Pinning Performance of $(Nd_{0.33}Eu_{0.2}Gd_{0.47})Ba_2Cu_3O_y$ Single Crystal

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***Abstract* - The critical current density J_c, the pinning force density $F(=BJ_c)$, and the relaxation rate *Q* were determined from magnetic hysteresis loops (MHL) measured from 65 K to 90 K on a twinned $(Nd_{0.33}Eu_{0.2}Gd_{0.47})Ba_2Cu_3O_y$ single crystal with a strip-like surface structure. The strong second peak observed on the MHL at 65 K continuously decreased with increasing temperature but persisted up to 84 K. None of the $J_c(B)$ and $F(B)$ dependences scaled, let alone in a narrow range of *T*. A strong effect of twin channeling was observed but no special pinning effect due to the strip-like surface structure was recognized.**

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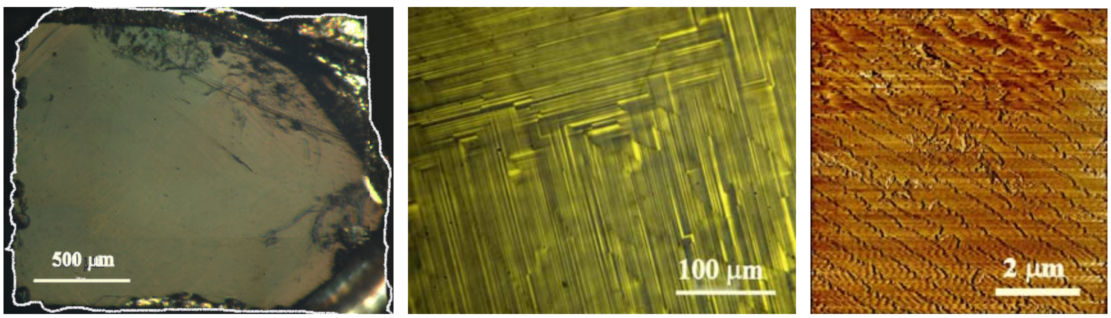
I. INTRODUCTION

Bulk high-T_c superconductors possess a big potential for application as quasi-permanent magnets capable of trapping magnetic field by order of magnitude higher than the best conventional magnetic materials. Even with the moderate electromagnetic performance of $YBa_2Cu_3O_y$ (Y-123) it was possible to trap magnetic field as high as 17 Tesla in a pellet of only 26.5 mm in diameter and 12 mm thick [1]. LRE-123 compounds (LRE=light rare earth, Nd, Sm, Eu, Gd) can carry significantly higher engineering currents than Y-123 [2-4]. Thus, in an LRE-123 bulk a similarly high magnetic field could be trapped at a significantly higher temperature than in the case of Y-123 (29 K) [1]. Binary and ternary LRE-123 compounds offer for pinning structure tailoring one more degree of freedom, in the variation of the LRE ions ratio. To date, such materials have been studied mostly on melt-textured (MT) samples. Although the MT superconductors are a great promise for applications, as they can be fabricated in rather large blocks and a relatively low cost, their structure suffers from many pores, cracks, and imperfections appearing mainly during the oxygenation process. These do not only deteriorate the mechanical strength of the compound but also make the current flow not well defined. Both from physical and technological point of view, studying of the more perfect single-crystalline form of the material should be of interest. Recently, a new kind of nanoscale pinning structure, mediated by the LRE elements ratio, was discovered in twinned MT samples of (Nd,Eu,Gd)-123 [5]. It was a fine lamellar structure with period of 3-5 nm, aligned with the twin planes and filling the channels between them. As the thickness and period of the lamellas was comparable with the coherence length and thus also the vortex core size, vortex motion along the regular twin boundaries (channeling effect) was prevented. Consequently, vortex pinning was enhanced, especially in high magnetic fields, and the irreversibility field increased nearly twice. A fine strip-like structure with period of a several tens of nm has been also observed by atomic force microscopy (AFM) and scanning tunneling microscopy (STM) on surfaces of various LRE-123 single crystals [6,7]. This was also the case of the present single crystal sample (Figure 1). The question arises, what is the origin of this strip-like structure and whether it contributes to the pinning performance or not. In this paper we present magnetic study of the critical current density, J_c, the pinning force, F, and the logarithmic relaxation rate, Q, on a twinned $(Nd_{0.33}Eu_{0.2}Gd_{0.47})Ba_2Cu_3O_y$ single crystal with a special focus onto the role of the observed stripes.

II. EXPERIMENTAL DETAILS

High purity commercial powders of Nd_2O_3, Eu_2O_3, Gd_2O_3, and $BaCO_3$ were mixed in the nominal composition $(Nd_{0.33}Eu_{0.2}Gd_{0.47})Ba_2Cu_3O_y$. The single crystal was grown from the self-melt in air. The form, twin structure, and the stripes observed on the investigated sample are shown in Figure 1. The crystal was 0.5 mm thick and approximately 2 x 1.5 mm^2 in size.



a **b** **c**

Fig.1. (a) Optical microscopic image of the investigated NEG-123 single crystal with contours marked by the white line; (b) the twin structure observed in polarized light; (c) STM image of the crystal surface at RT.

Magnetization hysteresis loops (MHLs) were measured by means of a vibrating sample magnetometer (VSM) in the PPMS (Quantum Design) equipped with 9 Tesla magnet. The MHLs were measured with magnetic field applied parallel to the *c*-axis, in the temperature range 65 K to 90 K. Most curves between 65 K and 77 K were measured with the field sweep rate 0.72 T/min; the dynamic relaxation was studied using two additional sweep rates, 0.36 T/min and 0.12 T/min. The MHL curves at temperatures 80 K and higher were measured with the field sweep rates 0.36 T/min and 0.12 T/min. Critical current density, J_c, values were estimated using the Bean critical state formula for a sample with rectangular cross-section [8], $J_c=2\Delta M/[a^2c\ (b-a/3)]$, where M is the total magnetic moment and ΔM the vertical difference between the MHL branches (in units of magnetic moment), c is the sample dimension along the *c*-axis and a and b are the lateral sample dimensions, $a \leq b$. Note that this formula does not involve demagnetisation effects and thus applies strictly only for high magnetic fields. For a thin sample ($c < a$, b) the J_c resulting from this expression for low magnetic fields is somewhat underestimated due to the demagnetization effect. It is, however, a common practice to use this formula for the whole field range and for sake of compatibility we will do the same.

The crystal was oxygenated at 410^o C, a temperature rather high for the optimum oxygenation of LRE-123 materials, however the critical temperature was still high (93.7 K).