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Electrical Resistivity of Nickel-Rich Nickel-Indium Alloys between 10 and 800 K

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Introduction The morphology of the grain boundary precipitation in the nickel-rich nickel-indium alloy system has been extensively studied /1 to 4/. However, relatively little research work has been devoted to the electrical and magnetic properties /5 to 8/. It is well known that the electrical resistivity measurements on a magnetic binary alloy system provide useful information about their characteristic electronic, structural, compositional, and magnetic situations. The electrical resistivity depends not only on the electronic structure, but also on the mechanisms of the relaxation of the conduction electrons which are due to the scattering by structural defects of the lattice, phonons, magnons, and electron-electron interactions. According to theoretical studies /9, 10/, the derivative of the electrical resistivity with respect to temperature should vary like the magnetic specific heat near the Curie temperature T_C. This means that a monotonous temperature dependence of the electrical resistivity ρ near the Curie temperature will show a singularity in $d\rho/dT$ at T_C. Basing on these considerations, we are motivated to study the electrical and magnetic properties of this nickel-rich nickel-indium alloy system.

In this study, we report investigations of the electrical resistivity of nickel-rich nickel-indium alloys as a function of temperature and discuss the significance of the results.

Experimental procedure The nickel-indium alloy samples containing 0.0, 1.5, 3.0, 5.0, and 7.5 at% of In, were prepared by melting. The melting ingots with appropriate amounts of Ni and In were homogenized at 1325 K for three days to remove any microscopic segregation. From these ingots, samples in the form of rectangular parallelepipeds were cut by a low speed diamond saw. Typical sample dimensions were roughly 1x2x10 mm^3. Four Mo electrodes were lightly spot-welded to each sample. The width, thickness, and distance between the potential leads were determined by means of a very accurate Vernier caliper.

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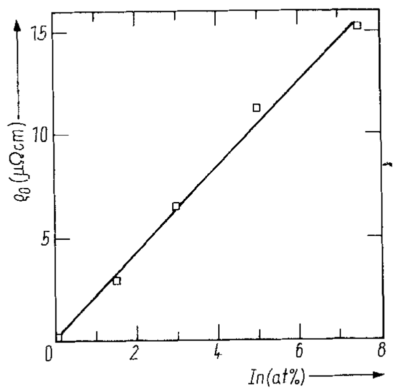

Fig. 1. Electrical resistivity of the $Ni_{1-x}In_x$ system at 10 K as a function of indium concentration (at%)

The electrical resistivity of all samples was determined by using the conventional four-probe technique. Temperatures between 10 and 300 K were achieved in a Displex closed-cycle refrigeration system (Model CS-202, Air Products). Temperatures between 300 and 800 K were produced by a Marshall furnace. The furnace could be either evacuated or filled with helium gas. The stability of temperatures was held constant to ±0.1 K by automatic temperature controllers.

Results and discussion Fig. 1 shows the values of ρ_0 of our Ni-In alloys as a function of In content at 10 K. The increase in the electrical resistivity is about 2.0 μΩcm per at% of In. This plot confirms the expected good quality of the alloys prepared by the methods described above. Fig. 2 shows the electrical resistivity of

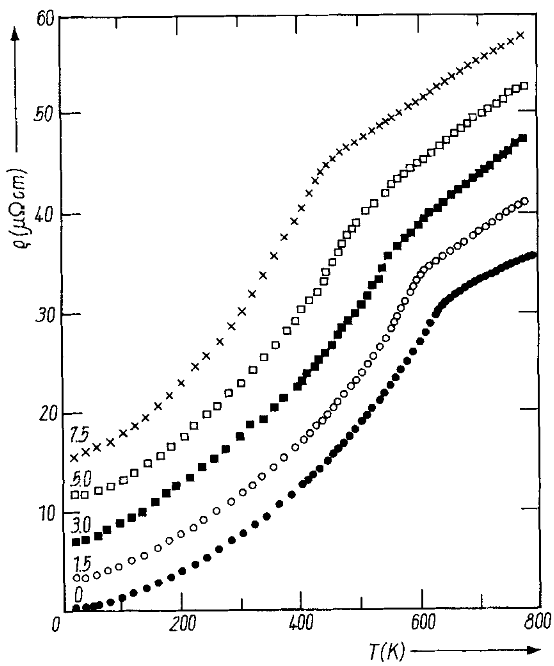

Fig. 2. Electrical resistivity of the $Ni_{1-x}In_x$ system as a function of temperature between 10 and 800 K. The curves are labelled with In concentration (at%)

