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SYNTHESIS AND TRANSPORT PROPERTIES OF POROUS SUPERCONDUCTING CERAMICS OF $YBa_2Cu_3O_{7-\delta}$

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Abstract. This work presents the method of producing an open porous structure that is based on a ceramic high superconductor $YBa_2Cu_3O_{7-\delta}$ "filled with a sugar supplement". The results of the electric resistance measurements at different external magnetic fields are also presented. The obtained results have revealed a significant influence of the pore presence in the superconducting samples on the electrical resistance values, especially below the T_c temperature.

1. INTRODUCTION

Over the past dozens of years low-temperature superconducting materials have been applied to expensive scientific investigations, construction of strong electromagnets, medical scanners or magnetic levitation. Currently, a significant progress in the production techniques of high-temperature superconductors gives hope for similar spectacular applications for materials of this group. For example, the first experimental superconductive wires in Copenhagen and Detroit were built as early as in 2001 [1]. It seems most likely that further investigations into this group of materials will make it possible to use superconductive wires commonly. It is well known that electric current in a circuit composed of superconducting wires is limited by the resistivity of the external load and the physical properties of the superconductor. Therefore, it seems interesting to investigate high temperature superconducting materials as potential candidates for application in current limiters in a future power network. Superconducting wires make it possible to have a flowing current of high density. This current can be controlled by an external magnetic field. However, if a superconductor has a high critical field, it requires a high magnetic field to control the superconducting current. This problem may apply to some high-temperature superconductors, for example, $YBa_2Cu_3O_{7-\delta}$ (YBCO), improved by a melt processing technique, reveals high critical magnetic field (H_c) [2]. Therefore, the purpose of this work has been to obtain a material of specific properties, that is: a potentially high critical current and a low critical magnetic field. We have tried to approach the problem by changing the superconductor's 3D microstructure. Our work has been focused on the sensitivity of a porous $YBa_2Cu_3O_{7-\delta}$ superconductor to the external magnetic field. It has been assumed that the porous microstructure will enhance the magnetic field's influence on the material.

2. EXPERIMENTAL

The number of publications concerning the methods of creating an open porous ceramic structure $YBa_2Cu_3O_{7-\delta}$ is limited and they include various techniques. The most popular technique uses polyure-

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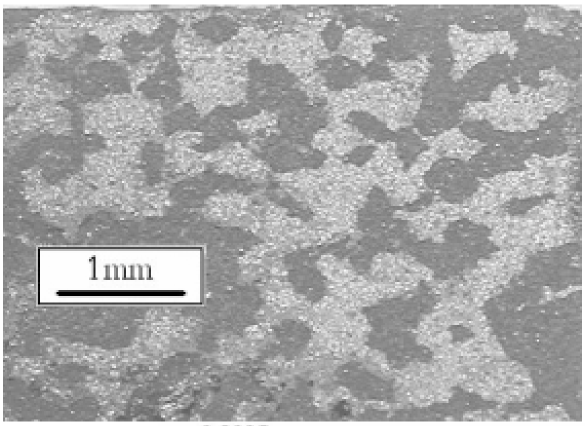

Fig. 1. Optical micrograph showing the porous YBCO sample filled by wax (better contrast). Dark (YBCO) and light area in image is evaluation in ratio of one to one.

