High Critical Current Density in the Heavily Pb-Doped $Bi_2Sr_2CaCu_2O_{6+\delta}$ Superconductor: Generation of Novel Pinning Centers

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Critical current density (J_c) is a parameter of primary importance for potential applications of high temperature copper oxide superconductors (HTSCs). It is principally limited by the breakdown of zero-resistive current due to thermally activated flux flow at high temperatures and high magnetic fields. Here we report a dramatic increase in J_c in $Bi_2Sr_2CaCu_2O_{6+\delta}$ (Bi-2212) single crystals doped with a large amount of Pb.

Keywords: high temperature copper oxide superconductors/ Bi-2212 phase/ single crystals/Pb doping/ critical current density

HTSCs exhibit an unusual magnetic field - temperature (*H* - *T*) phase diagram which is quite different from that of conventional superconductors. The major origin is strongly two-dimensional (2D) characters of HTSCs, as well as short coherence lengths and elevated critical temperatures (T_c*'s*), which dramatically change the vortex state in magnetic fields perpendicular to the CuO_2 layers; vortex lines become ill-defined and transform into pancake vortices confined within the CuO_2 layers which couple only weakly between the layers. Then, the role of thermal fluctuation on the dynamics of vortices is enormously enhanced, and flux flow occurs in a wide temperature range below T_c, resulting in a finite resistivity. A practically important boundary in the *H-T* phase diagram is called the irreversibility line (IL) which marks the boundary between the regions of reversible and irreversible magnetic behaviors. It is believed that the vortices are pinned by defects in crystals below the IL, while they can move in response to external forces above the IL, which means the vanishment of finite *Jc*. From the viewpoint of practical applications it is particularly important to expand this irreversible regime and, at the same time, to increase J_c.

A key to increase J_c is to generate efficient pinning centers in crystals. Recent studies using heavy ion irradiation have clearly exemplified that aligned columnar defects serve as flux pinning centers and the IL shifts upward. A similar improvement was recently reported for composites in which

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Scope of Research

Novel inorganic materials that have new, useful or exotic features such as superconductivity, ferromagnetism and quantum spin ground state are synthesized by novel methods. Particularly the search for spin ladder materials is intensively conducted by means of a high pressure synthesis at 3-8 GPa, where materials of high density unavailable under ambient pressure can be obtained

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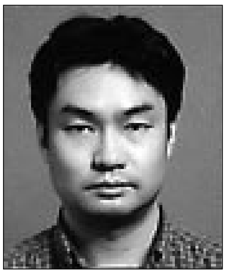

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MgO nanorods of 20 nm in diameter were embedded in matrix Bi-2212 films. However, these methods are rather formidable and not useful in practical material processing.

We have studied the single crystal growth of Bi-2212 and found that the partial replacement of Bi by a large amount of Pb (0.6 per formula unit) surprisingly affects the magnetic properties of Bi-2212. Electron microscopy has revealed characteristic microstructures which is probably responsible for the observed enhancement in J_c: thin (≈ 10 nm) plate-like domains having a modulation-free structure appear with spacings of 50 - 100 nm along the b axis. This simple and ordinary chemical substitution would offer an alternative, technologically more promising method to prepare high-performance Bi-2212 wires which can be used at high temperatures and high magnetic fields.

Nonmagnetic Impurity Effects on a 2-Leg Quantum Spin Ladder Compound $SrCu_2O_3$

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Nonmagnetic impurity effects on a 2-leg quantum spin ladder with a large spin gap of about 400K were investigated. Surprisingly, only a few % of impurity was found to drive the host gapeless and antiferromagnetically ordered at a composition dependent temperature below 10K

Keywords: Quantum spin ladder/ Spin gap/ Nonmagnetic impurity/ Magnetic susceptibility/ Specific heat/ NMR and NQR/ Inelastic neutron scattering

Quantum spin ladder is a newly found quasi-one dimensional (1D) system with an energy gap, “spin gap”, between the singlet spin liquid ground state and the first triplet excitation state, as also seen in Haldane and spin-Peierls materials (see ICR Annual Report Vol. 2). $SrCu_2O_3$ is a high pressure phase discovered by us which comprises 2-leg ladders made of antiferromagnetic Cu-O-Cu linear bonds. These ladders are connected with each other spatially but are separated from each other magnetically because of the 90° Cu-O-Cu bond and spin frustration at the interface. This oxide is the very first even-leg spin ladder system for which the existence of such a spin gap (~ 400 K in width) has been confirmed experimentally through the measurements of the magnetic susceptibility, the nuclear spin relaxation time, T_1 and inerastic neutron scattering.

There are interests in exploring the possible onset of magnetic states induced by impurities in gapped 1D antiferromagnets and many theoretical and experimental works have been made on spin-Peierls and Haldane materials. We have studied effects of a nonmagnetic impurity introduced into $SrCu_2O_3$ and found that the impurity causes an unusual magnetic state.

Zn^{2+} was chosen as the nonmagnetic impurity because its ionic radius is similar to that of Cu^{2+}. Magnetic susceptibility, specific heat, NMR, NQR and inelastic neutron scattering studies were performed for $Sr(Cu_{1-x}Zn_x)_2O_3$ ($x \le 0.08$). All these experimental results have given us the following picture quite consistently. It is wrong to assume that a Zn atom induces a free moment localized around it as naively expected from the gapped nature of the host. Instead, the original ground state is disturbed in a more extended way such that a finite density of states appears in the energy gap and grows without affecting the magnitude of the gap until the gap closes finally around $x = 0.04$. The system behaves as a gapless 1D antiferromagnet and experiences an antiferromagnetic ordering at a low temperature. The Néel temperature showed a systematic Zn concentration dependence with a broad maximum at around 4 % substitution (T_{Nmax} ~ 8K).