अतिवालकता तथा निम्नतापिकी

SUPERCONDUCTIVITY AND CRYOGENICS
अतिचालकता तथा निम्नतापिकी

अतिचालकता तथा निम्न तापिकी प्रभाग के कार्यकलाप मुख्यतः अतिचालकता संबंधी मूल अनुसंधान पर वल देते हुए निम्न तापमान तकनीकों के क्षेत्र में तथा अतिचालकता चुम्बकीय प्रणालियों के विकास के क्षेत्र पर केंद्रित हैं। द्वितीयक आर्द्रता मानक को भी स्थापित किया गया है और यह विभिन्न उद्योगों को अशांक किए शिक्षा प्रदान करता है। इतिहास-साथी -10° से. से लेकर +25° से. तक की रेखा डू स्वाइंट (असांक) जनरेटर तैयार किया गया है और इसमें सुधार किया गया है। इसके अतिरिक्त यह प्रभाग इस प्रयोगशाला के विभिन्न अनुसंधान गुणों को निम्नतापिकी द्रव (क्लियम और नाइट्रोजन) की आपूर्ति करता है।

अतिचालकता और चुम्बक के परस्पर संबंध पर मूल अध्ययन किया जा रहा है। इंटर क्लू परिमेटर क्रिटिकल धारा घनत्व अतिचालकता आर्दर परिमाण के उत्तर प्रणालि (SCOPF) एस टी एम/एस टी एस आयन इरेडियशन तथ्य त्रोपों पर एस टी एस अध्ययन और सो यू जे जी (Cu-d-d) की भूमिका क्रूप्ति में आउट ऑफ प्लेन कंदक्षण पर (interobital) इलेक्ट्रॉन संबंधों पर अध्ययन किया जा रहा है। Yb(Pr)-123 और चुम्बकीय क्रम त्रोपों को मापने से नई जानकारी मिली है। जेनरेटिंग खराबियों की संभावना के उच्च चालक Bi(Pb)-2223 ग्रेन सीमाओं पर प्रभाव आयन इरेडियशन सबस्टीट्यूशन द्वारा उत्पन्न धातिक प्रणाल में जाँच पड़ताल की गयी थी। Cu-1234 प्रणाली में यह पाया गया कि इंटर-ग्रेन शब्द विकल्प में सुधार लाता है और इंटर ग्रेन शब डिंकल्ट में सुधार लाता है। स्काफ (SCOPF) में Zn और Fe में ए गए उत्तर-चढ़ब्रो की जाँच पड़ताल की गयी।
SUPERCONDUCTIVITY AND CRYOGENICS

The main focus of the activities of Superconductivity and Cryogenics Division are in the area of low temperature techniques with emphasis on basic research on superconductivity and development of superconducting magnet systems. The secondary humidity standard is also maintained and it provides calibration services to various industries. In addition to this, a portable dew point generator in the range –10°C to +25°C has been designed and developed. Besides, the division takes care of supply of cryogenic fluids (helium and nitrogen) to various research groups of the laboratory.

In the area of basic studies the focus has been on the correlation of superconductivity and magnetism, inter- and intra-granular critical current densities, superconducting order parameter fluctuations (SCOPF), STM/STS studies of ion irradiation induced defects, and the role of Cu d-d interorbital electron correlation on the out-of-plane conduction in cuprates. By measuring both electrical transport and magnetic ordering in Yb(Pr)-123, new light is thrown on correlation of superconductivity and magnetism in these systems. By STM/STS studies the possibility of generating defects in MgB₂ superconductor, the effect on grain boundaries in Bi(Pb)-2223 superconductor, and possibility of mass flow in metallic glasses generated by ion irradiation were investigated. In Cu-1234 system, it was found that the intra-grain Jc improves with Zn substitution and inter-grain Jc improves with Mg substitution. SCOPF was investigated in varying Zn and Fe substituted Er-123 system.
Superconducting Magnet Technology

An 11 Tesla Superconducting Magnet

The 11 Tesla (50 mm bore dia.) Superconducting (SC) magnet, which has been developed for Indira Gandhi Centre for Atomic Research under a Consultancy agreement, was tested for its reliability and stability. In the first run both the outer (Nb-Ti) and the inner (Nb₃Sn) magnet coils were connected in series on the top plate of the cryostat. The coils were energized up to 92.6 A producing 10 T. Fig.(7.1) shows the graph of Current–Field relation for the outer & inner coils in series. The magnet was kept at this current value for one hour and no drift in the magnetic field value was observed. The observed field homogeneity was 0.06 % over 10 mm DSV.

