

# NANOENGINEERED PINNING CENTRES IN SUPERCONDUCTING THICK FILMS FOR HIGH-MAGNETIC FIELD POWER APPLICATION

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## Introduction

For power applications of superconducting films, the critical current density ( $J_c$ ) and the thickness of the film ( $d$ ) should be as high as possible.  $J_c$  decreases with both thickness (for films thicker than a few hundred nanometers) and magnetic field, so artificial pinning centres in addition to natural ones are required.

The earliest cost-effective method used for introducing artificial pinning centres was the so-called substrate decoration, i.e., growing nanoscale islands (nano-dots) of certain materials on the substrate prior to the deposition of the superconducting thin film [1]. Later on other two approaches proved to be successful: building up a layered distribution of a second phase using a multilayer deposition (quasi-superlattices) [2], and, respectively, by distribution of a secondary phase as a result of a compositional change in the target [3].

Here we report on the artificial pinning centres induced in  $\text{YBa}_2\text{Cu}_3\text{O}_7$  (YBCO) thick films by substrate decoration and quasi-multilayer approach using Au, Ag, Pd,  $\text{LaNiO}_3$  (LNO),  $\text{PrBa}_2\text{Cu}_3\text{O}_7$  (PrBCO) and non-superconducting (ns) YBCO, and by using a nanocrystalline YBCO target with 4 wt.%  $\text{BaZrO}_3$  (BZO) nanoinclusions.

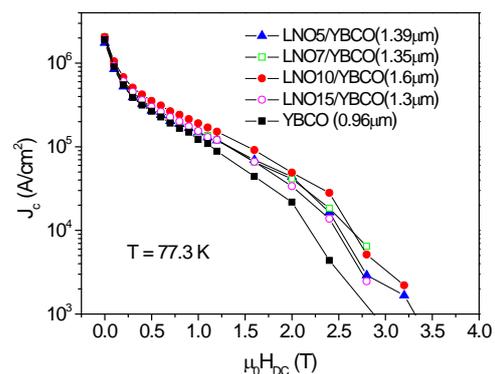
## Experimental

All the nano-engineered films were grown by Pulsed Laser Deposition using an excimer laser KrF 248 nm. Details of the growth parameters can be found elsewhere [4-6]. Films were characterized by XRD, AFM, SEM, TEM. Superconducting transitions were determined from AC susceptibility. Critical current density  $J_c$  was determined from DC magnetization loops within the frame of a critical state model  $J_c = 6m/a^3d$  (where  $m$  is the irreversible magnetization or half-width of the magnetization loop,  $a$  is the side dimension of the substrate, and  $d$  the film thickness). Pinning

force  $F_p = J_c \times \mu_0 H_{DC}$  was also determined from the DC magnetization loops. Frequency-dependent  $J_c(f)$  was estimated from the position of the maximum ( $h^*$ ) in the  $\chi''(h_{ac})$  dependencies following the approach of Brandt [7],  $J_c = h^*/0.8d$ . From  $J_c(f)$  dependencies we have discovered [4] that pinning potential  $U_0$  depends logarithmically on the current density and is related to the slope  $b$  of the  $J_c(f)$  dependence in a double logarithmic plot by  $U_0 = k_B T(1+1/b)$ . The c-axis correlation of nano-engineered pinning centres was studied through angle-dependent transport measurements in maximum Lorentz force configuration.

## Results and discussion

Substrate decoration with Au, Ag, Pd for optimized nano-dots architecture led to an increase of optimum thickness in the  $J_c(d)$  dependence from 0.2  $\mu\text{m}$  (in reference pure YBCO) to about 0.8  $\mu\text{m}$ , while substrate decoration with LNO led also to an increase in  $J_c(H_{DC})$ , as can be seen in Fig. 1



**Fig. 1. Field dependence of critical current density of YBCO films decorated with 5, 7, 10 and 15 laser pulses of LNO, and of a reference pure YBCO film.**

Although LNO-decorated samples showed an increase in the bulk pinning force, pinning potentials  $U_0$  (77K,  $H_{DC}$ ) are very close to those of reference sample, indicating that artificially-induced pinning centres have the

same nature (screw dislocation) as in pure YBCO films.

