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Elastic behavior of neodymium based manganites

G. Lalitha, P. Venugopal Reddy *

Department of Physics, Osmania University, Hyderabad 500 007, India

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ABSTRACT

With a view to investigate the elastic behavior of $Nd_{0.67}A_{0.33}MnO_3$ (where A = Ca, Sr, Ba, Pb) manganite system, the samples were prepared by the sol gel method. After characterizing the samples structurally, a systematic investigation of ultrasonic longitudinal and transverse sound velocities of all the samples was undertaken by pulse transmission technique in the temperature range, 100–300 K. It has been found that all the elasticity parameters, including Debye temperature, are found to increase continuously with increasing ionic radii of the dopant ion. All the samples are also found to exhibit anomalies in both the longitudinal and transverse velocities near their ferro to para magnetic transition (T_C) temperatures. Apart from this, $Nd_{0.67}Ca_{0.33}MnO_3$ sample is also found to exhibit, a transition at its charge ordering temperature (T_{co}). An explanation for the observed elastic anomalies based on a mean field theory has been given.

1. Introduction

In the recent past, the fascinating features of the divalent doped manganite system, $R_{1-x}A_xMnO_3$, (R = Rare earth and A = divalent alkaline earth metals) resulting from charge, spin, and lattice dynamics have created enormous interest leading to tremendous scientific activities [1,2]. One of the important features of these materials is the simultaneous occurrence of ferro to paramagnetic and metal to insulator transitions. In addition, these materials also exhibit colossal magneto resistance phenomenon in the vicinity of their transition temperatures. It has been established that the double exchange (DE) mechanism [3] alone cannot explain the complex magneto transport and several other properties of manganites especially those in the vicinity of their transition temperatures. However, later on it has been realized that the contributions from electron–phonon interactions leading to Jahn–Teller phenomenon also play a major role in explaining the complex conduction mechanism.

Magnetic transitions of a magnetic material are accompanied by transformations in the crystal lattice [4]. Sound velocity and elastic properties are sensitive to changes in the magnetic state. Apart from this, there is a lot of experimental evidence indicating the presence of electron–lattice coupling. For instance, near T_C dramatic changes are observed in the lattice degree of freedom [5], anomalous lattice expansion [6] and anomalous sound velocity hardening [7] indicating that the lattice behavior is closely related to the electronic and magnetic properties. All these evidences unambiguously indicate that the lattice behavior might be responsible for the observed anomalous variations in the thermo-physical properties such as elastic constants, thermal expansion, and magnetic specific heat. Among these properties, a study of elastic behavior is very interesting and important due to the fact that the measurement of elastic moduli, especially by ultrasonic technique is a nondestructive and sensitive tool, not only for studying the defects and microscopic process in solids, but also it is successful in explaining the systems undergoing magnetic and structural phase transitions [8].

Further, although a few studies on the elastic behavior of CMR materials are available in the literature, no effort to arrive at a comprehensive model based covering various types of anomalies viz., anomalies in the vicinity of magnetic transition temperature (T_C), Charge order transition temperature (T_{co}) antiferromagnetic transition temperature (T_N) was made by any group or individual. Therefore, efforts have been going on in this laboratory to develop a model covering various types of anomalies exhibited by various types of CMR materials, for the last 3 years. Earlier, studies were concentrated on Lanthanum based manganites [9,10]. In order to generalize the results, the present study is aimed at investigating the elastic behavior of $Nd_{0.67}A_{0.33}MnO_3$ (where A = Ca, Sr, Ba, Pb) system [11,12]. In fact, the same materials system, ($Nd_{0.67}A_{0.33}$-MnO_3) was investigated earlier in our laboratory, mainly to understand the influence of nano-size on their electrical and magnetic properties [13]. Although in the present investigation also, the same materials were used, their preparation method was different and the motivation of the two studies is also different. As a matter of fact, with a view to achieve high density samples, a synthesis based on repeated calcinations followed sintering at

* Corresponding author. Tel./fax: +91 40 27090020.
E-mail address: paduruvenugopalreddy@gmail.com (P. Venugopal Reddy).

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Table 1
Densities of neodymium based manganites.

Compositional formula	Sample code	Bulk density	X-ray density (kg/m^3)	Porosity%
$Nd_{0.67}Ca_{0.33}MnO_3$	NCMO	5262	6297	16
$Nd_{0.67}Sr_{0.33}MnO_3$	NSMO	5474	6512	16
$Nd_{0.67}Ba_{0.33}MnO_3$	NBMO	5694	6902	18
$Nd_{0.67}Pb_{0.33}MnO_3$	NPMO	6203	7589	18

Table 2
Ultrasonic velocities and transition temperatures of neodymium based manganites.

Sample code	V_l (m/s)	V_s (m/s)	T_C (K)
NCMO	3185	1870	136
NSMO	3694	2015	262
NBMO	3929	2171	249
NPMO	4387	2230	252

Table 3
Elastic data of neodymium based manganites.

Sample code	E_0 (GPa)	η_0 (GPa)	σ_o	V_m	θ_D (K)
NCMO	63.48	25.50	0.24	4359	440
NSMO	79.02	30.24	0.31	4700	469
NBMO	97.94	37.72	0.30	5089	506
NPMO	118.30	43.60	0.36	5256	523

high temperatures was employed in the present investigation. The study is also aimed at understanding the variation elastic behavior with increasing ionic radii of the dopant ion along with their lattice behavior and the results of all these investigations are presented in this paper.

