Top seeding growth and superconducting properties of bulk YBCO - Ag composites

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ABSTRACT: Melt textured YBCO composites have been prepared by top seeding growth with an addition up to 20\% wt of submicrometric silver particles. Polarized optical microscopy, SEM and EDX analysis show single domain monoliths with an homogeneous distribution of silver particles in the range of 5 to 50 \(\mu\)m. Inductive critical current measurements of small pieces confirmed an increase of \(J_c^{\text{ab}}\) by a 250\% reaching values of \(2.5 \times 10^6\) A/cm\(^2\) at 5K and \(10^5\) A/cm\(^2\) at 77K. These results are contrasted with global measurements of trapped magnetic field. The progress required towards high quality large samples is discussed.

1. INTRODUCTION

Single domain melt textured (MTG) superconductors have been proposed as one of the most promising material for large scale applications since the main limitation of polycrystalline materials, i.e. grain boundaries, are overcome. However there are still a number of defects that limit their critical current density \(J_c\) like cracking. It has been reported, Singh J P (1989), that the addition of silver particles into the YBCO matrix may enhance the mechanical properties of MTG – YBCO by increasing the fracture toughness. Nevertheless, the relationship between microstructure and mechanical properties with \(J_c\) of MTG – YBCO has not been clearly established yet.

In this paper the enhancement of \(J_c\) by silver addition related to a decrease of the amount of microcracking and porosity is studied for millimetre samples. The potential use of these composites on trapped field applications where strong magnetic forces induce material cracking justifies these investigations. The scalability of this process to samples of larger dimensions required for the mentioned applications is discussed.

2. EXPERIMENTAL

Single domain melt textured YBCO (MTG YBCO) have been grown by the top seeding method described at Yu R (1997). Both Y211 and Ag\textsubscript{2}O have been varied, more precisely the following compositions have been tested: [ Y123 + 0.28 Y211 + 0.06 CeO\textsubscript{2} ] + 10,15,20 \% wt Ag\textsubscript{2}O and [ Y123 + 0.63 Y211 + 0.06 CeO\textsubscript{2} ] + 10,15,20 \% wt Ag\textsubscript{2}O. The samples obtained by this melt texturing technique have single domain growth till the boarders (12 mm in diameter) of the pellet with the typical cross shape indicating the ab crystallographic axis.

Differential Thermogravimetric Analysis measurements have confirmed that the peritectic temperature \(T_P\) of the system YBCO decreases with the amount of silver from \(T_P \sim 1002^\circ\) C until \(T_P \sim 972^\circ\) C. Above a 6\% wt Ag\textsubscript{2}O a saturation of \(T_P\) \((T_P \sim 972^\circ\)C) is reached, in agreement with
Wiesner U (1998). Hence, all above the samples have been grown under the same temperature treatment.

The final amount of Y211 precipitates retained in the single domain was determined by paramagnetic susceptibility, Martinez B (1996). In all samples here presented this amount reaches ~20 %wt which indicates that there is a pushing effect of the Y211 particles for large contents of initial Y211 precipitates, i.e. 0.63 mol Y211 (~30% wt Y211), Uhlmann D R (1976).

Small pieces were cut from the monoliths to perform SQUID measurements applying the magnetic field $H \parallel ab$ and $H \parallel c$, care was taken in dimensions to avoid demagnetising effects.

On the other hand, samples of 12 mm in diameter and 3-4 millimetres thick were used to measure the $H \parallel c$ component of remanent magnetic flux maps using a Hall probe technique.

3. MELT GROWTH PROCESS AND MICROSTRUCTURE

The silver particles distribution in the single domain monoliths observed by polarized light microscopy, after mechanical polishing, is show in Figure 1. A homogeneous dispersion of silver particles, with particle size range from 5 – 50 micrometers, within the YBCO matrix is obtained. The global shape of the silver particles in the YBCO matrix tends to be more spherical than disk-like, supporting the trapping and pushing theory reported at Nakamura Y (1998).

Figure 1. (a) : Optical microscopy photograph of an ab plane showing the silver particle distribution. (b) : Average crack distance as a function of the silver content estimated from electron microscope images.

Scanning electron microscopy has been used to investigate the effect of the silver addition on the microcrraking density of the samples. The samples have been observed in an ac / bc cross section to study the cracks usually appearing parallel to the ab planes. The average distance between cracks estimated from the electron microscope images can be seen in Figure 1b. Notice that the estimated average distance between cracks increases for Ag$_2$O content above 10% wt. Thus, showing that the microcrack density can be modified by proper tuning of Ag$_2$O addition.

