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Effect of Magnetic Field and g Irradiation on the Properties of Tl-2212 Superconducting Tape

The critical temperature and critical current of Tl-2212 superconducting sample in the form of a tape have been studied near T_c under magnetic field and gamma irradiation. T_c decreases from 109 to 94 K with increase of magnetic field up to 300 mT. In 77-109 K range, J_c decreases rapidly in low fields up to around 50 mT followed by a very slow decrease in J_c up to 300 mT. T_c of the sample did not change up to 100 MR γ dose and then started to decrease from 109 to 102 K with increase of γ dose up to 800 MR, most of the change taking place in high doses. The critical currents of the sample decreased steadily with γ irradiation up to 600 MR after which no further change was noticed.

Keywords: high-T_c compounds, Tl-based cuprates, γ irradiation, critical currents, transition temperature

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1. Introduction

A lot of efforts have been carried out for the production of superconducting wires and tapes from high temperature superconductors. The Powder In Tube (PIT) method does not require sophisticated devices and is widely applied especially for Bi-based compounds (Li et al.; Dou, Liu; Larbalastier et al.). Extensive research studies have been carried out to produce Bi-based tapes before they were commercialized (Dou, Liu 1993; Larbalastier et al.; Grasso et al.; Iyer et al.). But relatively less work has been done to produce Tl-based tapes (Fox et al.; Gladyshevskii et al.; Ren et al.; Glowacki, Ashworth). One reason for this is due to the fact that Tl is quite volatile and toxic. But, the closer spacing between insulating planes in the thallium compounds enhances flux pinning and brings hope to increase the critical current densities above 77 K. Besides, the formation rates of the Tl-based superconductors are faster compared to the Bi-based ones. Tl-based superconductors can be synthesised in a few hours but 100-150 hours of annealing time is required to synthesis the Bi-based superconductors. Due to the high degree of structural anisotropy and high critical temperature (T_c) values of the Tl-based superconductors we think that it may be possible to obtain superconducting samples containing less microcracks and having better flux pinning capacity using the Tl-based superconductors.

Various types of irradiations could be used to modify the properties of high temperature superconductors (HTSs) and to increase their critical currents (Venturini et al.; Barbour et al. 1992). But, γ rays may be more convenient for the tapes compared with particles and ions as γ rays can penetrate through the sheaths and affect the inner superconductor producing

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uniform distributions of defects. There are several reports in the literature about the effects of γ irradiation on bulk HTS samples but very few on the tapes (HAMDAN et al.; ISHIBASHI et al.; DE et al.; OZKAN et al. 1994; ALBISS et al.; OZKAN et al. 2000) especially at high γ doses. In this report, we present the effects of γ irradiation (up to high doses) on the critical temperature and critical current of Tl-2212 superconducting sample.

2. Experimental

The high purity Tl_2O_3, BaO_2, CaO and CuO oxides were adjusted to get the $Tl_2Ba_2CaCu_2O_x$ (Tl-2212) phase. The adjusted molar ratios were mixed and ground in an agate mortar for 2 hours and pressed into disc-shaped pellet under about 30 MPa pressure. The pellet was wrapped with gold foil to prevent Tl loss and heated at 890 °C for 3 hours under oxygen flow and then furnace cooled to room temperature. At this stage, a Tl-2212 superconducting bulk sample was obtained as will be shown by x-ray results.

The Powder-In-Tube method was used to prepare the Tl-based superconducting tape. The bulk sample was ground for two hours to get the smallest grain size of the powder after which a silver tube with outer diameter of 6 mm and inner diameter of 4 mm was filled by this powder. The powder should be well packed into the tube to guarantee maximum stacking of the grains. After covering the ends of the tube with metallic cabs, it was drawn several times with intermediate annealing to a wire of outer diameter of 3 mm. The wire was then pressed under 10 MPa pressure after which it was annealed at 800 °C for 5 hours.

Silver paste was used to fix four linear probes with 3-4 mm spacing on the surface of the sample for the electrical measurements. The sample and the connection leads were firmly fixed in a sample holder to avoid mechanical stresses during the measurements and irradiation. Electrical measurements were achieved using Lake Shore 7507 Hall-effect measurements system. To measure the resistivity, constant current pulses in two directions were applied to the outer probes with a current source (Keithley 220) and the voltage drops were measured through the inner probes with a nanovoltmeter (Keithley 2182). The samples were cooled in a closed cycle cryostat (Advanced Research Systems) and the temperature was controlled using Lake Shore 340 temperature controller. The V-I data were collected in 1 K intervals from 100 to 110 K and the critical currents were determined using 1 µV criteria below which the material was considered superconductor. At each temperature the data were collected in different magnetic fields (B) up to 300 mT, applied perpendicular to the current direction. The electrical resistivities, T_c and I_c values have been determined before and after 6 successive γ irradiations up to an integrated dose of 800 MR using the Co^{60} source at Ankara Nuclear Research and Training Centre.

