Magnetic Field Enhanced Texture of Low Aspect Ratio $Bi_2Sr_2CaCu_2O_{8+x}/AgMg$ Wires as Measured by Electrical Transport

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***Abstract*—It has been shown previously that texture can be achieved in $Bi_2Sr_2CaCu_2O_x$ (Bi2212) bulk and tape conductors by applying a background magnetic field during the partial-melt stage. In this paper, we report on the texturing of low aspect ratio multifilamentary Bi2212/AgMg wires that were partial melt processed in a 12 T background magnetic field. To determine the effects of the applied magnetic field on the transport properties, the critical current was measured using the four point method. Transport measurements were carried out in magnetic fields up to 5 T with varying magnetic field angle. It was found that some texture is induced, resulting in electrical properties that vary with magnetic field orientation.**

***Index Terms*—Bi2212/AgMg, critical current, texture.**

I. INTRODUCTION

CRYSTAL growth and orientation of $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi2212)/AgMg crystals were carried out previously on high aspect ratio tapes by applying a background magnetic field up to 12 T during the partial melt stage [1]–[3]. Critical current and anisotropy depends strongly on crystal growth orientation [4]. We report on investigations on texturing of Bi2212/AgMg low aspect ratio multifilamentary wires using a 12 T background magnetic field during the partial melt stage. Samples were produced by Oxford Superconductor Technology (OST) applying the powder in tube technique. This research is part of the path to develop the new generation of superconducting magnets [5]. To determine if a textured microstructure can be produced, in-field processed samples were characterized electrically measuring the dependence of the transport critical current versus field angle in applied magnetic fields up to 5 T at 4.2 K. Microstructures were investigated applying using Scanning Electron Microscopy (SEM).

II. EXPERIMENTAL DETAILS

Unreacted Bi2212/AgMg low aspect ratio wire, provided by OST, was used for these investigations. The wire consists of 595 filaments with cross-sectional dimensions of 1.05 mm $\times$ 0.68 mm. A total of 12 samples, each 45 mm long, were placed in a ceramic sample holder and introduced in a vertical furnace installed inside the NHMFL large bore resistive magnet. Samples were heat treated in a 12 T background field oriented perpendicular to wide surface of the wires. Heat treatment was carried out using the partial melt process in continuous O_2 flow following the temperature-time profile shown in Fig. 1, which is significantly shorter than the conventional Bi2212 heat treatment temperature-time profile.

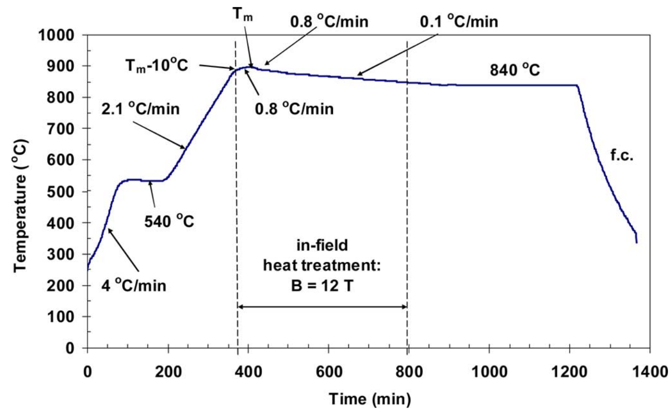

Fig. 1. Temperature-time profile used during heat treatment process of Bi2212/AgMg wires in a 12 T background magnetic field.

Magnetic field was applied starting at peak temperature $T_m-10°C$ with T_m between 885–890°C and held for 5 h until temperature reached $T_m-40°C$. The total heat treatment process took about 18 h. Critical currents of the samples were measured at 4.2 K using the four-point method and a 1 $\mu V/cm$ voltage criterion. To eliminate damage caused by Lorentz forces, samples were glued to a piece of G-10. Transport measurements were carried out using a probe with a rotating sample holder to allow for measurements at varying field angles from 0° to 90° in magnetic fields up to 5 T. The applied magnetic field was perpendicular to the transport current for all angle orientations.

