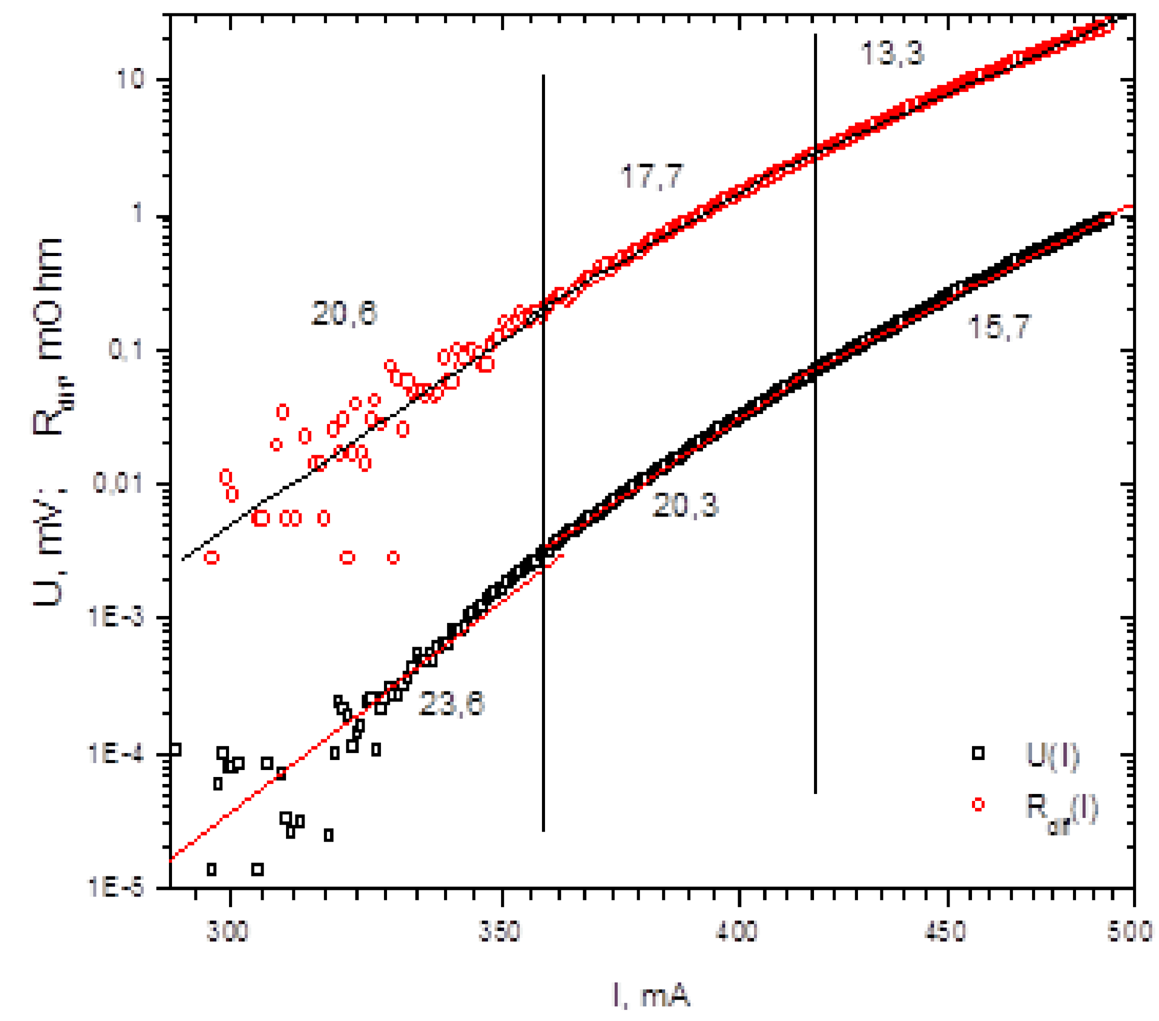

Fig. 4. Current-voltage characteristics $U(I)$ and differential resistance $R_{dif}(I) \equiv dU/dI$ for YBCO(BZO1,5%) films.

Depinning of an elastic vortex stringsettled in the pinning potential well created by columnar defect and exerted to the inhomogeneous Lorentz force action caused by the Meissner transport current flow in the surface layer of width λ (λ – is the London penetration depth) was considered recently in [4] and is illustrated on the Fig. 5, 6.

