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Magnetic field induced pinning effect in $YBa_2Cu_3O_{7-\delta}$ + $BaZrO_3$ superconductor

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Abstract : YBCO + $BaZrO_3$ composites were prepared through solid state route employing nitrate precursors of BZO yielding submicron particles. In fact, presence of BZO brings about a significant modification in the microstructure of the composites. The resistive broadening in the tail part is suggested to be associated with the link between the grains and to be extremely sensitive to magnetic field. The magneto-resistance of the samples has been investigated within the thermally activated flux creep (TAFC) and Ambegaokar and Halperin (AH) phase slip models. It is assumed that the global zero resistance state at T_{c0} region of HTSC are governed by the excitations in the weak link network. Invoking Beans critical state model, enhancement of J_c in composite samples in presence magnetic field at temperature (T) of 40 K has been observed.

INTRODUCTION

** The inhomogeneities in HTSC arising due to crystallographic natural defects (dislocations, twin planes) are not effective to pin the vortices. There are numerous techniques for creating artificial defects in materials such as chemical doping, particle irradiation, including electron, proton, neutron, and heavy ion irradiation which improve flux pinning.

** BZO fine particles exclude themselves as effective flux pinning centers in the textured YBCO [1]. BZO acting as artificial pinning centers has a high melting temperature with respect to YBCO so that the growth kinetics should be slow leading to small particles. Zirconium does not substitute in the YBCO structure and show non-reactivity with YBCO, and it can grow epitaxially with YBCO. It has a large lattice mismatch (~ 9 %), therefore strain between the phases could introduce defects for enhanced pinning.

** The critical current density can be enhanced by creating pinning centers for vortices, which may be caused by defects. Defects with size in the range of few times of YBCO's coherence length (~ a few nanometers) have been found to act as a means to inhibit vortex motion, which results in the significant enhancement of J_c at high temperatures and applied magnetic fields [2].

** This work tries to probe in to the current conduction process in the YBCO+BZO composites in the presence of magnetic field and critical current density J_c in different BZO composites.

** The temperature dependence of the dc magnetization is measured at varying external field.

** J_c is calculated considering the Bean's Critical State Model based on the following relation [3,4]

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

Where, a < b are the lattice parameters and $\Delta M = |M+| - |M-|$ which is extracted from M (H) loop

Experimental Details

YBCO was prepared by solid state reaction method and synthesis of $BaZrO_3$ was done by employing nitrate precursors like $Ba(NO_3)_2$ and $ZrO(NO_3)_2$ x H_2O in (1:1 molar ratio) with a calcination temperature of 900^0 C. YBCO + $BaZrO_3$ composites were made from a mixture of pre-reacted powder of YBCO and $BaZrO_3$. A series of polycrystalline composite samples of YBCO + x $BaZrO_3$ (where x = 1.0, 2.5, 5.0 and 10.0 wt.%) have been prepared by the standard solid-state route. Characterized by XRD, SEM, Magneto-resistance and M-H studies.

Result and Discussions

Using the Scherrer equation,

$$\tau = \frac{K\lambda}{\beta \cos\theta}$$

where K is the shape factor, λ is the x-ray wavelength, typically 1.54 Å, β is the line broadening at half the maximum intensity (FWHM) in radians, and θ is the Bragg angle, τ is the mean size

* Appearance of peaks (003), (004), (005) and (006) in the XRD pattern reveals a (00l)-orientation of YBCO. The presence of BZO (200) peak centered in the 2θ range of 43.50-44.00, gives an evidence for the formation of BZO crystallites with (h00) orientation.