Fig. 7.1 : Current-Field relation for the outer and inner coils connected in series

The magnet was kept at 11 T for one and half hours to check the stability of the magnet.

This is the first indigenously developed superconducting solenoid magnet producing 11 T in a 50 mm working bore. The SC magnet in operation was demonstrated to IGCAR scientists.

Superconductivity Studies

Basic Studies on High Temperature Superconductors

Polycrystalline samples of Pr doped Yb₁₋ₓPrₓBa₂Cu₃O₇₋δ (i.e., Yb(Pr)-123) system for 0≤x≤1 have been investigated for resistivity (ρ) and magnetization (M) as a function of temperature in normal and superconducting state. The gradual decrease in superconducting critical temperature Tₘ(x) is found to be correlated with the x dependent ratio of resistivity slope (dp/dT)₉₀ (corresponding to the linear ρ(T) region) and residual resistivity ρ₀. In particular, the observed difference of critical Pr concentration where superconductivity is destroyed (xₙ) in Yb(Pr)-123 (xₙ ≈ 0.65) and Y(Pr)-123 (xₙ ≈ 0.55)
matches with the difference in the value of Pr concentration where the ratio \( \frac{\Delta p}{\Delta T} \) tends to go to zero in them. The M(T) data of Yb(Pr)-123 samples show magnetic ordering for \( x > x_c \) at characteristic temperatures, \( T_c \), that increases with \( x \). Interestingly, the Yb(Pr)-123 sample with Pr content \( x=0.6 \) near \( x_c \) reveals several anomalous features like transition from metallic to semiconducting-like \( \rho(T) \), an excessive broadening of the diamagnetic transition and weakening of the M(T) signal related with antiferromagnetic ordering of Pr ions. These observations can be consistently interpreted by assuming the presence of dynamically fluctuating striped phase in these systems.

The effect of swift heavy ion (SHI) irradiation on the surface of Bi-O layers of polycrystalline Pb doped Bi-2223 superconductors has been studied using Scanning Tunneling Microscope (STM) technique. The STM images of the unirradiated Pb doped Bi-2223 samples show perfect periodicity of neighbouring atoms whereas the topographs of the irradiated samples reveal atomic displacements and disorder caused by SHI irradiation. The microstructures of these samples are found to be depth dependent. Studies of the electronic structure of the unirradiated and irradiated superconductors have been performed by Scanning Tunneling Spectroscopy (STS). These measurements show setting in of increased non-metallicity on the surface of Bi-O layers as a result of irradiation.

Surface modification induced in four metallic glasses by 4.64 MeV/u\(^{28}\)Si ion irradiation has been investigated in detail using optical microscopy, SEM and STM. Results obtained in two separate runs have been presented here. The effects of ion fluence (\( \phi \)) and tilt angle (\( \theta \)) on surface modification have been studied both qualitatively and quantitatively. It has been found that for \( S_\theta \) values smaller than that for track formation, swift heavy ion irradiation leads to smoothing of the irradiated surfaces. The smoothing is evident from decreasing mean roughness \( R_g \) and reduction in height of the ‘hills’ and filling up of the ‘valleys’ in the SEM and STM pictures. The observations have been explained on the basis of the theory of shear flow within the framework of the viscoelastic model.

Low anisotropic CuBa,Cu\(_{12-y}\)O\(_{12-y}\) (Cu-1234) high temperature superconducting materials doped with Zn (up to 2%) at Cu-sites were synthesized using high temperature-high pressure technique. High field magnetization were carried out between 5K and 77K in fields up to 14T. Critical current densities \( J_c \) of the different samples were estimated using the critical state method. It is revealed that Zn-induced pinning centers increase \( J_c \) of Cu-1234 several fold, depending on field and temperature. From the experimentally determined field – temperature region in which a higher Zn content leads to higher \( J_c \), we have suggested the existence of a cross-over from quite efficient extended (in the c-direction) pinning centers to point-like (inefficient) pinning centers at a certain temperature depending on the field value. Such an effect can be attributed to the fact that, unlike other HTSC systems, in Cu-1234 there is a second critical temperature \( T_{c_2} \) of about 70-80K (in zero field) and 60-70K (in 15T), related to the overdoping of the pyramidal basal plane (outer CuO\(_2\) planes). In view of such different doping levels in the 4-fold and 5-fold Cu-O planes in the Cu-1234 lattice, further investigations of such materials with Ba-site substitutions are underway vis-a-vis their \( T_c \) and superconducting anisotropy factor. AC susceptibility studies conducted on the least anisotropic Mg-substituted Cu-1234 at different fields (up to 10 Oe) and frequencies (up to 1KHz) have revealed an increase in the \( J_c \) of the intergranular regions (weak links) with increasing Mg content. Intragranular \( J_c \), however, remained unaffected.