2. Experimental techniques

$Nd_{0.67}A_{0.33}MnO_3$ (where A = Ca, Sr, Ba, Pb) samples were prepared by the sol–gel process, details of which are given elsewhere [14]. The samples were characterized structurally by X-ray diffraction technique (XRD) with Cu Kα (λ = 1.541 Å) radiation (Phillips Expert diffractometer). Scanning Electron Microscopy (SEM) (on Hitachi SEM SU-1500) was performed to examine the surface morphology of the samples. AC susceptibility measurements were carried out using mutual inductance bridge principle to determine the T_C values. The bulk densities (ρ) of the samples were measured by an immersion method and the X-ray densities were calculated using lattice parameters obtained from the XRD data and are given in Table 1. With a view to investigate the elastic behavior, especially in the vicinity of magnetic transition temperature (T_C), the longitudinal and transverse velocity measurements were undertaken by the pulse transmission technique in the temperature range, 100–300 K using a specially designed sample holder CAASS [15]. The specialty of the sample holder is that there is no need to

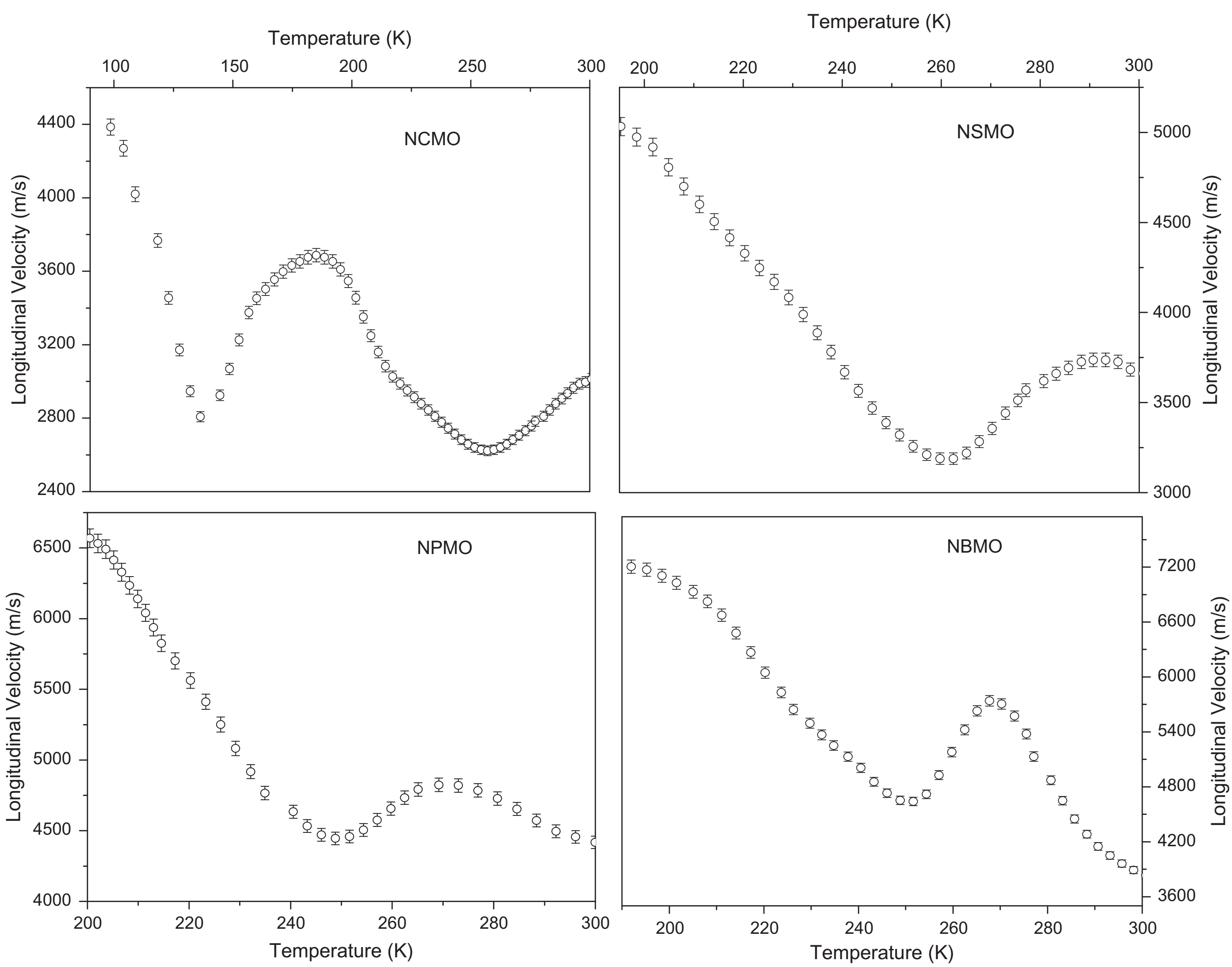

Fig. 1. Variation of longitudinal velocity with temperature including error bars.