Quasi-multilayers with Ag, Pd and ns-YBCO with thicknesses up to about 5  $\mu\text{m}$  have very high critical currents (up to 800 A/cm width) due to their thickness and a much slower decrease in  $J_c(d)$  dependence, as can be seen in Fig. 2 for Ag/YBCO quasi-multilayers.

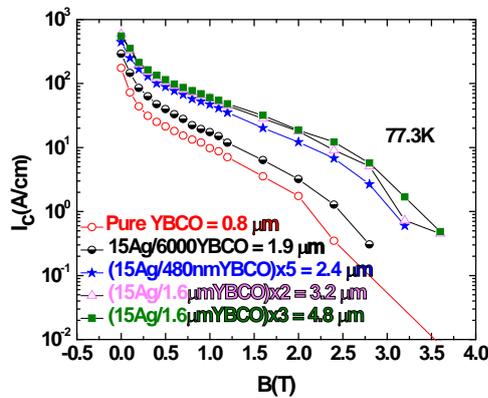


Fig. 2. Field dependence of critical current for Ag/YBCO quasi-multilayers. Figure 15 in the legend represents the number of laser shots on Ag for each quasi-layer.

PrBCO/YBCO quasi-multilayers behave quite differently: the increase of superconducting parameters ( $J_c$ ,  $I_c$ ,  $F_p$ ,  $U_0$ ) occurs only in high fields. An example is the  $J_c(f)$  dependence in Fig. 3. Note that smaller the slope, the higher  $U_0$ .

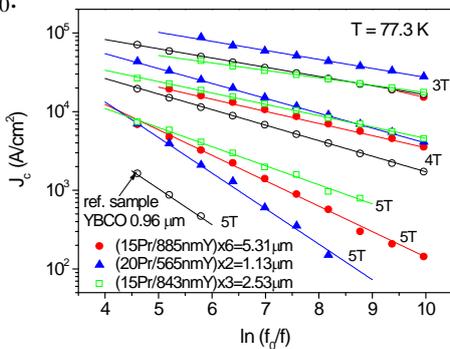


Fig. 3. Frequency-dependent critical current density for several PrBCO/YBCO quasi-multilayers.

Superconducting films grown from the BZO-doped nano-crystalline target showed an increase of all superconducting parameters, for all DC applied fields. Till now we have investigated 1.3  $\mu\text{m}$  thick films from this system. Growth and measurements of thicker films will be attended in the near future. Measurements of transport critical current density in fields applied at various angles to the film surface allowed (together with TEM)

the study of c-axis correlation of nano-engineered pinning centres. The results showed c-axis correlated pinning centres (proved by the appearance of a local maximum for fields parallel to the c-axis), and an overall decrease of anisotropy factor of critical currents ( $I_c^{ab}/I_c^c$ ) for most of the cases, and in a broad range of applied fields, as compared with the value of about 5 for YBCO single-crystals, as can be seen in Fig. 4. This result is important for the use of nano-engineered pinning centres in tapes for coils and magnets fabrication.

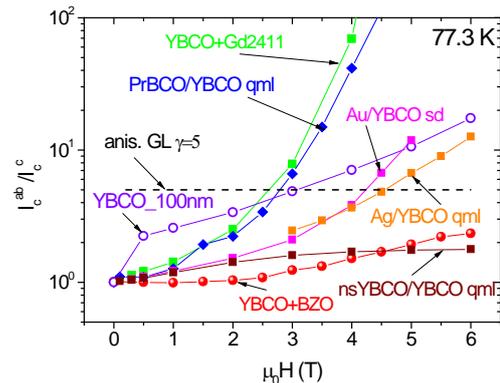


Fig. 4. Critical current anisotropy factor for various samples with nano-engineered pinning centres.

In conclusion, the improvement of superconducting parameters by nano-engineered pinning centres depend strongly of the method used, the material used for nano-dots, and the architecture of nano-composites.

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