III. RESULTS AND DISCUSSION

Fig. 2 shows $I_c(B)$ results for a sample heat treated at zero background magnetic field. Curves at low field angles ($\theta = 0°, 1°, 1.5°, 2°$) almost coincide with curves at higher field angles ($\theta = 45°, 60°, 90°$) indicating that there is effectively no texture in the microstructure. In Fig. 3, data for samples heat treated at 12 T are shown, in which a clear separation of the

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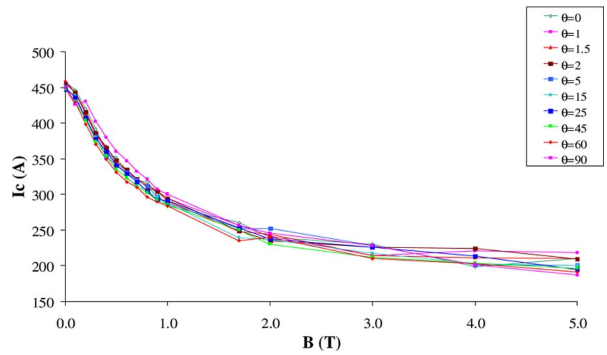

Fig. 2. I_c vs. B curves for a wire heat treated in zero applied magnetic field.

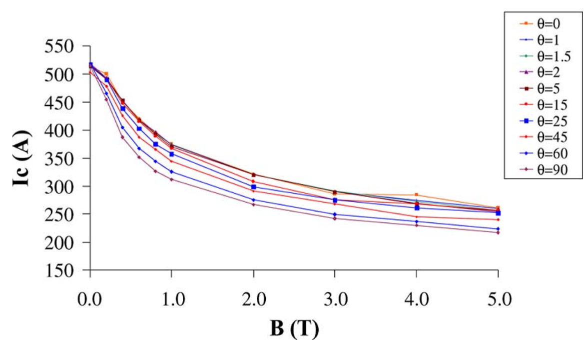

Fig. 3. I_c vs. B curves for a wire heat treated in a 12 T background magnetic field.

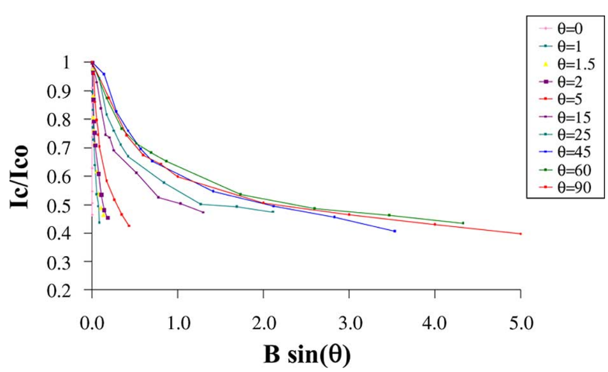

Fig. 4. $I_c/I_{co}(Bsin(\theta))$ curves for a wire heat treated in a 12 T background magnetic field.

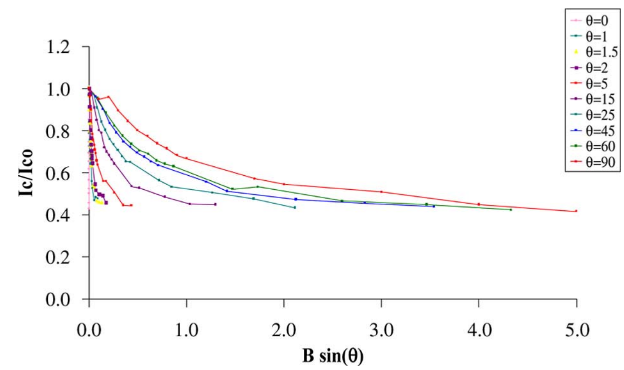

Fig. 5. $I_c/I_{co}(Bsin(\theta))$ curves for a wire heat treated in zero applied field.

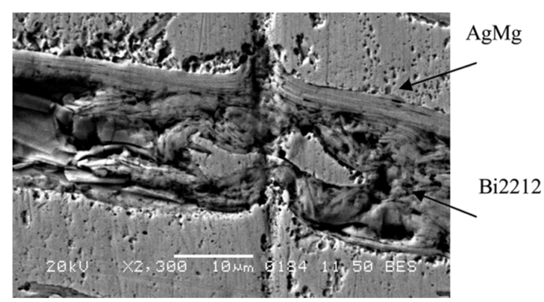

Fig. 6. Scanning electron micrograph of a sample heat treated in zero magnetic field. No preferred orientation is observed in the Bi2212 colonies.

