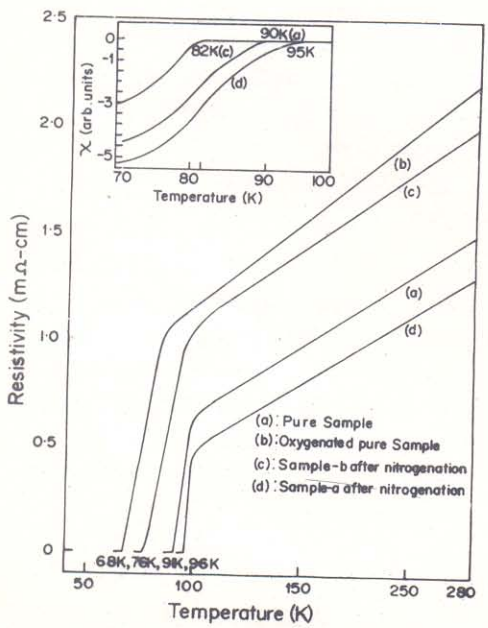
CONDENSED MATTER PHYSICS

HIGH TEMPERATURE SUPERCONDUCTORS

1.1 Basic studies

The crucial importance of interlayer coupling in the high Tc phenomenon of cuprate superconductors was brought forth by systematic studies of Bi-2122 carried out using the scanning tunnelling miscroscopy and spectroscopy techniques. A series of samples were prepared in the oxygen rich and oxygen deficient environments. Measurements showed that oxygen had a significant deleterious effect on superconductivity with Tc (R=o) values ranging from 70 K for the oxygenated sample to 91K for the air quenched sample (Fig.). By STM studies it was possible to directly observe the increase in the excess oxygen intercalated in the twin Bi-O layers of the Bi-2122 unit cell, while in the high temperature quenched sample, the oxygen intercalation was minimum.



The STS studies of these samples revealed that oxygen intercalation transformed the Bi-O layers from quasi metallic to insulating. When the Bi-O layers turned more resistive, the superconducting phase coherence between Cu-O layers across the demiunitcells in the C-direction, was expected to be adversely affected and thereby caused a significant decrease in Tc(R=O). The heat treatment needed was optimised by low temperature nitrogenation. The STM of the sample so produced showed clean Bi-O layers free from interstitial oxygen and the STS spectra was of metallic type, devoid of energy gap and having an enhanced LDOS at Ef. The Tc (R=O) of the sample was found to be 96K and the transition width was 3K.

Expertise was developed to synthesize Y-124 cuprate samples under ambient oxygen pressure using suitable catalysts. Zn and Ga substitutions at the Cu-sites were studied in detail and the results indicated that Zn atoms were substituted in twin Cu-O planes while Ga atoms in twin Cu-O chains. The effect of quasihydrostatic pressure on these samples transformed them first in orthorhombic Y-123 and subsequently in tetragonal Y-123. The effect of subsequent oxygenation was to reverse the process. Interestingly, however, this way the volume fraction of Y-124 was found to progressively increase. Extensive collaboration was carried out with IIT (Kanpur) in the area of low field microwave absorption in pure and substituted Y-123; with University of Rajasthan on XANES of Fe doped Bi-2122 and with Anna University on growth and characterization of bulk high Tc superconductors; with IIT (Bombay) on XPS and XANES studies of Ti, Zr and Ce substituted Y-123 samples and with Shivaji University on optical studies of Y (RE)- 123 system.

Detailed Hall effect measurements were performed on Zn substituted Y-123 system in collaboration with the CNRS laboratory at Meudon. The measurements depicted little change in the carrier concentration while the mobility of the charge carriers was found to be more significantly reduced with Zn doping. A manifestation of this was the localization revealed by the resistance-temperature curves on Zn

doped samples. The magnetization studies were carried out on both the laser ablated epitaxial thin films and the CVD processed thin films of Y-123, irradiated with helium ions, in collaboration with LEPES-CNRS laboratory at Grenoble. Synthesis and characterization of bulk single crystals of noncopper system, were also attempted.

1.2 Processing studies

On experimental basis, Bi(Pb)SrCaCuO and YBaCuO powders were processed separately by precipitation method using nitrates as starting material. The powder homogeneity was found to be better and the processing time shorter, as compared to the standard ceramic route. The high Tc 2212 material was observed to transform to 2223 phase when reacted with CaO and CuO at 860°C in the presence of Pb. The powder synthesized by this method was found to have high phase purity. Ac susceptibility measurements on high Tc superconductors were carried out at varying magnetic fields.

