Temperature dependence of lower critical field of YBCO Superconductor

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Abstract. We report the detailed study of the temperature dependence of the lower critical field (H_{c1}) of the $YBa_2Cu_3O_7$ superconductor by magnetization measurements. The curve shows the multiband gap behavior of the sample. It is found that the sample is not a single BCS type superconductor. H_{c1} is measured as the point at which the curve deviates from a Meissner-like linear M(H) curve to a nonlinear path. The H_{c1} for YBCO at different temperatures from 10K to 85K has been determined by magnetization measurements M(H) with applied field parallel to the c-axis. The sample phase purity has been confirmed by Rietveld fitted X-ray diffraction data. The amplitude (1-17Oe) dependent AC susceptibility confirms the granular nature of superconducting compound. Using Bean model we calculated the temperature dependency of inter-grain critical current density and $J_c(0)$ is found as 699.14kAcm^{-2}.

INTRODUCTION

Lower critical field (H_{c1}), is an intrinsic parameter related to the mechanism of superconductivity in type –II superconductors. Measurements of H_{c1}, the upper critical field, (H_{c2}) and coherence length (ξ) give a complete description of the mixed state parameters of the type-II superconductor. The H_{c1} is defined as the field at which magnetization curve starts deviating from its linear path or one can say that the field at which magnetic vortices first penetrate a type-II superconductor. Also, H_{c1} is directly related to the free energy of a flux line and contains information regarding essential mixed state parameters, such as the penetration depth, λ and the Ginzburg–Landau parameter, κ. Also, the multi-band superconducting gap can be measured from the H_{c1} and magnetic penetration depth λ. The H_{c1} has already been determined by different methods as mentioned in earlier reported literature [1-4]. Hafiez et.al. determined H_{c1} by two different methods i.e. the transition of field from a Meissner-like linear M(H) curve to a nonlinear path and second is by measuring the onset of the trapped moment Mt and a linear temperature dependence of lower critical filed was found. Some has characterized dc magnetization measurement by a Vibrating Sample Magnetometer (VSM) and Hall sensor methods [5-7]. D. X. Chen et. al. calculated H_{c1} for YBCO compound from hysteresis loop by fitting the data with an extended critical state model. Moreover, The temperature dependence of H_{c1} data has been investigated and several results concluded that $H_{c1}(T)$ function does not follow BCS theory. Generally, it is expected that the temperature dependence lower critical field H_{c1} follow Bardeen-Cooper-Schrieffer (BCS) theory. However, $H_{c1}(T)$ measurement consistently shows an upturn at $T<T_{c/2}$ when it does not obey the BCS theory, also popularly known as the non BCS behavior [2,8,9].

In this paper we report the detailed magnetization measurements on YBCO superconductor. We studied the critical current density of YBCO sample from detailed AC magnetic susceptibility measurements. Also, the report includes the complete M(H) curve at 10K and variation of DC magnetization with field at different temperatures (10K - 85K). The data of M(H) curve permits a more precise determination of the lower critical field. The lower critical field was determined from the magnetization measurements using procedure based on first deviation from perfect diamagnetism. Further it explains the temperature dependence of the lower critical fields H_{c1} and found a non BCS type behavior.

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EXPERIMENTAL

The sample $YBa_2Cu_3O_7$ is prepared through conventional solid state reaction route. After initial grinding, calcinations are done at 890°C and 905°C temperatures with intermediate grinding. Finally the sample is annealed with flowing oxygen at 920°C for 12 h, 600°C for 12 h and 450°C for 12 h and subsequently slow cooling is done to room temperature. The sample is characterized by the X-ray powder diffraction technique using Rigaku X-ray diffractometer (Cu-Kα line). Rietveld analysis of the sample is performed using Fullprof program. Detailed AC susceptibility, magnetization measurements and transport measurements are done on Physical Properties Measurement System (Quantum Design-USA PPMS-14T).

RESULTS AND DISCUSSION

Figure 1 shows the Rietveld fitted XRD pattern of synthesized YBCO sample. As no extra peaks of impurity are found so the sample is considered as homogeneous and pure. The synthesized sample is crystallized in

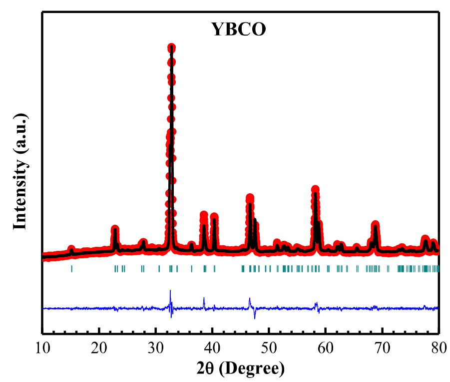

FIGURE 1: Rietveld fitted XRD pattern of YBCO, oxygen annealed sample.

orthorhombic structure within Pmmm space group. The fitted values of lattice parameters *a*, *b* and *c* are 3.823(2), 3.887(6) and 11.685(3) Å, respectively. These values are close to oxygen stoichiometric ($\delta = 0$) YBCO compound. Rietveld fitting confirms the good quality of the synthesized sample.