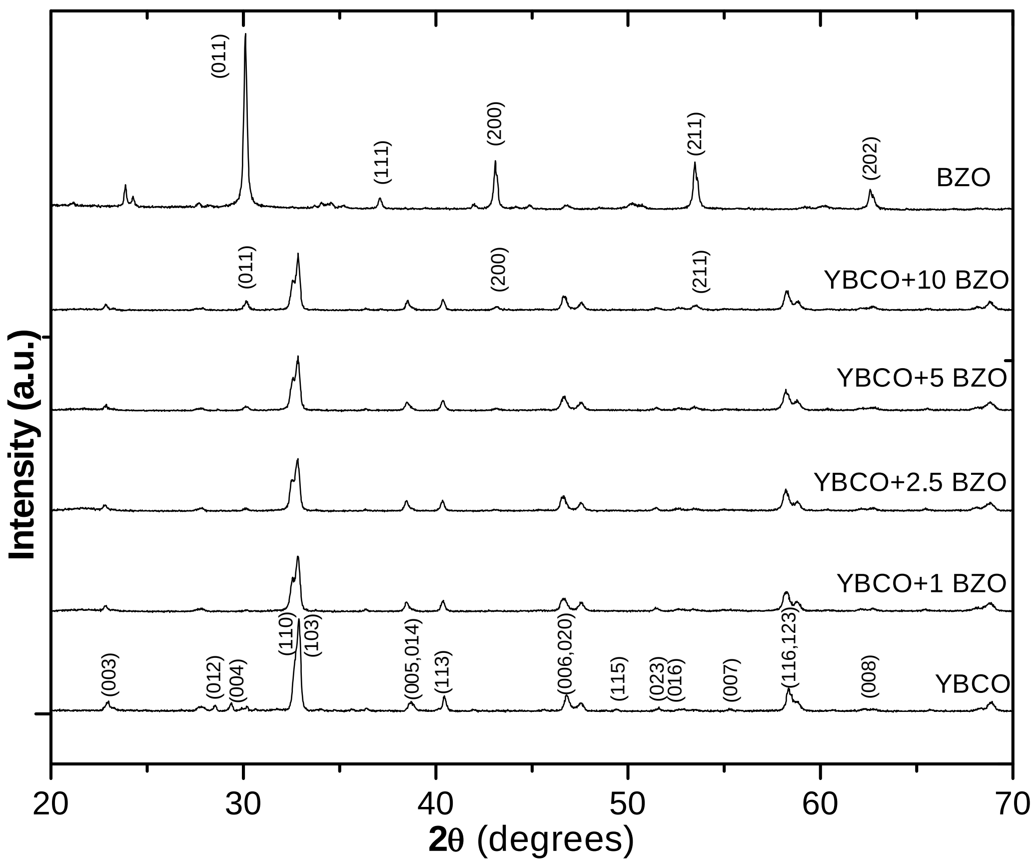


Fig. 1. XRD Patterns of BZO, YBCO and YBCO+ BZO composites with different BZO wt. %.

