Synergetic effect of 200 MeV Ag ions and Y_2O_3 inclusions on critical current density in $Y_{1-x}Ca_xBa_2Cu_3O_{7-d}$ thick film

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$Y_{1-x}Ca_xBa_2Cu_3O_{7-ä}$ (x = 0.1) +Y_2O_3 (10 wt.%) composite thick film prepared by diffusion reaction technique is irradiated with 200 MeV Ag ions. Micro Raman reveals the microstructural changes. Beans critical state model was employed to calculate the critical current density estimated from the width of magnetization loops obtained at 40 K. The enhancement of J_c from $1.4x10^4 Acm^{-2}$ to $6.7x10^4 Acm^{-2}$ with irradiation upto fluence $5x10^{11}$ ions-cm^{-2} in YCaBCO samples is observed indicating that flux pinning increases due to the creation of columnar defects induced by irradiation. Addition of Y_2O_3 increases the J_c in the pristine sample to $8.3x10^4 Acm^{-2}$ but decreases with increasing fluence. The insulating inclusions Y_2O_3 causes J_c increment by the process of flux pinning. Combined effects of inhomegenity and columnar defects due to irradiation have degraded the superconducting volume. The interaction energy between vortex and defects dominate over the pinning energy. Hence the pinning sites are not used effectively and J_c starts decreasing with irradiation.

Key words: *SHI irradiation, Pinning energy, Critical current density*

INTRODUCTION

The method of atomic replacement in $YBa_2Cu_3O_{7-ä}$ (YBCO) has proven to give valuable insight into the superconducting properties. YBCO coated conductors are candidates for future practical applications [1,2]. Doping of Ca^{+2} with Y^{+3} in YBCO films increases holes concentration [3], improves superconductor coupling between grains [4,5] and thus turns an oxygen deficient YBCO sample from insulator to superconductor. Ca preferentially occupies the Y site of YBCO especially when the doping concentration is lower than 11 wt.% [6]. This doping also increases the intergrain critical current J_c in spite of minimal lowering of T_c in the higher concentrations of Ca-doped YBCO films [4]. However, J_c rapidly decreases as the temperature increases under magnetic ûelds. The main reasons for this J_c depression are the intrinsic crystalline anisotropy of the system and the thermal ûuctuations. Nevertheless, the lack of effective pinning centers should be noted as another important reason. A Variety of oxides such as $BaMO_3$ (M= Zr, Ir, Hf, Sn) have been found to be effective pinning centers [7-9]. Investigations reveals that one of most promising approaches to enhance critical current density of HTSCs in presence of magnetic field is to introduce three dimensional defects of artificial pinning centers (APCs) in

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the YBCO matrix [10] one such example is Y_2O_3 nanoparticles [11]. Another significant approach of pinning is irradiation. Swift Heavy Ion (SHI) irradiation is very useful tool for modification of the properties of thick and thin films. It penetrates deep into the surface producing long and narrow disordered zone along its trajectory. This disordered columnar zone provides flux pinning along its entire length rather than occasional pinning at randomly distributed points or impurities. Columnar defects due to SHI are more effective than point defects at pinning flux lines at high temperature and fields [12]. In this present work we have studied the synergetic effect of non superconducting inclusion of Y_2O_3 (10 wt. %) and SHI irradiation of 200 MeV of silver ions on $Y_{1-x}Ca_xBa_2Cu_3O_{7-ä}$ (YCaBCO) thick films. Magnetic studies are further carried to investigate critical current density at 40 K

Experimental procedure

YCaBCO thick films were prepared using diffusion reaction technique. The stiochiometric amount of high purity chemicals of Y_2O_3, $BaCO_3$, CuO, and $CaCO_3$ was taken to prepare $YBa_2Cu_3O_5$ (Y211) + Ca substrates calcined at 850 ˚C. The diffusion reaction involves the reaction of substrate with an overlayer of $Ba_3Cu_5O_8$ sintered at 920 ˚C leading to the formation $Y_{1-x}Ca_xBa_2Cu_3O_{7-ä}$ (x = 0.1) film of thickness 10-12 µm. For YCaBCO composite 10 wt. % of Y_2O_3 was mixed with $Ba_3Cu_5O_8$ and then coated on the substrates. This was followed by oxygen annealing at 500 ˚C for 12 hrs. The prepared samples were irradiated using 200 MeV Ag ions at IUAC, New Delhi. Microstructural examination of samples was done using Raman spectroscopy. Magnetization hysteresis was measured at 40 K using vibrating sample magnetometer (VSM). Critical current density (J_c) was extracted.