3. Results and discussion

The x-ray diffraction pattern of the sample (obtained using CuK_α radiation) showed that the sample contains mainly the Tl-2212 superconducting phase. The lattice parameters were calculated from the d-values by a least squares computer program “x-ray” as, a = 3.846 and c = 29.255 Å. These are in good agreement with the corresponding values reported in the literature (TORARDI et al.; SUBRAMANIAN et al.). In a previous work (OZKAN et al. 2000), the effect of γ irradiation on the x-ray diffraction pattern of Tl-2212 was studied. This study showed that the positions and widths of the x-ray diffraction peaks do not change much but the peak intensities decrease by about 10-40% with γ irradiation up to 100 MR.

The electrical resistivity versus temperature (R-T) curves at different magnetic fields of the Tl-2212 superconducting sample are shown in figure 1. The inset shows T_c values at different fields obtained from the R-T plots. At almost zero applied magnetic field, the sample shows a sharp transition at T = 109 K. The graphs indicate that the R-T curves shift to lower temperatures and T_c decreases from 109 to 94 K with increase of B up to 300 mT.

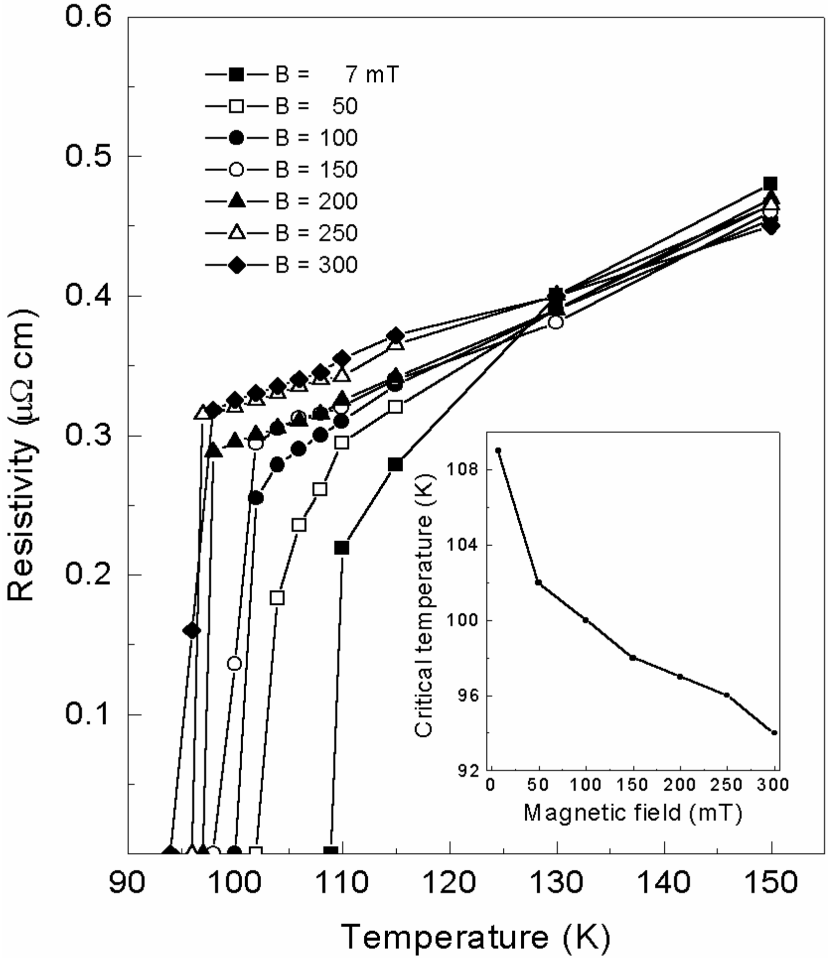

Fig. 1: Electrical resistivity versus temperature for Tl-2212 sample under different magnetic fields. Inset: Variation of critical temperature with magnetic field.

The maximum critical current density of the Tl-2212 sample was found to be 250 A/cm^2 at 77 K which is expected to be higher at temperatures less than 77 K. The variations of the critical current density J_c with magnetic field at different temperatures are shown in figure 2. The critical current density of the sample decreases rapidly with low values of applied magnetic field up to 50 mT which is attributed to the effect of the weak links between the grains (HAN 1995). In the high field regime in the range 50–300 mT, J_c follows a linear relationship in the log J_c vs. log B curves. The J_c-B data in the magnetic field range 50–300 mT were fitted to the power law relation $J_c(B) \propto B^{-n}$ where n took values form 0.3 to 0.6 for temperatures in the range 77-100 K. This power law variation was also found with $n \cong 0.5$ in a melt-processed Y-based superconductors (MURAKAMI et al.) and for polycrystalline samples (WANG et al.; DOU et al. 1992). The strong field dependent critical current is due to the relatively random arrangement of the grain boundaries which was observed by the Scanning Electron Microscope (SEM) photographs of the surface of a piece of the sample after etching the silver layer.