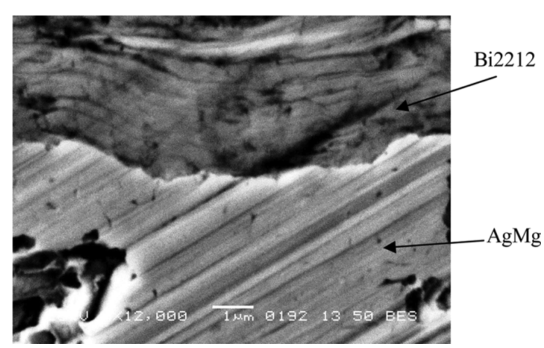

Fig. 7. Scanning electron micrograph of a sample heat treated in a 12 T magnetic field. An orientation preference in Bi2212 colonies is observed.

curves for all field angles $(\theta = 0°, 1°, 1.5°, 2°, 45°, 60°, 90°)$ is observed.

I_c/I_{c0} versus the effective applied field $Bsin(\theta)$ curves also clearly show the same trend. In Fig. 4, a separation in the curves is visible for samples heat treated at 12 T between angles $\theta = 0°, 1°, 1.5°, 2°, 15°$ and $\theta = 45°, 60°, 90°$. This is not observed for samples heat treated without applied field, shown in Fig. 5.

Microstructural analysis was carried out using SEM. Samples were mounted in epoxy resin, polished and then slightly etched in a dilute solution of 1 part of 60% perchloric acid (HClO4) and 99 parts of II-butoxy-ethanol $(CH_3(CH_2)_3OCH_2CH_2OH)$ to expose the microstructure. Fig. 6 shows a cross-sectional view of a sample heat treated at zero applied field. As can be seen, texture in this sample is low as confirmed by the angular dependence measurements. This is partially due to the presence of porosity. A preferred orientation, however, can be seen in Fig. 7 for a sample heat treated at 12 T, consistent with the transport measurements. This micrograph also shows significantly higher density than the image in Fig. 6.

Calculations for average grain misalignment φ_{avg} were made using (1) and following the specific approach detailed by Xu [6]–[8].

$$\varphi_{avg} = \arctan(\mathrm{B_b}/\mathrm{B_a}) \quad (1)$$

It was found that 40% of colonies of grains were aligned for samples heat treated in magnetic field, while only 10% of samples heat treated without field were effectively aligned. Thus, there is great potential for improvement in both cases. Average grain misalignment angles were $\varphi_{\mathrm{avg}} = 26.56°$ and $\varphi_{\mathrm{avg}} = 40.60°$ respectively.

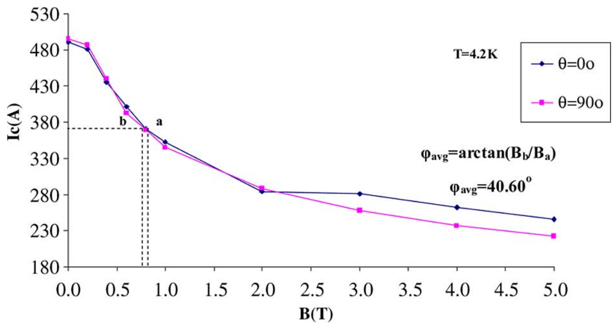

Fig. 8. $I_c(B)$ plot used to calculate the average grain misalignment angle. Data shown here is for a sample processed in zero magnetic field.

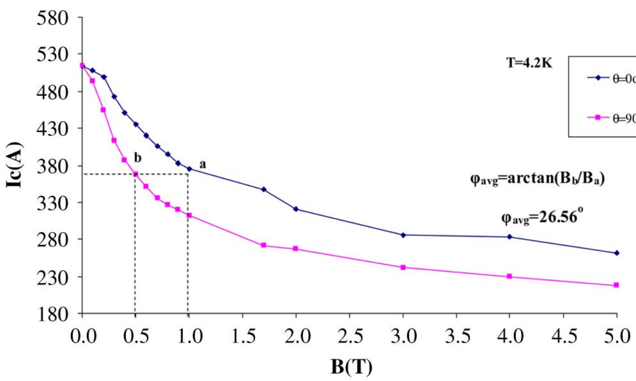

Fig. 9. $I_c(B)$ plot used to calculate the average grain misalignment angle. Shown here is data for a sample processed in a 12 T magnetic field.

Figs. 8 and 9 show $I_c(B)$ curves for two orientations $\theta = 0°$ and 90° for samples heat treated without and with a 12 T applied field used for average grain misalignment angle calculations.

IV. Conclusion

Using a 12 T background magnetic field, texture can be induced in low aspect ratio Bi2212/AgMg multifilamentary wires. Samples were characterized by electrical transport at various field angles up to 5 T. For comparison, samples from the same batch of wire were heat treated with and without 12 T applied field under identical conditions. Grain misalignment calculations show that almost 40% of grains were aligned for samples heat treated at 12 T whereas for samples heat treated at zero magnetic field only 10% was aligned.

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