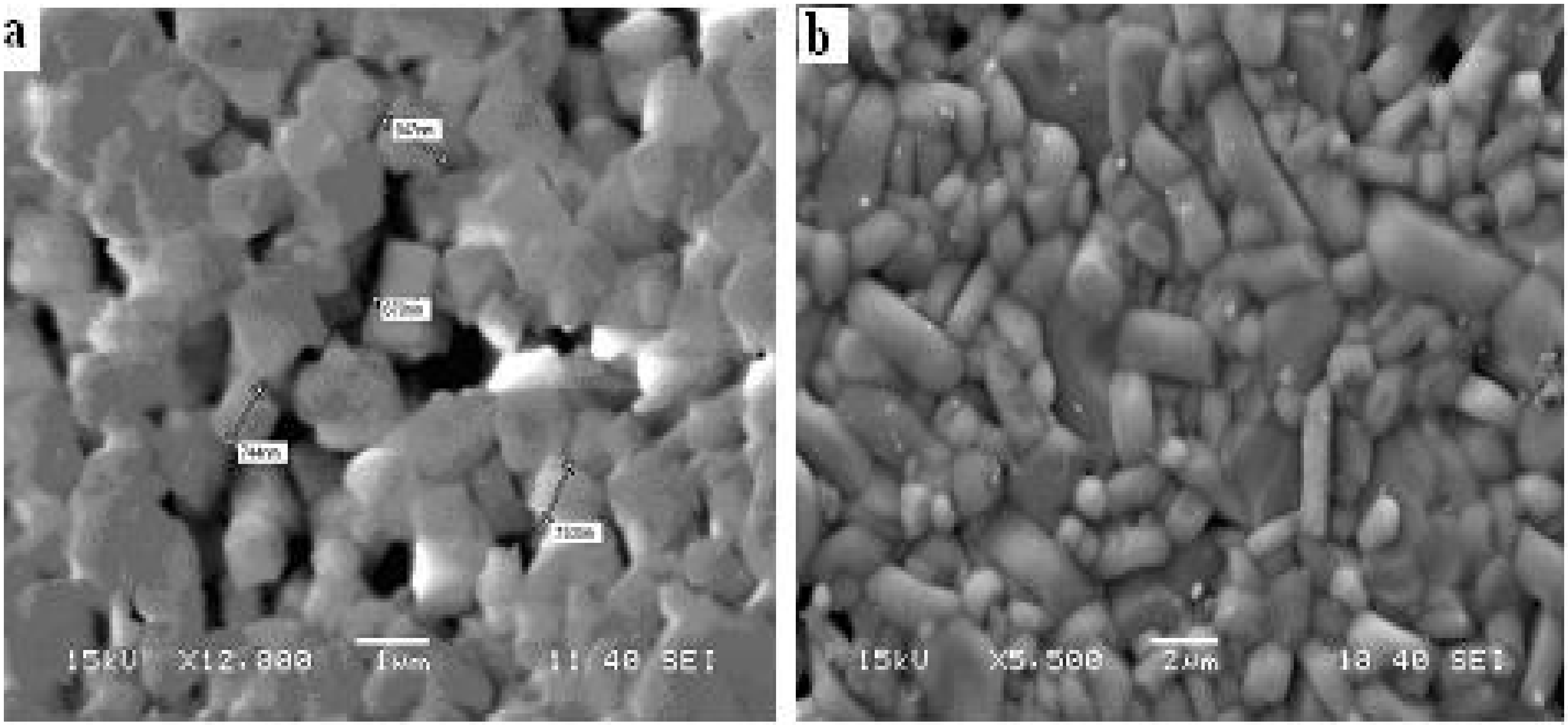
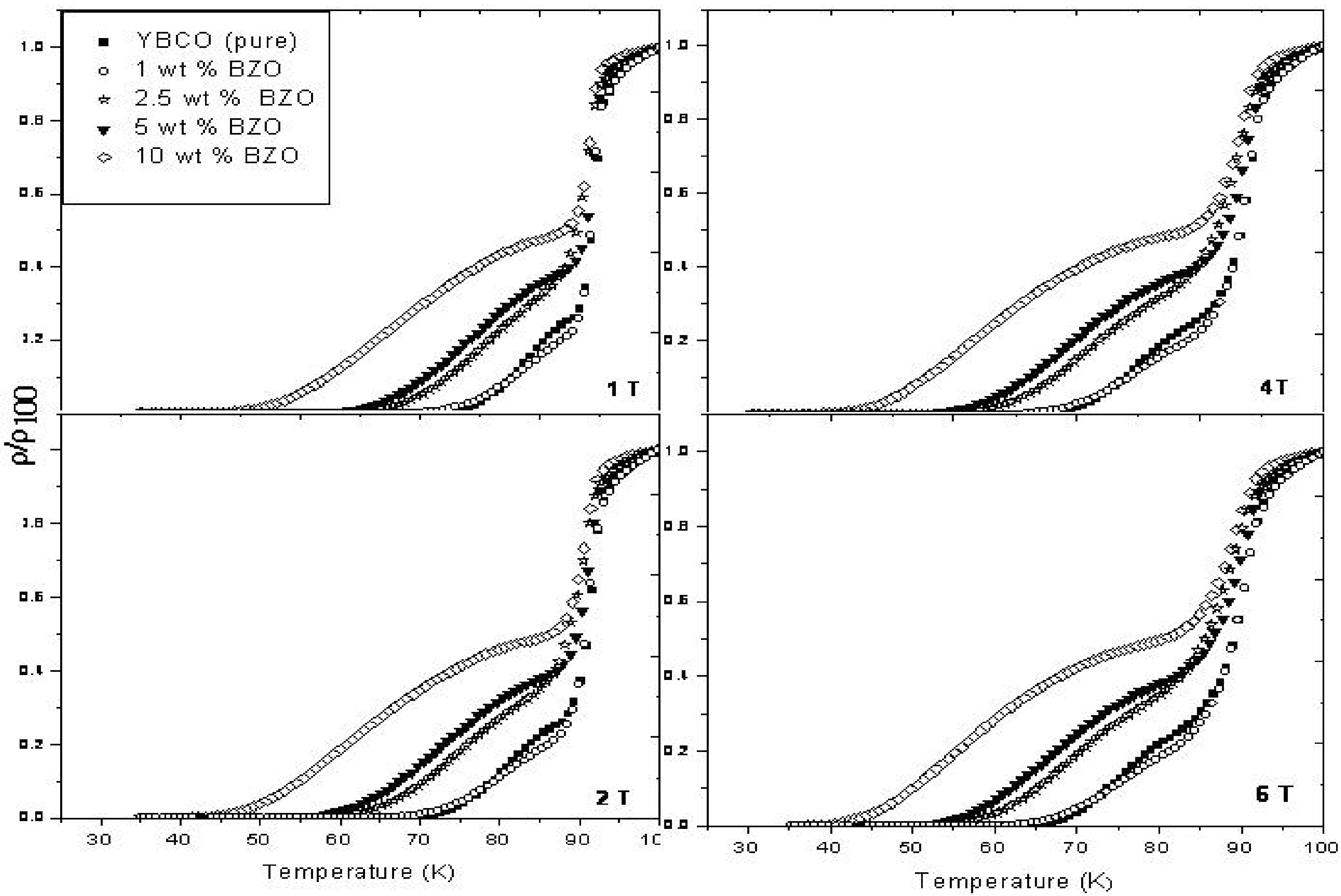