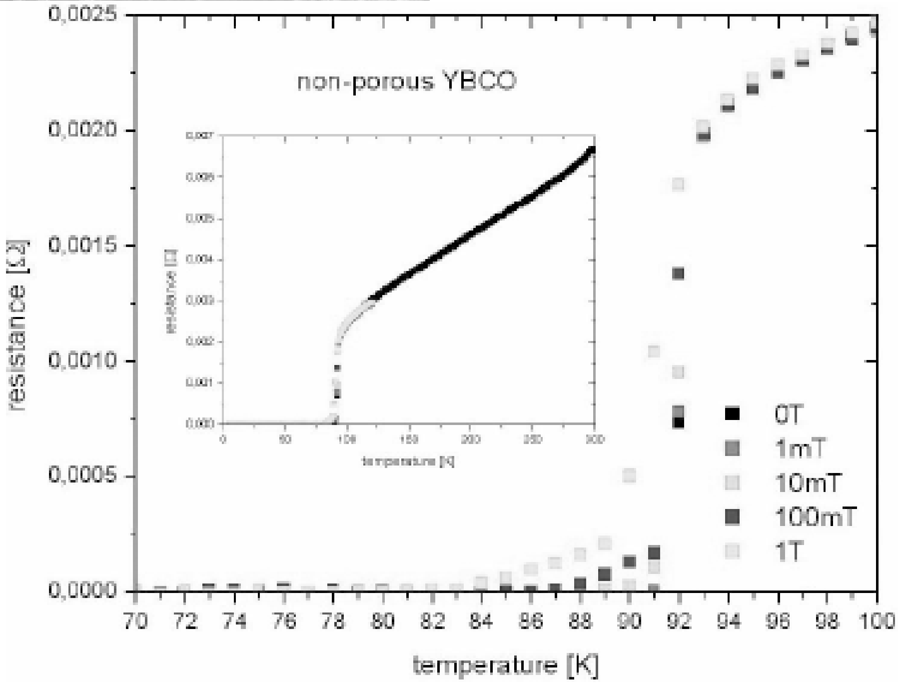

Fig. 2. Electrical resistance versus temperature from 4K to 300K and external magnetic field up to 1 T for a solid sample and the same data in the temperature region from 70K to 100K.

thane foams as a frame for very fine powder of YBCO [2,4-7]. In this work a technique of mixing the superconducting sample with sugar was applied [3,8].

Porous $YBa_2Cu_3O_{7-\delta}$ samples were prepared in the following way. First, ceramic samples of $YBa_2Cu_3O_{7-\delta}$ were by a typical solid state technique [9]. Next, the bulk ceramic of YBCO was ground and divided into three fractions: 0.125-0.2 mm; 0.2-0.25 mm and 0.25-0.4 mm. The same procedure was applied to the sugar. Then, the grains of YBCO and sugar (of the same size) were mixed in the 1:1 volume ratio and pressed under a pressure reaching 1.2 GPa. The pressed pellets were heated slowly up to 300 °C with the rate of 12 deg/h and from 300 °C to 500 °C with the rate of 60 deg/h in order to gently remove the sugar filler. After this stage, the samples were heated up to 935 °C with the rate of 40 deg/h and sintered at that temperature for 36 h. In the final preparation stage, the samples were annealed in flowing oxygen at the temperature of 475 °C for 36 h. A solid sample without pores was prepared with the use of the same initial material and sintered in the same conditions as the series of porous samples.

In order to increase the mechanical resistance of the porous samples, they were impregnated with colophony dissolved in ethanol and cut into bars of similar dimensions. The later electrical resistance

