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Ultrasonic investigation of $Nd_{0.5}Sr_{0.5}MnO_3$

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Abstract

Results of ultrasonic studies of the magnetoresistive compound $Nd_{0.5}Sr_{0.5}MnO_3$ in a broad temperature range (1.5–180 K) are reported. With decreasing temperature the pronounced acoustic mode hardening was observed at about $T_{CO} = 145$ K. The change of sound velocity around T_{CO} was explained by a strong coupling between the acoustic phonons and the charge-ordered states. © 2001 Elsevier Science B.V. All rights reserved.

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The present work is devoted to the investigation of $Nd_{0.5}Sr_{0.5}MnO_3$, which is a typical material with distorted perovskite structure showing a metal–insulator phase transition. With decreasing temperature $Nd_{0.5}Sr_{0.5}MnO_3$ undergoes a transition from paramagnetic into a ferromagnetic (FM) metallic state ($T_C \approx 250$ K) and then to an antiferromagnetic (AFM) charge/orbital ordering (CO/OO) insulating state ($T_{CO/OO} \approx 150$ K) [1], in which AFM A-type (AFM_A) and AFM CE-type (AFM_{CE}) phases coexist and are strongly correlated [2,3]. The origin of the metal–insulator phase transition in $Nd_{0.5}Sr_{0.5}MnO_3$ lies in the essential interplay between spin, charge, orbital and lattice degrees of freedom. The main purpose of this work is to study the peculiarities of the transition into the CO phase using ultrasonic method, which is a very powerful tool for the determination of structural changes.

The $Nd_{0.5}Sr_{0.5}MnO_3$ single crystals were grown from polycrystalline rods in an infrared image furnace using the floating-zone method. The precursor materials were prepared by mixing appropriate quantities of Nd_2O_3, $SrCO_3$, and MnO_2. The powder was ground and calcined 3 times at 1300°C for 12 h and then pressed into rods, which were sintered at 1400°C for 12 h. At room temperature the samples are of orthorhombic structure with lattice parameters in good agreement with data presented in earlier studies [1,2,3]. X-ray Laue diffraction analysis has shown that the crystals were slightly twinned. Such a twinning is common for the doped manganites. It takes place in the vicinity of the high-temperature transition from the initial cubic into distorted (rhombohedral or orthorhombic) phase. Taking into account the twinned character of the crystal structure, the direction [1, 1, 1] of the initial perovskite cube was chosen for our experiments and the sample was then cut along this axis. Relative velocity and attenuation of the longitudinal ultrasonic waves were measured using a phase comparison and phase sensitive (quadrature) method [4,5].

The temperature dependence of the sound attenuation δ and relative sound velocity $\Delta v/v_0$ (decreasing temperature) are presented in Fig. 1(a) and (b), respectively. Pronounced sound mode hardening was detected at the temperature of about $T_{CO/OO}$, similar to that observed in $La_{0.67}Ca_{0.33}MnO_3$ [6]. The phase transition also manifests itself through the sound attenuation signal δ seen as a main maximum at $T = 145$ K. This temperature can be defined as $T_{CO/OO}$. In comparison with

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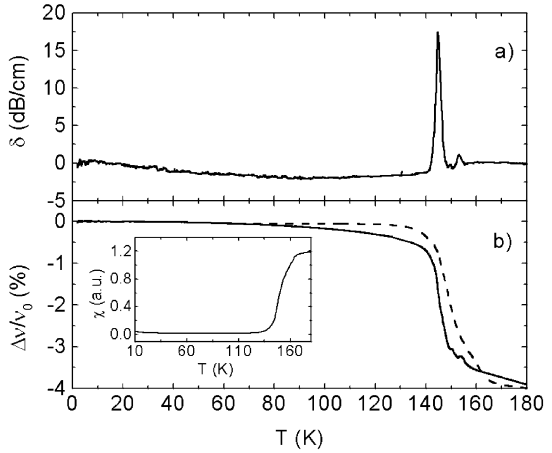

Fig. 1. (a) The temperature dependence of the sound attenuation δ. (b) The temperature dependence of the relative sound velocity $\Delta v/v_0$. The dashed line is a theoretical fit. The inset shows the temperature dependence of the magnetic susceptibility χ.

$La_{1-x}Ca_{0x}MnO_3$ [6] ($x = 0.33$, 0.63) (in which the change $\Delta v/v_0$ with temperature was of the order of 5–10%) in $Nd_{0.5}Sr_{0.5}MnO_3$ this change here was slightly smaller, about 4%.

Based on the Hamiltonian of small polarons with strong nearest-neighbor repulsion, J. D. Lee and B. I. Min showed that the CO transition produces a large sound velocity renormalization around T_{CO} [7]. Using the generalized susceptibility function [8] and considering a coupling between acoustic phonons and electrons participating in the CO they obtained for the sound velocity

$$\Delta v/v_0 = (1 + g^2(0)\chi(T))^{-1/2} - 1,$$

where $\chi(T)$ is the AFM spin susceptibility and $g(0)$ is the parameter of the electron–phonon coupling strength at $k = 0$ (k is the wave vector). The magnetic susceptibility of the same crystal measured as a functions of temperature (Fig. 1(b), inset) shows a significant change at a temperature around T_{CO}. Using this approach, we performed a fit of the sound velocity measured within the metal-to-insulator phase transition (dashed curve in Fig. 1(b)). One can see that the theoretical results are in the satisfactory agreement with the experimental data. However, it is by now well established that OO plays a significant role in the transport properties of manganites and, obviously, should be taken into the theoretical consideration. Assuming a more complex magnetic structure for $Nd_{0.5}Sr_{0.5}MnO_3$ (coexistence of the CO CE-type AFM structures, accompanied by the $d_{3z^2-r^2}$-type OO and A-type AFM ordering with the $d_{x^2-y^2}$-type OO) should lead to a theory for sound behavior more complicated than the one discussed above [6].

In conclusion, we have reported the results of the ultrasonic studies of the colossal magnetoresistive compound $Nd_{0.5}Sr_{0.5}MnO_3$. The significant hardening of the acoustic mode was observed at the metal-to-insulator phase transition with decreasing temperature. The change of sound velocity around $T_{CO/OO}$ was explained by a strong coupling between acoustic phonons and charge-ordered states. It would be interesting to compare the sound mode behavior in $Nd_{0.5}Sr_{0.5}MnO_3$ at the metal–insulator phase transition, induced by the magnetic field and the temperature. Ultrasonic investigation of $Nd_{0.5}Sr_{0.5}MnO_3$ in magnetic fields has been recently performed [9].

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