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The isothermal section of the Er–Fe–Sb ternary system at 773 K

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Abstract

The phase relation of the Er–Fe–Sb ternary system at 773 K has been investigated mainly by means of X-ray powder diffraction with the aid of optical microscopy and differential thermal analysis. This section consists of 12 single-phase regions, 22 two-phase regions and 11 three-phase regions. A ternary compound Er_6FeSb_2 has been confirmed.

Keywords: Er–Fe–Sb; Phase relation; X-ray diffraction

1. Introduction

Our group has investigated the phase relationship and the crystal structure of the RE–T (transition elements)–Sb ternary system systematically [1–5]. The partial phase diagram in the Er–Fe–Sb system (Sb ≤ 50 at.%) at 1173 K and a ternary compound Er_6FeSb_2 were reported [6]. The binary diagrams of the Er–Fe, Er–Sb and Fe–Sb systems bounding the Er–Fe–Sb are presented in [7]. At 773 K, there are four intermediate phases $Fe_{17}Er_2$, $Fe_{23}Er_6$, Fe_3Er, Fe_2Er in the Er–Fe binary system, two compounds ErSb and Er_5Sb_3 in the Er–Sb system, and two intermediate phases FeSb, $FeSb_2$ in the Fe–Sb system. In this paper, we report the isothermal section of the Er–Fe–Sb ternary system at 773 K.

2. Experimental

For sample preparation, the purity of Er, Fe and Sb used in this work is 99.9, 99.9, and 99.95%, respectively. Most of samples, having masses of 3 g, were prepared in an electric arc furnace under high pure argon atmosphere using a non-consumable tungsten electrode and a water-cooled copper crucible. The Sb-rich alloys were melted by induction melting in a sintered Al_2O_3 crucible under high pure argon atmosphere. As Sb is easy to volatize, before melting an extra amount of Sb was added to compensate for the weight loss. During melting, we used the electric current as low as possible to minimize the loss of antimony by vaporizing. All alloys after melting were subjected to a homogenizing anneal in evacuated quartz tube. The samples with more than 40 at.% Er were annealed at 1123 K for 240 h, the samples with more than 40 at.% Fe were annealed at 1093 K for 300 h and the samples with more than 60 at.% Sb were annealed at 773 K for 25 days. Then, they were cooled at a rate of 10 K/h to 773 K and kept there for 1 week, finally, quenched into liquid nitrogen.

X-ray powder diffraction and optical microscope were used to analyze the samples. The samples were ground to powder not coarse than 40 μm, and annealed in an evacuated tube for 5 days at 600 K to remove the lattice strains produced by the grinding. The X-ray powder diffraction was performed on a Rigaku D/Max 2500 V diffractometer with Cu Kα radiation and graphite monochromator operated at 40 kV, 250 mA. The Materials Data Inc. software Jade 5.0 [8] and the Powder Diffraction File (PDF release 2002) were used for the phase analysis.

3. Results and discussion

3.1. Binary system

In this work, we have studied the binary systems Er–Fe, Er–Sb and Fe–Sb at 773 K to identify binary compounds before the ternary phase analysis. In the Er–Fe system, four binary compounds $Fe_{17}Er_2$ [9], $Fe_{23}Er_6$ [10], Fe_3Er [9], Fe_2Er [9] were confirmed.

In the Er–Sb system, we confirmed the existence of ErSb and Er_5Sb_3 at 773 K. This result is in good agreement with that reported in [7].

In the Fe–Sb binary system, we observed two binary compounds $Fe_{1+x}Sb$ and $FeSb_2$. It was observed that there was solid

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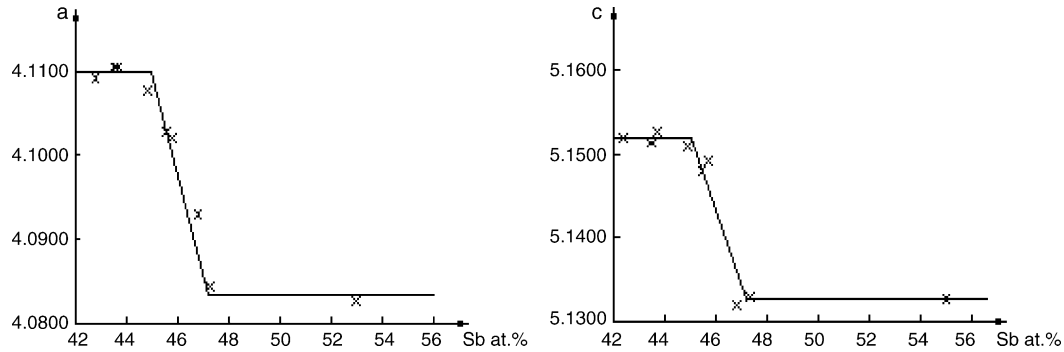

Fig. 1. Determination of the maximum solid solubility of $Fe_{1+x}Sb$ by means of lattice parameters.