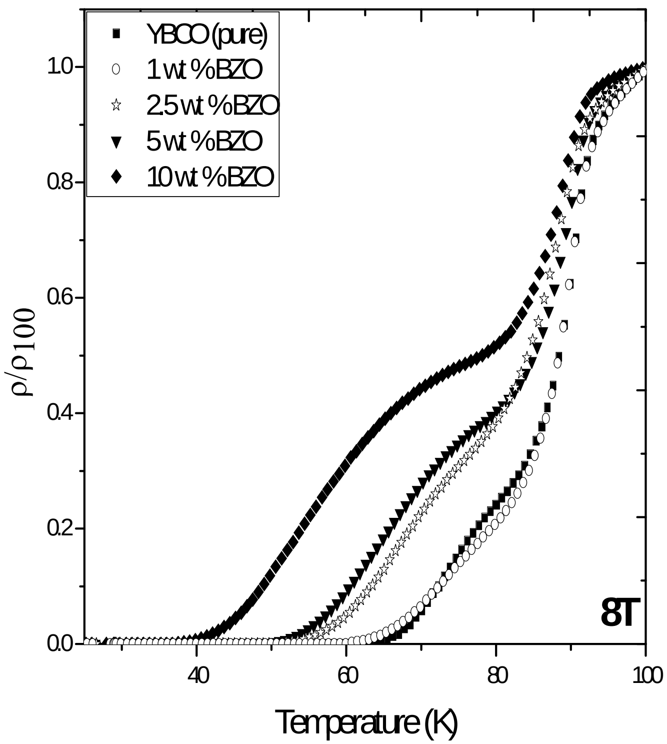
Fig. 2. SEM micrograph of (a) BZO powder and (b) YBCO bulk sintered.

* Normalized resistivity and temperature derivative of resistivity for different BZO composite samples of YBCO in an external field of 8 T are presented in Figure 3,4. Clearly two distinct peaks are observed for the onset of critical temperature. It is ascertained that impurities appear to decrease Tc_{on2} greatly to the lower-temperature values as function of BZO content.

* For $T < T_{c0}$, the Superconducting grains provide the channel for the transport of supercurrent. For $T_{c0} < T < T_c$, the volume of the grains are not adequate enough to provide a percolative path for supercurrent and the ρ-T transition shows a tail with $\rho \neq 0$. Only when $T \leq T_{c0}$, a percolative path through the SC component is established and a global superconductivity is established in the sample with $\rho = 0$.

* BZO being a dielectric material probably acts as a weak link, which causes the global resistivity transition temperature to decrease. Inclusion of 1 wt. % of BZO of less than 1000 nanometric size in YBCO matrix is found to have enhanced the intragrain vortex pinning.


