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UPPER CRITICAL FIELD IN Y_{0.8}Ln_{0.2}Ba_{2}Cu_{3}O_{7-\delta}, Ln = Dy, Er and Tm SUPERCONDUCTORS

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Abstract. Resistively measured upper critical field, $H_{c2}(T)$, for fields up to 120 kOe are reported for the new superconductors Y_{0.8}Ln_{0.2}Ba_{2}Cu_{3}O_{7-\delta}, Ln = Dy, Er and Tm. A concave curvature is observed for all the $H_{c2}(T)$ vs. $T$ graphs at lower fields. Origin of the curvature from the anisotropy of $H_{cg}$ and alternatively from critical fluctuations are discussed.

Discovery of superconductivity in Y_{1}Ba_{2}Cu_{3}O_{7-\delta} or YBCO type compounds, was soon followed by the finding that the upper critical field, $H_{c2}(T)$, at a temperature, $T$, in these compounds is about an order of magnitude higher [1]. The present work reports 4-probe resistive measurements of $H_{c2}$ in single phase Y_{0.8}Ln_{0.2}Ba_{2}Cu_{3}O_{7-\delta} for Ln = Dy, Er and Tm. In addition, the common feature of the broadening of the superconducting transition in presence of a magnetic field, observed [2, 3] also for YBCO, is investigated.

The samples were prepared [4] as oxygenated sintered pellets XRD showed the 123-phase [1, 4] and clear orthorhombic splitting. Impurity phases were much less than 5%. Electrical leads were either silver pasted into finely drilled holes or soldered to Cu or Cu-over-Au film-strips, vacuum evaporated onto the samples. The sample current (typically 1 mA) was perpendicular to the applied magnetic field, $H$. The sample was inside a tubular He-exchange-gas chamber, designed to be inserted into a superconducting magnet and allow sample temperatures up to 300 K. An agreement of the resistivity data taken during heating and cooling was ensured in all cases, as shown in figure 1 of [5]. A carbon glass thermometer, used for $H > 0$, was calibrated in-situ at $H = 0$ against Ge and Pt thermometers.

Resistance, $R$, vs. temperature, $T$, graphs with $H$ as a variable parameter (Fig. 1), show that the effect of $H$ on $R$ is negligible between the on-set ($R = R_n$) point and 100 K. Hence as a preliminary experiment, it was measured at 300 K for one of the samples, Ln = Tm. It gave $dR/dH = -0.06$ m$\Omega$/T for 8 T < $H < 12$ T. This confirms the negative magnetoresistance reported earlier [6] for YBCO for the same transverse geometry, although the magnitude measured by them up to 200 K was smaller. Sensitiveness of these transport properties to factors like O-stoichiometry and granular structure and hence to the sample preparation details might explain the difference in magnitude. In fact it is not clear whether this unusual negative sign is due to any such effect or due to any new and unusual mechanism [8].

Fig. 1. - Superconducting transitions and the estimate (inset) of the upper critical field, $H_{c2}(T)$, from these graphs defining $T$ at 0.50 $R_n$.

Fig. 2. - $H_{c2}(T)$ vs. $T$ graph defining $T$ at 0.75 $R_n$ (erect triangles), 0.50 $R_n$ (squares) and 0.25 $R_n$ (inverted triangles) points on the $R - T$ graphs (not shown).

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In addition, each of the $H_{c2} - T$ graphs shows a concave curvature [7] near the $(T_c, 0)$ point in contrast to a linear behaviour expected from WHH and other theories of $H_{c2}$. Hence for estimating $H_{c2}' (0)$, the orbital critical field at 0 K, the linear portion value of $(dH_{c2} / dT)$ and the corresponding extrapolated $T_c$ of table I are used. These high values of the slope and $H_{c2}' (0)$, calculated in table I, are comparable to those reported [2, 3] for YBCO. Similar $T_c$ and $(dH_{c2} / dT)$ have been reported [8] for YBCO and full substitution of Y by Dy, Er and Tm, but without details on whether the slope varies at lower $H$. Still it can be concluded that partial or full substitution of Y by magnetic ions did not affect $H_{c2}$ to any substantial degree. This is now understood to be due to a very short coherence length.

The near parallelism and $\Delta T$ proportional to $\Delta H$ between the transition graphs are observable for $H > 8$ T. It results in the linear $H_{c2}$ vs. $T$ dependence observed for such higher fields (Fig. 2). Anisotropy of $H_{c2}$ [1] and the fact that our sample consists of differently oriented grains can explain the characteristic broadening of the transitions at lower fields, and hence the curvature of $H_{c2}$ vs. $T$ graph. The broadening is due to more and more unfavourably oriented grains becoming normal as $H$ is increased. Beyond 8 T no further broadening occurs, implying that only the favourably oriented grains contribute to the superconductivity in this region.

An alternative mechanism involving critical fluctuations [9] has been used by Oh et al. [1] to explain the above-mentioned broadening of the resistive transition in YBCO single crystals and highly oriented films. In our polycrystalline samples the measured effect is due to grains at different orientations to $H$. Still on fitting our limited $H_{c2} (T)$ vs. $t = (T_c - T) / T_c$ data to the same type of expression

$$H_{c2} (T) = \phi_0 / [2\pi L^2 (T)] = \phi_0 t^{2\nu} / [2\pi L^2 (0)]$$

the value $\nu = 0.7 \pm 0.1$ and $L (0) = (1.7 \pm 0.7) \, \text{Å}$ were obtained. Since this magnitude of $L (0)$ is not unlikely for an average of coherence, the implication of the other result lengths [1] is now considered. The theoretical mean field value of $\nu$ is $1/2$, and $\nu > 1/2$ is taken as an indication of critical fluctuations. Mathematically $2\nu > 1$ in the above equation is a manifestation of the observed concave curvature of the $H_{c2} - T$ graphs. Such an explanation, not involving differently oriented grains, is essential in case of single crystals showing such curvature [1]. But it cannot explain the observations [7] of such curvatures for Nb-Ti and Nb$_3$Sn low-$T_c$ superconductors, in which the critical regions should be much narrower [9]. More experiments on single crystals, checked to be free of sample inhomogeneities, and further theoretical considerations are needed to identify the real mechanism or mechanisms giving rise to the now widely observed concave curvatures of $H_{c2} - T$ graphs near $T_c$.

**Note added during proof correction.**

The above type of fit has recently been interpreted from an interesting Flux Creep Model by M. Tinkham in Phys. Rev. Lett. 61 (1988) 1658.

**Table I. - Estimate from the 0.50$R_n$ graph of $H_{c2}$ vs. $T_c$ of $(dH_{c2} / dT)$ over the linear portion $(H_1, H_2)$. An extrapolation of this portion back to $H_{c2=0}$ gave $T_0 =$ T.**

<table>
<thead>
<tr>
<th>Ln</th>
<th>$(H_1, H_2)$ in T</th>
<th>$(dH_{c2} / dT)$ in T/K</th>
<th>$T_c$ in K</th>
<th>$H_{c2}'(0)$ in T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dy</td>
<td>(0, 8)</td>
<td>-1.7</td>
<td>85.2</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>(10, 12)</td>
<td>-4.0</td>
<td>85.8</td>
<td>220</td>
</tr>
<tr>
<td>Er</td>
<td>(8, 11.5)</td>
<td>-1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tm</td>
<td>(8, 11)</td>
<td>-3.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>