Low Sr doping effects on critical current density and pinning mechanism of $YBa_2Cu_3O_{7-\delta}$ single crystals

2014 J. Phys.: Conf. Ser. 568 022014

(http://iopscience.iop.org/1742-6596/568/2/022014)

Low Sr doping effects on critical current density and pinning mechanism of $YBa_2Cu_3O_{7-\delta}$ single crystals

R F Lopes[1], V N Vieira[2], A P A Mendonça[2], F T Dias[2], D L da Silva[2], P Pureur[1], J Schaf[1] and J J Roa[3]

[1]Instituto de Física, Universidade Federal do Rio Grande do Sul, 91501-970, Porto Alegre, RS, Brazil
[2]Instituto de Física e Matemática, Universidade Federal de Pelotas, 96010-900, Pelotas, RS, Brazil
[3]Department of Materials Science and Metallurgical Engineering, University of Barcelona, 08028, Barcelona, Spain

e-mail: rovanfl@gmail.com

Abstract. We report on isotherm dc magnetization hysteresis loops, $M(H)$ to $70K \leq T \leq 82.5K$ of $YBa_{2-x}Sr_xCu_3O_{7-\delta}$ (x = 0, 0.02 and 0.1) single crystals with the purpose to study the influence of the low Sr doping effects on the $YBa_2Cu_3O_{7-\delta}$ critical current density, $J_C(H)$ and normalized flux pinning force density, $f(h)$. The $M(H)$ measurements were performed in a commercial SQUID magnetometer with $H \leq 50kOe$ applied parallel to the c axis of the samples. The extended Bean critical state model was applied to $J_C(H)$ determination. The magnetic irreversibility fields, $H_{irr}(T)$ were obtained from $M(H)$ loops. The $f(h)$ behavior was determined from $F_P/F_{P,max}$ versus H/H_{irr} plots where F_P is the pinning force density ($\boldsymbol{F}_P = \boldsymbol{J} \times \mu_0\boldsymbol{H}$). The results show that the low Sr doped samples transport higher $J_C(H)$ than the pure one. The application of the Dew-Hughes scaling functions to the $f(h)$ plots designates the core normal punctual type as majority pinning mechanism of samples. We suggest that the core normal punctual pinning mechanism, responsible to the enhancement of the $J_C(H)$ transported by $YBa_{2-x}Sr_xCu_3O_{7-\delta}$ samples, is possibly connected to the segregation of Sr atoms precipitates at the crystalline structure of these samples.

1. Introduction

The chemical doping of the high temperature superconductors (HTSC) structure is applied successfully as a tool to investigate the effectively relation established between flux pinning mechanisms and $J_c(H,T)$ behavior in these materials. In special the enhancement of $J_c(H,T)$ is reported in the literature to $YBa_2Cu_3O_{7-\delta}$ single crystals when Y, Ba and Cu atoms are partially substituted correspondingly by Ca, Sr and Zn atoms [1-8]. However, scarce and not concluding are the results listed at the literature which investigate the interconnection between $J_c(H,T)$ and the pinning mechanisms and its chemical doping level concentration dependence at the $YBa_2Cu_3O_{7-\delta}$ single crystal structure [3-7].

Specified for the partially substitution of Ba atoms by Sr atoms at $YBa_2Cu_3O_{7-\delta}$ structure its solubility is almost 50% [9-11]. The smaller Sr atomic radius introduces lattice distortion in the $YBa_2Cu_3O_{7-\delta}$ structure [11]. Otherwise the enhancement of the $J_c(H,T)$ was confirmed to the

$YBa_2Cu_3O_{7-\delta}$ single crystals with Sr concentrations lower than 6% ($x \leq 0.12$) [2,3,5]. Some authors point the establishment of a defect structure constitutes of a high density of twin planes decorated with local Sr atom precipitates as responsible to the enhancement of the $J_c(H,T)$ [2,3] however no information about how this affects the pinning mechanism dynamics is presented.

With the purpose of collaborate to the elucidation of some aspects of the previous considerations, we report on a series of isotherm DC magnetization measurements performed in $YBa_{2-x}Sr_xCu_3O_{7-\delta}$ ($x = 0, 0.02, 0.1$) single crystals with the aim to study the role of the low Sr doping on the enhancement of the $J_c(H,T)$ and its interconnection to the normalize pinning force density, $f(h)$ mechanism.