YBCO (pure)
1 wt % BZO
2.5 wt % BZO
5 wt % BZO
10 wt % BZO
1 T
2 T
4 T
6 T
ρ/ρ100
Temperature (K)
Temperature (K)



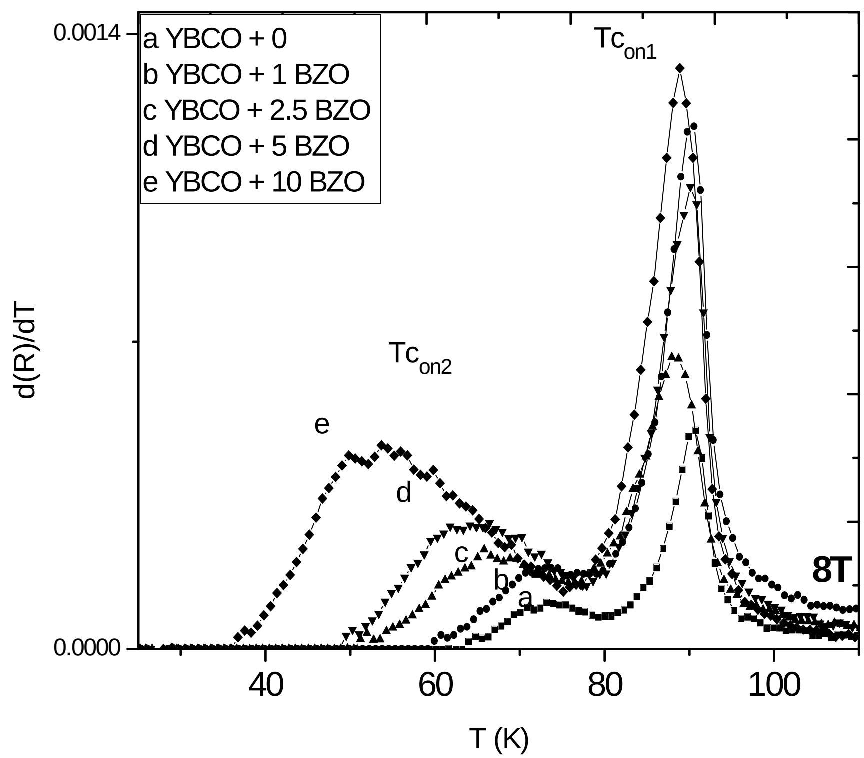


Figure 3. Normalized resistivity versus temperature of YBCO+ x BaZrO3 composites (x = 0, 1, 2.5, 5 and 10 wt %) measured for different B (1- 8 T).

Figure 4. Temperature derivative of resistivity in 8 T .

* BZO sub-micron particles distributed randomly within YBCO matrix serves as defects for pinning centers. The random crystalline orientation of fine BZO prepared by chemical process is effective in preventing the vortex motion at high field and at high temperature [5]. MacManus- Driscoll et al. [6] have reported enhancement of J_c in YBCO coated conductor with $BaZrO_3$.

* Our observation for critical current density (J_c) shows an increase from 8 x 10^4 A cm^{-2} to 2 x 10^5 A cm^{-2} for pristine YBCO and BZO 5 wt. % composite samples respectively in 1-16 (Tesla) field at a temperature of 40 K.

* The temperature dependence of the dc magnetization measured at an external field of 500 Oe is presented in Fig. 5. At a temperature of about 92 K the zero field cooled (ZFC) and field cooled (FC) curves start to open, indicating an irreversibility effect induced by the flux pinning.

