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High Temperature Superconductors - J_c's Creeping Up

In the past six months scientists have made significant advances in raising the critical current densities (J_c) of bulk samples of the $YBa_2Cu_3O_{7-x}$ (1:2:3) superconductor. For many applications the high temperature superconductors will need to be able to carry electric currents of the order of 10^6 amp/cm² in magnetic fields up to 10 T. Up until about six months ago the top current densities at 77 K (liquid N_2 temperature) was ~10^4 amp/cm² in a 1 T field, except in thin films where much higher current densities have been attained.

The first advance was reported by Bell Laboratory scientists [a group headed by E. M. Gyorgy] who found that by irradiating a 1:2:3 single crystal with fast neutrons, the sample could carry a current of 6 x 10^5 amp/cm² at 77 K and 0.9 T, which is about 100 times larger than that of the unirradiated crystal. The neutron irradiation produced defects, which served as pinning sites for the magnetic vortices in the 1:2:3 compound. The pinning of the vortices prevents the vortices from moving in the solid and thus the material can carry a higher current. As far as we are aware only one crystal has been irradiated to date and these results will need to be verified. Assuming this result can be reproduced, there are only a few applications whereby this technique will be useful, since the improvement in J_c by irradiation is limited to single crystals and the majority of uses which require high J_c's employ polycrystalline materials. Another problem, is that the $YBa_2Cu_3O_{7-x}$ superconductor becomes radioactive and that short-lived radioactivity must be allowed sufficient time to decay, so the sample can be handled without elaborate safety equipment. This requires about a week before it can be handled. To circumvent this problem, single crystals of the 1:2:3 were irradiated by 3.5 MeV protons to introduce the defects. Some success was realized, but the J_c value (~2 x 10^5 amp/cm²) was about three times smaller than for the fast neutron irradiated sample.

Fortunately, more recently scientists in Japan and the U.S.A. have come up with another way of introducing defects to pin the magnetic vortices and improve the J_c values in polycrystalline materials. This, of course, is much more significant from a practical point of view and increases the likelihood of many important technological uses for the 1:2:3 superconductor. The defects were produced by carefully heat treating off-stoichiometric samples, causing a finely divided second phase to precipitate out of solution. Japanese scientists headed by Y. Shiohara of the International Super-

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conductivity Technology Center used a melt process to disperse non-superconducting Y_2BaCuO_5 (2:1:1) particles in the 1:2:3 superconducting phase. The critical current was 3 x 10^4 amp/cm^2 at 77 K and 1 T. This is not a real big improvement, but it is a good start. Bell Laboratory scientists headed by S. Jin used a slightly different approach to introduce the defects. They started with $YBa_2Cu_4O_8$ (1:2:4) compound, which in itself is a superconductor, and then by proper heat treatment the 1:2:4 decomposes to the 1:2:3 superconductor and CuO. The CuO compound forms a two phase composite with the 1:2:3 superconductor and probably has some affect on the movement of the vortices. This material had a J_c of 10^5 amp/cm^2 at 77 K and 0.9 T. These critical currents are not quite as good as that obtained by irradiation of a single crystal, but the increases in J_c over previous values are technologically more significant.

Advances in Thin-Film Superconductors

The critical currents in thin films have always been higher than those of the bulk material, so increasing J_c in the $YBa_2Cu_3O_{7-x}$ films is not as big a driving force, as some of the other problems associated with thin films, i.e. epitaxy, substrate compatibility, heat treating after deposition, increasing sample thickness, speed of deposit, etc. Recently X. D. Wu of the Los Alamos National Laboratory developed a pulsed laser deposition technique to form high quality 1:2:3 films at extremely high deposition rates (~150 Å per second compared to a normal rate of ~2 Å per second). Films as thick as 1800 Å have been grown without any annealing, and are found to have a sharp transition with a zero resistance at 90 K. Critical currents have not been measured but Wu expects them to be of the order of 10^6 amp/cm^2 at 77 K.

Another advance in thin film superconductivity is the preparation of heterostructures which consist of alternate layers of the 1:2:3 superconductor and a non-superconductor, in this case $PrBa_2Cu_3O_7$. Since the two rare earth compounds have the same structure, the two can be grown epitaxially one upon the other. Such heterostructures will be the cornerstone for many electronic applications. As a matter of fact, at least one such device has been prepared. Scientists [from Bellcore and Rutgers] have taken a three layer 1:2:3 heterostructure with two Y layers separated by a Pr layer on a gold substrate and have fabricated a Josephson weak-link device by photolithography and argon ion beam etching. Such devices employing low temperature superconductors are used today in microwave detectors and SQUIDS (superconducting quantum interference devices), but they need to be operated at liquid He temperatures, 4 K. When the 1:2:3 devices become available they will be used at 77 K, which means the microwave detectors and SQUIDS will be cheaper to build and cheaper to run. These devices, based on the Josephson effect, will probably be the first main market for the 1:2:3 superconductors.

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