Figure 2(a) exhibits the real part of AC susceptibility ($\chi^{/}$) at different (1Oe-17Oe) ac magnetic field amplitudes. It is important to note that the DC bias field is zero. The diamagnetic transition is observed at around 91.3K. Two step transition is very clear even on applying a small field amplitude of 1Oe, corresponds to flux removal from intra

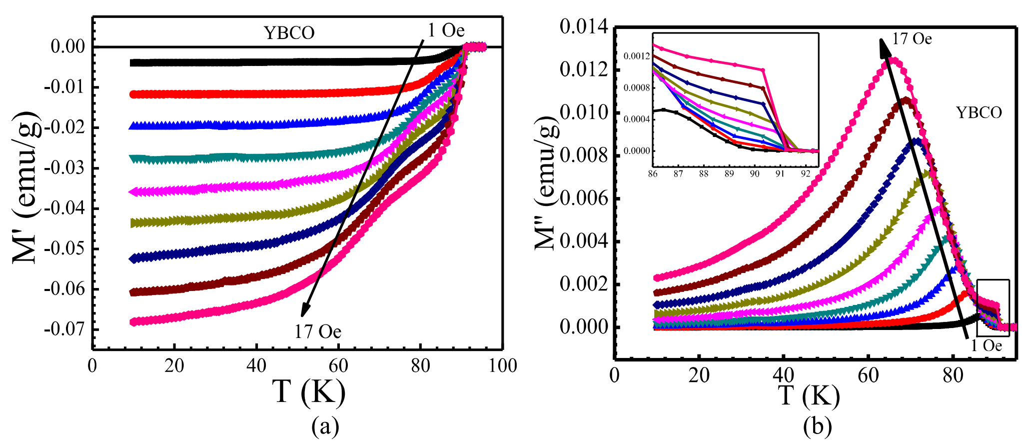

FIGURE 2: (a) Real part and (b) imaginary part of AC linear susceptibility measurements of YBCO taken at different ac field amplitudes with 333Hz constant frequency.

and inter grain region of the YBCO superconductor. This defines the granular nature of the studied sample. The first transition near T_c i.e. intra granular transitions is observed at 91.3K and transition at lower temperature is inter granular transition which is found at around 87.4K. The intra grain transition remains unaffected under high magnetic field amplitude but on applying high field the inter granular transition moves toward lower temperature. On varying magnetic field from 1Oe to 17Oe, the inter granular transition shift from 87.4K to 78.4K.

Figure 2(b) shows the imaginary part of the AC susceptibility (χ//) for YBCO sample and the inset part is the clear view of intra granular peak. Similar to real part, clearly two peaks are observed in the χ// versus T plot being taken at various AC amplitudes (1Oe-17Oe). The first peak (intra) occurs at around 90K and second peak (inter) at around 86.5K with AC amplitude of 1Oe. With an increase in AC amplitude from 1Oe to 17Oe, the first peak though remains unaltered at around 90K, the second peak has a shift of 20.6K towards lower temperature. This clearly indicates that though intra grain T_c is unaltered with AC amplitude, the inter grain T_c is decreased significantly with field. Using Bean model [11] we calculated the temperature dependency of inter-grain critical current density. The relation is given by

$$J_c(T_P) = H_a/\sqrt{ab}$$

Here, 2a × 2b where a < b, is cross section of sample, H_a, is applied ac field amplitude and $J_c(T_P)$ is the inter-granular critical current density at T_P and T_P is the temperature of the inter-grain peak. The calculated values are plotted with temperature in Fig. 3(a). J_c is estimated in the neighborhood of T_c, where the shift of the inter-grain peak's extendibility towards lower temperatures is within the limit of driven field. The temperature dependence of J_c is found to obey power law given by [12]

$$J_c(T)=J_c(0)(1-T_p/T_c)^n$$

Here, T_c is the zero resistivity critical temperature. Values of $J_c(0)$ and 'n' at 333 Hz obtained from experimental fitted data are 699.24kAcm^{-2} and 0.9 respectively which is in agreement with ref.[13]. The obtained value of $J_c(0)$ is quite high. The inter-granular current density obtained by using equation (2) is plotted in Fig. 3(b).