2. Experimental details

The $YBa_{2-x}Sr_xCu_3O_{7-\delta}$ ($x = 0, 0.02$ and 0.1) single crystals referred in the text as ScY, ScSr002 and ScSr01 were prepared by self flux method [9,10]. The samples were analyzed by X ray diffraction (XRD) and polarized light microscopy (PLM) [9,10,13]. The XRD results for the doped samples confirm the Y123 orthorhombic structure lattice and points to the linear reduce of c crystallographic parameter as Sr doping level is enhanced. These results are in agreement with those reported in the literature for well oxygenated Sr doped single crystals [10-12]. The figure 1(a) displays the XRD obtained to ScSr01 sample. The doped samples PLM results, not showed, identify the presence of a high density of twin planes as contrasted to the pure sample [3,9,10]. The figure 1(b) displays the critical temperature transition, T_c of the samples characterized from zero field cooled DC magnetization measurements, with applied magnetic field H=10Oe. The T_c values are in agreement with those reported in the literature for $YBa_{2-x}Sr_xCu_3O_{7-\delta}$ single crystals [10-12].

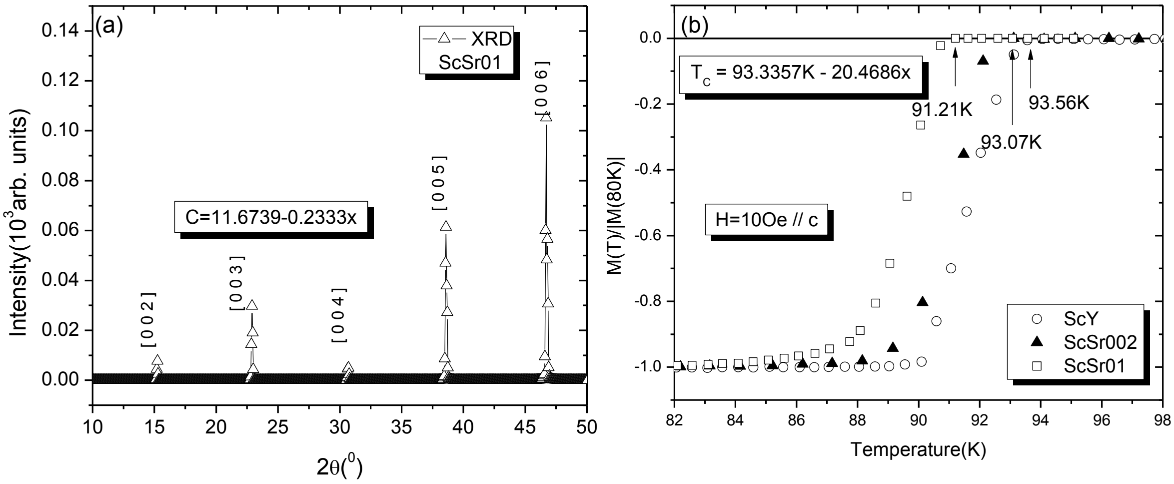

Figure 1. (a) The XRD of the sample ScSr01. (b) the $M_{ZFC}(T)$ plots where the $T_C(x)$ is indicated by the arrows.

The isothermal DC magnetization measurements were performed with a quantum design SQUID magnetometer. The usual $M(H)$ hysteresis loops measurement procedure was adopted [4] and the magnetization of the samples was recorded to $70K \leq T \leq 82.5K$ while magnetic fields, up to 50 kOe, were applied parallel to c crystallographic axis of the samples. The possible demagnetization factor contribution to the $M(H)$ data was checked.

3. Experimental results

The figure 2(a) display the magnetization hysteresis loops, $M(H,T)$. The SMP arrow identify the second magnetization peak (SMP) [2-4,8,14-16] whereas the $\mu_0H_{irr}(T)$ arrow defines the irreversible magnetic filed extracted from $M(H,T)$ data [2,8]. The figure 2(b) displays the $J_c(H,T)$ data calculated from the application of the extended Bean critical model [5-8] to the $M(H,T)$ data of the figure 2(a). According to this model the $J_c(H,T) = 20\Delta M(H)\eta^{-1}$ where η is a flat sample geometric parameter [5-8].

