New Superconducting Materials with High Field Applications

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Expertise in developing methodology for synthesizing novel materials (Oxides, Chalcogenides and Intermetallics) for dielectric and superconducting properties, microemulsion synthesis of nanostructures, X-ray crystallography (powder and single crystal).

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Superconducting materials have found wide applications in medical (magnetic resonance imaging, biotechnical engineering), electronics (SQUIDs, transistors, particle accelerators etc), industrial, Power generation, and transportation (Fig.1). One of the major problems is viability of using these materials at ambient condition. So the major challenge is to find new superconducting materials with high critical temperature (T_c) and high critical field (H_c).

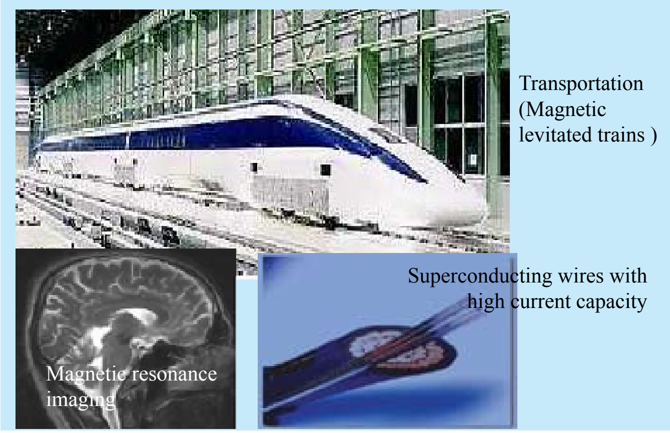

Figure 1: Some applications of superconductors

Superconductors are characterized by the absence of resistance and show perfect diamagnetism (completely expel the applied external magnetic field) (Fig. 2) and is normally explained on the basis of electron- phonon interaction(BCS theory) [1] which leads to the formation of pairs of electrons which being in phase are able to move in a crystal without friction. A major breakthrough in the field of superconductivity was in 1986 when Bednorz and Muller discovered superconductivity at ~ 30 K in La-Ba-Cu-O ceramics [2]. The maximum T_c today is 165 K (under high pressure) in a mercury-based copper oxide [3].

Recently in 2008, Kamihara *et al* [4] discovered superconductivity at 26 K in an oxypnictide La(O/F)FeAs. This report of superconductivity has regenerated interest in the field of superconductivity. New oxypnictide superconductors with the general formula Ln(O/F)FeAs (Ln = rare earth metal) were discovered with the highest T_c of 55 K [5] in the Sm(O/F)FeAs compound.

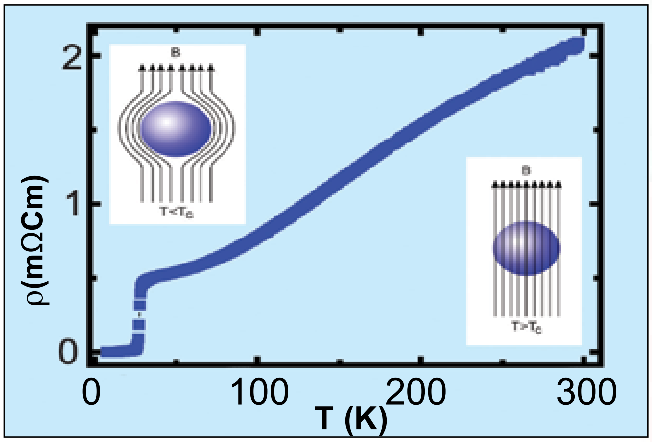

Figure 2: Variation of resistivity with temperature for $LaO_{0.9}F_{0.1}FeAs$ superconductor.