Table 1
The variation of lattice parameter of $Fe_{1-x}Sb_x$

Samples	Lattice parameters	
	a (Å)	*c* (Å)
$Fe_{57.6}Sb_{42.4}$	4.1097 (3)	5.1520 (3)
$Fe_{56.45}Sb_{43.55}$	4.1110 (4)	5.1512 (5)
$Fe_{56.33}Sb_{43.67}$	4.1119 (3)	5.1529 (4)
$Fe_{55.12}Sb_{44.88}$	4.1082 (6)	5.1511 (9)
$Fe_{54.39}Sb_{45.61}$	4.1031 (2)	5.1484 (2)
$Fe_{54.21}Sb_{45.79}$	4.1027 (4)	5.1494 (4)
$Fe_{53.19}Sb_{46.81}$	4.0926 (4)	5.1319 (4)
$Fe_{52.64}Sb_{47.36}$	4.0843 (3)	5.1329 (3)
$Fe_{45}Sb_{55}$	4.0825 (3)	5.1323 (4)

solubility of Sb in $Fe_{1+x}Sb$. In order to determine this range, nine powder samples of $Fe_{1+x}Sb$ were prepared. After adding adequate highly pure silicon powder to these samples as an internal standard, we collected the X-ray powder diffraction data. The lattice parameters were refined by using the Jade 5.0 program and listed in Table 1. The variation of the lattice parameters of FeSb with Sb is shown in Fig. 1. From Fig. 1, we concluded that the maximum solid solubility of Sb in $Fe_{1+x}Sb$ was about 2.2%.

Table 2
Details of the phase regions in the Er–Fe–Sb ternary system at 773 K

Samples	Fe (at.%)	Er (at.%)	Sb (at.%)	Phase composition
1	94	6	0	$Fe + Fe_{17}Er_2$
2	84	16	0	$Fe_{17}Er_2 + Fe_{23}Er_6$
3	77	23	0	$Fe_{23}Er_6 + Fe_3Er$
4	71	29	0	$Fe_3Er + Fe_2Er$
5	50	50	0	$Fe_2Er + Er$
6	30	70	0	$Er + Fe_2Er$
7	0	80	20	$Er + Er_5Sb_3$
8	0	60	40	$Er_5Sb_3 + ErSb$
9	0	33.3	66.7	$ErSb + Sb$
10	20	0	80	$Sb + FeSb_2$
11	40	0	60	$FeSb_2 + FeSb$
12	80	0	20	$FeSb + Fe$
13	60	22	18	$Fe + Fe_{17}Er_2 + ErSb$
14	60	26	14	$Fe_{17}Er_2 + Fe_{23}Er_6 + ErSb$
15	52	32	16	$Fe_{23}Er_6 + Fe_3Er + ErSb$
16	48	36	16	$Fe_3Er + Fe_2Er + ErSb$
17	40	46	14	$Fe_2Er + Er_6FeSb_2 + Er_5Sb_3$
18	10	52	38	$Er_5Sb_3 + ErSb + Fe_2Er$
19	20	70	10	$Fe_2Er + Er_6FeSb_2 + Er$
20	6	70	24	$Er_6FeSb_2 + Er + Er_5Sb_3$
21	10	20	70	$Sb + FeSb_2 + ErSb$
22	24	20	56	$FeSb_2 + FeSb + ErSb$
23	40	20	40	$FeSb + Fe + ErSb$

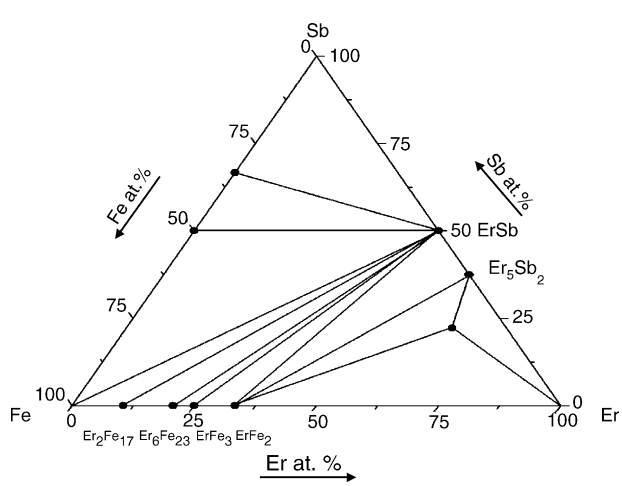

Fig. 2. The isothermal section of the Er–Fe–Sb ternary system at 773 K.

Table 3
Crystallographic data of the initial components and binary compounds for the Er–Fe–Sb at 773 K

Phase	PDF no.	Space group	Lattice parameters			Reference
			a (Å)	*b* (Å)	*c* (Å)	
Fe	87–22	$Im\bar{3}m$	2.860	–	–	[11]
$Fe_{17}Er_2$	65–080	$P6_3/mmc$	8.430	–	8.279	[9]
$Fe_{23}Er_6$		$Fm\bar{3}m$	11.994	–	–	[10]
Fe_3Er	43–373	$R\bar{3}m$	5.086	–	24.46	[9]
Fe_2Er	65–758	$Fd\bar{3}m$	7.283	–	–	[9]
Er	65–866	$P6_3/mmc$	3.558	–	5.587	[12]
Er_5Sb_3		$Pm\bar{3}m$	11.674	9.156	8.004	This work
ErSb		$Fm\bar{3}m$	6.106	–	–	[13]
Sb	85–322	$R\bar{3}m$	4.308	–	11.274	[14]
$FeSb_2$	80–430	$Pnn2$	5.832	6.537	3.197	[15]
εFeSb		$P6_3/mmc$	4.07	–	5.13	[16]
$FeEr_6Sb_2$		$P\bar{6}2m$	8.091	–	4.125	This work

3.2. The phase relationship of the Er–Fe–Sb system at 773 K

The isothermal section of the Er–Fe–Sb ternary system at 773 K has been determined (Fig. 2) on the basis of our X-ray data and metallographic results. There are 11 three-phase regions, 22 two-phase regions and 12 single-phase regions in this section. A ternary compound Er_6FeSb_2 has been confirmed. Details of the two-phase and three-phase regions were given in Table 2. The structural information of the phases in the Er–Fe–Sb system at 773 K was listed in Table 3.

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