Preface

The phenomenon of superconductivity—vanishing of electrical resistivity and becoming perfect diamagnet in certain materials below a particular temperature—is certainly one of the most unusual and exciting phenomena of the condensed matter physics. Superconductivity is observed in a broad range of materials including more than half of the metallic elements and a wide range of alloys and compounds including crystalline and amorphous materials. The superconductivity phenomenon and the superconducting materials have been a source of experimental and theoretical research.

The discovery of superconductivity in 1986 by George Bednorz and Alex Müller in a layered copper oxide compound with a critical temperature above 30 K was the beginning of a new era of research called ‘High Temperature Superconductivity’. After this initial discovery, a whole family of high temperature superconductor was discovered which includes material with transition temperature as high as 136 K. These superconducting compounds contain four or more elements and the crystal structures of these compounds are of new types. They seem to be rather complicated but there is a common structural element, a Cu-0$_2$ plane, through which the supercurrent flows. The other planes sandwiching the Cu-0$_2$ planes play a vital role that the they accommodate additional oxygen atoms or defects to provide carriers to the Cu-0$_2$ planes. The transition temperature ($T_c$) strongly depends on the concentration of the carriers in the Cu-O$_2$ planes, which closely relates to structures in the charge reservoirs and the number of Cu-O$_2$ planes. High temperature superconductors often include various kinds of lattice imperfections and impurity phases which are non-superconductive. They contribute variety of microstructures, strongly affecting the critical current density ($J_c$) because they closely relate to the weak link at boundary between superconductive grains as well as to the pinning of magnetic fluxoids. The application vistas of superconductivity have also widened very much since the
discovery of high temperature superconductors, as many of the application can be realized at liquid nitrogen temperature (77 K) rather than going down to 4.2 K of the costly liquid He temperature. The cuprate family of high temperature superconductors continues to be of immense theoretical and experimental interest since the origin of high temperature superconductivity in cuprate materials is one of the biggest puzzles in Physics.

The structural, superconducting and flux pinning properties of high temperature superconductors can be improved by doping and to make the materials suitable for the application at higher temperatures and higher fields. Doping can also be used as a powerful method to explore the mechanism of high temperature superconductivity. There exists a large number of reports on rare earth (RE) doping on High temperature superconductors.

Among the variety of high temperature superconductors Bi-based superconductors, $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_y$ (Bi-2212) and $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ (Bi-2223) are the most widely used materials in many applications due to their favorable properties comparing with other high temperature superconductors. Wire and tape production process has been well developed for these Bi-based superconductors. Bulk materials of Bi-2212 and Bi-2223 superconductors are already being used for current leads in several practical application systems. In Bi-based superconductors, large scale RE doping is possible only in $\text{Bi}_2\text{Sr}_2\text{Cu}_1\text{O}_y$ (Bi-2201) and Bi-2212. In Bi-2223 (Bi-based superconductor showing highest $T_C$) higher amounts of RE doping is not possible. Most of the existing RE doping studies in Bi-2212 are at Ca site and in Pb free samples. No such work explains the variation of transport $J_C$ in self and applied magnetic fields. The present investigation has been undertaken in order to understand the effect of RE modification on structural, superconducting and flux pinning properties of Pb doped Bi-2212 [(Bi,Pb)-2212].

Chapter 1 is an overview of 'High Temperature Superconductivity'. This chapter briefly explains high temperature superconducting materials, commonly used terms in superconductivity, important aspects of high temperature superconductors, different theoretical proposals for high temperature superconductivity, applications and importance of high temperature
superconducting materials. A brief review of reported doping studies on Bi­
2212 and the scope of the present work are also included in this chapter.

Chapter 2 deals with the different stages of sample preparation used in
this work. This chapter also explains the characterization techniques used for
the analysis of the samples such as differential thermal analysis (DTA), X-ray
diffraction analysis (XRD), Scanning electron microscopy (SEM), Energy
dispersive X-ray analysis (EDX) and details of superconductivity
measurements such as $R-T$, $T_c$, transport $J_c$ and $J_c-B$ measurements.

Chapter 3 describes the effect of stoichiometric addition of RE viz. La,
Nd, Gd, Sm, Dy and Yb on the structural and superconducting properties of
(Bi,Pb)-2212. The results show that there is a clear morphological change for
(Bi,Pb)-2212 grains with RE addition. Elemental analysis confirms that the
cations such as Sr, Ca and Bi are replaced by RE but Sr is replaced most. The
superconducting properties such as $T_c$ and $J_c$ are highly enhanced by the
substitution of RE$^{3+}$ in the cationic sites Sr$^{2+}$ and Ca$^{2+}$ due to the changes in
carrier concentration. Results show that the $T_c$ and $J_c$ values strongly depend
on the added RE.

The rare earth cerium (Ce) shows entirely different transport properties
comparing with other RE additions even though structural changes are similar.
Chapter 4 compares the superconducting properties of Ce added (Bi,Pb)-2212
with other RE additions. The changes in these superconducting properties are
due to possible valancy of 4+ of Ce whereas other REs have 3+ valance state.

Chapter 5 compares the structural and superconducting properties of
RE modified Bi-2212 samples with and without Pb and found that RE doping in
(Bi,Pb)-2212 shows better superconducting properties than RE addition in
Bi-2212, without Pb. The reason for the better superconducting properties are
due to the improvement of inhomogeneities, reduced porosity and anisotropy in
Bi-2212 due to combined effect of RE and Pb.

Chapter 6 gives an account of the flux pinning properties of RE modified
(Bi,Pb)-2212. The field performance of $J_c$ ($J_c-B$ characteristics) of the samples
improves with RE addition and reaches a maximum for an optimum RE
concentration which depends on the RE. At higher levels of addition the flux
pinning properties also deteriorate. This chapter also describes the flux pinning properties of Pb free and Pb added RE modified superconductors. It is found that the Pb doped samples have highly enhanced flux pinning properties comparing with Pb free samples.

Since it is found that RE addition in (Bi,Pb)-2212 mainly replaces Sr, a detailed study on the structural and transport properties of the system Bi$_{17}$Pb$_2$Sr$_{2x}$RE$_x$Ca$_{11}$O$_y$ (RE = Yb, Gd, Nd & La) is conducted (chapter 7). Here, all the samples show metal – insulator (MI) transition at higher concentration of RE, but the concentration at which MI transition occurs varies with RE. In chapter 8 we discuss the results of substitution of RE at different cationic sites such as Bi, Sr and Ca. The structural, superconducting and flux pinning properties of the systems are studied and found that these properties are site dependant. Chapter 9 summarizes the overall conclusions drawn from the entire work along with scope for further directions in the topic.