Journal of Applied Sciences

ISSN 1812-5654

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 8 (4): 682-686, 2008
ISSN 1812-5654

Magnetic Properties and Electrical Resistivity of Half-Metallic Ferromagnetic Compounds as the Half Heusler PtMnSb

[1]M.A. Kouacou, [3]A.A. Koua, [1]Z. Yeo, [2]A. Akichi, [1]A. Tanoh and [1]M. Koffi
[1]Department of Electrical and Electronic Engineering,
Institut National Polytechnique Houphouët-Boigny (INP-HB),
BP 1083 Yamoussoukro, Côte d'Ivoire
[2]Department of Mechanics and Energetic Engineering,
Institut National Polytechnique Houphouët-Boigny (INP-HB),
BP 1083 Yamoussoukro, Côte d'Ivoire
[3]Laboratory of Nuclear Physic and Radioprotection, UFR SSMT,
University Cocody, 22 BP 582 Abidjan 22, Côte d'Ivoire

Abstract: The aim of this study is to investigate magnetic properties of an example of half-metallic and ferromagnetic compounds, namely, the half Heusler PtMnSb. From the magnetic measurements, it can be shown a change from a localized magnetism due to the spin waves thermally excited, to an itinerant magnetism with spin fluctuations is to reduce the moments in this compound. Furthermore, the electrical and thermal resistivity measurements were performed. The resistivity results with respect to the magnetic properties are confirmed and a transition of a half-metallic state to a metallic state at 100 K is observed.

Key words: Spin electronic, half-metallic ferromagnets, half Heusler, spin fluctuations

INTRODUCTION

The electric transport in the magnetic materials is often strongly modified by the application of a magnetic field. The spin electronics i.e., the phenomena of electronic spin-dependent transport became in some years a very active research field in magnetism. Conduction electrons behaviour depends on the orientation of their spin in relation to the local magnetization of the material. The physical quantities characterizing the transport become dependent on the majority or minority character of the spin. The fundamental studies in the spin electronics domain are generally focused on two themes. One is concerned with the highly spin-polarized materials as the half-metallic ferromagnets. The half-metals discovered by de Groot *et al.* (1983) are the materials whose band-structure shows a metallic state for up-spin electrons whereas an energy gap occurs at the Fermi level for down-spin electrons. Hence, the conduction electrons are highly spin-polarized at the Fermi level. These systems are therefore exemplary materials for the study of the spin electronics (Pierre and Karla, 2000; Borca *et al.*, 2000; Komesu *et al.*, 2000). The other is about the manganites whose study with colossal magnetoresistance (CMR) permitted the electronic correlations comprehension and the role of the constraints, for epitaxial manganites films (Tokura and Tomioka, 1999; Ramos *et al.*, 2002; Garcia-Munoz *et al.*, 2002; Souza-Neto *et al.*, 2004; Singh *et al.*, 2006).

In this present study, the magnetic properties of a half-metallic compound example are to be investigated in relation with the first theme that we are described, half Heusler PtMnSb. Moreover, electrical and thermal resistivity measurements were performed. These measurements have allowed investigating the effects of spin fluctuations in this compound.

MATERIALS AND METHODS

Preparation and crystallographic properties: PtMnSb polycrystalline samples were prepared by melting of stoichiometric amounts of pure constituents in induction arc furnace under argon atmosphere. The resulting buttons were annealed at 650 to 800°C in argon-filled quartz tubes during 14 days under high vacuum and cooled down to room temperature in a furnace, in order to

---

Corresponding Author: M.A. Kouacou, Department of Electrical and Electronic Engineering,
Institut National Polytechnique Houphouët-Boigny (INP-HB),
BP 1083 Yamoussoukro, Côte d'Ivoire
Tel: 0022508453984 Fax: 0022530646660

