Synopsis

Thesis title: *Studies on the critical current density in several pure and hybrid cuprate superconductors.*
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High temperature superconductors (HTS) exhibit promisingly high critical current density (J_c). It is known that J_c depends on the temperature (T), applied magnetic field (H) and the density of the pinning centres (n_p). In the presence of a magnetic field, intrinsic pinning centres in these layered superconductors are crucial for optimizing J_c. However, introducing additional pinning centres in the intergranular region may affect the pinning mechanism and hence J_c. The pinning mechanism depends on the size, shape, density and orientation of pinning centres. We have studied the critical current density of several bulk $RBa_2Cu_3O_{7-\delta}$ (RBCO) systems at several combinations of temperature (T) and magnetic field (H) where R stands for rare earth element. All the samples have been synthesized using the conventional solid-state reaction (SSR) route. We have also investigated transport and magnetic J_c properties to understand the nature of the pinning which are summarised as follows.

We have studied in **Chapter 3** a few RBCOs with R = Y, Gd, Nd and Eu to understand the role of rare earth (R) atoms in the different properties. Current-voltage (IV) characteristics have been used to extract J_c using an electric field criterion, E = 0.01 mV/cm below the onset critical temperature (T_c). The maximum granular critical current density, J_{cG} (T) of RBCO is found in the range 7×10^7 to 1.5×10^7 mA/cm^2. By changing the intrinsic magnetic moment via four different rare-earth (R) atoms the interlayer coupling between superconducting planes is modified strongly. Variations of J_{cG} (T) and J_c (T) as a function of $[1-\varepsilon^2]$, $\varepsilon = T/T_c$ are used to extract an exponent, n, which we propose to be important to understand the nature of the vortex pinning by distributed magnetic moments. Also, the effect of the grain boundary angles on pinning exponents extracted from both J_c (T) and J_{cG} (T) has been discussed [**P. Mandal, D. Rakshit, I. Mukherjee, T. Sk, A. K. Ghosh, Physics Letters A 436 128072 (2022)**].

The variation of J_c (T) is affected strongly due to the change of electric field criteria. The sensitiveness of J_c and J_{cG} becomes prominent with the lowering of T. $BaZrO_3$ (BZO) added YBCO is used for detailed study in **Chapter 4**. $J_c(T)$ and $J_{cG}(T)$ have been extracted by using $JE(IV)$ characteristics for E = 0.001, 0.005, 0.01 and 0.02 mV/cm. The exponent n = 1.1 extracted from the variation of $J_c(T)$ and J_{cG} (T) as a function of $[1-\varepsilon^2]^n$, remain almost unchanged for all four criteria which indicate that δT_c pinning is dominating in BZO added YBCO. The Ambegaokar-Baratoff (AB) and the Ginzburg-

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Landau (GL) descriptions of J_c (T) and J_{cG} (T) have been studied to understand how varying criteria may change the extraction of several associated coefficients. Extrapolated J_c ($T = 0$) and J_{cG} ($T = 0$) are also highly sensitive to the criterion used [**P. Mandal, Ajay Kumar Ghosh, Mod. Phys. Lett. B 38 2450050 (2024)**].

In **Chapter 5**, several concentrations ($x = 0.0$, 2.5, 5.0, 7.5 and 10.0) of micro-particles of BZO are used as additional pinning centres in the intergranular region of YBCO to study the impact of the addition of the micro-particles on the J_c (T) and J_{cG} (T) in YBCO superconductors in the vicinity of T_c. T_c's of all the samples range between 87.0 - 92.0 K. The nonlinear behaviour of IV has been investigated by using an equation, $V = aI^{\eta}$, η being an exponent. J_c (T) and J_{cG} (T) have been fitted using an exponential equation. Following the Ambegaokar-Halperin-Nelson-Siggia (AHNS) theory, we have extracted the superfluid phase stiffness (J_s) by using $J_s(T) = [\eta - 1]T/\pi$. Micro-particles of BZO influence the J_c. However, J_s (T) does not exactly follow J_c (T) [**P. Mandal, D. Rakshit, T. Sk, A. K. Ghosh, J. Supercond. Nov. Magn. 35 1079 (2022)**].

Both the J_c (T) at the zero magnetic field and magnetic critical current density (J_{cm} (T)) in a composite system consisting of bulk YBCO superconductor and insulating $BaTiO_3$ (BTO) have been studied by using IV and magnetization (M) as a function of H respectively in **Chapter 6**. Vortex pinning by insulating nanoparticles of BTO from the inter-granular network is investigated up to the magnetic field of 7.0 T. The highest J_{cm} of YBCO (**S11**) is found to be 1.9×10^5 A/cm^2 at 2.0 K and $H = 0.158$ T. The maximum J_{cm} of YBCO + 4.0% BTO (**S13**) is found to be 0.5×10^5 A/cm^2 at 2.0 K and $H = 0.138$ T. The highest pinning force densities (F_p) have been observed to be F_p (2.0 K, 6.6 T) = 3.16×10^9 N/m^3 and 1.45×10^9 N/m^3 for the **S11** and **S13** respectively. By analysing J_{cm}, the possibility of crossover from collective pinning (CP) to strong pinning (SP) and how it is affected by BTO has been investigated by using $J_{cm} \propto H^{-\alpha}$. $\alpha = 5/8$ is observed in the range of 20.0 – 60.0 K. Possible scenario of the strong pinning (SP) induced by insulating nanoparticles has also been studied by using an exponent [**P. Mandal, D. Rakshit, T. Sk, Ajay Kumar Ghosh, Applied Physics A 129 650 (2023)**].

Changes in transport properties of NBCO superconductors by several concentrations ($x = 0.0$, 0.5, 1.0, 1.5 and 2.0) of Sn nanoparticles have been studied in **Chapter 7**. We have studied how the nanoparticles in the inter-granular region affect η (T) and the pinning behaviour of NBCO. An exponential variation of J_c (T) of the form $J_c^{wk}(T) = J_c^{wk}(0)\exp(-T/T_0)$ reveals that weak pinning scenario gets affected to some extent but without a systematic increase in J_c (T) even after the addition of the Sn nanoparticles. We observed that an increase in J_c (T) may be realistic only at the lower concentration of Sn nanoparticles, $x = 0.5$ [Manuscript communicated].

Further research will be carried out to improve critical current density and flux pinning mechanisms in bulk composite superconducting systems.

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