INVESTIGATION OF EXTENDED AND LOCALISED STATES IN A HIGH–TEMPERATURE SUPERCONDUCTING CERAMIC

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DECLARATION

I declare that this dissertation is my own, unaided work and is being submitted for the degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

P. de Villiers

28^{th} June 1994

DEDICATION

In Loving Memory of my Grandfather

Richard Neville Miller

1928 – 1983

ABSTRACT

In High–T_c superconductors there are suggestions of a non–zero density of quasi–particle states in the energy gap. Thermally activated normal excitations can be reconverted into ground state superfluid Cooper pairs for temperatures below the critical transition temperature (T_c). The core excitations of a vortex and the quasi–particle density inherent in High–T_c superconductors describe the localised and extended states, respectively, that contribute to the distinct dissipative processes. In the most frequently applied geometries, the behaviour of the two different processes cannot be separated as they both have similar linear dependencies on current and applied magnetic field.

A disc shaped sample of sintered $YBa_2Cu_3O_{7-\delta}$, high – T_c superconductor, was used to investigate circular flux flow and inductive voltages due to a Lorentz force, (**J x B**). The dissipation due to a flow of quasi–particles is detected as a radial potential drop. The circulating vortices also produce a voltage drop for the disc geometry. The induced voltage observed, is assumed to be the sum of two terms, $\alpha_q W_n$ and W_φ, where they represent the quasi–particle and flux motion induced parts, respectively. The portion of the quasi–particle contribution to the dissipation is represented by the dependence of $\alpha_q \equiv \alpha_q(T,J,B)$. Alternatively, α_q, can be regarded as a normalization of the dissipation through the critical temperature region when all contributions from circulating vortices have been accounted for. The second term, W_φ, is proposed to consist of a quadratic radial dependence and the induced part, Γ_φ, due to the circulating vortices. The temperature dependence of Γ_φ is plotted for each of the specific magnetic fields and current densities used. Γ_φ is shown to consist of a Γ_o term representing the rate at which circulating vortices cut a surface described by the above quadratic dependence. From the experimental

observations it can be concluded that dissipation due to quasi-particle motion is the major factor contributing to transport properties of a "123" ceramic High-T_c.

Γ_φ is analyzed in terms of the Thermally Activated Flux Flow model (TAFF), $\Gamma_\varphi = \Gamma_0 U(T,B)/T \exp[-U(T,B)/T]$, to extract the Activation Energies for each current/magnetic field consideration. The values found for the term. U(T,B) are consistent for all the different current and magnetic field combinations. The sample design provides for a non-uniform current density in the radial direction, which causes an intrinsic Proximity boundary as the centre of the disc is driven 'normal' (at fixed T and B) before the rest of the sample. These intrinsic weak links caused by the oxygen stoichiometry of the particular sample, impede the path of circular motion of the vortices. With regard to this proximity effect, the TAFF is influenced and the activation energies have a temperature and magnetic field dependence of the form, $U(T,B) = U_c \exp(-B/B_0)\cdot(1-t^2)^{3/2}$. The values found for $U_0 \approx 0.15$ eV and $B_0 \approx 4.2$ T are comparable to reported data for these parameters.

PREFACE

Reasons for undertaking the study:

The field of High Temperature, (High T_c), Superconductivity has attracted a very large number of researchers since its origin in 1986. Not only are the technological benefits sufficient reason to study these materials, but the inherent physical perplexities are very challenging to Solid State physicists. The mechanisms governing electronic transport in Conventional Superconductors, (generally, superconductors not composed of CuO planes), exist in these new ceramic materials and hence, finding a non–dissipative electron condensate at higher temperatures is one of the main interests in the technological viability of these systems.

In these high T_c systems the onset of dissipation and trend towards the normal metallic state, is a smooth curve over the temperature interval. The particular behaviour of quasi–particle and localised, or core excitations, in relation to dissipative processes, is not well understood. This study was motivated by an original idea to study this particular problem and hence, shed some light on the physical mechanisms prevalent below the Critical Transition temperature (T_c). After some initial investigation and with the help of an intuitive analysis procedure the results called for an extensive study into the effects that were seen from the preliminary data. This in depth study of magnetic field and current dependencies constitutes the basis of this dissertation.

Background of study:

The phenomenon of flux creep and flux flow in the presence of an applied Lorentz force, was extensively studied on conventional Type II superconductors in the early 1960's. The realization that flux lines can only move dissipatively marked an important step to the present understanding of superconductivity. Anderson and Kim laid the foundation for most of the theories relating the dissipative mechanism to the motion of depinned magnetic flux bundles. The classical bar shaped geometries of Type II superconductors that were studied provided only implicit information regarding the dissipation due to localised states within the vortices and extended states in the form of quasi–particles,(normal carrier electrons that have been excited across the energy gap).

In the new High–T_c superconductors the vast broadening of transition due to thermally activated flux creep, fluctuations, quasi–particles excitations well below T_c etc, have enabled researches to study a much larger 'mixed' domain. The evidence for the two dissipative mechanisms (extended and localised states) within a superconductor moving up through the temperature range towards T_c, is well demonstrated by the longitudinal Seebeck and transverse Nernst thermoelectric effects. The Seebeck effect comes about due to the motion of hole/electron quasi–particles diffusing thermally in the same direction as the applied temperature gradient, and hence the net thermal diffusion current sets up space charges and a longitudinal electric field. With the addition of a transverse magnetic field, the Nernst effect originates from the thermal diffusion of the core excitations. An electric field is set up perpendicular to the applied field and temperature gradient. In analogy to the above mentioned thermoelectric effects, the thermal excitation can be replaced with an applied current and two distinct electric fields will be generated. The process in which flux can be induced to flow in a circular path within a superconductor, due to an applied Lorentz force, is well understood. However, separating the contributions due to vortex motion and quasi–particle motion still remains a novel approach.

Scope and Purpose of the Study:

The preliminary investigation was aimed at the mere detection of the two processes that were being studied. An experiment was carried out to determine the difference in results with and without an applied magnetic field. Having obtained the satisfaction that the technique and analysis was consistent, the experiment was moved to another cryostat for a complete current and high magnetic field investigation.

A sample of melt–processed $YBa_2Cu_3O_{7-\delta}$ was selected and carefully prepared to the specifications of the experiment. Firstly, resistive measurements were carried out in zero magnetic field for three current densities in the temperature region $50K < T < 300K$. A set of magnetic field values were selected and the magneto–resistance was measured for these values in the same temperature interval. The purpose of the analysis employed was to extract unique parameters defined by the theoretical approach outlined in Chapter 3. Using a well documented theoretical model, the Activation Energies, are also found and compared to measured values of other groups using completely different methods.

Special Attributes of the Author:

This investigation relied partly on the author's knowledge of Solid State Physics gained during his tertiary education [B.Sc.Hons(Physics)]. Some of the experimental techniques necessary for this study were established during the Honours degree in which two projects were completed on High T_c superconductors.

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