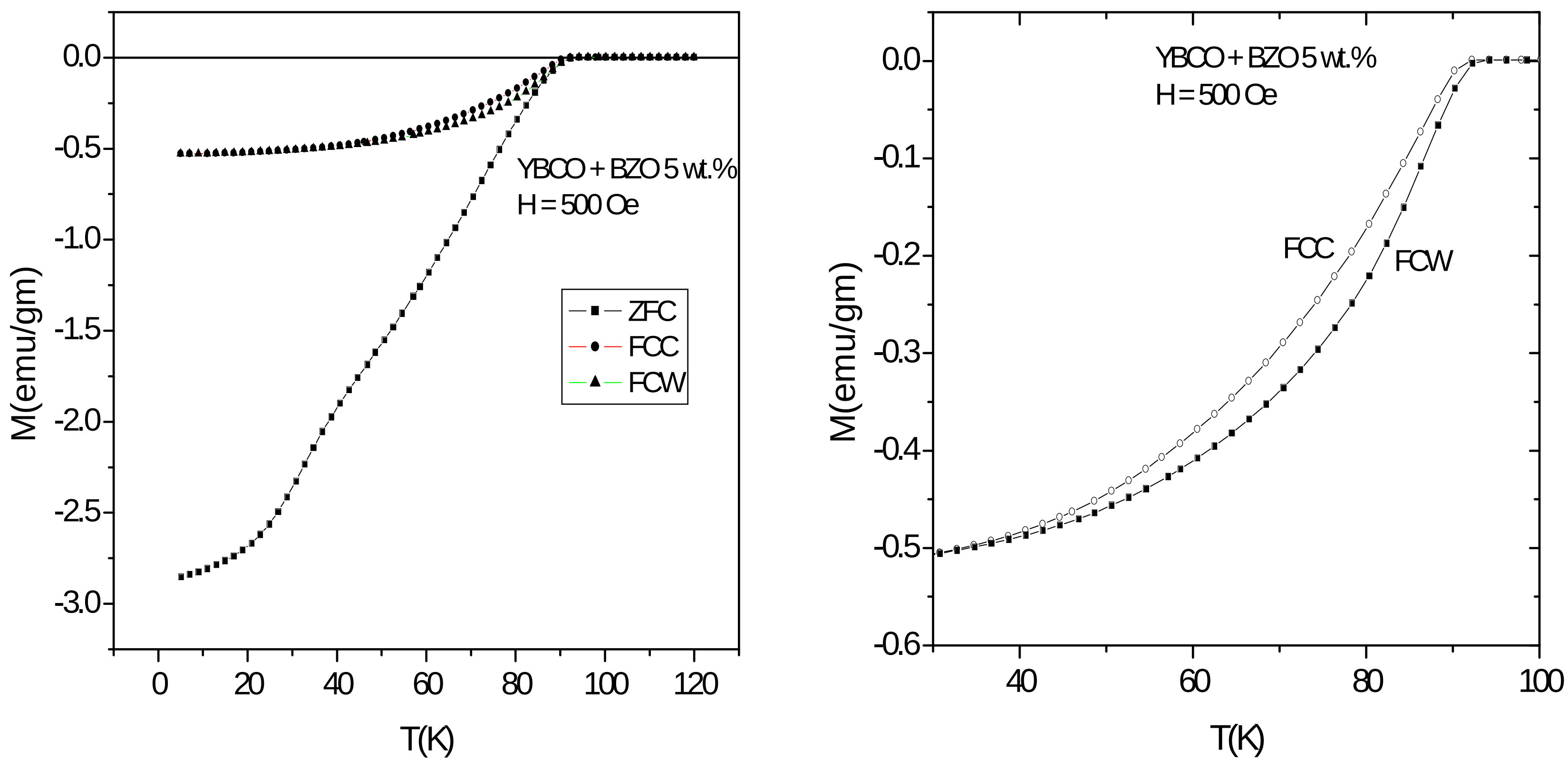


Fig. 5 Magnetization (M) vs. Temperature (T) at a constant low field showing the hysteretic behaviour observed for FCC and FCW in YBCO + BZO (5 wt %) sample.