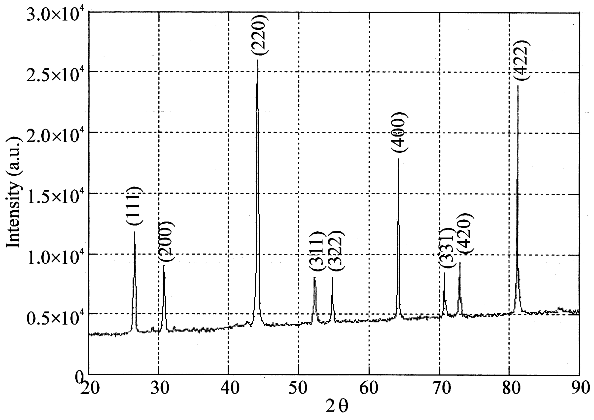

Fig. 1: X-ray diffraction diagram of PtMnSb at 300 K

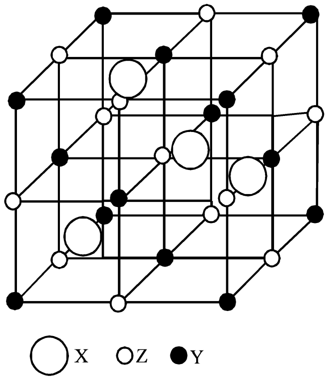

Fig. 2: Crystal structure of half-Heusler compounds

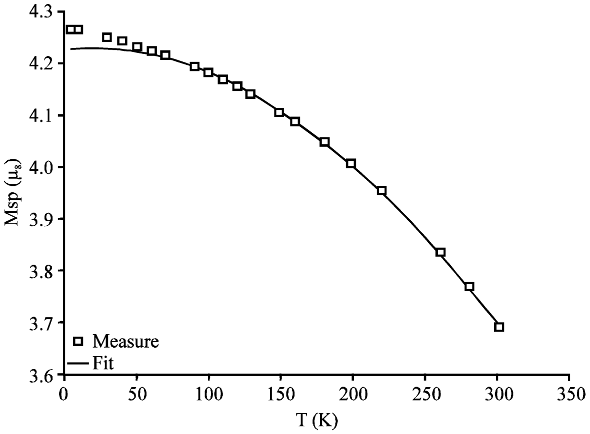

Fig. 3: Temperature variation of spontaneous magnetization for PtMnSb. The continuous line is a T^2 fit between 90 and 300 K

obtain a good crystallographic order. During arc-melting, the weight losses were less than 0.2% of the total mass. The final achieved sample that we used was a bar of 1.9 mm width and 1.5 mm height with 0.35605 g weight. After annealing, the crystal structure of the samples was examined by X-ray powder diffraction (XRD) using Cu K_α radiation. The X-ray diffraction data show that the ternary equiatomic stannides contained no second phases in investigated 2θ range (20-120°) within the detection limit of the conventional XRD techniques. Hence, this XRD (Fig. 1) shows the existence of one cubic phase with superlattice lines characteristic of half Heusler $C1_b$ MgAgAs-type structure. The lattice parameter a = 6.153 Å obtained is in conformity with the results found by another authors (Masumoto and Watanabe, 1970; Hames and Crangle, 1971; Otto *et al.*,1989a)

Experimental methods: Magnetic measurements were performed between 5 and 300 K with a supra-conductive bobbin in field below 10 T. For each temperature, a complete magnetization curve M(H) was recorded. Arrott-Below plots (M^2 versus H/M) were generally not linear and a quadratic fit was used to obtain the spontaneous magnetization.

The electrical and thermal resistivity (in null field), was measured from 5 to 300 K using the conventional four-probe method with AC current.

