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Physica B 358 (2005) 323–331
PHYSICA B
www.elsevier.com/locate/physb

The effect of substitution of Lu for Ho on some physical properties of $Lu_xHo_{1-x}Ni_2$ solid solutions

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Received 25 August 2004; received in revised form 24 January 2005; accepted 24 January 2005

Abstract

Experimental data on the structure, magnetization, electrical resistivity and heat capacity of polycrystalline $Lu_xHo_{1-x}Ni_2$ alloys with $x = 0.0$, 0.2, 0.4, 0.6, 0.8 and 1.0 are represented.

X-ray diffraction analysis performed at room temperature was used to study the structure of the $Lu_xHo_{1-x}Ni_2$ solid solutions and parent binary compounds. It was found the formation of the C15-type Laves-phase superstructure (space group $F\bar{4}3m$). Magnetic measurements showed that the samples with $x \leqslant 0.8$ are ferromagnets with relatively low (below 20 K) Curie temperatures T_C. At high temperatures, all studied solid solutions are Curie–Weiss paramagnets. Temperature dependences of the electrical resistivity are typical of alloys exhibiting the metallic conductivity. The Debye temperature, phonon and conduction-electron contributions as well as magnetic part of the heat capacity have been determined from heat capacity measurements. The magnetocaloric effect was estimated from measurements performed in a low magnetic field of 0.42 T.

PACS: 61.66.Dk; 75.60.Ej; 84.37.+q; 75.40.–s

Keywords: Intermetallic crystal structure; Magnetization; Heat Capacity; Rare earth

1. Introduction

Earliest crystallographic studies showed that the rare-earth intermetallic compounds RNi_2 (R = rare-earth metal) crystallize with the formation of the cubic $MgCu_2$-type structure (Laves-phase), space

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doi:10.1016/j.physb.2005.01.468

group Fd3m. However, since 1988, some authors reported that the observed structure differs from the ideal structure. For $LaNi_{2.18}$ and $CeNi_{2.16}$, Paul-Boncour et al. [1] reported about the presence of superlattice reflections, which were indexed to belong to the C15-type unit cell with the double lattice parameter. Furthermore, the existence of structure deviations has been discussed also for $TmNi_2$ [2] and YNi_2 [3]. In 1993, Latroche et al. [4] showed that most of the RNi_2 compounds crystallize in a cubic structure characterized by a regular arrangement of vacancies at rare-earth sites, which form a superstructure (space group $F\bar{4}3m$) that is similar to the cubic Laves-phase structure. The lattice parameter of the structure is twice as large as that reported for the RNi_2 Laves phase.

Based on results of earlier magnetic measurements performed for RNi_2 compounds [5], one can suppose that, in these compounds, the d-band of nickel is filled. According to most of the papers on the magnetism of R–Ni compounds, it can be assumed that no magnetic moment on nickel atoms exists. However, Mizumaki et al. [6] have investigated magnetic moment of Ni in $GdNi_2$ compound by means of magnetic circular dichroism in the core-level X-ray-absorption spectroscopy and they revealed that nickel magnetic moment does exist. Tristan [7] has postulated the possible existence of the residual magnetic moment on nickel atoms in Gd_3Ni compound which results in an increase in the total magnetic moment of a sample. It is evident that, in R–Ni alloys, electrons located at the unfilled f-level of lanthanide atoms are the principal source of the magnetic moment of the alloys. Moreover, the existing exchange interactions between the localized 4f magnetic moments (through the conduction electrons) produce the magnetic order at low temperatures. Crystalline electric fields (CEF) and exchange interactions increase the degeneracy of the rare-earth ground multiplet. Depending on their relative magnitudes, one or more CEF levels can make contribution to the magnetic order. The $HoNi_2$ compound is characterized by the ferromagnetic order and the relatively low Curie temperature [8]. Ibarra et al. [9] have reported that the Curie temperature of $HoNi_2$ is 16 K, whereas other authors have reported the Curie temperature to be equal to 22 K [10]. Our earlier measurements performed for the $Y_xHo_{1-x}Ni_2$ system have showed that T_C of $HoNi_2$ is equal 17.6 K [11]. Measurements of the magnetic susceptibility of $LuNi_2$ exhibited only the existence of the Pauli paramagnetism at 2–298 K [12].

The aim of the present work is to study the properties of the $Lu_xHo_{1-x}Ni_2$ system over the wide composition range, to analyze the influence of nonmagnetic Lu on physical properties of the magnetically ordered $HoNi_2$ compound, and to compare the results with those obtained for the $Y_xHo_{1-x}Ni_2$ system [11].

2. Experimental

The polycrystalline solid solutions and parent compounds have been prepared according to a technique described in our work [11]; the annealing was performed at 800 °C for 10 days. All measurements were performed under the same conditions used for the $Y_xHo_{1-x}Ni_2$ system [11].

3. Results and discussion

3.1. Structural investigations

The purpose of the structural investigations is to determine the structure of the $Lu_xHo_{1-x}Ni_2$ solid solutions and to analyze changes in the lattice parameter with changing composition. The X-ray diffraction analysis was performed for all solid solutions under study. A comparison of the measured X-ray diffraction patterns with that expected for the C15-type structure (space group Fd3m) showed that the fundamental reflections correspond to this structure. However, all experimental patterns exhibit several relatively weak reflections, which do not belong to this structure. Earlier, it was shown for the $Y_xHo_{1-x}Ni_2$ system [11] that the adequate description of the atomic position parameters can be obtained within space group $F\bar{4}3m$. The final refinement of the lattice parameter was performed using a least-squares method that yields the $2a$ value equal to 1.427 and 1.411 nm for $HoNi_2$ and $LuNi_2$, respectively. It is seen from Fig. 1 that the substitution of lutetium