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Resistivity and Specific Volume in Magnetic Materials

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The correlation between resistivity and volume changes in manganite of system $LaMnO_3$ under the influence of temperature *T*, hydrostatic pressure *P* and magnetic field *H* was considered. It was shown that each of the factors *T*, *P*. *H* gives its contribution in the amount of the resistivity, which is determined by the specific or molar volume of the material. The estimation of contributions values was made. Analysis considered regularities indicate that mechanical, thermal, magnetic and galvanic properties are closely linked and used this link are realized through volume changes in specific volume.

Keywords: Stress, Manganite, Resistivity, Pressure, Magnetic field.

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1. INTRODUCTION

At present, thanks to the development of experimental features, a huge number of works on the study of resistive properties of multi-component magnetic materials under the influence of temperature, pressure, magnetic fields were appeared. Interest to the study of these materials is due to their availability because of diversity of properties. Overview of the main investigation was made in references [1-3]. The large number of anomalies, effects, features was found in manganite materials containing additives of chemical elements different percentage For example, the giant magnetoresistance was revealed in certain thermal and magnetic range. Peculiarities of behavior of conductivity, various anomalies were studying but are still lacking full understanding and description of the phenomena. Use high pressure as new affecting parameter and the study of the physical properties of solids under simultaneous three thermodynamic parameters (temperature, magnetic fields, and pressure) significantly expanded the information base. The conductivity of a number manganite in the big range of temperatures (up to 350 k), pressures (up to 1.8 GPA) and magnetic fields (up to 8 Oe) were investigates in the paper [4].

Analysis of the results (and review the results obtained by other authors) [5] revealed similar influence of all these three parameters. There are intervals in which the resistivity has almost linear dependence between extreme. curve knees. This behavior is typical for many materials. The same response to various factors, suggests the unified nature of this influence. Authors [5] suggested that all observed effects have a single mechanism associated with the activity of elastic stresses in the solid, because of cross effects (termoelasticity, compressibility, magnetostriction). Take into account the elastic properties of material when examining resistivity properties allows afresh on nature conductivity. The present investigation devote to development of new approaches.

2. EXPERIMENT

Experimental methodology and used equipment for measurements of resistivity under high pressure, low temperature and strong magnetic field detailed in the book [5]. Experimental results of author (Polyakov [4]) were selected for the analysis as an example. Results of measurement of resistivity in $La_{0.9}Mn_{1.1}O_3$ depending on the temperature at various pressures and magnetic fields has presented in the Fig. 1.

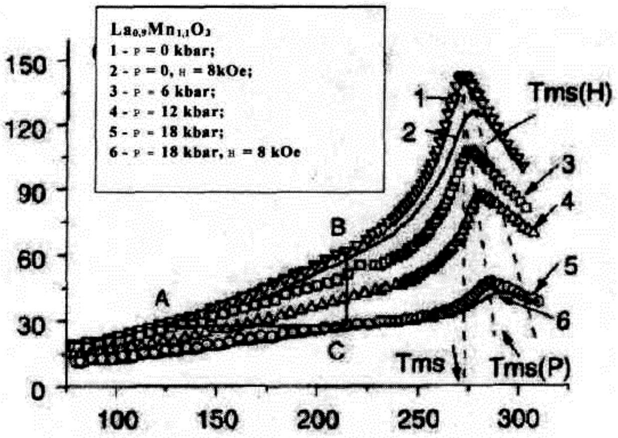

Fig. 2 – Dependences of resistivity (ρ, mΩ·cm) versus temperature (*T*, K) for $La_{0.9}Mn_{1.1}O_3$ [4]

Fig. 1 shows that, the resistivity depends on three parameters: temperature *T*, pressure *P*, magnetic field *H*. i.e.

$$\rho = \rho(T, P, H), \qquad (1)$$

The thermal coefficient of resistance $(\partial\rho / \partial T)_P$ depends on pressure and pressure coefficient of resistance $(\partial\rho / \partial T)_T$ depends on the temperature (Fig. 2, 3):

However, the review of the experimental data [5-8] shows that influence of temperature, pressure, magnetic field affects the volume of material, and the nature of

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this impact is similar to resistivity. As example on the Fig. 4 the result of measuring of the cell crystals volume for systems LaMnO$_3$ depending on the temperature in the range 77-300 K. were presented [6]. Other result about temperature, pressure and magnetic field influence were described in the reference [5-8].

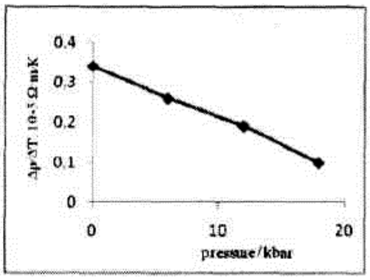

Fig. 2 – Influence of pressure on the thermal coefficient of resistivity

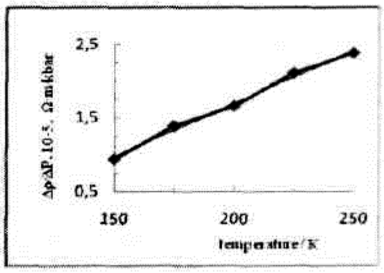

Fig. 3 – Influence of temperature on the baric coefficient of resistivity

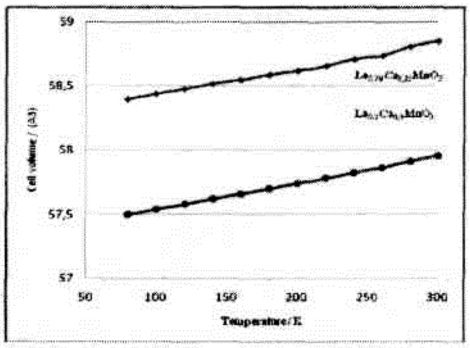

Fig. 2 – Dependences of volume of lattice cell versus temperature [6]

