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# Observation of large magnetoresistance of magnetic Heusler alloy $Ni_{50}Mn_{36}Sn_{14}$ in high magnetic fields

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The magnetic and electrical properties on magnetic Heusler alloy $Ni_{50}Mn_{36}Sn_{14}$ were studied in magnetic fields up to 18 T in 4.2–270 K temperature range. It was found that at the vicinity of 160 K the resistivity jump of 46% is accompanied by the magnetic phase transition. Furthermore, the large magnetoresistance effect of 50% by the magnetic field induced magnetic phase transition was observed. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2374868]

Recently, it has been found that ferromagnetic Heusler alloys $Ni_{50}Mn_{50-y}X_y$ ($X$=In, Sn, and Sb) with the cubic $L2_1$-type ($L2_1$) structure show martensitic transformation below the Curie temperature $T_C$.[1] The result of neutron diffraction measurements for $Ni_{50}Mn_{36}Sn_{14}$ shows that the martensite phase has an orthorhombic four-layered (4$O$) structure with space group of *Pmma*.[2] In addition, the magnetization ($\sigma_O$) in the 4$O$ phase is smaller than that ($\sigma_L$) in the $L2_1$ phase.[3–7] These results indicate that the $Ni_{50}Mn_{50-y}X_y$ alloy will exhibit field-induced magnetic and structural transitions such as those of the $Ni_2MnGa$ system,[8–10] which is called "ferromagnetic shape-memory alloys." Especially, results on these Heusler alloys Ni–Mn–$X$ attracted interest from the point of view of high performance magnetic materials controlled by magnetic fields.[5–7]

In the previous paper, we reported the magnetic field-induced reverse martensitic transformation from the 4$O$ to the $L2_1$ structure, accompanied by the magnetic transition from the $\sigma_O$ to the $\sigma_L$ phase in $Ni_{50}Mn_{36}Sn_{14}$.[11] Furthermore, the result shows that high magnetic fields over 5 T are required to completely lead the field-induced reverse transformation in this compound. In this study, the magnetization and electrical resistivity measurements for Heusler alloy $Ni_{50}Mn_{36}Sn_{14}$ were carried out in magnetic fields up to 18 T, in order to investigate the magnetoresistance effect.

Polycrystalline $Ni_{50}Mn_{36}Sn_{14}$ compound has been prepared by induction melting under an argon atmosphere. The ingot was cut into a small pillar with a size of $1.08\times1.76\times2.50\ mm^3$. The pillar sample was confirmed to be a single phase with the $L2_1$ structure by x-ray powder diffraction measurements at room temperature. The magnetization $\sigma$ was measured by an extraction-type magnetometer in magnetic fields $B$ up to 18 T using a superconducting magnet. The electrical resistivity $\rho$ was measured by a standard four-probe technique in magnetic fields up to 17 T.

Figure 1 shows the temperature dependence of the magnetization ($\sigma$-$T$) at 1 mT (a) and 17 T (b). The magnetic phase transition is seen at the vicinity of 160 K for 1 mT and 120 K for 17 T with a large hysteresis over 50 K. From the data for 1 mT, the Curie temperature $T_C$ is determined to be 325 K, and the martensitic transformation starting temperature $M_s$, the martensitic transformation finishing temperature $M_f$, the reverse transformation starting temperature $A_s$, and the reverse transformation finishing temperature $A_f$ are determined to be 171, 125, 150, and 195 K, respectively. The $\sigma$-$T$ behavior and $T_C$ are consistent with previous results,[1,2,11] although other characteristic temperatures are low by about 50 K. In this study, we selected the present sample having

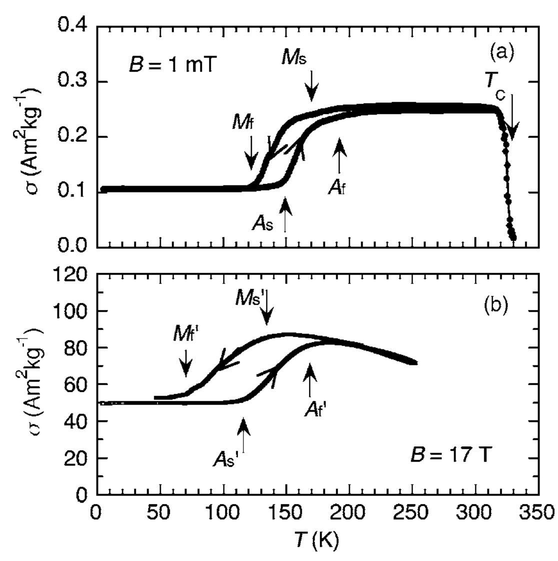


FIG. 1. Temperature dependence of the magnetization of $Ni_{50}Mn_{36}Sn_{14}$ at 1 mT (a) and 17 T (b). The vertical arrows indicate the Curie temperature $T_C$ and the characteristic temperatures of the martensitic transformation at 1 mT and 17 T. The measurements were carried out for the heating and cooling processes and the arrows indicate the thermal hysteresis.