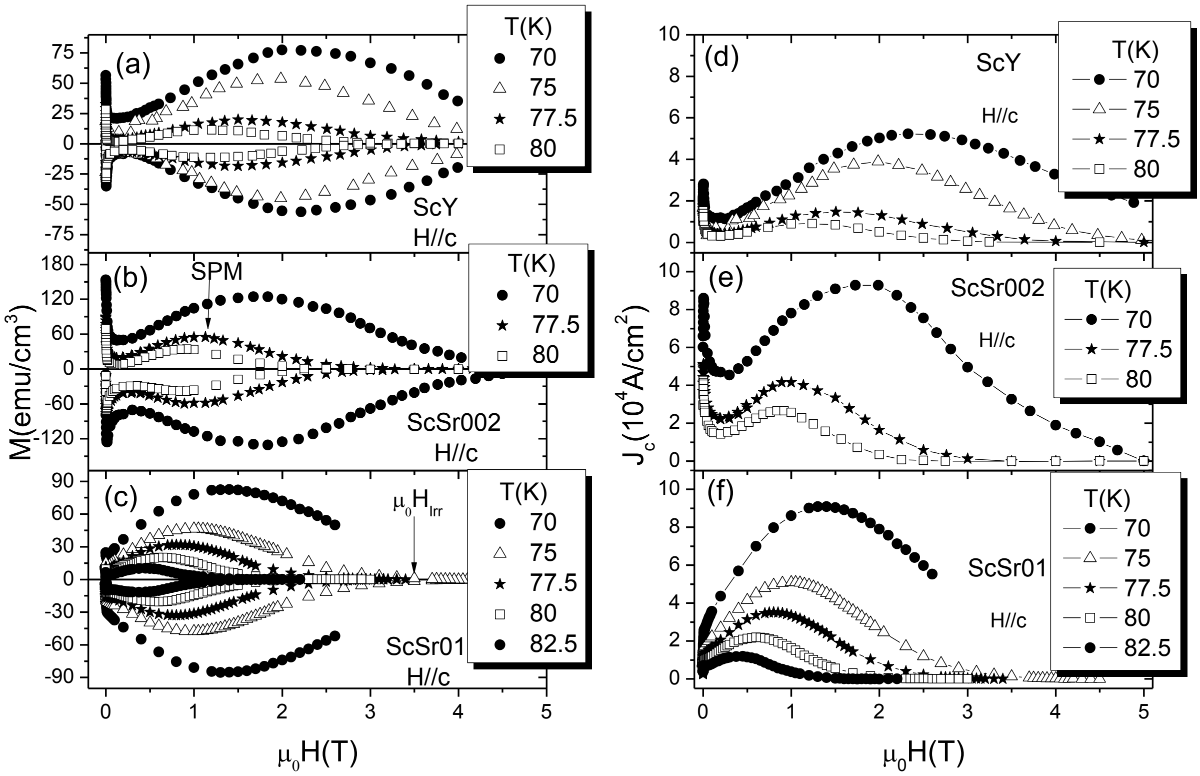

Figure 2. (a), (b) and (c) the $M(H)$ curves for the samples ScY, ScSr002 and ScSr01 respectively, the arrows indicate the irreversibility field $H_{irr}(T)$ and the second peak magnetization SPM. (d), (e) and (f) $J_C(H,T)$ for samples ScY, ScSr002 and ScSr01 respectively.

The $H_{irr}(T)$ data obtained from $M(H)$ measurements reproduce those reported by references 9 and 10 for the irreversible magnetic temperature, $T_{irr}(H)$ obtained from $M(T)$ measurements of $YBa_{2-x}Sr_xCu_3O_{7-\delta}$ (x = 0; 0.10; 0.25; 0.37 and 0.5) single crystals. The H-T plots of the $H_{irr}(T)$ data of our samples are fitted by $H_{irr}(T) \approx [1- T(H)\ T_{irr}(H{=}0)^{-1}]^{1.5}$ power law which is supported by giant flux creep scenario, the same behavior is reported to the $T_{irr}(H)$ data of $YBa_{2-x}Sr_xCu_3O_{7-\delta}$ ($x \leq 0.5$) single crystals [9,10]. Otherwise the identification of SPM in the $M(H)$ plots of our samples corresponds to the maximization of the flux pinning potential of samples.