3. RESULTS AND DISCUSSION

Comparison of the results of the resistivity ρ (Fig. 1) and volume change ΔV shows that changes in the observable T, P, H the relationship $\rho(T, P, H)$ and $\Delta V(T, P, H)$ have the same behavior. This suggests that the resistivity depends on the specific (or molar) volume of material, which is defined as the volume of units of mass (or quantities of matter). Then:

$$d\rho = \frac{\partial\rho}{\partial V}\frac{\partial V}{\partial T}_{P,H} dT + \frac{\partial\rho}{\partial V}\frac{\partial V}{\partial P}_{T,H} dP + \frac{\partial\rho}{\partial V}\frac{\partial V}{\partial H}_{P,T} dH$$

The thermal expansion of volume is characterized by the volume coefficient of thermal expansion $\alpha_T = \frac{\partial V}{\partial T}_{P,H}$. The use of high pressure leads to essential changes in the volume, characterized by a factor of compressibility $k_P = \frac{\partial V}{\partial P}_{T,H}$. The change of size and volume of magnetic solid under influence of magnetic field (magnetostriction) also sufficiently well understood and is characterized by anisotropic magnetostriction coefficient $b_{i,j} = \frac{\partial V}{\partial H}_{P,T}$.

In the studied range of temperatures and pressures resistivity and volume change increases linearly, factors have permanent value. The corresponding thermal coefficient of volume expansion [6] (Fig. 4) is $\alpha_T = 5.2 \cdot 10^{-5}$ K^{-1}. This coefficient obtained by X-ray measurements of the crystal lattice (microscopic thermal expansion) corresponds to the coefficient for macroscopic thermal expansion [7]. The compressibility of the sample La$_{0.9}$Mn$_{1.1}$O$_3$ equals to $k_P = 3.3 \cdot 10^{-12}$ Pa^{-1} (For close composition LaMnO$_3$ the compressibility factor is $k_P = 5.2 \cdot 10^{-12}$ Pa^{-1}) [8]. The magnitostriction factor for LaMnO$_3$ equals $b = 2.33 \cdot 10^{-10}$ Oe^{-1} according to fig. 7.13 in ref. [5]. The factor is small for this material, and its contribution to the volume changes compared to deposits of T, P a lot less. However, for other manganite modifications this coefficient can be large enough and positive and negative [5].

Take into account the constancy of thermal and pressure coefficients and smallness of contribution magnetic field (only for materials studying on the Fig. 1), we have:

$$d\rho = \frac{\partial\rho}{\partial V}(\alpha_T dT + k_P dP)$$

In the Table 1 the estimation of the volume density of resistivity $\frac{\partial\rho}{\partial V}$ according to result fig. 1 is offered the coefficient of thermal expansion $\alpha_T = 5,2\ 10^{-5}$ K^{-1}, coefficient of compressibility $k_P = 3.3 \cdot 10^{-12}$ Pa^{-1}, magnetostriction coefficient is $b_{ij} = 0$. We obtained that the density of resistivity is approximately constant value and equal to $d\rho = \frac{\partial\rho}{\partial V} = 7 \cdot 10^{-2}$Ω/m^2.

Most probably the volume density of resistivity is parameter of material, which determines the conductive properties and depends on specific (unit) volume of material. The change of unit volume by any reason (influence of temperature, pressure, magnetic field) lead to the change of resistivity. Specific (or molar) volume V$_0$ also is a parameter of solids (as for gaseous state), and determined by atomic and crystal structure.

This change in volume results in the mass density and charge density of electronic clouds, that attended by the modified electronic and elastic properties of solid. The relationship between electronic and elastic properties was discussed in the ref. [5] too.

So the mechanical, thermal, magnetic and resistive properties of solids are closely linked and this link is supplied by 3D solid changes.

Table 1 – Estimation of the volume density of resistivity

Pressure P,GPa	ΔT, K	Change of resistivity $\Delta\rho$, $10^{-5}\Omega\cdot$m	Change of volume ΔV, 10^{-3}m^{-3}	Volume density of resitivity $\Delta\rho/\Delta V$, $10^{-2}\,\Omega$/m^2
1 atm	150	52	7,8	6.6
0,6	150	40	5,8	6,9
1,2	150	28	3,8	7,3
1,8	150	15	1,8	7,2

4. CONCLUSIONS

1. The resistivity is determined by the combined action of temperature, pressure, magnetic field Thermal resistance coefficient depends on pressure and pressure coefficient resistance depends on temperature. Similarly affected and magnetic field at thermal and pressure resistance coefficients. Mechanical, electric, magnetic, heat properties of the material are closely linked.

2. Dependency of the resistivity from temperature, pressure, magnetic fields corresponds to volume changes of material.

3. We suppose that the volume change is the reason of the resistivity change, and the density of resistivity $\left(\frac{\partial\rho}{\partial V}\right)$ is parameter of material.

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