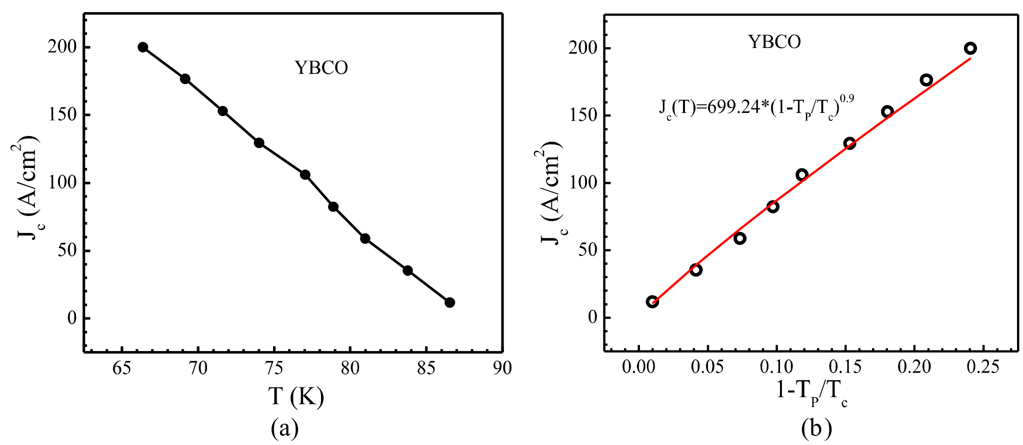

FIGURE 3: (a) Variation of J_c with respect to T_P of YBCO sample. (b) Temperature dependence of critical current density (symbols) and its fitted curve (solid line) as per equation (2) for YBCO sample.

In Figure 4, we present the magnetic hysteresis loop of YBCO sample at 10 K with the varying applied field. It is well known that the width and behavior of this hysteresis loop is the clear indication of the bulk critical current density in type II superconductors. The wider the hysteresis loop, the higher the bulk critical current density will be. This is in agreement with the calculated value of J_c of the studied sample. Inset (a) of Fig. 4 shows the variation of DC magnetization with field (M-H) at several temperatures (10K to 85K) below superconducting transition temperature (T_c). Now we calculate the lower critical field (H_{c1}) from M-H curves by using most popular method in which the estimated value of H_{c1} is the point from where the linear curve deviate its path towards non linear curve. It is seen that with increasing temperature, the M-H curve shifts towards the zero value i.e. the value of lower critical field decreases with increase in temperature towards T_c. The variation of lower critical field (H_{c1}) with temperature is shown in Inset (b). This curve fitted in a general equation of lower critical field i.e. $H_{c1}(T)=H_{c1}(0)*(1-(T/T_c)^2)$. Unlike to some other reports [9,10] our data, $H_{c1}(T)$ doesn't obey the general equation of BCS theory. At low temperature value the curve completely diverts from BCS type behavior.

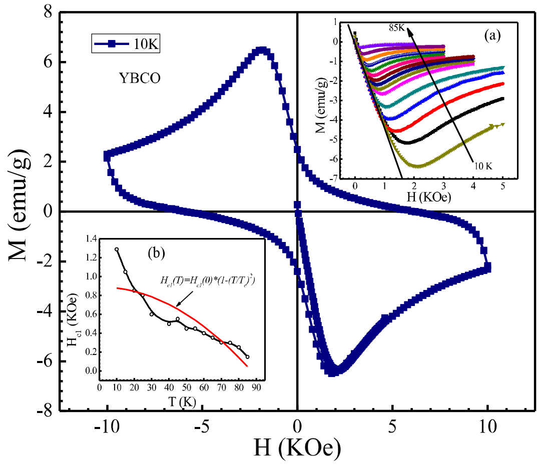

FIGURE 4: M-H plot of $YBa_2Cu_3O_7$ sample with temperature at 10K. Inset (a) Magnetic field dependent magnetization of $YBa_2Cu_3O_7$ sample with temperature (b) Variation of lower critical field H_{c1} with temperature and solid line represents the BCS fit.

It happens due to the existence of Fermi Surfaces (FSs) of different sizes and anisotropies [14]. This result is in good agreement with other reports [2,8]. This behavior may be the sign of multiband nature of superconductivity [5,7,14].

CONCLUSION

In summary, we extracted critical current density through magnetization measurement and it is found as 699.24kAcm^{-2}. Also, we measured the complete hysteresis loop of a polycrystalline YBCO sample at 10K and studied the H_{c1} as functions of temperature. The obtained data were fitted with high temperature BCS equation and found that $H_{c1}(T)$ function does not follow BCS theory. The sample shows multiband nature of superconductivity.

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