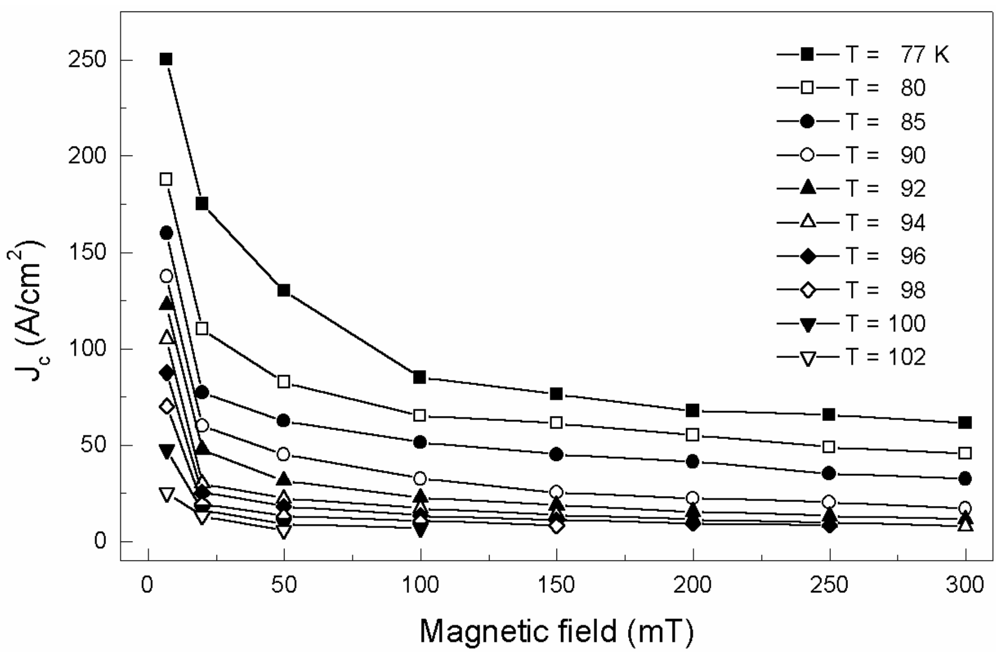

Fig. 2: Magnetic field dependencies of the critical current density at different temperatures for Tl-2212 sample.

The R-T plots of the Tl-2212 sample before and after different γ irradiations are shown in figure 3 while the variation of the critical temperature with γ irradiation is shown in the inset. The transition widths enlarge with γ irradiation and T_c decreases by about 7 K up to 800 MR. T_c did not change up to 100 MR doses then it started to decrease steadily form 109 to 106 K up to 600 MR. This was followed by a rapid drop in T_c to 102 after 800 MR γ doses. We propose that γ irradiation causes ionization and disorder that may reduce the anisotropy of the oxygen and carrier distributions in the structure of the sample (JORGENSEN et al.; BARBOUR et al. 1989). This may be the reason for the observed decrease of T_c and J_c of the sample under γ irradiation.

The J_c vs. T data of the sample before and after different γ doses (figure 4) obtained in 80-108 K range were fitted to the expression, $J_c \alpha (1\text{-}T/T_c)^n$, where, T_c was assumed as the temperature for which I_c drops below 200 mA. Before the irradiations, the parameter n had value n ≅ 1 which did not change with the irradiations. For the SNS-type grain boundaries, n is reported to take values from 1.5 to 2.0 and for the SIS-type boundaries n is evaluated to be 1.0 (MASUDA et al.; DOU et al. 1990; HAN et al. 1993). These data indicate that the boundaries in the Tl-2212 sample are effectively SIS-type that was not changed with γ irradiation.