Results and Discussions

Micro-Raman Analysis

Fig. 1. Shows the micro-Raman exhibiting

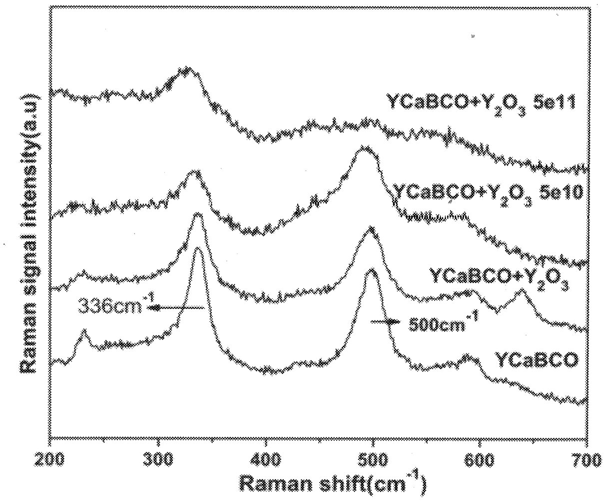

Fig. 1. Micro-Raman spectrum of YCaBCO composite thick films with different ion fluence of 200 MeV Ag ions.

peaks positioned at energy shifts 336 cm^{-1} and ~500 cm^{-1}. The presence of 500 cm^{-1} peak shows a high degree of oxygenation of the films [13].The peak at 336 cm^{-1} and 500 cm^{-1} is associated with the vibration along c-axis of oxygen of CuO_2 planes(O2-O3 out of phase) and the apical sites (O4) of orthorhombic YBCO. The peak softens for YCaBCO+Y_2O_3 irradiated. There is decrease in peak shift and softening of peaks gives clear evidence of oxygen depression in the damaged zone [14]. The occurrence of impurity phase is confirmed by the presence of $BaCuO_2$ phase shown by Raman peak at frequency 640 cm^{-1} for YCaBCO added with Y_2O_3 sample. The impurity phase is minimized in irradiated samples.

Magnetic Measurements

Magnetization measurements have been performed to estimate the current density. It is effective for estimation of critical current density (J_c) as well as for investigation of the magnetic pinning force. Fig. 2(a) shows magnetization as a function of applied field for YCaBCO thick film irradiated with 200 MeV silver ions at 40 K. Each loop has a peak near the lower critical point H_{c1}, beyond this point flux penetrates the material and the magnetization decreases gradually. The width of loops increases with irradiation fluences. This behavior of the irradiated sample is attributed to increase in flux pinning which reflects higher capacity to pin the vortices hence enhancement in J_c. Magnetization width of $Y_{1-x}Ca_xBa_2Cu_3O_{7-ä}$+ Y_2O_3 decreases with irradiation doses. This can be accounted for large number of defects created by inclusion of Y_2O_3 and columnar defects. Large numbers of defects are responsible for inhibiting the

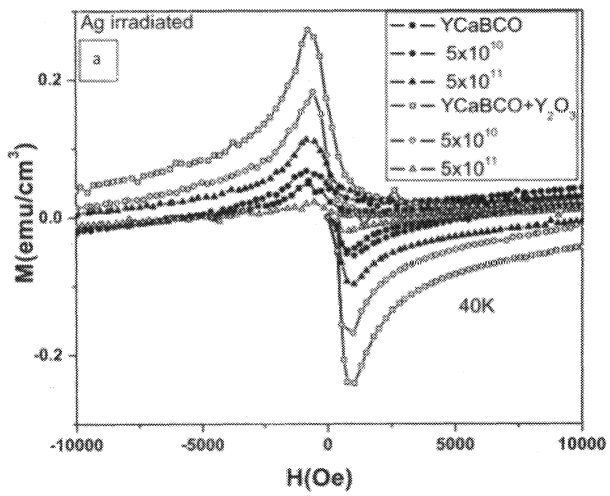

Fig. 2(a). Magnetization loop at 40K of $Y_{1-x}Ca_xBa_2Cu_3O_{7-ä}$? and $Y_{1-x}Ca_xBa_2Cu_3O_{7-ä}$ + Y_2O_3 thick film irradiated with 200 MeV silver.

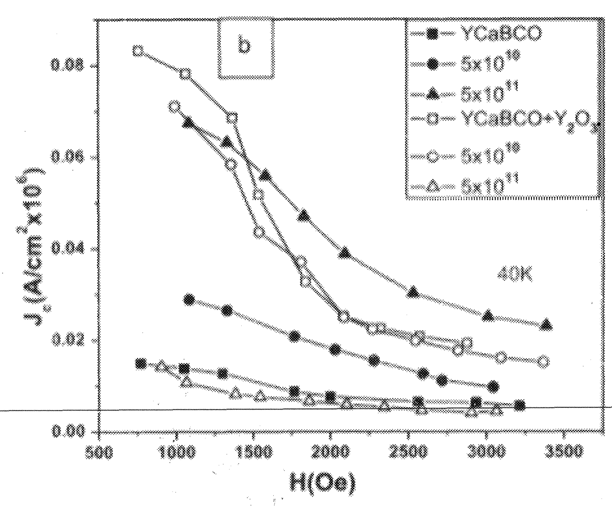

Fig. 2(b). Magnetic Field dependence of critical current density for YCaBCO and YCaBCO + Y_2O_3 irradiated with 200 MeV Ag ions at 40K with varying field