RESULTS AND DISCUSSION

Magnetic properties: The PtMnSb alloy is a half Heusler ferromagnetic phase (Otto *et al.*, 1989a) and half-metallic (de Groot *et al.*, 1984; de Groot and Buschow, 1986) of witch the Curie temperature is 572 K and the saturation moment, 4 μ_B per formula. The half Heusler phases with MgAgAs-type structure (Fig. 2) have a face-centered cubic cell, except that one of the X sites is empty, giving a formula XYZ and crystallize in the $C1_b$ structure (space group $F\bar{4}3m$). Due to the vacant site, the overlap between the transition metal wave-functions is smaller, which gives rise to the formation of narrow gap near the Fermi level and these compounds exhibit half-metallic or semiconducting behaviour (Tobola *et al.*,1998; Lue *et al.*, 2001; Yasuhiro *et al.*, 2003; Chaput *et al.*, 2006; Kroth *et al.*, 2006; Zhou *et al.*, 2007).

The temperature dependence of the spontaneous magnetization, reported on Fig. 3, presents an anomalous behaviour at low temperature. The spontaneous magnetization M_{sp} witch reaches 4.25 μ_B per formula at 2 K (Fig. 3) varies linearly as $T^{3/2}$ below 90 K, like in Heisenberg ferromagnets at low temperature, as one can observe it on Fig. 4. Above 100 K, the square of the spontaneous magnetization obeys to a T^2 law which is the classical behaviour for itinerant ferromagnets. Such anomalous behaviour has already been observed in the

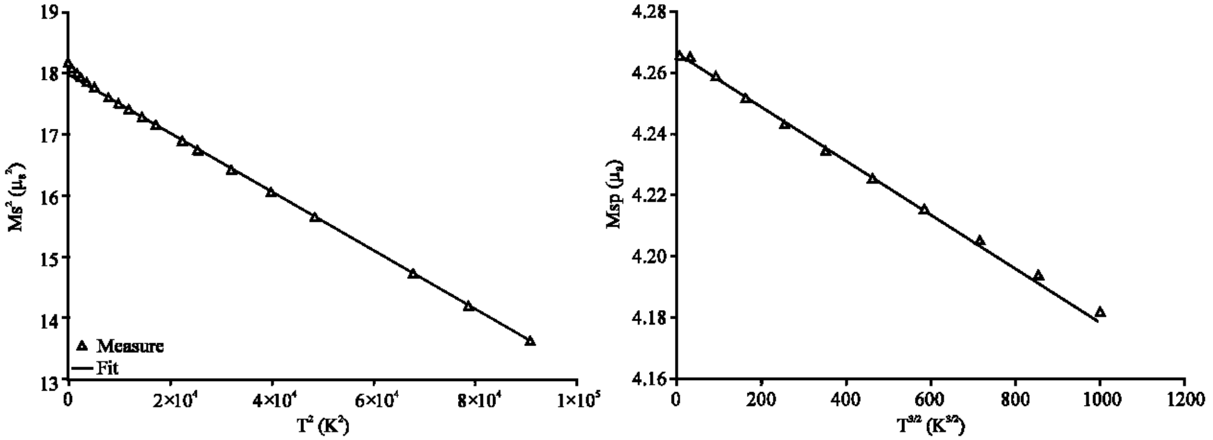

Fig. 4: Spontaneous magnetization dependant Temperature for PtMnSb (a) above 100 K and (b) below 90 K

NiMnSb case (Hordequin *et al.*, 1996, 2000; Pierre *et al.*, 1997; Ristoiu *et al.*, 2000) and has been interpreted as the passage from a localized magnetism due to the spin waves excited thermally to an itinerant ferromagnetism in which the spin fluctuations reduce the moments. This transition can be associated with the half-metallic character of PtMnSb at low temperature, knowing that the Stoner-type spin fluctuations cannot appear in the half-metals. Thus, the magnetic measurements are in conformity with the previous studies (Otto *et al.*, 1989a; Hordequin *et al.*, 1996, 2000; Pierre *et al.*, 1997; Ristoiu *et al.*, 2000). However, the magnetic moment, 4.25 μ_B per Mn atom, found is somewhat higher than the expected value, 4.0 μ_B per Mn atom determined from band structure calculations (Hames and Crangle, 1971; Otto *et al.*, 1989a; van Engen *et al.*, 1983; de Groot *et al.*, 1983). The discrepancy could be due to the asymmetry of the compound stoichiometric composition in which Mn could be in higher quantity than the other components of the PtMnSb alloy.