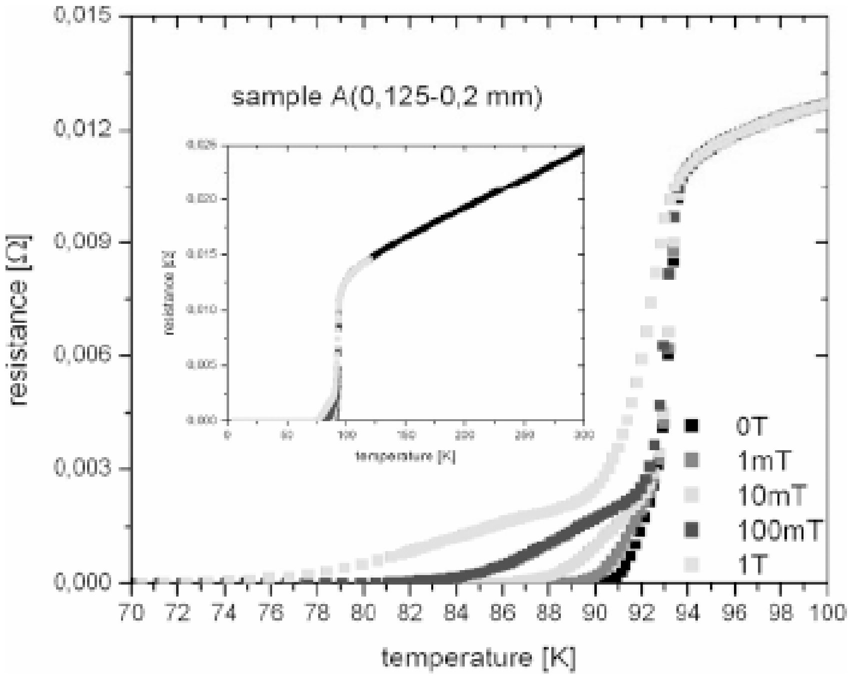

Fig. 3. Electrical resistance versus temperature from 4K to 300K and external magnetic field up to 1 T for porous sample (group 0.125-0.2 mm) and shows the same data in the temperature region from 70K to 100K.

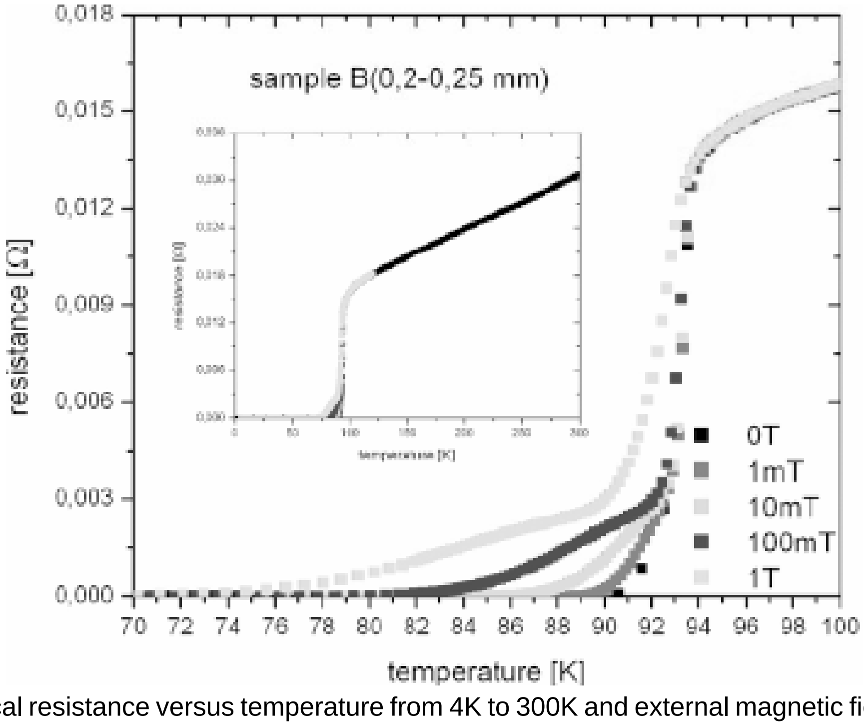

Fig. 4. Electrical resistance versus temperature from 4K to 300K and external magnetic field up to 1 T for porous sample (group 0.2-0.25mm) and the same data in the temperature region from 70K to 100K.

characteristics were measured in various external magnetic fields (up to 1 T). The four-point method measurement of electrical resistance with thermo-electric voltage compensation was used to increase the accuracy of electrical measurements.

3. RESULTS AND DISCUSSION

The technique applied in this work has made it possible to obtain material with about 50% volume of pores. Fig. 1 presents an example of an optical

