ELSEVIER

Journal of Alloys and Compounds 429 (2007) 116–118

Journal of ALLOYS AND COMPOUNDS

www.elsevier.com/locate/jallcom

The isothermal sections of the phase diagram of the Nd–Mg–Ni ternary system at 1123 and 673 K (Ni-rich part)

Huaiying Zhou, Songli Zhang, Qingrong Yao *, Wenjia Li

Department of Information Materials Science and Engineering, Guilin University of Electronic Technology, Guilin, Guangxi 541004, PR China

Received 15 January 2006; received in revised form 31 March 2006; accepted 5 April 2006
Available online 10 July 2006

Abstract

The isothermal sections of the Nd–Mg–Ni ternary phase diagram at 1123 and 673 K (Ni-rich part) were investigated by X-ray diffraction (XRD), scanning electron microscopy (SEM) and differential thermal analysis. The 1123 K isothermal section consists of 8 single-phase regions, 14 two-phase regions and 7 three-phase regions. The 673 K isothermal section consists of 11 single-phase regions, 21 two-phase regions, and 11 three-phase regions. In addition, the existence of two ternary compounds $NdMg_2Ni_9$ and $NdMgNi_4$ has been confirmed, and the Nd_2MgNi_9, $Nd_5Mg_2Ni_{23}$ and Nd_3MgNi_{14} compounds do not exist at 1123 and 673 K isothermal sections. No solid solubility was observed in our work.

Keywords: Nd–Mg–Ni phase diagram; Ternary isothermal section; X-ray diffraction

1. Introduction

Magnesium and Mg-based hydrogen storage alloys are known to have much higher hydrogen storage ability than rare earth (AB_5) and Laves phase (AB_2) hydrogen storage alloys. Thus, magnesium and Mg-based hydrogen storage alloys are promising as energy conversion and storage material [1]. However, due to their poor hydrogen absorption/desorption kinetics and easy corrosion in alkaline aqueous solution, Mg–Ni-based alloys are limited to the practical applications. Therefore, in order to improve cycle life of discharge, some investigations have been done [2–5]. Especially, the latest investigations of the RE–Mg–Ni (RE = La, Ce, Pr and Nd) hydrogen storage alloys have led to a new series of ternary alloys, such as $REMgNi_4$ and $REMg_2Ni_9$ (RE = La, Ce, Pr and Nd). But the rigorous conditions of the hydrogen absorption/desorption of the $REMgNi_4$ and $REMg_2Ni_9$ compounds were the major limitation to their practical applications [6–8].

The phase diagram is an important basis for material research and applications. Ref. [9] reported the Nd–Ni binary phase diagram. There are eight intermetallic compounds in the Nd–Ni system, namely: Nd_3Ni, Nd_7Ni_3, NdNi, $NdNi_2$, $NdNi_3$, Nd_2Ni_7, $NdNi_5$ and Nd_2Ni_{17}. Among them, Nd_2Ni_{17} exists only at high temperature region. The Mg–Ni binary phase diagram was reported in Ref. [10] and the existence of Mg_2Ni and $MgNi_2$ was confirmed. The Mg–Nd binary phase diagram was taken from Ref. [11] and five intermetallic compounds, $Mg_{12}Nd$, $Mg_{41}Nd_5$, Mg_3Nd, Mg_2Nd and MgNd were found in the Mg–Nd system. And the existence of $NdMgNi_4$ and $NdMg_2Ni_9$ was reported in Refs. [12–14]. Up to the present, the phase diagram (Ni-rich part) of the Nd–Mg–Ni ternary system has not been reported.

2. Experimental details

The starting materials used for the alloys were of high purity (Nd: 99.5%; Mg: 99.9%; Ni: 99.9%). The samples were prepared by sintering pressed tablets (3–5 g) of the well-proportioned mixed elements powder. Secondly the prepared tablets were sealed in evacuated silica tubes and annealed in a box furnace at 1123 and 673 K for 2 weeks, respectively, and then quenched into ice-water mixture. Besides, some samples were prepared with the mixed powders of NdNi, Mg and Ni. The NdNi alloy was synthesized by melting in an argon atmosphere in a vacuum arc furnace. In the present work, 208 samples were prepared by the above methods.

The prepared powders were investigated by X-ray diffraction, which was carried out on Rigaku D/Max 2500PC X-Ray diffractometer (Cu Kα radiation)

* Corresponding author. Tel.: +86 773 5601516.
E-mail address: qingry96@gliet.edu.cn (Q. Yao).