Electrical resistivity measurements: The PtMnSb resistivity thermal variation is represented in Fig. 5. The anomalous behaviour observed below 70 K confirms the magnetization measurements discussed in the above section. For temperatures lower than 70 K, the resistivity follows a T^2 function variation, $\rho(T) = A_{01} + B_1T^2$, with $A_{01} = 22.15$ μΩ.cm (residual resistivity) and $B_1 = 1.43\ 10^{-3}$ μΩ.cm/K^2 whereas, $\rho(T) = A_{02} + B_2T^{1.67}$, with $A_{02} = 24.45$ μΩ.cm and $B_2 = 2.37\ 10^{-3}$ μΩ.cm/K$^{1.67}$ at temperatures above 100 K. This discontinuity, already carried out in the case of NiMnSb (Hordequin *et al.*, 1996, 2000; Pierre *et al.*, 1997; Ristoiu *et al.*, 2000) was related to a transition from a half-metallic state due to the spin waves below 70 K to a metallic state above 100 K due to the spin fluctuations. The transition temperature seems to be 100 K. Generally, the electrical resistivity of a ferromagnetic material is characterized at T = 0 K by the residual resistivity due to the impurities, crystallographic disorder or crystal defects and above 0 K the magnetic contribution due to spin-disorder scattering (with the spin fluctuations and/or with the spin waves) and electron-photon scattering appears. For spin waves scattering, a conduction electron conserves its spin because the spin waves energy is not sufficient to upturn a single spin. Instead, for spin fluctuations scattering, the spin inversion is possible. At low temperature, the resistivity due to the magnetic spin-disorder contribution varies thermally as T^2 function (Mills and Lederer, 1966) while at more high temperature the spin waves give a linear thermal variation and the spin fluctuations give a $T^{5/3}$ function variation according to Ueda and Moriya (1975). In the present case, at low temperatures, the process of scattering with spin inversion being forbidden, only spin wave contributions

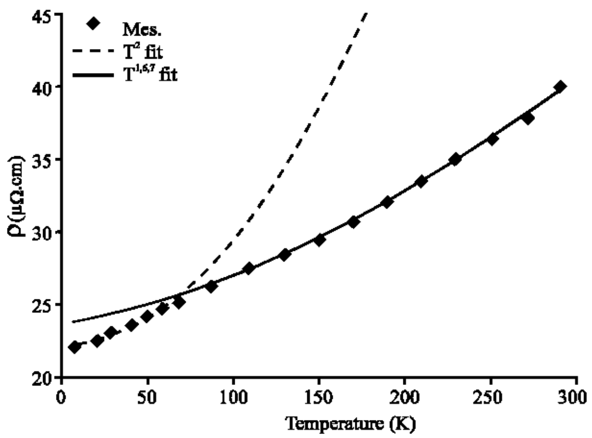

Fig. 5: Resistivity versus temperature for PtMnSb. The lines are T^2 fit below 70 K and $T^{1.67}$ fit above 100 K

to the resistivity can be noticed (the photons contribution being negligible) while above the transition temperature, in addition to the spin waves, one must take into account the spin fluctuations and photons contributions. However, the value 1.67 of the critical exponent β found at T > 100 K, slightly higher than 1.35 found by Hordequin *et al*. (2000), but in good agreement with the typical spin fluctuations exponent (β = 1.66), indicates that the spin fluctuations contribution is predominant. Furthermore, the residual resistivity 22.15 μΩ.cm obtained, higher than the value found by Otto *et al*. (1989b) 6.8 μΩ.cm could indicate a likely atomic disorder in our sample.