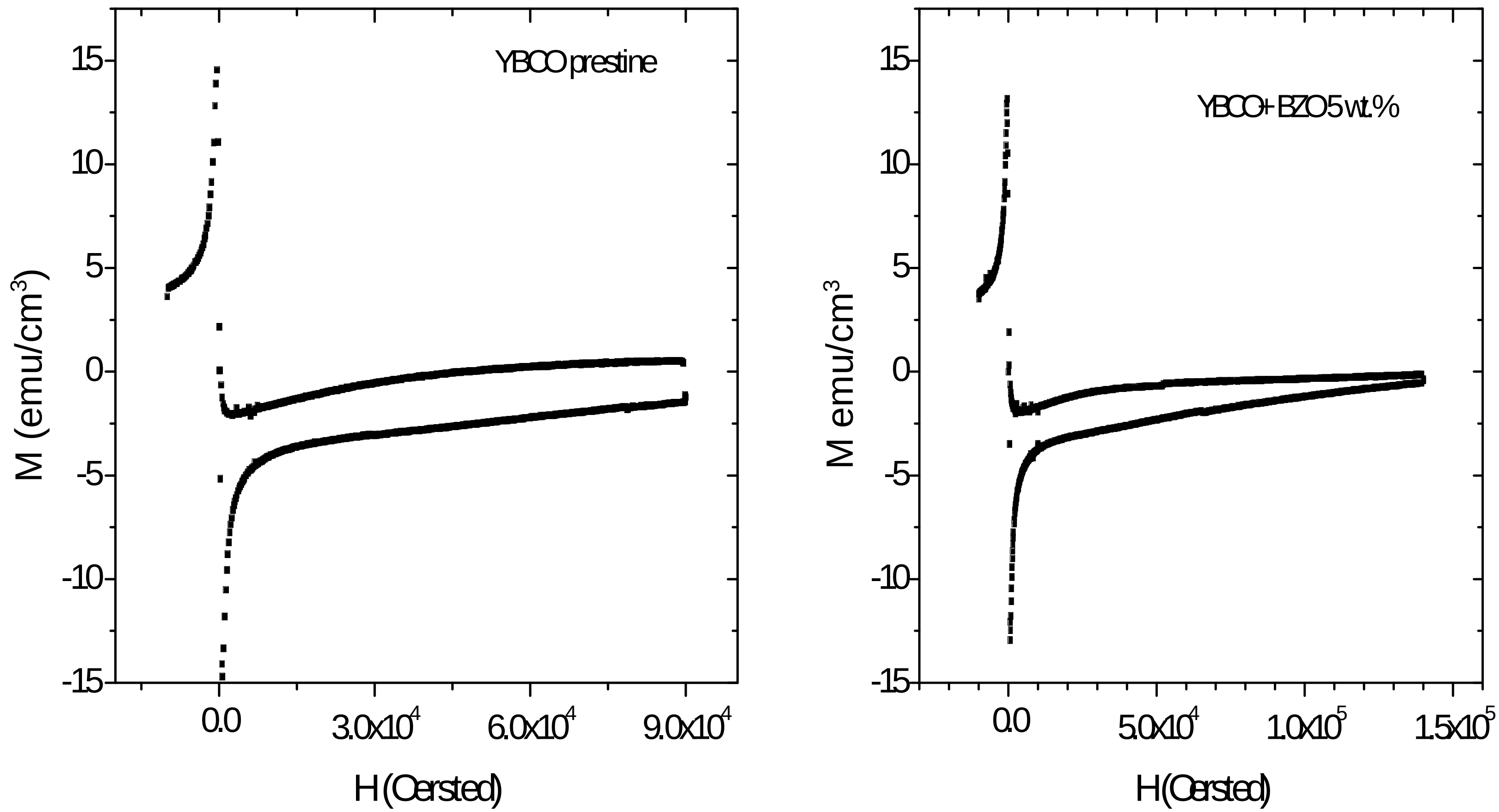


Fig. 6 M-H plot for pristine YBCO and YBCO + 5 wt % BZO sample for J_c measurement.

CONCLUSION

*** The magneto-resistivity data obtained as a function of temperature in the tail region shows two key features: first an anomalous secondary peak at T_{c2} well below 92 K as a function of BZO content with varying magnetic fields and secondly a drop in global resistivity transition temperature following the incorporation of excess BZO to the grain boundaries.**

*** BZO, because of its better compatibility with YBCO shows slightly higher T_c and higher resistivity slope than the pristine sample for x = 1 wt.%.**

*** Due to flux pinning effect of submicron BZO particles, in presence of magnetic field, critical current density (J_c) is also seen to have improved in the composites.**

*** The critical current density is dependent on particle size i.e. nanocrystalline has higher J_c as compared as microcrystalline size in agreement with [7].**

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