The $J_c(H,T)$ of the Sr doped single crystals showed in the figure 2(b) are higher than that observed to the ScY sample. For instance to $T = 70$K and $\mu_0 H \sim 2$T the $J_c(H,T)$ of ScY, ScSr002 and ScSr01 are correspondingly 5 10^4Acm^{-2}, 9.2 10^4Acm^{-2} and 8 10^4Acm^{-2}. The enhancement of the $J_c(H,T)$ observed to Sr doped samples is in agreement to those reported at the literature for $YBa_2Cu_3O_{7-\delta}$ single crystal with Sr concentrations lower than 6% ($x \leq 0.12$) [2,3,5].

The figure 3 displays the plots of the normalized pinning force density, $f = F_P/F_{P,max}$ versus the reduced field, $h = H/H_{irr}$ to ScY, ScSr002 and ScSr01 samples [1,6,8,14,17]. The $F_P(H,T)$ data, not showed here, was determinate from $\boldsymbol{F}_P = \boldsymbol{J} \times \mu_0\boldsymbol{H}$ definition, where $F_{P,max}$ corresponds to the upper $F_P(H,T)$ data.

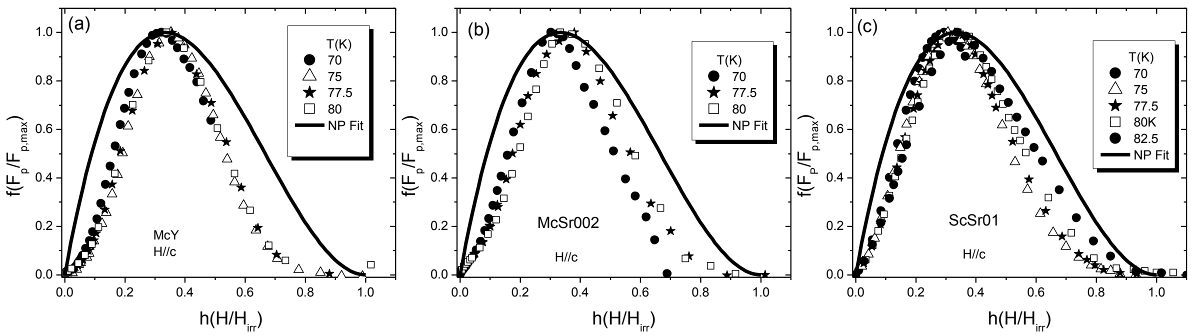

Figure 3. (a), (b) and (c) Normalized pinning force density $f = F_P/F_{P,\max}$ versus reduced field $h = H/H_{\mathrm{irr}}$ plotted with the core, normal, point pinning function of the Dew Hughes model, black line, for the samples ScY, ScSr002 and ScSr01 respectively.

The $f(h)$ data approximately scales in terms of an common behaviour to 70K ≤ T ≤ 82.5K. The NP fit solid line in these figures represents a fitting associated to the Dew-Hughes (DH) model [17,18]. This model was originally conceived to classify the differently pinning mechanism of the conventional superconductors which are classified in magnetic or core types subdivided in normal or Δk modalities. In the DH model the pinning mechanisms are identified through the application of the scaling law described in the equation 1 to the $f(h)$ data performance.

$$f(h) = \mathrm{A}(h)^{\mathrm{p}}(1-h)^{\mathrm{q}}, \qquad (1)$$

In the equation 1 A is a numerical parameter and p and q are fitting parameters related to the geometric characteristic of the pinning mechanisms. In the case of the HTSC the $\mu_0H_{c2}(T)$ parameter originally applied to determine the h is substituted for $\mu_0H_{\mathrm{irr}}(T)$ parameter [1,6,8,14,17].

For all the previous pinning mechanisms cited in the text and associated to the equation (1) fitting, the $f(h)$ data behaviour of our samples approximately matches to the core normal point pinning mechanism, where in figures 3(a), 3(b) and 3(c) are represented by the NP fit solid line. This particular pinning mechanism is obtained adopting p = 1 and q = 2 in the equation (1) [17]. According to the DH model the other way of identify the characteristic pinning mechanism from $f(h)$ data behaviour consists in establishes the reduced field parameter value that corresponds to the maximum $f(h)$ data value [17]. This specified parameter is called h_0 and its value determined for our samples is approximately 0.34 which is in agreement with h_0 = 0.33 classify by DH model to the core normal point pinning mechanism [17].