CONCLUSION

The magnetization and electrical resistivity measurements performed on PtMnSb show the same features as the half-metal NiMnSb and prove spin fluctuations existence. These spin fluctuations cause the transition from a localized magnetism in which collective spin-wave excitations are predominant to a high temperature itinerant-like ferromagnetism in which spin fluctuations have the main contributions. On the other hand, this compound exhibits a transition from a half-metallic state to a metallic state between 70 and 100 K. However, complementary measurements of magnetoresistance, anisotropic magnetoresistance (AMR), Hall resistivity and thermoelectrical power are required to better characterize this compound transport properties.

ACKNOWLEDGMENTS

We wish to thank L. Ranno to have permitted the measurements in laboratory of magnetism Louis Néel, CNRS Grenoble, France. Thanks are also given to the director, the staff of this laboratory and Kouacou thesis supervisor J. Pierre for their help.

REFERENCES

Borca, C.N., T. Komesu, Hae-Kyung-Jeong, P.A. Dowben, D. Ristoiu, C. Hordequin, J. Pierre and J.P. Nozières, 2000. Effective surface Debye temperature for NiMnSb(100) epitaxial films. Applied Phys. Lett., 77(1): 88-90.

Chaput, L., J. Tobola, P. Pécheur and H. Scherrer, 2006. Electronic structure and thermopower of Ni($Ti_{0.5}Hf_{0.5}$)Sn and related half-Heusler phases. Phys. Rev. B., 73: 045121-045127.

de Groot, R.A., F.M. Müller, P.G. Van Engen and K.H.J. Buschow, 1983. New Class of Materials: Half-metallic ferromagnets. Phys. Rev. Lett., 50: 2024-2027.

de Groot, R.A., F.M. Müller, P.G. van Engen and K.H.J. Buschow, 1984. Half-metallic ferromagnets and their magneto-optical properties. J. Applied Phys., 55: 2151-2154.

de Groot, R.A. and K.H.J. Buschow, 1986. Recent developments in half-metallic magnetism. J. Magn. Magn. Mater., 54-57: 1377-1380.

Garcia-Munoz, J.L., C. Frontera, M.A.G. Aranda, C. Ritter, A. Llobert, L. Ranno, M. Respaud, J. Vanacken, J.M. Broto, 2002. Electronic and magnetic transitions in Bi-Sr-Mn-O oxides: High temperature charge-ordering. J. Mag. Mater., 242-245: 645-647.

Hames, F.A. and J. Crangle, 1971. Ferromagnetism in Heusler-type Alloys based on Platinum-group or Palladium-group Metals. J. Applied Phys., 42: 1336-1338.

Hordequin, C., J. Pierre and R. Currat, 1996. Magnetic excitations in the half-metallic NiMnSb ferromagnet: From Heisenberg-type to itinerant behaviour. J. Magn. Mater., 162: 75-84.

Hordequin, C., D. Ristoiu, L. Ranno and J. Pierre, 2000. On the cross over from half-metal to normal ferromagnet in NiMnSb. Eur. Phys. J., B 16: 287-293.

Komesu, T., C.N. Borca, H.K. Jeong, P.A. Dowben, D. Ristoiu, J.P. Nozières, S. Stadler and Y.U. Idzerda, 2000. The polarization of Sb overlayers on NiMnSb (100). Phys. Lett., A 273: 245-251.

Kroth, K., B. Balke, G.H. Fecher, V. Ksenofontov and C. Felser Hong-Ji, 2006. Diluted magnetic semiconductors with high Curie temperature based on $C1_b$ compounds: $CoTi_{1-x}Fe_xSb$. Applied Phys. Lett., 89: 202509-202511.

Lue, C.S., Y. Oner, D.G. Naugle and J.H. Jr. Ross, 2001. Magnetism of new semi-Heusler compounds FeVSn and CoVSn. IEEE Trans. Magn., 37 (4): 2138-2140.