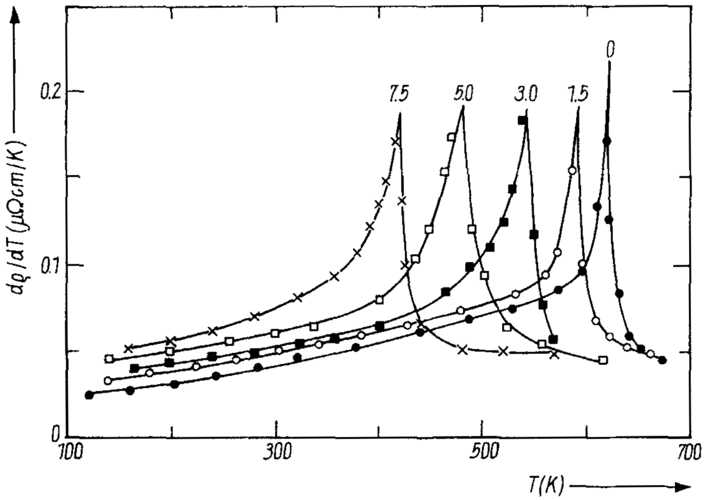

Fig. 3. dρ/dT of the $Ni_{1-x}In_x$ system as a function of temperature between 100 and 700 K. The curves are labelled with In concentration (at%)

our Ni-In alloys containing 0.0, 1.5, 3.0, 5.0, and 7.5 at% of In between 10 and 800 K. It is obvious that the ρ versus T curves undergo an abrupt slope change which results from the ferromagnetic-paramagnetic phase transitions. Fig. 3 presents dρ/dT versus T curves of these Ni-In alloys in the temperature range between 100 and 700 K. The Curie temperature T_C is determined from this plot as the temperature at which dρ/dT diverges. These dρ/dT versus T plots for the above alloys are very similar to the λ-type anomaly as shown in the type I ferromagnet /11/. The values of T_C determined from such plots are shown in Fig. 4. The Curie temperature decreases monotonously with a slope of roughly 26.7 K per at% of In.

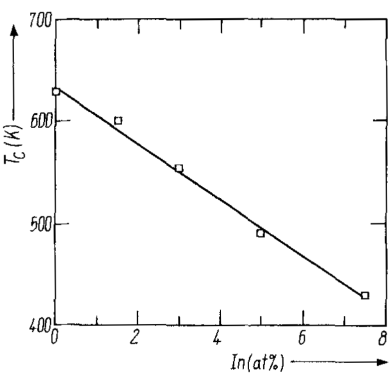

Fig. 4. Curie temperature of the $Ni_{1-x}In_x$ system as a function of indium concentration (at%)

According to the itinerant electron model, the Curie temperature T_C is defined as a temperature where the enhanced susceptibility χ diverges. Above T_C, χ is given by

$$\chi = 2N\mu_B F/(1 - U_{eff}F) ,$$

Table 1

The experimental values of $\Delta\rho_o$ and ΔT_C of the nickel-rich $Ni_{1-x}R_x$ systems with R = Cu, In, and Ti

R	$\Delta\rho_o$ (μΩcm)	ΔT_C (K/at% R)
Cu	0.9	11
In	2	26.7
Ti	3.8	35

where N is the total number of atoms, μ_B is the Bohr magneton, U_{eff} is the effective correlation energy, and F is the state density at the Fermi level of the material in which U_{eff} is not taken into account. Since T_C determined from the condition that $U_{eff}(T_C)F(T_C) = 1$ is proportional to $\sqrt{1 - 1/U_{eff}F}$ /12/, the dependence of T_C on In concentration may reflect the variation of U_{eff} and F, especially in the form of the product $U_{eff}F$, with In concentration. However, at the present time, there is no satisfactory quantitative theory for the dependence of T_C on In concentration in the Ni-In system.

The electrical resistivity of the nickel-rich $Ni_{1-x}R_x$ system with R = Cu and Ti has been reported before /13, 14/. Table 1 shows the experimental values of T_C (the slope of the decrease of Curie temperature with respect to R) and $\Delta\rho_o$ (the slope of the increase of residual electrical resistivity with respect to R) for $Ni_{1-x}R_x$ systems with R = Cu, In, and Ti. From Table 1, we recognize that ΔT_C is a monotonously increasing function of $\Delta\rho_o$ in the nickel-rich $Ni_{1-x}R_x$ systems. However, the detailed relationship between ΔT_C and $\Delta\rho_o$ is complicated. We have not figured out the exact expression yet. Further studies are needed.

In conclusion, we have reported an experimental study on the electrical resistivity of the nickel-rich nickel-indium alloy system as a function of temperature between 10 and 800 K. The Curie temperature is found to decrease from roughly 630 K for pure nickel to roughly 430 K for the Ni-7.5 at% In sample. The residual electrical resistivity is increased roughly by 2.0 μΩcm per at% of indium.

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