0925-8388/$ – see front matter © 2006 Published by Elsevier B.V.
doi:10.1016/j.jallcom.2006.04.006

using JADE5 software [15]. Some alloys were analyzed by electron-probe micro-analysis technology in order to determine the solubilities of some of the single phases.

3. Results and discussion

3.1. Binary intermetallic compounds

In the Ni-rich part of Nd–Mg–Ni ternary system, Ref. [16] reported that eight binary intermetallic compounds, namely: Mg_2Ni, $MgNi_2$, NdNi, $NdNi_2$, $NdNi_3$, Nd_2Ni_7, $NdNi_5$ and Nd_2Ni_{17}, were observed. The compound of Nd_2Ni_{17} is a high temperature phase. The compound was not detected in our work, and the XRD pattern of this composition resulting a mixture of Ni and $NdNi_5$. The XRD analysis showed that seven binary intermetallic compounds, Mg_2Ni, $MgNi_2$, NdNi, $NdNi_2$, $NdNi_3$, Nd_2Ni_7 and $NdNi_5$, have been confirmed in this work.

3.2. Some ternary compounds

The X-ray results confirm the existence of $NdMgNi_4$ and $NdMg_2Ni_9$ in Nd–Mg–Ni ternary system, which were reported in Refs. [12,13]. The $NdMgNi_4$ sample was prepared by sintering and pressing tablets of the Nd, Mg, Ni powders in a sealed quartz tube with 0.5 MPa Ar gas at 1123 K for 10 h. Fig. 1 showed the X-ray diffraction pattern of the $NdMgNi_4$ single-phase with $AuBe_5$ structure type and $F\bar{4}3m$ space group [13].

The existence of La_2MgNi_9, $La_5Mg_2Ni_{23}$ and La_3MgNi_{14} has been confirmed in Ref. [17]. We prepared some alloy samples with composition of Nd_2MgNi_9, $Nd_5Mg_2Ni_{23}$ and Nd_3MgNi_{14}. The results of XRD analysis of our alloy samples show such compounds were not observed in our work. The X-ray diffraction pattern of Nd_2MgNi_9 consists of that of $NdNi_5$ and $NdMgNi_4$.

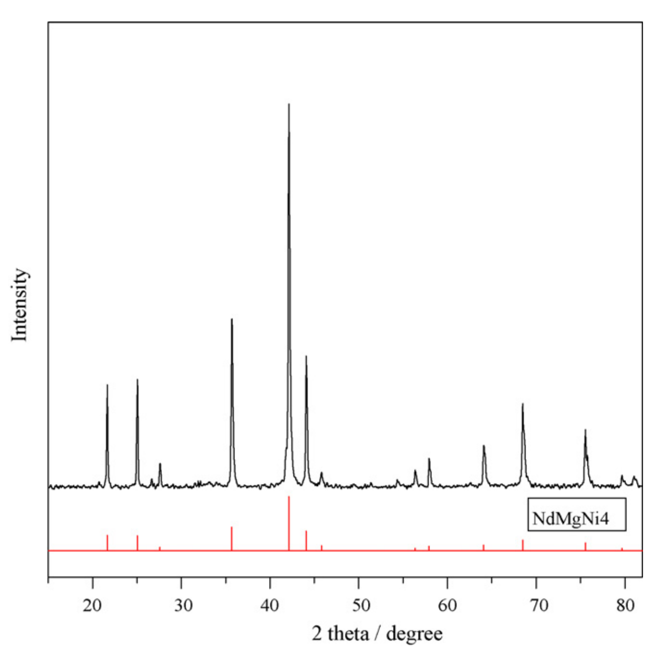

Fig. 1. X-ray diffraction pattern of $NdMgNi_4$ single-phase compound.

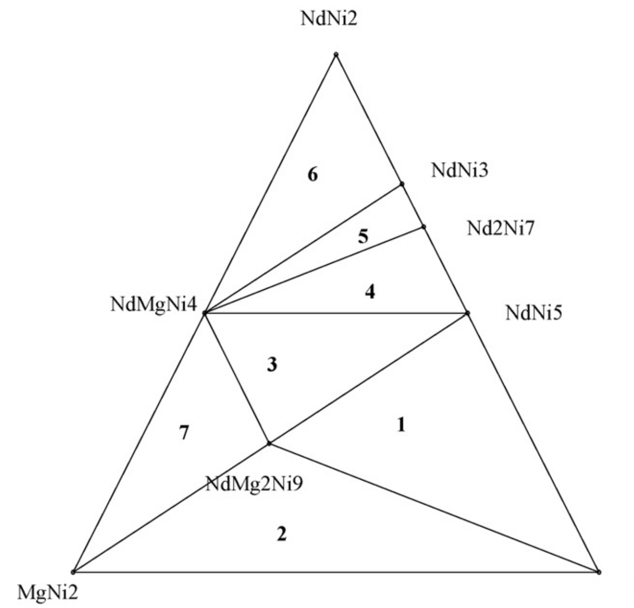

Fig. 2. A 1123 K isothermal section of the phase diagram of region the Nd–Mg–Ni ternary system (Ni-rich part).

