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The 773 K isothermal section of Er–Ni–Sb phase diagram

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Abstract

The isothermal section of the Er–Ni–Sb ternary system at 773 K has been investigated mainly by X-ray powder diffraction with the aid of differential thermal analysis and scanning electron microscopy. The formation of the previously reported ErNiSb and Er_5Ni_2Sb, was confirmed. No new ternary compounds were observed.

Keywords: Rare earth alloys; Transition metal alloys; Crystal structure; Phase diagram; X-ray diffraction

1. Introduction

Among the RE–Ni–Sb related ternary system (RE=rare earth elements) only Ce–Ni–Sb system has been studied [1]. The Er–Ni–Sb ternary system has not been studied over the full concentration region. Partial investigation revealed the existence of ErNiSb, $ErNi_2Sb_2$, $Er_{42}Ni_{16}Sb_{42}$ and Er_5Ni_2Sb ternary compounds [2–5].

The three binary systems bounding the Er–Ni–Sb system have been described in detail in the literature. There are three intermediate phases in the Er–Sb system [6]: Er_5Sb_3, ErSb and $ErSb_2$. Phase diagrams of the Er–Ni and Ni–Sb binary systems are presented in [7]. Eleven intermediate phases occur in the Er–Ni system: Er_3Ni, Er_3Ni_2, ErNi, $ErNi_2$, $ErNi_3$, Er_2Ni_7, $ErNi_4$, Er_4Ni_{17}, Er_5Ni_{22}, $ErNi_5$ and Er_2Ni_7. All these phases exist at fixed compositions. There are five intermediate compounds: Ni_3Sb, Ni_5Sb_2, Ni_7Sb_3, NiSb and $NiSb_2$ in the Ni–Sb system [7].

2. Experimental details

The present investigation was carried out with 167 samples having masses of about 3 g. The starting materials used for sample preparation were erbium (99.8 wt.%) nickel (99.999 wt.%) and antimony (99.9 wt.%). Samples with 0–50 at.% of Sb content were prepared by arc melting on a water-cooled copper crucible with a non-consumable tungsten electrode under pure argon atmosphere. The samples were re-melted three times in order to achieve homogeneity. For the alloys containing antimony, an electric current as low as possible was used to minimize the weight losses by vaporization of Sb. Samples with more than 50 at.% of Sb were prepared by induction melting in a sintered Al_2O_3 crucible under pure argon. All alloys after melting were subjected to a homogenizing anneal in evacuated quartz. Most of the samples, which are near to the Er-rich and Ni-rich region, were annealed at 1223 K for 21 days; each sample with more than 50 at.% Sb was annealed at 823 K for 30 days. Subsequently, the samples were cooled to 773 K at a rate of 10 K/h and kept at 773 K for 5 days, then quenched in an ice water mixture.

X-ray powder diffraction and scanning electron microscopy with energy dispersive analysis were used in the present investigation. X-ray phase analyses were performed on Rigaku 3015 X-ray diffractometer with Cu Kα radiation and Ni filter operated at 40 kV and 30 mA.

3. Results and discussion

3.1. Boundary binary systems

We have studied the binary systems Er–Ni, Ni–Sb and Er–Sb at 773 K to identify binary compounds. In the Er–Ni system we have obtained the following binary

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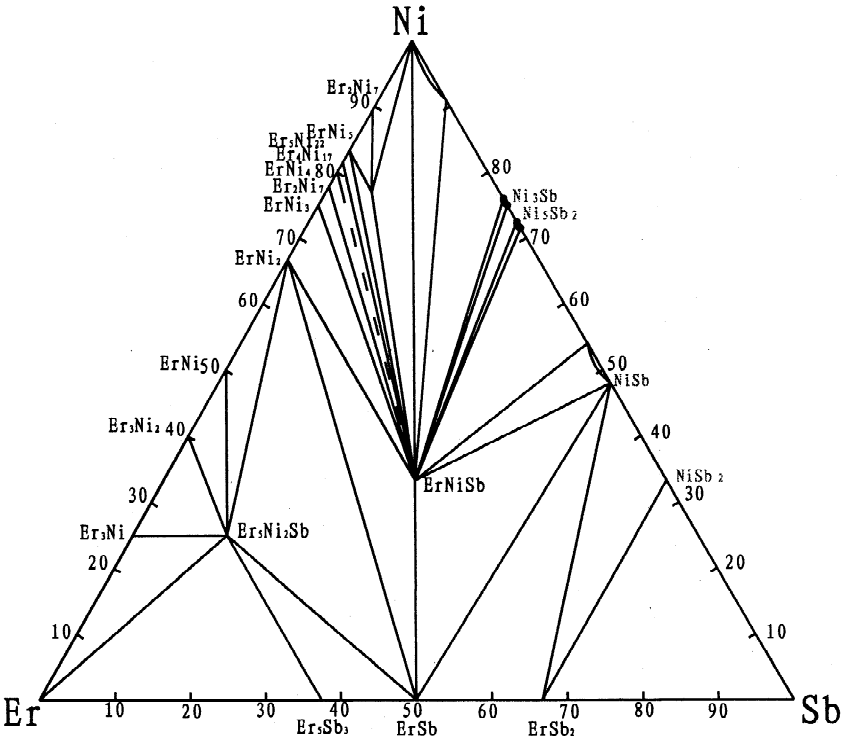