Host of studies reported on Pr substituted Y-123 have been inconclusive about the valence state of Pr and the non superconducting state (NSC) in Pr-123. Strategic heat treatment planned to turn a NSC Pr-123 into SC Pr-123 is expected to generate a new understanding about oxygen site vacancies and the reordering mechanism. AC susceptibility studies
on single crystals of NSC Pr-123 with various heat treatments are in progress.

Zn concentration variation effects on superconducting order parameter fluctuations (SCOPF) are compared in ErBa$_2$Cu$_{3-x}$Zn$_x$O$_{7-5}$ polycrystalline bulk samples for x=0.0, 0.03, 0.05, 0.12 and 0.18; perhaps as a first ever study. The SCOPF in pure and Zn doped samples are 3D. Zn seems to cause suppression of 2D fluctuations. SCOPF dimensionality shows independence from carrier concentration variation due to Zn in the planes and also suggests strong coupling between two nearest CuO$_2$ planes in the unit cells in pure and Zn doped samples. Fluctuations remain almost invariant to Zn doping vis-a-vis the pure sample.

Fe substitutions in ErBa$_2$Cu$_{3-x}$Zn$_x$O$_{7-5}$ shows large reduction in superconducting order parameter fluctuations (SCOPF) near the dynamic critical region, suggesting an anomalous crossover and slow suppression of superconductivity. Near Tc the SCOPF suggest Cu-O network coupling deterioration. The SCOPF show invariance (marked dimensionally variation) to low (increased) concentration of Fe and increased oxygen content dependence. Higher Fe concentration seems to promote dimensionally reversal.

**Critical Currents**

Work on transport critical currents in doped high temperature superconductors of Bi(Pb)SrCaCuO and the YBaCuO series was continued to investigate the role of pinning centres in these materials. Measurements of the critical current density Jc (transport), at 4.2K on f-level doped samples showed a striking dependence of Jc on dopant concentration for some particular dopants, while the effect was not so significant for Jc measured at 77K. In most other cases, however, a similar behaviour of Jc at 77K and at 4.2K was observed which clearly point towards the role of these dopants in influencing the inter-grain and intra-grain Jc of these superconductors. Detailed investigation of these results and their correlation with X-ray diffraction (XRD) scanning electron microscopic (SEM) studies is presently underway.

**Theoretical Studies**

Theoretical studies have been made to study the role of Cu d-d inter-orbital electron correlation on the out-of-plane conduction in cuprates. Condensation energy and spectral function have been calculated for various doping concentration for superconducting and normal states of bi-layer cuprates. Studies for impurity concentration dependence on coherence length in cuprate superconductors have been made. Reviewed transport behaviour of high temperature cuprate superconductors along c-axis and physical behaviour of nano-wires.

![Fig. 7.3: Simple and compact dew point generator (Mini RH generator)](image)
Humidity Standards

Humidity generation based on two-pressure technique is considered to be excellent, traceable and fundamental calibration standard. Last year a portable relative humidity (RH) generator based on this principle was developed. As an extension to this device, a simple and compact dew point generator (mini RH generator) has been designed and developed. In this device the generated RH or dew point is measured using a capacitance type hygrometer (Model Testo 650). With this device we are able to generate dew point in the range of −10°C to +25°C without any difficulty. The developed unit is totally indigenous, very handy (weight ~ 5Kg), mobile and versatile. The novelty of the device is in the design, development and use of a simple expansion valve. We have submitted the required documentation to the IPR section for filing an Indian patent on this development. It finds immense application in the Indian Industries. Figure 7.3 depicts the developed dew point generator (mini RH generator).

************