New magnetic properties of MnSb alloy produced after subjecting it to a high pressure and temperature

N. P. Grazhdankina, I. V. Medvedeva, and A. V. Pasheev
Institute of Metal Physics, Ural Scientific Center of the Academy of Sciences of the USSR

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MnSb ferromagnetic alloy was subjected to a high, quasi-hydrostatic pressure of 77 kbar and temperature in the range of 800 K to 1400 K, which greatly reduced the magnetization and Curie temperature and led to an anisotropic variation of the volume of the alloy's unit cell.

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The MnSb ferromagnet belongs to the class of compounds with a hexagonal, NiAs-type structure ($P6_3/mmc$ space group). Such compounds typically have vacancies in the metal and metalloid sublattices and, as a result, are highly homogeneous $Mn_{1+\delta}Sb (0 \leqslant \delta \leqslant 0.22)$, which greatly reduces the Curie temperature T_c and magnetiza-

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tion σ with increasing δ.[1] At present, there is no single mechanism for exchange coupling in MnSb, since the reason for variation of T_c and σ as a result of filling the structural vacancies with interstitial manganese atoms in $Mn_{1+\delta}$ Sb is not known. Experiments on diffuse scattering of polarized neutrons in these alloys[2] indicate that the Mn interstitial atoms, which do not have a magnetic moment, change the electron energy spectrum. This change, however, has not been accounted for. We note that a possible strong influence of volume on T_c and σ of the alloys in question has not been taken into account by Yamaguchi and Watanabe.[2]

We have attempted in this investigation to fill the structural vacancies in MnSb at high pressure and temperature in a constant chemical composition of the alloy. An MnSb alloy prepared in advance with $T_c = 596$ K, $n_f = 3.3\,\mu_B$, and lattice parameters $a = 4.149$ Å and $c = 5.772$ Å was subjected to the action of 77-kbar quasi-hydrostatic pressure at temperatures of 800, 1000, 1200, and 1400 K, after which the magnetic, electric, and x-ray diffraction studies were carried out.

Figure 1 shows the temperature dependences of magnetization of the MnSb alloy in the original state (curve 1) and after subjecting it to 77-kbar pressure at different temperatures (curves 2, 3, and 4). We can see from the given curves that the magnetic moment and the Curie temperature decrease appreciably in all the cases. At $P = 77$ kbar and $T = 1400$ K the ferromagnetism vanishes over a broad temperature range (curve 4). An increase of magnetization in the high-temperature region and merging of all the curves as one approaches T_c of the original MnSb is apparently attributable to the fact that the alloy returns to a thermodynamic equilibrium that is close to the original state (curve 5). We should mention that the magnetization curves of all the alloys measured at 77 K have a characteristic shape $\sigma(H)$ for ferromagnets with a magnetization saturation.

X-ray diffraction studies showed that the indicated variation of magnetic proper-

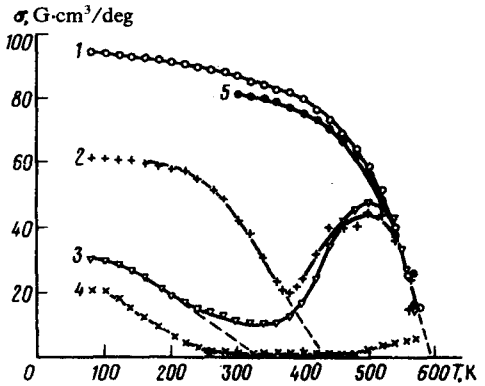

FIG. 1. Temperature dependences of the magnetization of MnSb alloy measured in a field $H = 8$ kOe (1) in the original state and after the application of pressure: (2) $P = 77$ kbar, $T = 800$ K; (3) $P = 77$ kbar, $T = 1000$ K; (4) $P = 77$ kbar, $T = 1400$ K; (5) the curve was plotted after the alloy, which was processed at $P = 77$ kbar and $T = 800$ K, was heated to 600 K.