The matches of the maximum $f(h)$ data range of figures 3(a), 3(b) and 3(c) to the core normal point DH fitting is a strong evidence that the majority pinning of our samples is governed by the normal point type and that the low Sr doping do not change considerably the characteristic pinning mechanism associated to the origin of the SPM in the ScY sample. Otherwise we probably associate the core normal point pinning mechanism of the ScSr002 and ScSr01 samples to the establishment of Sr precipitate clusters at its crystalline structure like remarked by Saito et al [3] to the $\mathrm{YBa_{1.99}Sr_{0.01}Cu_3O_{7-\delta}}$ single crystal TEM analysis.

4. Conclusions

In this work we report on isotherm dc magnetization hysteresis loops, $M(H)$ to 70K ≤ T ≤ 82.5K of $\mathrm{YBa_{2-x}Sr_xCu_3O_{7-\delta}}$ (x = 0, 0.02 and 0.1) single crystals with the purpose to study the influence of the low Sr doping effects on the $\mathrm{YBa_2Cu_3O_{7-\delta}}$ critical current density, $J_C(H)$ and normalized flux pinning force density, $f(h)$ mechanism. The low Sr doping (x ≤ 0.1) of the $\mathrm{YBa_2Cu_3O_{7-\delta}}$ single crystals resulted in the enhancement of the $J_c(H,T)$ for all selected temperatures as compared to the no doped sample.

The *f*(*h*) data of studied samples approximately scales in terms of an common behaviour that according to the DH model could be associated to the manifestation of the core normal point pinning mechanism. We suggested that the establishment of Sr precipitate clusters at crystalline structure of the doped samples as responsible to the activation of the normal point pinning resulting in the enhancement of $J_c(H,T)$ of the $YBa_{2-x}Sr_xCu_3O_{7-\delta}$ single crystals.

Acknowledgments

The authors would like to thanks to CAPES and CNPQ scientific agencies and PRONEM 03/2011 (under contract: 11/2042-7) scientific program for partially financing this work.

References

[1] Rogacki K, Dabrowski B and Chmaissem O 2006 *Phys. Rev. B* **73** 224518
[2] Küpfer H, Zhukov A A, Will A, Jahn W, Meier-Hirmer R, Wolf Th, Voronkova V I, Kläser M and Saito K 1996 *Phys. Rev. B* **54** 644
[3] Saito K, Nissen H U, Beeli C, Wolf T, Schauer W and Küpfer H 1998 *Phys. Rev. B* **58** 6645
[4] Vieira V N and Schaf J 2004 *Physica C* **408-410** 533
[5] Shimoyama J, Tazaki Y, Ishii Y, Nakashima T, Horri S and Kishio K 2006 *Journal of Physics*: *Conference Series* **43** 235
[6] Wang Z H, Zhang H, Gao J, Yang T, Qiu L and Yao X X 2002 *Supercond. Sci. Technol.* **15** 1766
[7] Ishii Y, Tazaki Y, Nakashima T, Shimoyama J, Horri S and Kishio K 2007 *Physica C* **460-462** 1345
[8] Hussain M, Kuroda S, Takita K 1998 *Physica C* **297** 176
[9] Vieira V N and Schaf J 2002 *Phys. Rev. B* **65** 144531
[10] Vieira V N and Schaf J 2003 *Physica C* **384** 514
[11] Kakihana M, Eriksson S G, Börgesson L, Johansson L G, Ström C and Käll M 1993 *Phys. Rev. B* **47** 5359
[12] Licci F, Gauzzi A, Marezio M, Radaelli G P, Masini R and Chaillout-Bougerol C 1998 *Phys. Rev. B* **58** 15208
[13] Roa J J, Oncins G, Dias F T, Vieira V N, Schaf J and Segarra M *et al*. 2011 *Physica C* **471** 544
[14] Kobliscka M R, van Dalen A J J, Higuchi T, Yoo S I and Murakami M 1998 *Phys. Rev. B* **58** 2863
[15] Küpfer H, Wolf Th, Lessing C, Zhukov, A A, Lançon X, Meier-Hirmer R, Schauer W and Wühl H 1998 *Phys. Rev. B* **58** 2886
[16] Klein L, Yacoby E R, Yeshurun Y, Erb A, Müller-Vogt G, Breit V and Wühl H 1994 *Phys. Rev. B* **49** 4403
[17] Dew-Hughes D. 1974 *Philos. Mag.* **30** 293
[18] Kramer E. 1973 J. *J. Appl. Phys*. **44** 1360