Artificial pinning centers on the MgB_2 surface: the influence on the vortex flow in magnetic field

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***Abstract* — Superconducting properties of high-quality films of the first multiband superconductor, magnesium diboride, have been investigated. The dominating role of thermally activated flux flow for the low parts of the superconducting transition are responsible for the resistivity of MgB_2 near the superconducting transition. A novel method to self organize nano particles with different hierarchical distance parameters on surfaces, was used to adsorb nano particles on MgB_2 films. The influence of a homogenous network of Co nano particles, which were deposited on the surface of the MgB_2 layers, on the resistive transition broadening in a magnetic field has been investigated.**

***Index Terms* — magnesium diborid, superconductivity, nanoparticles**

I. INTRODUCTION

The superconducting MgB_2 has a high critical current density up to $j_c = 1.6 \times 10^7$ A/cm at 15K [1] what makes it very attractive for technical applications. On the other hand, a broadening of the superconducting transition under applied magnetic, as found in resistivity measurements [2], would severely limit potential applications for MgB_2. Magnesium diboride exhibits an anomalous magnetic behaviour with dendritic magnetic instabilities for vortex penetration [3] and ‘‘noise-like’’ jumps of the magnetization in an applied magnetic field [4], which should influence the resistive behaviour of this novel superconducting material.

Recent experimentals have demonstrated that the dendritic instability is sensitive to external conditions [5-8]. Indeed it was shown that covering MgB_2 films with a layer of gold or aluminium suppresses the dendrite formation [7] or changes their propagation direction [8]. The embedding in MgB_2 film of a self-organized array of magnetic nanoparticles is expected to be strong stabilizing factor especially in applied magnetic fields matching with average distance between embedded magnetic nanoparticles. We investigated in present work an influence of self-organized array of Co nanoparticles which covered MgB_2 film.

II. SAMPLE PREPERETION AND CHARACTERIZATION

The MgB_2 film with a thickness about 500 nm on Sapfire substrate was prepared using “two-step” synthesis technology described in details in [9].

The specimen labeled No2 consisted of the MgB_2 thin film which was to one half of its area covered with Co nanoparticles. Two cuts with a diamond wheel saw near the boundary of the covered area was performed so that we got two samples (Fig.1 a): first sample without any cover (No 2) , and second one fully covered with Co, (No2Co).

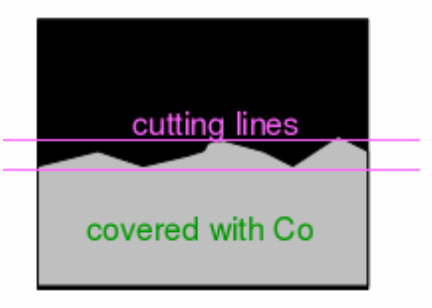

Fig. 1 a

Fig. 1 b

Aluminum wires of 50 μm in diameter were attached to the samples by ultrasonic bonding for four-probe resistance measurements using AC Lock-In-technique. The common electrical current 10-100 μA flown during measurements through both directly connected samples (Fig 1 b). The influence of the value of the current becomes invisible for

$I \leq 60$ μA. All the presented on Figures 2,3 resistive measurements were performed with I = 50 μA. We used 'Oxford Instruments' He/He-cryostat and a Dewar containing superconducting solenoid which was "freshly" cooled from room temperature to 4.2 K without applied magnetic providing absence of remanence magnetization. The critical temperature T_c was determined from the mid-points of the $R(T)_{B=const}$ curves.

III. RESULTS AND DISCUSSION

The Figure 2 demonstrates that the uncovered sample (No2) did not show explicit linear dependence of ln(R) on T_c/T at any H - applied external perpendicular magnetic. The dependencies are smooth, monotonous but without clear linear regions. We consider this fact as a sequence of an innhomogeneouity of the sample. The quantitative behavior of ln(R) on T_c/T with varied H is in good agreement with our work [2].

