CORRELATED ENHANCEMENT OF H_{C2} AND J_C IN CARBON NANOTUBE-DOPED MgB_2

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In the last few years, several groups have achieved a good improvement of the transport properties of MgB_2, especially in thin films. However, in polycrystalline MgB_2, one of the most important remaining challenges is to increase the upper critical field (H_{c2}), which in the case of undoped clean material is too low for most possible applications, while, at the same time, improving the critical current density (J_c). C-nanotubes (CNT) inclusions, with diameters close to the MgB_2 coherence length ($\xi_{ab}(0)$~3.7-12nm; $\xi_c(0)$~1.6-3.6 nm) may be very good candidates for vortex pinning if they do not completely dissolve in the matrix but remain as tubes acting as columnar defects. Another interesting issue is that theoretical models predict a significant H_{c2} enhancement in the dirty limit and an anomalous $H_{c2}(T)$ upward curvature.
We used the 50 T mid-pulse magnet to perform four-probe transport measurements in bulk MgB_2 samples doped with double wall CNT's (nominal C contents $0 < x < 0.125$). Samples were prepared in Bariloche as described elsewhere.[1,2] The actual amount of C in the lattice, x_s, is less than the nominal CNT content as determined by X-ray diffraction. $H_{c2}(T)$ and $H_{irr}(T)$ for C-doped samples with x = 0.025, 0.1, 0.125, as determined by the onset criteria of the measured resistance as a function of field curves, are shown in Fig.1 (a). The inset displays H_{c2} as function x_s for 4 and 20K and the extrapolation to 0K for all samples. $H_{c2}(0)$ presents a maximum near $x_s \approx 0.045$ (x =0.1) and a decrease above 0.045 similar to the J_c behavior [1].

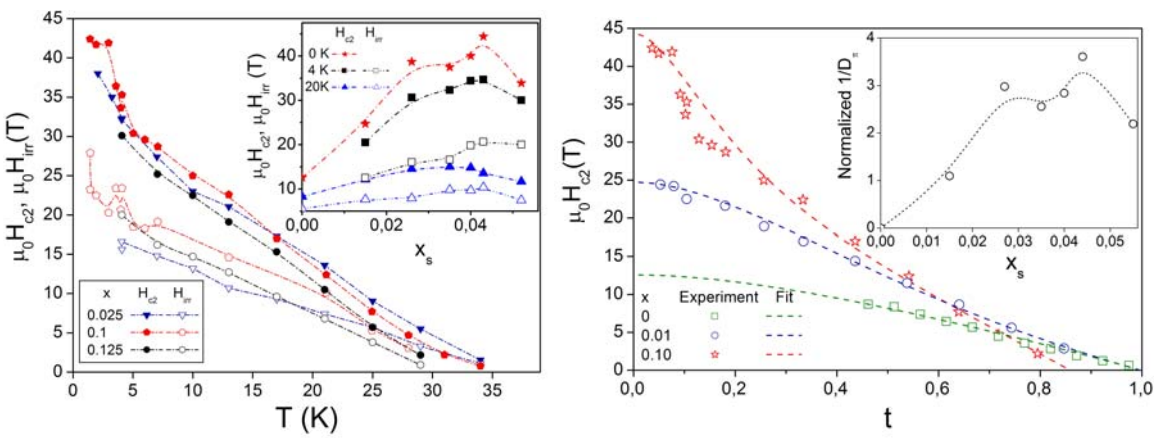

Fig. 1. (a) Transport measurements of the upper critical field (H_{c2}) and the beginning of the dissipation (H_{irr}) in the R(H) curves for x = 0.025, 0.1 and 0.125 samples. The inset shows H_{c2} and H_{irr} as a function of substitution C-content (x_s) at 4K (squares) and 20K (circles), and the H_{c2} extrapolation at 0K (stars). **(b)** H_{c2} vs $t = T/T_{c0}$ for x = 0, 0.01 and 0.1 samples and fit to data using equation 1 (dash lines). The inset shows the dependence of $1/D_\pi$ with x_s.

Fig. 1(b) shows $H_{c2}(T)$ as a function of the reduced temperature t, including the experimental values and the curves obtained by fitting the experimental data with the theoretical model of ref[3], for x = 0, 0.01 and 0.1 samples. The upward curvature, characteristic of a two gap effect, is clearly observed near $t \approx 0.2$ for the x = 0.1 sample. The clear difference between the samples can be explained as an effect of a change in the scattering mechanism into the bands. The inset shows that $1/D_\pi$ follows the same dependence of $H_{c2}(0)$ as a function of x_s signifying that C-doping is affecting the π-band.

Conclusions

$H_{c2}(T)$ can be described by the two-bands model for a dirty two gaps superconductor that takes into account the interband scattering. H_{c2} in MgB_2 bulk samples may be increased up to record value $H_{c2}(0) \approx 44.4$ T by adding 10 %at DWCNT. This greatly exceeds the upper critical field performance of other intermetallic superconductors such as Nb_3Sn, confirming that this compound is very attractive for applications.

References

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[3] Gurevich, A., *Phys. Rev. B* **67**, 184515-184528 (2003).