No other new ternary compound was found under the present circumstance.

3.3. The 1123 and 673 K isothermal sections (Ni-rich part)

The 1123 and 673 K isothermal sections have been obtained by using the phase analysis result in the present work. The 1123 K isothermal section consists of 8 single-phase regions, 14 two-phase regions and 7 three-phase regions. The partial isothermal section was shown in Fig. 2. The X-ray diffraction pattern of the three-phase region $NdMg_2Ni_9 + NdNi_5 + Ni$ is shown in Fig. 3. The 673 K isothermal section consists of

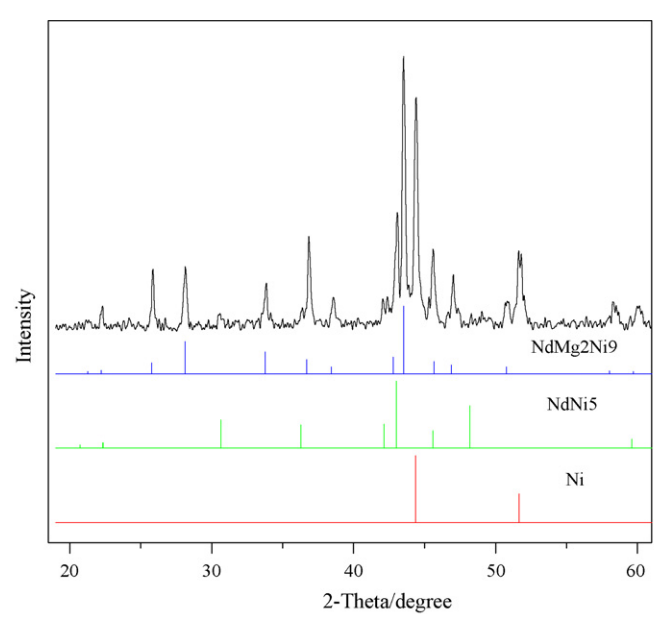

Fig. 3. The X-ray diffraction pattern of the three-phase region $NdMg_2Ni_9 + NdNi_5 + Ni$.

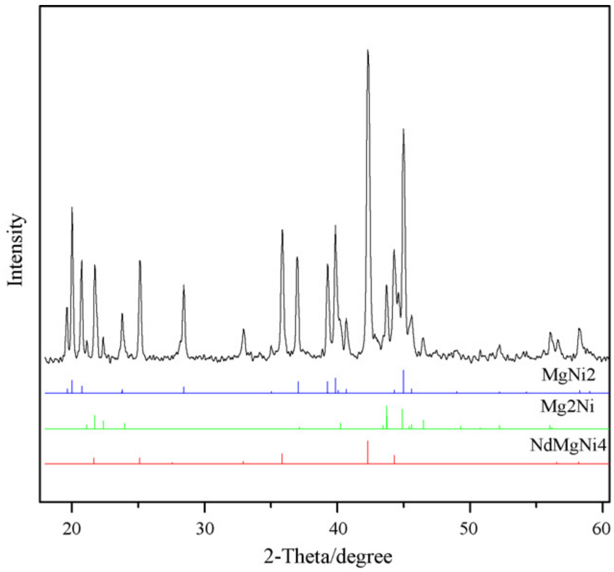

Fig. 4. The X-ray diffraction pattern of the three-phase region $NdMgNi_4 + MgNi_2 + Mg_2Ni$.