pinning energy to be used effectively. We observed that unirradiated YCaBCO doped with Y_2O_3 has the largest magnetization width and with the highest fluence of $5x10^{11}$ions/cm^2 the width is the smallest. Critical current was estimated from the magnetization width employing Beans critical state model [15] using equation (1)

$$J_c = \frac{20\Delta M}{a(1-\frac{a}{3b})} \tag{1}$$

Here $\Delta M = M_+ - M_-$ which is extracted from M (H) loop and a < b where a and b is the thickness and width of the bar shaped sample respectively. Fig. 2(b) shows J_c vs H graph. The highest J_c is recorded for YCaBCO doped Y_2O_3 unirradiated thick film. We observe enhancement of J_c in all the cases expect for YCaBCO composite irradiated with fluence of $5x10^{11}$ ions/cm^2. The maximum values of J_c are tabulated in Table 1.

Table 1. Critical current density (J_c) tabulated

Sample	Fluence (ions/cm^2)	J_c (A/cm^2x10^4)
YCaBCO	unirradiated	1.477
	$5x10^{10}$	2.902
	$5x10^{11}$	6.736
YCaBCO+ Y_2O_3	unirradiated	8.327
	$5x10^{10}$	7.077
	$5x10^{11}$	1.432

The synergetic effect of Y_2O_3 creating defects and irradiation with SHI producing columnar defect have resulted in lower J_c. This may be due to the fact that vortex-defects interaction energy dominant over pinning energy. Hence J_c decreases with more defects at higher fluences. Fig. 3. shows the temperature dependence of magnetization in a low applied field of H=0.05T for YCaBCO irradiated with silver ions with fluence of $5x10^{11}$ions/cm^2.

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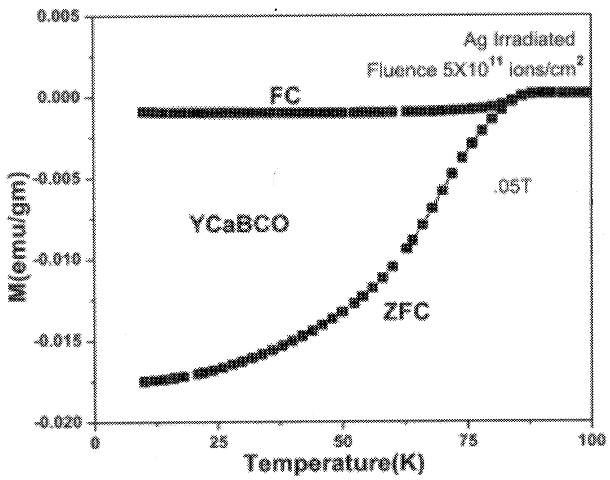

Figure 3. Temperature dependence of magnetization for YCaBCO irradiated with silver ions with fluence of $5x10^{11}$ ions $/cm^2$.

Both field-cooled (FC) and zero-field-cooled (ZFC) magnetization was studied. In ZFC measurements the sample is cooled in zero fields where a small magnetic field (0.05T) is applied. In the FC procedure, where the Meissner expulsion is measured, the sample is cooled in a small applied field. Below about 92 K the ZFC and FC curves start to open, indicating an irreversibility effect induced by the flux pinning. This measurement confirms that the transition

temperature of the irradiated YCaBCO does not drastically reduce T_c. The onset of irreversibility where the two curves merge is connected with the onset of the upper transition at 83 K. Higher magnetization is observed in the FC case as compared to the ZFC case because of columnar defects introduced by irradiation acts as pinning centers in the matrix of YCaBCO.

Conclusions

Thick films of YCaBCO composite with Y_2O_3 were irradiated with 200 MeV of silver ions. The greater magnetization width show higher J_c due to pinning effect of nanosized columnar defects. Unirradiated YCaBCO+10 wt. % Y_2O_3 have highest J_c with value 8.3 x 10^4 A/cm^2 as pinning force is optimum. As the interaction energy between vortex and defects dominates over the pinning energy the J_c decreases at higher fluence of the composite. Both FC and ZFC magnetization studies reveal that transition temperature is not drasticallty affected by irradiation in the range studied.