Fig. 1. The isothermal section of the Er–Ni–Sb system phase diagram at 773 K.

compounds: Er_3Ni, Er_3Ni_2, ErNi, $ErNi_2$, $ErNi_3$, Er_2Ni_7, $ErNi_5$ and Er_2Ni_{17}. The existence of $ErNi_4$, Er_4Ni_{17} and Er_5Ni_{22} has not been confirmed because no X-ray diffraction data (PDF cards) for these three phases are available. So in this work we use the results reported in Ref. [14].

In the Ni–Sb system at 773 K, four binary phases

Table 1
Crystallographic data of initial components, binary and ternary compounds for the Er–Ni–Ti system

Phases	Space group	Structure type	Lattice parameters (nm)			Refs.
			a	*b*	*c*	
Er	$P6_3/mmc$	Mg	0.35553		0.55842	[8]
Er_3Ni	$Pnma$	CFe_3	0.68098(6)	0.9435(2)	0.62433(9)	This work
Er_3Ni_2	$R\bar{3}$	Er_3Ni_2	0.8472		1.5680	[9]
ErNi	$Pnma$	BFe	0.699	0.412	0.514	[10]
$ErNi_2$	$Fd\bar{3}m$	Cu_2Mg	0.7127			[11]
$ErNi_3$	$R\bar{3}m$	Be_3Nb	0.4973		2.441	[12]
Er_2Ni_7	$R\bar{3}m$	Er_2Co_7	0.4909		3.607	[13]
$ErNi_4$	$C2/m$	Ni_4Pu	0.4855	0.8444	1.0231 $\beta=99.54°$	[14]
Er_4Ni_{17}			0.4869		8.407	[22]
Er_5Ni_{22}			0.4862		7.177	[22]
$ErNi_5$	$P6/mmm$	$CaCu_5$	0.4854		0.3964	[22]
Er_2Ni_{17}	$P6_3/mmc$	$Ni_{17}Th_2$	0.828		0.801	[15]
Ni	$Fm\bar{3}m$	Cu	0.35236			[16]
Er_5Sb_3	$Pnma$	Sb_3Y_5	1.16915(5)	0.91248(4)	0.80190(4)	This work
ErSb	$Fm\bar{3}m$	NaCl	0.6106			[17]
$ErSb_2$	$C222$	$HoSb_2$	0.3259	0.5866	0.7926	[18]
Sb	$R\bar{3}m$	As	0.43084		1.1274	[19]
NiSb	$P6_3/mmc$	AsNi	0.3935		0.5136	[20]
Ni_5Sb_2	$C2$	Ni_5Sb_2	1.29458	0.54271	1.14568 $\beta=151.71°$	[21]
Ni_3Sb	$Pmmm$	Cu_3Ti	0.53207	0.42808	0.45147	[21]
$NiSb_2$	$Pnnm$	FeS_2	0.51823	0.63168	0.38403	[23]
ErNiSb	$F\bar{4}3m$	AlLiSi	0.62683			[2]
Er_5Ni_2Sb	$I4/mcm$	Mo_5B_2Si	0.7531		1.3178	[5]

Ni_3Sb, Ni_5Sb_2, NiSb and $NiSb_2$ have been confirmed. In order to identify the existence of the Ni_7Sb_3 binary phase, we prepared several samples with 28.0 at.% Sb which were annealed at 1223 K for 21 days in evacuated quartz tube and then cooled to 773 K at a rate of 10 K/h and kept at 773 K for 5, 20 and 45 days, respectively, prior to quenching into an ice water mixture. The X-ray diffraction patterns of these samples are the same and concordant with that of Ni_5Sb_2 [21]. This means the Ni_7Sb_3 does not exist.

In the Er–Sb system at 773 K the Er_5Sb_3 with Sb_3Y_5 structure type, ErSb with NaCl structure type and $ErSb_2$ with $HoSb_2$ structure were identified. The Er_4Sb_3 phase reported in Ref. [24] was not obtained.

3.2. The isothermal section of the Er–Ni–Sb system at 773 K

The isothermal section of the Er–Ni–Sb system phase diagram at 773 K has been constructed by using the phase analysis results obtained in the present work (Fig. 1). The existence of the ErNiSb and Er_5Ni_2Sb ternary compounds at 773 K was confirmed. No new ternary compounds were found. The $ErNi_2Sb_2$ and $Er_{42}Ni_{16}Sb_{42}$ phases were not obtained in the system at the investigated temperature. The maximum solid solubility of Sb in $ErNi_5$ is about 6.3 at.%. Crystal structure data of the initial components, and the binary and ternary phases of the Er–Ni–Sb system at 773 K are listed in Table 1.

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