Masumoto, H.K. and K. Watanabe, 1970. On Magnetic properties of a new intermetallic $C1_b$-type compound PtMnSb in the Pt-Mn-Sb system. Trans. JIM., 11: 385-390.

Mills, D.L. and P. Lederer, 1966. The contribution of s-d exchange scattering to the electrical resistivity of magnetic metals. J. Phys. Solids, 27: 1805-1813.

Otto, M.J., R.A.M. van Woerden, P.J. van der Valk, J. Wijngaard, C.F. van Bruggen, C. Haas and K.H.J. Buschow, 1989a. Half-metallic ferromagnets. I. Structure and magnetic properties of NiMnSb and related inter-metallic compounds. J. Phys.: Condens. Matter., 1: 2341-2350.

Otto, M.J., R.A.M. van Woerden, P.J. van der Valk, J. Wijngaard, C.F. van Bruggen and C. Haas, 1989b. Half-metallic ferromagnets. II. Transport properties of NiMnSb and related inter-metallic compounds. J. Phys. Condens. Matter, 1: 2351-2360.

Pierre, J., R.V. Skolozdra, J. Tobola, S. Kaprzyk, C. Hordequin, M.A. Kouacou, I. Karla, R. Currat and E. Lelièvre-Berna, 1997. Properties on request in semi-Heusler phase. J. Alloys Comp., 262: 101-107.

Pierre, J. and I. Karla, 2000. Giant magnetoresistance in RENiSb semiconductor (RE=Tb,Dy,Ho). J. Mag. Mag. Mater., 217: 74-82.

Ramos, A.Y., C. Giacomelli, E. Fabre-Nicolin and L. Ranno, 2002. Strain effects in epitaxially grown $La_{0.7}Sr_{0.3}MnO_3$ thin films. Physica, B 320: 83-85.

Ristoiu, D., J.P. Nozières and L. Ranno, 2000. Epitaxial NiMnSb thin films prepared by facing targets sputtering. J. Magn. Mater., 219: 97-103.

Singh, M.P., B. Carvello and L. Ranno, 2006. Giant Magnetoresistance in an all-oxide spacerless junction. Applied Phys. Lett., 89: 022504-022506.

Souza-Neto, N.M., A.Y. Ramos, H.C. Tolentino, E. Favre-Nicolin and L. Ranno, 2004. Local tetragonal distortion $La_{0.7}$ $Sr_{0.3}$ MnO_3 strained thin films probed by x-ray absorption spectroscopy. Phys. Rev., B 70: 174451-174459.

Tobola, J., J. Pierre, S. Kaprzyk, R.V. Skolozdra and M.A. Kouacou, 1998. Crossover from semiconductor to magnetic metal in semi-Heusler phases as a function of valence electron concentration. J. Phys. Condens. Matter, 10: 1013-1032.

Tokura, T. and Y. Tomioka, 1999. Colossal magnetoresistive manganites. J. Magn. Mater., 200: 1-23.

Ueda, K. and T. Moriya, 1975. Contribution of spin fluctuations to the electrical and thermal resistivities of weakly and nearly ferromagnetic metals. J. Phys. Soc. Jap., 39: 605-615.

van Engen, P.G., K.H.J. Buschow, R. Jongebreur and M. Erman, 1983. PtMnSb, a material with very high magneto-optical kerr effect. Applied Phys. Lett., 42: 202-204.

Yasuhiro, O., I. Shingo, A. Hideaki, S. Yotsuhashi, M. Yuzuru and K. Tsuyoshi, 2003. Effects of Sb-doping on electrical transport properties of co-based half-Heusler compound. Thermoelectric Materials 2003-Research and Applications, MRS Proceedings, 793: S8.5.

Zhou, M., L. Chen, C. Feng and D. Wang, 2007. Moderate-temperature thermoelectric properties of TiCoSb-based half-Heusler compounds $Ti_{1-x}Ta_xCoSb$. J. Applied Phys., 101: 113714-113719.