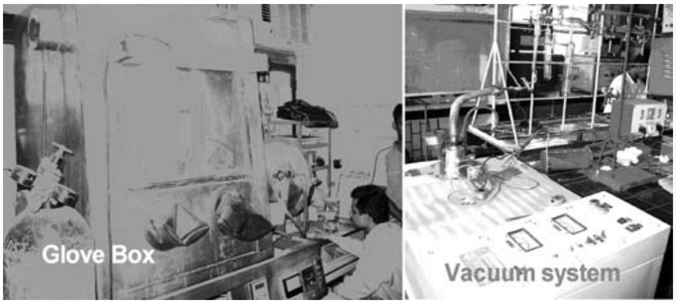

Figure3: Handling and synthesis of air sensitive materials

The synthesis of these superconductors is a challenge and very few laboratories in the world (mainly in USA, Japan and China) have been successful in making these materials. It requires specialized training in handling and manipulating air-sensitive materials (Fig.3). In India we have pioneered the development of these materials in our Laboratory at IIT Delhi. We have synthesized the superconducting oxypnictides of the type $La_{1-x}A_x O_{1-x}F_x FeAs$ [6,7] by doping of the alkali metal fluoride, of sodium and potassium which are commonly available, less hygroscopic and less expensive as compared to rare earth fluoride (otherwise used for fluoride doping) by sealed tube method. Our objective is to synthesize new oxypnictide superconductors with high critical temperature (T_C) and critical field (H_C). Superconductivity was observed at ~31 K for ‘x’ = 0.15 composition which is higher than the reported sodium free La(O/F)FeAs superconductors [7]. An extremely high upper critical field (122 Tesla) was observed for these KF doped superconductors as compared to the NaF doped superconductors [6,7]. So smaller Na+ ion (as compared to K^+) in $La_{1-x}A_xO_{1-x}F_xFeAs$ superconductors results in higher T_c as compared to K^+ doped one which however shows enhanced upper critical field. The substitution of cobalt ions at iron site in $CeOFe_{1-x}Co_xAs$ results in shrinkage of the both the lattice parameters (a and c) and for x = 0.1 composition superconductivity emerges with T_C of ~11 K [8]. Further increase in the cobalt concentration leads to suppression in T_C. Similar results have been obtained in the case of Pr analog compounds [9].

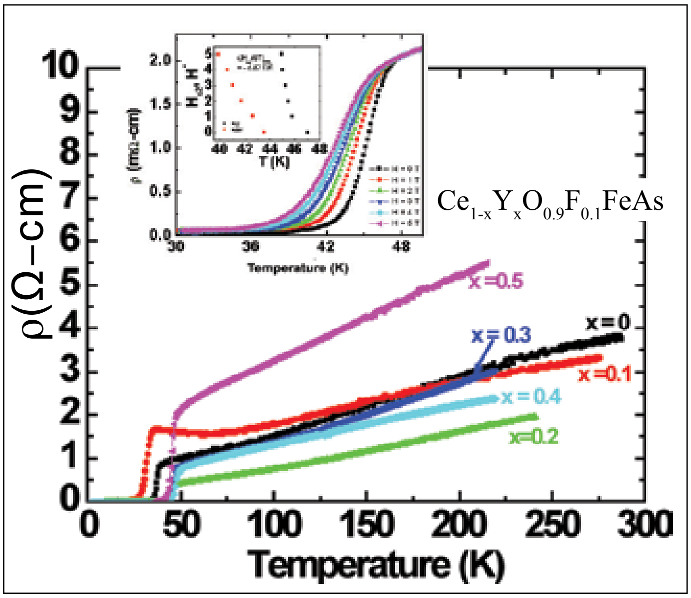

Figure 4: Variation of resistivity with temperature for $Ce_{1-x}Y_xO_{0.9}F_{0.1}FeAs$. Inset shows the magnetic field dependent resistivity variation with temperature.

We have been able to enhance the T_c and H_{c2} by doping antimony at the arsenic site in La(O/F)FeAs [10]. The effect of substitution of smaller yttrium ion at the cerium site in $Ce_{1-x}Y_x(O/F)FeAs$ leads to substantial enhancement of T_c , upper critical field (Hc_2) (Fig. 4) and critical current density (J_c) [11] as compared to Y free Ce(O/F)FeAs superconductors [12].

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Research Highlights

Facilities at IIT Delhi

- Glove-Box for handling air-sensitive materials
- Vacuum lines with glass and quartz tube sealing facility
- High Temperature programmable furnaces (165^0C)
- Powder X-ray diffractometer
- Low Temperature Four-probe resistivity setup (10-300K)
- SQUID Magnetometer
- EDAX (TEM)

Publications & Patent

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Research Projects

- “Investigations of new oxypnictide superconductors”, Sponsored by Department of Science & Technology
- “Ordered perovskite related structures and their properties”, Sponsored by Department of Science & Technology

Students Involved

- Jaiprakash, Gohil Thakur and Saroj Lochan Samal.