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References

1. Larbalestier, D., Gurevich, A., Feldmann, D. M. and Polyanskii, A., "High-T_c superconducting materials for electric power applications", *Nature* Vol. 414, pp 368-377. (2001)

2. Foltyn, S. R., Civale, L., Driscoll, J. L. M., Jia, Q. X., Maiorov, B., Wang, H. and Maley, M, "Materials science challenges for high-temperature superconducting wire", Nat. Mater. Vol. 6 pp 631-642.(2007)

3. Behera, D., Dash, S.K. and Mishra, N. C., "Transport characteristics and effect of Ag in controlling thermally activated phase-slip in Ca doped $YBa_2Cu_3O_{7-y}$", *Indian J. Phys.* Vol. 77, pp 133-138. (2003)

4. Danniels, G.A., Gurevich, A. and Larbalestier, D.C., "Improved strong magnetic field performance of low angle grain boundaries of calcium and oxygen overdoped $YBa_2Cu_3O_{7-x}$", *Appl. Phys. Lett.* Vol. 77, pp 3251-3253. (2000)

5. Hammeri, G., Schmehl, A., Schulz, R. R., Goetz, B., Bielefeldt, H., Schbeider, C. W., Hilgenkamp, H. and Mannhart, J., "Enhanced supercurrent density in polycrystalline $YBa_2Cu_3O_{7-ä}$ at 77K from calcium doping of grain boundaries", *Nature.* Vol. 407, pp 162-164. (2000)

6. Botterger, G., Schwer, H., Kaldis, E. and Bente, K., "Ca doping of $YBa_2Cu_3O_{7"ó}$

single crystals: structural aspects", *Physica C*. Vol. 275, pp 198-208. (1997)

7. Varanasi, C.V., Barnes, P.N., Burke, J., Bruke, L., Maartense, I., Haujan, T.J., Stinzianni. E. A., Dunn, K. A. and Haldar, P., "Flux pinning enhancement in $YBa_2Cu_3O_{7-x}$ films with $BaSnO_3$ nanoparticles", *supercond. Sci. Technol.* Vol. 19, pp L37-L41. (2006)

8. Ichinose, A., Naoe, K., Horide, T., Matsumoto, K., Kita, R., Mukaida, M., Yoshida, Y. and Horii, S., *"Microstructures and critical current densities of YBCO films containing structure-controlled $BaZrO_3$ nanorods", Supercond. Sci. Technol.* Vol. 20, pp 1144-1150. (2007)

9. Mele, P., Matsumoto, K., Horide,T., Ichinose, A., Mukaida, M.,Yoshida, Y., Horriiand, S. and Kita, R., "Incorporation of double artificial pinning centers in $YBa_2Cu_3O_{7-d}$ films", *Supercond. sci. Technol.* Vol. 21, pp 015019-015026. (2008)

10. Goyal, A., Kang, S., Leonard, K. J., Martin, P. M., Gapud, A. A., Varela, M., Paranthaman, M., Ijaduola, A. O., Specht, E. D., Thompson, J.R., Christen, D.K. and List, F.A., "Irradiation-free, columnar defects comprised of self-assembled nanodots and nanorods resulting in strongly enhanced flux-pinning in $YBa_2Cu_3O_{7-ä}$ films", *Supercond. Sci. Technol.* Vol. 18, pp 1533-1538. (2005)

11. Haugan, T., Barnes, P. N., Wheeler, R., Meisenkothen, F. and Sumption, M., "Addition of nanoparticle dispersions to enhance ûux pinning of the $YBa_2Cu_3O_{7-x}$ superconductor", *Nature* Vol. 430, pp 867-871. (2004)

12. Civale, L., Marwick, A. D., Worthington, T. K., Kirk, M. A., Thompson, J. R., Krusin-Elbaum, L., Sun, Y., Clem, J. R. and Holtzberg, F., "Vortex confinement by columnar defects in YBaCuO crystals", *Phys. Rev. Lett.* Vol. *67*, pp 648-651. (1991)

13. Branescu, M., Teodorescu, V.S., Socol, G., Balasz, I., Ducu, C., Jaklovszky, "Experiments on pulsed laser deposition and characterization of epitaxially in-situ grown $YBa_2Cu_3O_{7-x}$ thin films", J. Optoel, *Adv. Mat.* Vol. 17, pp 273-286. (2005)

14. Torres, A., Jimenezi, J., Gomez, P., Piqueras, "Raman and cathodoluminescence Study of Electron Irradiated BSSCO and YBCO Ceramics", J. Mat. Res. Soc. Vol. 373, pp 431-436. (1995)

15. Meslin, S., Iida, K., Hari Babu, N., Cardwell, D.A. and J.G. Noudem, *The effect of Y-211 precursor particle size on the microstructure and properties of Y-Ba-Cu-O bulk superconductors fabricated by seeded infiltration and growth, Supercond. Sci. Technol.* Vol. 19, pp 711-718. (2006)

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