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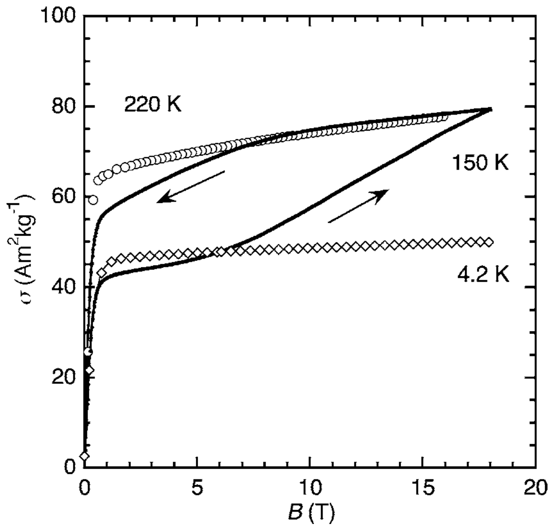


FIG. 2. High field magnetization curves of $Ni_{50}Mn_{36}Sn_{14}$ at 4.2 K (open diamonds), 150 K (solid lines), and 220 K (open circles). The magnetization curves at 150 K were measured after zero-field heating from 4.2 K. The arrows indicate the magnetization process with increasing and decreasing magnetic fields $B$.

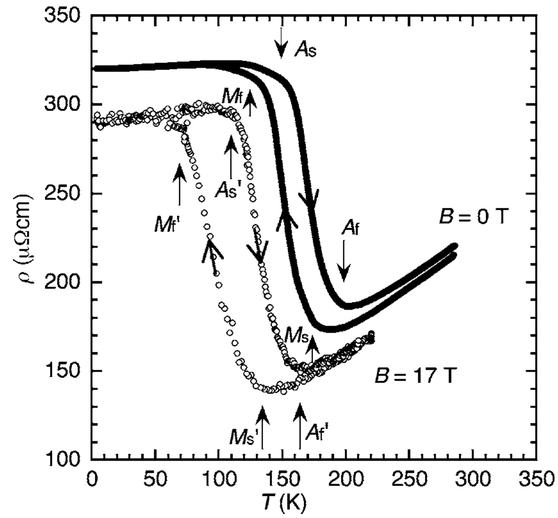


FIG. 3. Temperature dependence of the electrical resistivity of $Ni_{50}Mn_{36}Sn_{14}$ at 0 T (solid lines) and 17 T (open circles). The vertical arrows indicate the characteristic temperatures of the martensitic transformation at 0 and 17 T. The measurements were carried out for the heating and cooling processes and the arrows indicate the thermal hysteresis.

low $M_s$, $M_f$, $A_s$, and $A_f$, which is slightly different from the sample treatment reported in the previous study,[11] because it was difficult to measure the properties in high magnetic fields over 250 K. By applying 17 T, the characteristic temperatures decrease ($M'_s=135$ K, $M'_f=75$ K, $A'_s=110$ K, and $A'_f=166$ K) and the thermal hysteresis extends. The results obtained show that $\sigma_O$ in the 4$O$ phase is smaller than $\sigma_L$ in the $L2_1$ phase in fields up to 17 T.

Figure 2 shows the magnetization ($\sigma$-$B$) curves at 4.2, 150, and 220 K in magnetic fields up to 18 T. The $\sigma$-$B$ curve at 220 K ($L2_1$ phase) shows a ferromagnetic behavior and $\sigma$ is 77.8 A m$^2$ kg$^{-1}$ at 16 T. On the other hand, $\sigma$ at 4.2 K (4$O$ phase) is 49.9 A m$^2$ kg$^{-1}$ at 18 T, which is 40% smaller than that at 220 K. At $A_s<T<A_f$, a magnetic phase transition with large magnetic hysteresis is observed on the $\sigma$-$B$ curves. The $\sigma$-$B$ curve at 150 K is shown in this figure as a typical result, which was measured after zero-field heating from 4.2 K. This $\sigma$-$B$ curve of 150 K indicates that the magnetic phase is lower $\sigma_O$ phase in $B<5$ T, and it transforms into higher $\sigma_L$ phase in $5\leqslant B\leqslant 18$ T. At 18 T, $\sigma$ reaches up to 79.2 A m$^2$ kg$^{-1}$, which is almost the same value at 220 K. That is, magnetic field induces the reverse martensitic transformation from the 4$O$ to the $L2_1$ structures accompanied by the magnetic phase transition from lower $\sigma_O$ to higher $\sigma_L$.