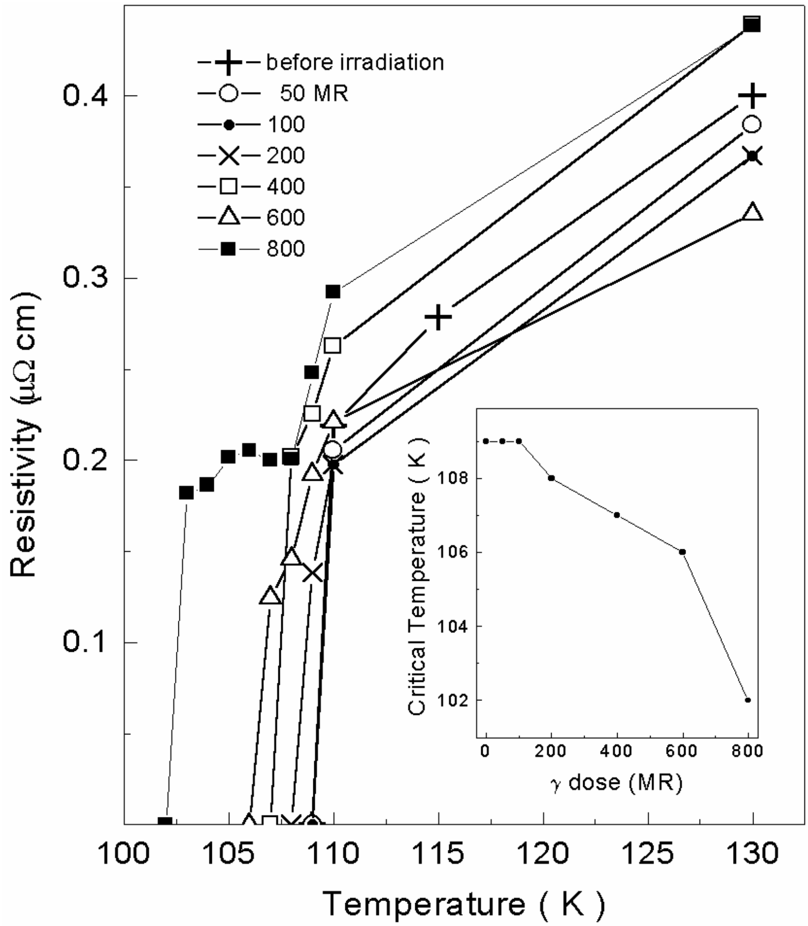

Fig. 3. Resistivity vs. temperature of Tl-2212 sample before and after different γ doses. Inset: The critical temperature before and after different successive γ doses.

From the T_c vs. γ dose (inset of figure 3) and J_c vs. T curves before and after different γ doses (figure 4), it is obvious that the Tl-based tape is less sensitive to γ irradiation than the commercial Bi-based tape studied in a previous paper (KAYED et al.). In environments exposed to γ rays, Tl-based tapes seem to be more convenient than Bi-based ones. Understanding the rate and mechanisms of damage recovery are important in device processing and material applications. Annealing the sample after irradiation may be one of the methods helping in damage recovery. However, detailed studies are necessary before coming to any definite conclusion. To the authors' knowledge, such studies have not been established yet for γ irradiated samples and may be achieved in a future work.

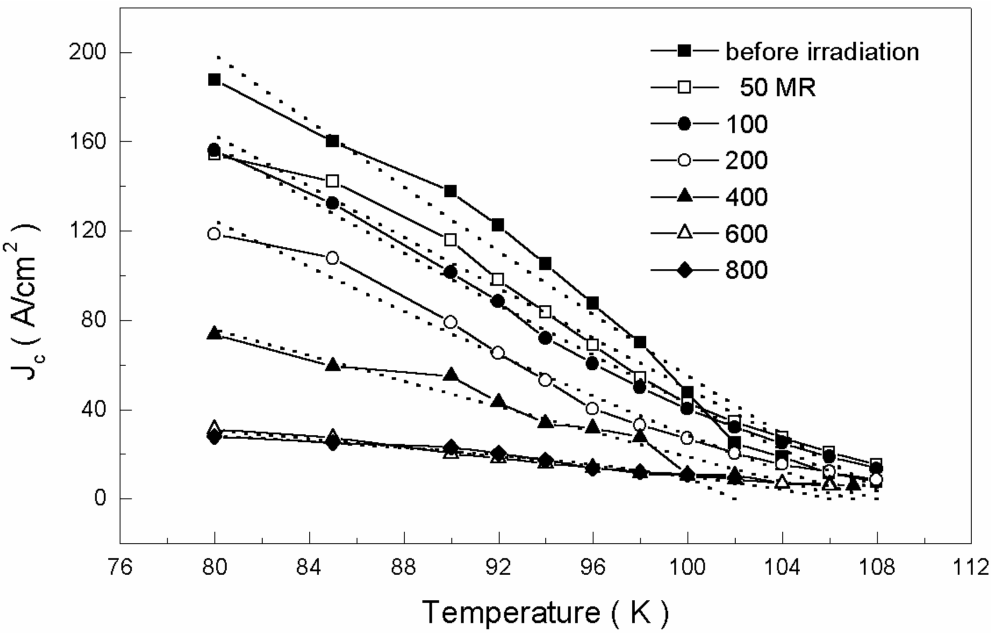

Fig. 4. The critical current density vs. temperature plots before and after different successive γ doses. The dotted curves represent the fitting to the function $J_c \propto (1-T/T_c)^n$.

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