4. SUPERCONDUCTING PROPERTIES

The inductive critical current density for $H \parallel ab$ and $H \parallel c$ has been measured for these

Figure 2: (a) Temperature dependence of $J_{C_{ab}}$ and $J_{C_{c}}$, the inset shows the value of the $J_{C_{ab}}$ (5K) as function of the Ag$_2$O content. (b) Magnetic field dependence of the $J_{C_{ab}}$ and $J_{C_{c}}$ at 77 K.
samples and calculated from the irreversible magnetization of the hysteresis loop using the anisotropic Bean model, Martinez B (1996,1998). For clarity only the 0% wt and 20 %wt samples are shown in the figures.

Figure 2(a) shows the dependence of the \( J_c \) with the temperature for both magnetic field \( H \parallel c \) (\( J_{c^{ab}} \)) and \( H \parallel ab \) (\( J_{c^c} \)). A strong increase of \( J_c \) is observed for the 20% wt Ag\(_2\)O sample for both magnetic field orientations at all temperatures, reaching values of \( J_{c^{ab}} \sim 2.5 \times 10^6 \) A/cm\(^2\) and \( J_{c^c} \sim 2.2 \times 10^5 \) A/cm\(^2\) both at 5 K and zero field. This represents an enhancement percentage of 250 % and 150% respectively compared with the sample with no Ag\(_2\)O addition. These values are among the highest ever reported in MTG YBCO. The inset of Figure 2a shows the value of \( J_{c^{ab}} \) (5K) as a function of the Ag\(_2\)O content manifesting that the enhancement of the \( J_c \) is strongly correlated with the silver content.

Figure 2(b) shows the magnetic field dependence of \( J_{c^{ab}} \) and \( J_{c^c} \) at 77K showing that the \( J_c \) has also increased strongly with the silver addition at 77K. It can be seen that the enhancement factor is more important for high field, reaching 250% at 4 T for \( H \parallel ab \).

However, one does not expect that silver precipitates of the order of 5-50 micrometers in diameter might be effective flux pinning centers. Instead, it is proposed that these silver precipitates blockade some of the current limiting factors, like microcraking, and thus enabling higher critical current densities without improving flux pinning properties.

In order to check the effect of silver on the sample global properties, trapped field in the remanent state measurements have been performed. Figure 3a and Figure 4a show the remanent flux distribution after a Field Cooled (FC) process for an applied field \( \mu_0 H_{ap}=0.3 \) T. A flux distribution according to a single domain sample is observed in both cases, but the perturbation of the flux at the edges is more evident in the 20% wt Ag\(_2\)O sample, and the central peak value decreases when silver addition increases (from 2550 G in the 0% wt sample to 1090 G in the 20% wt sample).

![Figure 3](image1.png)  
(a) Level curves of remanent flux distribution after a FC process for sample with 0% Ag\(_2\)O.  
(b) Circulating current calculated from flux mapping of Fig. 3a.

![Figure 4](image2.png)  
(a) Level curves of remanent flux distribution after a FC process for sample with 20% Ag\(_2\)O.  
(b) Circulating current calculated from flux mapping of Fig. 4a.
The current distribution on the whole sample has been determined by solving the inverse problem, using a 3-dimensional version of the method employed in Xing W (1994) on thin layers. It is based on the discretization of the magnetization on a 3-d lattice covering the sample. This assumption linearizes the problem of deriving the magnetization from the magnetic field measurements. The result is a method that makes no assumption on the geometry or regularity of current circulation on the basal planes and detects the existence of single or multiple domains. The induced current distribution $J(x,y)$ is shown in Figure 3b and Figure 4b. The circulating current vectors present a regular distribution that takes values around $2\times10^4$ A/cm$^2$ in the 0% wt Ag$_2$O sample, and reflects flux distribution asymmetries in the 20% wt Ag$_2$O sample which implies regions with smaller current density. A maximum value of $10^4$ A/cm$^2$ has been obtained for the 15% wt sample and $6\times10^3$ A/cm$^2$ for the 20% wt Ag$_2$O sample.

These trapped field measurements show that the enhanced properties of Ag-YBCO have not been scaled up to centimetre sized samples. Therefore, further work on the growth optimisation of large YBCO bulk samples has to be done in order to profit from the advantages of the Ag$_2$O addition in large YBCO monoliths.

4. CONCLUSIONS

Single domain YBCO – Ag composites have been obtained for different Ag$_2$O contents with a random distribution of small Ag particles with particle size from 5 – 50 micrometers. This material exhibits less microcracking, especially in the case of samples with high Ag$_2$O addition level between 10 – 20 % wt. The reduction of microcracking and consequently better quality of these composites seems to be the responsible for the strong enhancement of $J_C$ for both $H \parallel ab$ and $H \parallel c$ configurations. However, this enhancement observed at a millimetre scale has not been successfully scale up yet on the global properties (trapped field) of centimetre samples.

5. REFERENCES


6. ACKNOWLEDGEMENTS

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