Figure 3 demonstrates rather different type of dependencies of ln(R) on T_c/T with varied H of the same sample with embedded Co nano-particles (No2Co). One can conclude that magnetic nano-particles result in magnetic field which led to arising of the bend pointed on by arrow in weak applied magnetic fields ≤ 0.1 Tesla and even without applied external magnetic field. The influence of self-organized array of magnetic nano-particles becomes more visible for fields ≥ 1 Tesla.

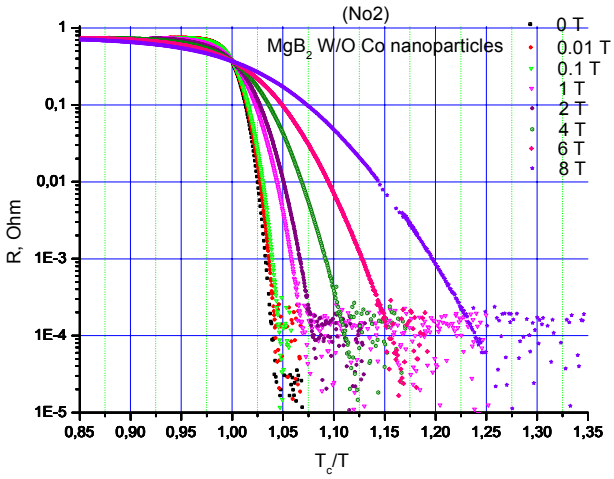

Fig.2

The arising and increasing of linear regions of the dependency with magnetic field is the evidence of re-ordering of bundles of vortexes in a state with higher homogeneouity than in the sample without Co nano-particles. [10] The increasing of the slope for the linear ranges of the curves at 1 T and 2 T with T_c/T and vanishing of described above concavity is the evidence of enhancement of pinning force due to matching effect between short-distance order parameter of vortices and average distance between self-organized embedded Co nano-particles. With increasing of magnetic field the matching effect vanishes but influence of produced by magnetic nano-particles magnetic field becomes stronger. It led to arising of a linear region with fewer slopes and pinning force. At lowest temperatures occurs one more crossover in type of vortex flow which overrides the mentioned above effect and recovers usual dependence, qualitatively the same as for noncovered by magnetic nano-particles sample in the same range of applied external magnetic field.

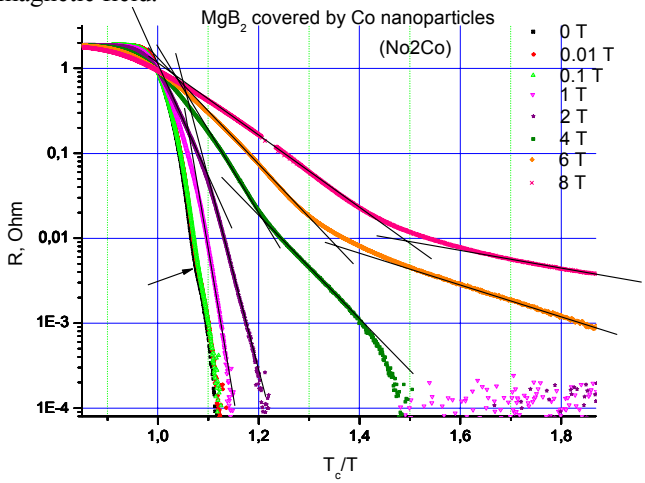

Fig. 3

To conclude we investigated influence of embedded self-organized array of Co nanoparticles on resistive transitions MgB_2 films. It was found rather strong influence of the nanoparticles in applied magnetic fields ≥ 1 Tesla. We believe that arising and increasing of linear regions of the dependency ln(R) on T_c/T with magnetic field is the evidence of stabilizing of bundles of vortexes in a state with higher homogeneouity which leds to increasing of pinning force especially in region where exists matching between average distance between vortexes and average distance between embedded self-organized array of Co nanoparticles. The further investigations with other magnetic material nanoparicles and better homogeneouity of microstructure

IV. ACKNOWLEDGMENTS

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