Figure 3 shows the temperature dependence of the electrical resistivity ($\rho$-$T$) at $B=0$ and 17 T. In these measurements, we observed the thermal hysteresis at the vicinity of 160 K for 1 mT and 120 K for 17 T, which is consistent with the magnetic phase transition, as shown in Fig. 1. The thermal variation of the $\rho$-$T$ curve is very small below 100 K ($[\rho(100\text{ K})-\rho(4.2\text{ K})]/\rho(4.2\text{ K})=1\%$), but it abruptly changes by 46% ($=[\rho(100\text{ K})-\rho(160\text{ K})]/\rho(100\text{ K})$) at the vicinity of 160 K, and then it increases with increasing $T$.

Figure 4 shows the magnetoresistance ($\rho$-$T$) in magnetic fields up to 17 T at 4.2, 150, and 220 K. In $B=0$ T, $\rho$ at 4.2 (4$O$ phase) and 220 K ($L2_1$ phase) are 320 and 180 $\mu\Omega$ cm, respectively, and they decrease linearly with increasing $B$. On the other hand, we observed the large negative magnetoresistance effect in $Ni_{50}Mn_{36}Sn_{14}$ at the vicinity of 160 K. The data at 150 K are shown in this figure as a typical result. On the initial (first) $\rho$-$B$ process, $\rho$ is 307 $\mu\Omega$ cm at $B=0$ T and decreases gradually in fields up to 5 T. Then, $\rho$ decreases rapidly with increasing $B$, and it reaches down to 154 $\mu\Omega$ cm at 17 T. The change of the negative magnetoresistance is about 50% in magnetic fields up to 17 T.

The $\rho$-$B$ curve for first decreasing $B$ process is not traced on the initial one, but it increases linearly with decreasing $B$ to 8.3 T. Subsequently, $\rho$ increases rapidly below 8.5 T, and it reaches up to 259 $\mu\Omega$ cm. This first $\rho$-$B$ loop is consistent with the $\sigma$-$B$ hysteresis loop, as shown in Fig. 2. That is, the large magnetoresistance is due to the reverse martensitic transformation induced by the field-induced magnetic phase transition. Just after this measurement, we remeasured the $\rho$-$B$ curves (second) in $B<12$ T at the same temperature,

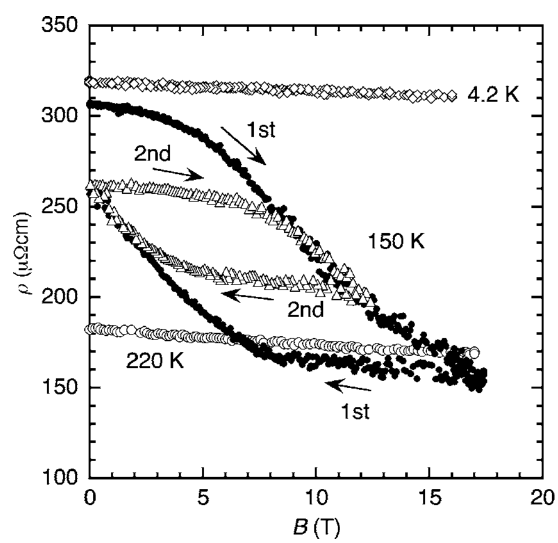


FIG. 4. Magnetoresistance of $Ni_{50}Mn_{36}Sn_{14}$ at 4.2 K (open diamonds), 150 K (solid circles and open triangles), and 220 K (open circles). The solid circle and open triangle show the data for the initial (first) and second (second) scans, respectively. The data at 150 K were measured after zero-field heating from 4.2 K. The arrows indicate the magnetization process with increasing and decreasing magnetic fields $B$.

which shows the reversible $\rho$-$B$ process for applying $B$ (open triangle in Fig. 4). In addition, $\rho$ of the second measurement is traced on that of the first measurement in $B>8.3$ T for the field increasing process and $B<2.3$ T for the field decreasing process.

In this study, we found that the electrical property as well as the magnetic one of $Ni_{50}Mn_{36}Sn_{14}$ is very unique. Especially, $\rho$ changes drastically at the vicinity of 150 K and is almost constant below 100 K. The properties of $Ni_{50}Mn_{36}Sn_{14}$ are probably due to the drastic change of the magnetic and electronic structures, accompanied with the martensitic transformation. By the neutron diffraction study for $Ni_{50}Mn_{36}Sn_{14}$, Brown *et al.* suggested that the suppression of $\sigma$ is due to some antiparallel alignment of moment in the 4$O$ phase.[2] Our result of thermoelectric power measurement indicates that the density of state at the vicinity of the Fermi level modifies drastically, accompanied by the martensitic transformation in $Ni_{50}Mn_{36}Sn_{14}$.[12] Therefore, in order to understand the basic properties of $Ni_{50}Mn_{36}Sn_{14}$, it is required to clarify the magnetic and electronic structures.

In summary, the magnetic and electrical resistivity measurements for $Ni_{50}Mn_{36}Sn_{14}$ were carried out in magnetic fields up to 18 T. We found that the alloy exhibits a large-negative magnetoresistance effect of 50%, accompanied by the magnetic field-induced reverse transformation at the vicinity of the martensitic transformation temperature.

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