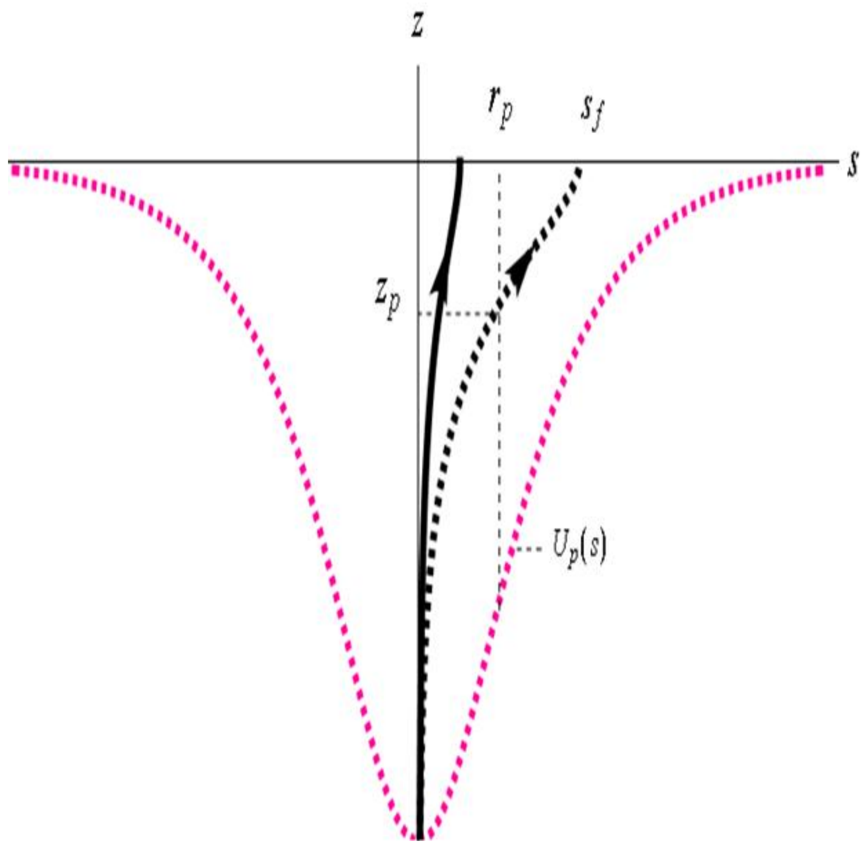

Figure 5. Elastic vortex string settled in the pinning potential well created by columnar defect and exerted to the inhomogeneous Lorentz force .

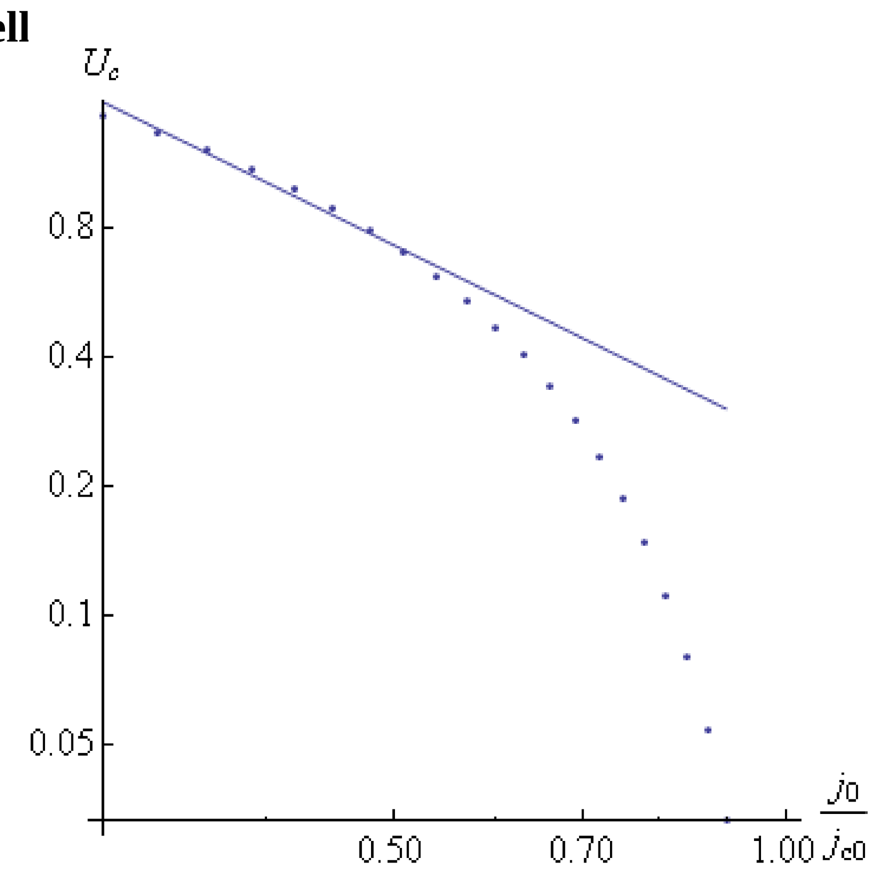

Fig. 6. Dependence of the vortex activation energy, $U_c(j_0)$ plotted in a double-log scale. The straight line corresponds to the dependence:

$$U_c(j_0) = U_c\left(\frac{j_c}{j_0}\right)^{\mu}; \quad \mu \cong 1{,}5$$

CONCLUSIONS

It was shown that usage of nanotechnological approaches in HTS thin films formation, such as addition of the impurity phase nanoparticles (BZO) or deposition of multilayer films HTS/insulator (YBCO/Y_2O_3), can significantly improve the current-carrying capabilities of HTS conductors and make them more attractive for power applications. These results are in agreement with those, obtained by other research groups. The additional defect nanostructure, which arises due to these deposition technology improvements, plays the role of strong pinning sites for Abrikosov vortices, preventing their motion, thus increasing the critical current value. Moreover, this additional nanostructure, which in YBCO(BZO) films emerges in form of point-like nanoparicles or linear nanorods can significantly improve J_c not only by its value, but also by its magnetic field and thickness dependencies.

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