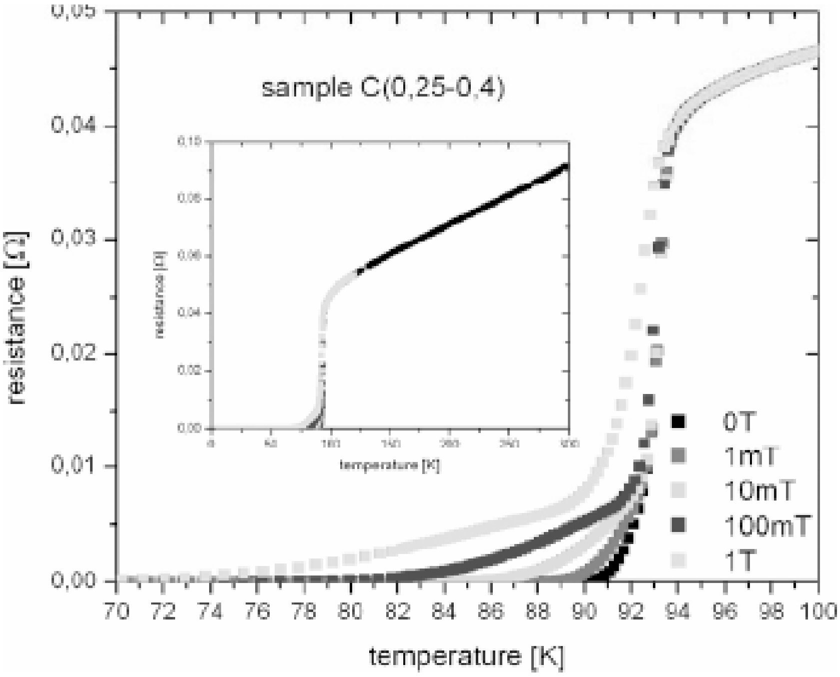

Fig. 5. Electrical resistance versus temperature from 4K to 300K and external magnetic field up to 1 T for porous sample (group 0.25-0.4 mm) and the same data in the temperature region from 70K to 100K.

micrograph showing the porous YBCO sample. Some straight lines were drawn on the picture at random. Next, the lines were divided into small segments, where they cross the dark and light areas, respectively. Later, the length of the segments was calculated and the YBCO to wax volume ratio was estimated. It may be seen that the areas of YBCO grains and the pores are approximately the same.

The measurements of the electric resistance characteristics for porous and high density samples show a metallic character of the electric conductivity above the critical temperature for all materials. Moreover, all the samples have similar properties in the zero external magnetic field. They reveal high $T_{c(\text{on set})} \approx 94$K, narrow width of the superconducting transition (about 2.5K) and zero electrical resistance at 91K. Significant differences between the porous and dense samples occur at external magnetic field, especially in the low temperature region of the superconducting transition $T_{c(\text{off set})}$ (Figs. 2-5).

The electric resistance characteristics reveal a significant broadening of the superconducting transition for porous samples compared with high density YBCO. Moreover, the observed differences may indicate that it does not depend on the size of pores. The aforementioned broadening of the electric resistance characteristic in the region of temperature under T_c does not have any support in the literature for typical good quality superconductive materials such as: foams, single crystals and thin layers [5,10,11]. In addition to that, the measurements of a dense sample agree with the literature results and they reveal typical changes of the resistance characteristic under the influence of an external magnetic field. The observed effects are most likely connected both with a non-homogeneous distribution of a magnetic field and with a larger number of weak links inside porous superconductors. In case of a high density YBCO, the magnetic field is pushed out of the superconductor during the transition to a superconducting state. But in case of the porous samples, the magnetic field does not have to be removed out of the bulk of the material. It may remain in the pores. As a result, the values of the magnetic field in this case present in non-superconducting pores could be higher than those of an external magnetic field. Initially, during the cooling process of a sample, a small amount of the material is in the superconducting state and the internal magnetic field is weakly reinforced. Hence, the electrical resistance characteristic of porous samples in the superconducting transition onset region does not differ significantly from the resistance characteristic for the dense samples. The situation changes when a significant part of the porous sample is in the superconducting state. Then, magnetic field is more reinforced locally. Therefore, we suppose that T_c for a part of the sample is lower than expected. As a result, a low temperature tail of resistance characteristic under the T_c region in comparison with a high density sample is observed. An assumed explanation is that the intergranular regions of our samples are clear in chemical terms. It is possible, because the porous sample is easily oxidized and the sucrose is burned out completely.

4. CONCLUSION

In conclusion we can state that the porous structure of a YBCO superconductor is more susceptible to an external magnetic field due to a local concentration in this field inside porosity samples. However, we have became conscious that an alternative explanation can be given assuming the existence of poor quality intergranular regions. Therefore, in order to verify this conclusion, we would suggest that similar research should be carried out with a superconductor of another kind, e.g. MgB_2, or low temperature superconductors.

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