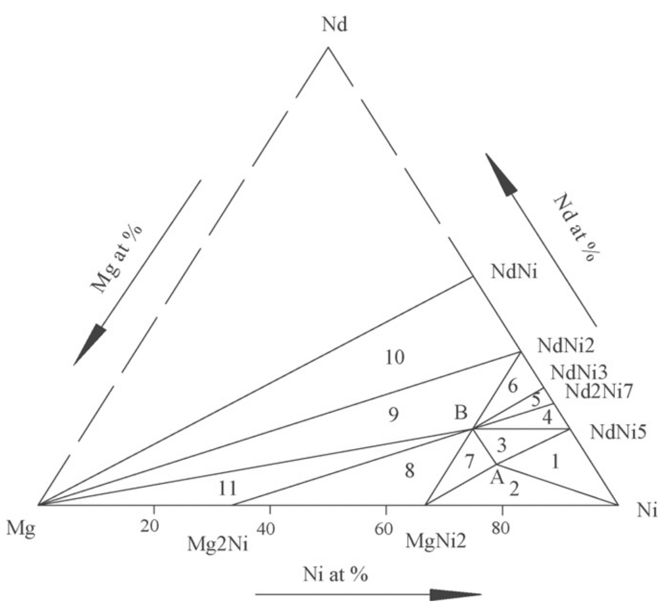

Fig. 5. A 673 K isothermal section of the phase diagram of the Nd–Mg–Ni ternary system (Ni-rich part). (A) $NdMg_2Ni_9$; (B) $NdMgNi_4$.

11 single-phase regions, 21 two-phase regions and 11 three-phase regions. The 673 K isothermal section is shown in Fig. 4. The X-ray diffraction pattern of the three-phase region $NdMgNi_4 + MgNi_2 + Mg_2Ni$ is shown in Fig. 5. No apparent solid solubility was observed in the regions.

4. Conclusions

In the Nd–Mg–Ni region, the intermetallic compounds, namely: Mg_2Ni, $MgNi_2$, NdNi, $NdNi_2$, $NdNi_3$, Nd_2Ni_7, $NdNi_5$, $NdMg_2Ni_9$ and $NdMgNi_4$, were observed. The 1123 K isothermal section consists of 8 single-phase regions, 14 two-phase regions and 7 three-phase regions. The 673 K isothermal section consists of 11 single-phase regions, 21 two-phase regions and 11 three-phase regions. The existences of other ternary compounds of Nd_2MgNi_9, $Nd_5Mg_2Ni_{23}$ and Nd_3MgNi_{14}, were not observed at 1123 and 673 K isothermal sections. In additional, no apparent solid solubility was detected in this work.

Acknowledgements

This work was supported by National Natural Science Foundation of China and Guangxi Provincial Natural Science Foundation.

References

[1] N. Cui, B. Luan, H.J. Zhao, H.K. Liu, S.X. Dou, J. Power Sources 55 (1995) 263.
[2] Y. Liu, H. Pan, M. Gao, Y. Zhu, J. Alloys Compd. 365 (2004) 246–252.
[3] S. Bouarichab, J. Huota, D. Guayb, R. Schulza, Int. J. Hydrogen Energy 27 (2002) 909–913.
[4] T. Kohno, H. Yoshida, F. Kawashima, T. Inaba, J. Alloys Compd. 311 (2000) L5–L7.
[5] L.B. Wang, J.B. Wang, H.T. Yuan, Y.J. Wang, Q.D. Li, J. Alloys Compd. 385 (2004) 304–308.
[6] Z.M. Wang, H.Y. Zhou, G. Cheng, Z.F. Gu, J. Alloys Compd. 384 (2004) 279–282.
[7] X. Xu, H.Y. Zhou, R.P. Zou, S.L. Zhang, Z.M. Wang, J. Alloys Compd. 396 (2005) 247–250.
[8] Z.M. Wang, H.Y. Zhoua, Z.F. Gu, G. Cheng, J. Alloys Compd. 381 (2004) 234–239.
[9] H. Okamoto, J. Phase Equilib. 13 (1992).
[10] A.A. Nayeb-Hashmi, J.B. Clark, Binary Alloy Phase Diagrams, 2nd ed., ASM International Materials Park, OH, 1991, pp. 2529–2530.
[11] S. Delfino, A. Saccone, R. Ferro, Metall. Trans. A21 (1990) 2109.
[12] K. Kadir, T. Sakai, I. Uehara, J. Alloys Compd. 257 (1997) 115–121.
[13] K. Kadir, D. Noreus, I. Yamashita, J. Alloys Compd. 345 (2002) 140–143.
[14] Z. Huaiying, X. Xin, C. Gang, J. Alloys Compd. 386 (2005) 144–146.
[15] Material Data JADE Release 5, XRD Pattern Processing, Materials Data Inc. (MDI), 1999.
[16] T.B. Massalsk, H. Okamoto, P.R. Subramanian, Binary Alloy Phase Diagrams, ASM International Materials Park, OH, 1990.
[17] T. Kohno, H. Yoshida, F. Kawashima, J. Alloys Compd. 311 (2000) L5–L7.