ties is accompanied by a strong deformation of the crystal lattice without changing its symmetry. By subjecting the alloy to 77-kbar pressure and $T = 800$ K, we can greatly reduce the parameter c ($c = 5.64$ Å) and slightly increase the parameter a($a = 4.16$ Å); as a result, the volume of a unit cell decreases considerably and the Curie temperature shifts ΔT_c / $\Delta V = 107.3$ deg/Å^3 with changing volume, which is a factor of 6 greater than its rate of change due to hydrostatic stress.[3] As a result of the application of pressure $P = 77$ kbar and $T = 1000$ K, the volume of a unit cell increases primarily due to an increase of the parameter a($a = 4.25$ Å, $c = 5.62$ Å), as a result of which $\Delta T_c/\Delta V$ is negative. The pressure $P = 77$ kbar and $T = 1400$ K change the lattice parameters slightly as compared with the previous case ($a = 4.25$ Å, $c = 5.66$ Å); however, a variation in the intensities of x-ray diffraction lines indicates that the vacancies can be filled. Analogous peculiarities are observed in the case of volume variation σ. As was established earlier by us,[4] the value of $\Delta\sigma/\Delta V$ for the MnSb alloy is positive as a result of hydrostatic stress; this value is also positive but much higher after the application of pressure $P = 77$ kbar and $T = 800$ K and it has a negative sign at $P = 77$ kbar and $T = 1000$ K and 1400 K.

Additional measurements of $\sigma(T)$ under uniform hydrostatic stress up to 10 kbar, which were performed using MnSb alloy treated at a pressure $P = 77$ kbar and $T = 1200$ K, showed that the baric coefficients of the Curie temperature and of magnetization retain their negative signs and are of the same order of magnitude as the original MnSb.[4]

The obtained experimental results can be qualitatively understood if we assume that the exchange interactions with different signs coexist in MnSb: an antiferromagnetic interaction along the hexagonal axis and a ferromagnetic interaction in the basal plane. We can decrease T_c by decreasing the parameter c or increasing the parameter a due to a weakening of ferromagnetism and strengthening of antiferromagnetism.

We can also assume that a part of the $3d$ electrons aggregates and forms a narrow, discrete $3d$ band. The negative signs of the values $(1/T_c)(dT_c/dp)$ and $(1/\sigma)$ $(d\sigma/dp)$

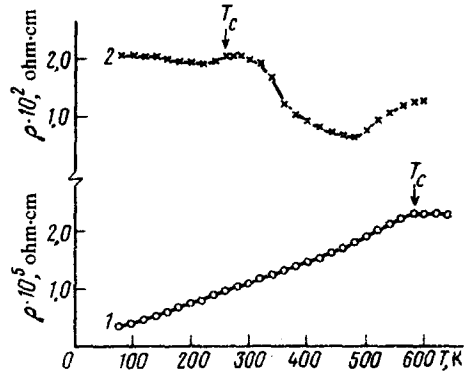

FIG. 2. Temperature dependences of the electrical resistivity of MnSb alloy (1) in the original state and (2) after subjecting it to a pressure $P = 77$ kbar and $T = 1200$ K.

of the alloy, which was processed under pressure $P = 77$ kbar and $T = 1200$ K, can be interpreted within the context of the band theory of ferromagnetism,[4] when the $3d$ band expands under pressure and the density of electronic states at the Fermi level decreases, which decreases T_c and σ.

A filling of vacancies at 77 kbar and high temperatures (1000–1400 K) is accompanied by an anisotropic variation of the unit cell's volume, which may distort the electron energy spectrum. This is indicated by the variation of the conductivity of the MnSb alloy after subjecting it to a pressure $P = 77$ kbar and $T = 1200$ K. As seen in Fig. 2, the metallic conductivity of the original alloy (curve 1) changes to a semiconducting conductivity (curve 2).

Thus, as a result of combined action of high pressure and temperature, we have obtained new states of the MnSb alloy without distorting the symmetry of the crystal lattice, which enabled us to determine the contributions of different exchange interactions and their variation at the interatomic spacing.

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