The Young's modulus and electrical and magnetic properties of $La_{0.5}Ca_{0.5-x}Te_xMnO_3$

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Abstract

The Young's modulus and the transport and magnetic properties of polycrystalline $La_{0.5}Ca_{0.5-x}Te_xMnO_3$ ($x = 0$, 0.05, and 0.1) have been studied systematically. It was found that with increasing Te content, the resistivity decreases, the Curie temperature T_C increases and the relative Young's modulus decreases. We suggest that Te doping destroys the charge ordering (CO) and induces the ferromagnetic (FM) metallic state accompanied by an evolution from the Q_3-type distorting mode to Q_2-type one. In addition, we found that the evolution from magnetic to electronic phase separation is close related to the rapid decrease in the ratio of two kinds of Jahn–Teller distortion modes Q_3 and Q_2, i.e., Q_3/Q_2.
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1. Introduction

In recent years, considerable progress has been made in understanding the physics of colossal magnetoresistance materials. The rich physics of colossal magnetoresistive compounds with perovskite structure is dominated by the intriguing competition between ferromagnetic double exchange coupling and charge/orbital ordering (CO/OO) [1–3]. Charge localization, prerequisite of charge ordering, is mutually exclusive with ferromagnetism in the double exchange mechanism which requires actual hopping of charge carriers. The general ground state of mixed valence manganites, e.g., $La_{1-x}Ca_xMnO_3$, is therefore either a ferromagnetic (FM) metal or an antiferromagnetic (AFM) charge-ordered insulator. The $x = 0.5$ compound, which is located on the phase boundary separating these two competing ground states, provides a rare opportunity for studies of these competing inter-

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action. The CO state is very sensitive to the chemical doping and the element bandwidth. Raveau et al. [4,5] have shown that cation substitution in the manganese site of CO $Pr_{0.5}Ca_{0.5}MnO_3$ destroys the CO insulating (COI) state and changes the material from the anti-ferromagnetic (AFM) COI to the FM metal (FMM) state with a little Cr doping. Recently, many studies show that the CO state can be transformed into FMM state by changing the size of the A-site cations [6,7]. Replacing divalent Ca ions within tetravalent Te ions will create a new double-exchange (DE) [8] channel in a mixed manganese valence state of Mn^{2+}–O–Mn^{3+} and create an opportunity to study the CMR [9,10].

In present Letter, we observed the effect of Te substitution for Ca by means of the resistivity ρ, the magnetization M, Young's modulus E along with the X-ray powder diffraction measurements of the samples $La_{0.5}Ca_{0.5-x}Te_xMnO_3$ ($x = 0$, 0.05, and 0.1) system. We found that for the $x = 0$ sample, the magnetism M exhibits two peaks in the M–T curve and the resistivity behaves insulating in the whole measured temperature range, which is attributed to the magnetic phase separation with the coexistence of AFM and FM phases. While for $x = 0.05$ and 0.1 samples, they undergo electronic phase separation with the coexistence of insulating and metal phases in the FM region. In addition, the Curie temperature T_C increases and the resistivity of the samples decreases with the increase of the Te-doping level and the insulator–metal (I–M) transition has been induced for $x = 0.05$ and 0.1. The Young's modulus measurement indicates that the relative Young's modulus decreases with the increase of the Te-doping level. Our results suggest that the Te doping can destroy the CO state and induce the FM metallic state accompanied by an evolution from the Q_3-type distorting mode to Q_2-type one. In addition, we found that the evolution from magnetic to electronic phase separation is close related to the rapid decrease in the ratio of two kinds of Jahn–Teller distortion modes Q_3 and Q_2, i.e., Q_3/Q_2.

2. Experimental techniques

Polycrystalline samples with nominal compositions $La_{0.5}Ca_{0.5-x}Te_xMnO_3$ ($x = 0$, 0.05, and 0.1) were synthesized by the conventional solid-state reaction method. Stoichiometric La_2O_3, $CaCO_3$, TeO_2

and MnO_2 powders were mixed and ground, and then heated in air at 750 °C and 1050 °C for 24 hours with intermediate grinding. Finally, the powder was pressed into bars for E measurements, sintered in the air at 1100 °C for 24 hours and then cooled down to room temperature. For the sample of $x = 0$, the powder sintered at 1100 °C for 24 h was again pressed into bars and sintered at 1300 °C for 24 h. X-ray powder diffraction was performed using Cu K_α radiation at room temperature. The resistance as a function of temperature was measured by the standard four-probe method from 5 K to 350 K with a Quantum Design Physical Property Measurement System (PPMS) ($2\,K \leqslant T \leqslant 400\,K$). The magnetic measurements were carried out with a Quantum Design superconducting quantum interference device (SQUID) MPMS system ($2\,K \leqslant T \leqslant 400\,K$, $0 \leqslant H \leqslant 5\,T$). $E(T)$ was measured by the free decay method of resonant bar in an acoustic frequency range with magnitude of kHz using cooling mode. The Young's modulus E is defined as follows:

$$E = \frac{4\pi^2 s d l^4}{m^4 I} f^2, \tag{1}$$

where f is the resonant frequency, s is the cross-sectional area, d is density, l is the length, I is the moment of inertia of the sample and m is 4.730 for the vibrating mode in the fundamental mode, in which the sample is suspended at two points whose span is $0.224l$ from two free ends of the sample. Based on Eq. (1), E is proportional to the square of the resonant frequency, i.e., $E \propto f^2$. Therefore, we substitute f^2 for E.

3. Results and discussion

Fig. 1(a) shows the X-ray diffraction (XRD) pattern of $La_{0.5}Ca_{0.5-x}Te_xMnO_3$ ($x = 0$, 0.05, and 0.1) samples. The powder X-ray diffraction at room temperature shows that all samples are single phase with no detectable secondary phases and the samples have an orthorhombic structure with the space group Pbnm. The structural parameters of the samples are refined by the standard Rietveld technique. As an example, one of the fitted pattern ($x = 0.1$) is shown in Fig. 1(b). It shows that the fitting between the experimental spectra and the calculate values is quite well.