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High-pressure effects on the resistivity and ferromagnetic transition of ceramic manganite $Ca_{1-x}Y_xMnO_3$

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Abstract

The effect of hydrostatic pressure up to 1 GPa on the electrical resistivity and on the ferromagnetic transition temperature T_c is systematically investigated for the electron-doped manganite $Ca_{1-x}Y_xMnO_3$ for low electron density ($x \leqslant 0.2$). We find that T_c is nearly constant for pressures roughly below 0.5 GPa and shows a linear increase for higher pressures, with a slope varying with the x content. Our results are discussed considering the enhancement of the electronic bandwidth with pressure related to double exchange and polaronic contributions. The unusual pressure dependence of T_c obtained can also be related to a competition scenario between double exchange mechanism and antiferromagnetic superexchange interactions proposed for electron-doped manganites.

Keywords: Ferromagnetic transition; Pressure effect; Polaron—exchange coupling competing interactions

Many experimental and theoretical studies have been devoted to the study of manganites due to the challenge of understanding their characteristic magnetoresistive properties [1]. In particular, the increase of the ferromagnetic transition temperature (T_c) with pressure was explained, for most of the hole-doped manganites studied, within a Zener double exchange scenario, in conjunction with a Jahn–Teller effect, considering that pressure both increases the relevant Mn–O–Mn orbital overlapping and reduces the electron-phonon coupling [2–4].

Considering that electron-doped manganites have not been extensively studied and that they present different transport properties than the hole-doped ones [5], we initiate the investigation of pressure effects in the $Ca_{1-x}Y_xMnO_3$ (CYMO) compound. For low electron doping levels ($0.05 \leqslant x \leqslant 0.25$), this compound is in the orthorhombic O phase. It shows a decreasing Mn–O–Mn bond angle with increasing x probably due to the mismatch between Ca and Y ions. It shows both a ferromagnetic and an metal–insulator transition (between 100 and 120 K depending on x), with large magnetoresistance effects [6].

Single-phase well-oxygenated ceramic CYMO samples were prepared by solid-state reaction. Resistivity as a function of temperature ($R(T)$) ($4\,K \leqslant T \leqslant 300\,K$) was measured (for $x = 0.07$, 0.10 and 0.15) following a standard four terminal DC technique, applying high hydrostatic pressures up to 1 Gpa. A self-clamping cell was used with a 50–50 mixture of kerosene and transformer oil as the pressure transmitting medium.

Resistivity curves as a function of temperature and pressure (Fig. 1) show a metallic conduction at room temperature followed by a semiconductor-like behavior with decreasing temperature, with a local maximum near T_c, determined as a peak in the derivative $(1/R)\,dR/dT$ ($T_c = 111$; 113 and 116 K for $x = 0.07$; 0.10 and 0.15, respectively).

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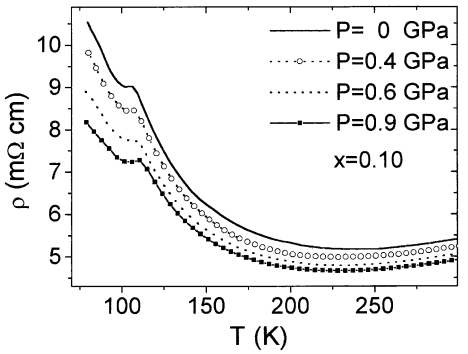

Fig. 1. Resistivity as a function of temperature at different pressures for the CYMO samples (only the curves for the $x = 0.10$ composition are shown for clarity).

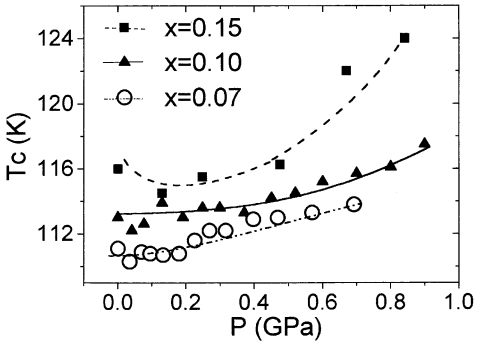

Fig. 2. Ferromagnetic transition temperature T_c as a function of pressure for compositions $x = 0.07$, $x = 0.10$ and $x = 0.15$. Lines are guides to the eye.

Our results show that T_c varies with pressure (Fig. 2) following a non-monotonic dependence for the Y compositions studied. T_c remains nearly constant for low pressures and then slightly increases for higher pressures with a slope $dT_c/dP \leqslant 7$ K/Gpa for $x \leqslant 0.10$, reaching the standard value for this T_c range of 20 K/Gpa only for the $x = 0.15$ composition.

For many hole-doped manganites the logarithmic derivative $d\ln T_c/dP$ as a function of temperature falls into a universal curve [3,4]. This is not the case for the $x \leqslant 0.10$ samples, considering their low dT_c/dP values. The universal curve can be established taking into account two positive contributions to the electronic bandwidth (W) dependence with pressure. One is related to the Mn–O–Mn bond stretching under pressure, which mainly depends on compressibility factors. The other, to the polaronic nature of charge carriers, which results in an increase of the $d\ln T_c/dP$ value due to the electron–phonon coupling reduction with pressure.

Our results are in agreement with an increase of T_c with pressure not enhanced by the polaronic contribution for $x \leqslant 0.10$ as it is for $x = 0.15$. Moreover, a reasonable quantitative agreement is obtained with the calculated values of $d\ln T_c/dP$ for other manganites, based only on the dependencies of W on the structural parameters [3]. This is a natural consequence of being in the Mn^{4+} rich part of the phase diagram where the Jahn–Teller distortion of the MnO_6 octahedra is still low.

The near independence of T_c for $x = 0.15$ for pressures up to 0.5 GPa also reveals the competition between antiferromagnetic and double exchange ferromagnetic interactions in this compound. This scenario was considered in the theoretical calculations in this system [7] that assert the existence of a rich phase diagram, specially for low doping levels. Then, the observed behavior can be related to the presence of a cluster-glass metallic state, as revealed in other electron-doped manganites [8], or to the possible existence of a canted phase, in accordance with the magnetic measurements on this samples [6].

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