Screen printed 20 micron films of 2212 material on polycrystalline zirconia were studied. Tc of 20 A cm^{-2} at 77K, was observed. Silver clad tapes of superconductor materials were fabricated using low purity commercial grade starting oxides/carbonates. Maximum Jc values obtained were 6.3×10^3 A cm^{-2} at 77K. The high Jc values obtained are believed to be due to an excellent grain alignment and the presence of impurity precipitates and lattice defects.

To study the effect on the resistivity and microstructure, heavy ion high energy irradiation studies of $YBa_2Cu_3O_7$ bulk samples were made at the Nuclear Science Centre, New Delhi. The effects of radiation such as X-ray and ions on Bi-based superconducters were studied. At high dose of oxygen, the resistance increased almost linearly with the dose or fluence. The studies suggested that the defects were probably associated with the oxygen stoichiometry of these materials.

1.3 Superconducting magnet applications

An 11 T superconducting magnet was fabricated and operated successfully for the first time in the laboratory. The hybrid magnet consists of a Nb-Ti magnet providing a background field of about 7.5 T and a Nb_3-Sn magnet providing an additional field of 3.5 T. The working bore of the magnet was 44 mm. A large number of mineral ores such as ball clay, wolframite, iron ore and synthetic rutile were processed using the high gradient magnetic separator fabricated earlier in collaboration with BHEL. Experiments conducted have proved the efficacy of the system for separating weakly magnetic impurities of micron size and obtaining high grade material.

1.4 High temperature SQUIDs

Thick films of Bi Sr Ca CuO superconductor were prepared on MgO substrates by the screen printing technique with the starting composition of 1112. The films were subjected to a two step heat treatment with the first step temperature kept between 874 and 898°C for a fixed duration of 45 min. while the second step temperature was maintained at 864°C for a duration varying from 0 to 104 hrs. Growth of the high Tc (2223) phase in the films was found to be very sensitive to the first step temperature and the duration of the second step. These films were used to fabricate rf SQUIDs utilising naturally present grain boundary Josephson weaklinks in a microbridge. Extremely small magnetic signals generated from a quartz analog watch and magnetic rock samples were detected using the BSCCO rf SQUID.

Superconducting thin films of Y Ba Cu O were prepared by rf magnetron sputtering technique using a single composite target of stoichiometry (123). The resputtering effects due to presence of negative ions were almost eliminated by increasing the sputtering gas pressure. The films were characterized. The films grown on (100) $SrTiO_3$ were highly a-axis oriented while films grown on MgO (100) and VSZ (100), were highly c-axis oriented. Microbridges were patterned on these films and microwave induced shapiro steps due to ac Josephson effect in the grain boundary weaklinks were clearly observed in their I-V characteristics.

CRYOGENIC SYSTEMS

The optimisation of various design parameters of

Stirling engine for maximum power and efficiency, was made and the mechanical design work started. The special refrigerator for immunisation programme was tested rigorously. The liquid nitrogen plant was maintained during the year and about 20,000 litres of liquid nitrogen was produced and distributed in the laboratory.

THEORETICAL STUDIES

A Jahn-Teller bipolaron hamiltonian induced by oxygen hole doping in Ba_{2-x} Sr_x CuO_4 was investigated in BCS scheme. The calculated doping dependance of the transition temperature Tc was in agreement with the experimental results. A modified BCS theory for the coherently excited pair of holes in anti-bonding bands under coulomb interaction was proposed. The results were compared with the experiments on normal to superconducting tunnelling conductance and low temperature specific heat in cuprates. An excitonic mechanism suggested for superconductivity in alkali fullerides showed that the halogen doped alkali fullerides may have higher Tc than alkali fullerides.

Electronic structure studies on disordered $Cu_{75}Pt_{25}$ alloy using KKRCPA method enabled the interpretation of the angle resolve photoemission data. Such studies on ordered pervskite $SrFeO_3$ and $SrCoO_3$ using LMTO method showed that the conduction bands consist of hybridized 3d orbitals of Fe or Co and 2p orbitals of oxygen and explained the experiments on magnetic moment on the systems. Bond orders, valence indices, net atomic charges and bond lengths were evaluated at the MINDO/3 and MNDO levels for uracil and 2-thiouracil. The calculated bond lengths were in good agreement with ab-initio results.