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Solid-state phase equilibria in the Fe–Pt–Pr ternary system at 1173 K

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Abstract

The solid-state phase equilibria in the Fe–Pt–Pr ternary system at 1173 K ($Pr \leq 70\%$) were investigated by X-ray diffraction (XRD), scanning electron microscopy (SEM) and energy dispersion spectroscopy (EDS) techniques. The 1173 K isothermal section consists of 13 single-phase regions, 22 two-phase regions and 10 three-phase regions. At 1173 K, we have observed that the maximum solid solubility of Pt in α-Fe is below 1.5 at.% and the solid solution region of Pt in γ-Fe is from 2 to 35 at.%; the maximum solid solubility of Fe in Pt is 18 at.%. The maximum solubility of Fe in $PrPt_5$, $PrPt_3$, $PrPt_2$, Pr_3Pt_4, PrPt, Pr_3Pt_2 and Pr_7Pt_3 is below 1 at.%. The maximum solubility of Pr in α-(Fe, Pt), γ-(Fe, Pt), FePt, $FePt_3$ and (Pt, Fe) (the solid solution of Fe in Pt) is 6, 2, 4, 4.5 and 1.5 at.%, respectively. In this work, it is found that the phase Pr_3Pt_4 does not exist in the ternary system. The binary compounds Fe_7Pr and Fe_2Pr and any new ternary compounds were not observed.

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

1. Introduction

The Fe–Pt, Pr–Pt, Fe–Pr binary systems bounding the Fe–Pt–Pr ternary systems have been widely investigated. It has been reported that three binary compounds, Fe_3Pt ($AuCu_3$ structure type), FePt ($AuCu_3$ structure type) and $FePt_3$ ($AuCu_3$ structure type), exist in the Fe–Pt binary system [1] and the formation has been reported of seven binary compounds, $PrPt_5$ ($CaCu_5$ structure type), $PrPt_3$ (Cu_2Mg structure type), $PrPt_2$ (Cu_2Mg structure type), Pr_3Pt_4 (Pd_4Pu_3 structure type), PrPt (BFe structure type), Pr_3Pt_2 (Er_3Ni_2 structure type) and Pr_7Pt_3 (Fe_3Th_7 structure type), in the Pr–Pt binary system [2]. It was, however, reported in Ref. [3] that $PrPt_3$ did not exist. According to Ref. [4], three compounds $Fe_{17}Pr_2$ (Th_2Zn_{17} structure type), Fe_7Pr (Th_2Zn_{17} structure type) and Fe_2Pr (Cu_2Mg structure type) exist in the Fe–Pr binary system; it was proposed that Fe_7Pr was probably the same compound as $Fe_{17}Pr_2$ for they have a nearly the same composition and a completely the same structure. In Ref. [5], Fe_2Pr was reported to be unstable except at high pressure. Crystallographic data for the binary compounds of the Fe–Pt, Fe–Pr, Pr–Pt systems are summarized in Table 1. The ternary diagram and ternary compounds of the Fe–Pt–Pr system were not reported.

The results of the investigation of the phase relations in the Fe–Pt–Pr system at 1173 K are given in the present work.

2. Experimental

The solid-state phase equilibria in the Fe–Pt–Pr system at 1173 K were constructed by using the results of the X-ray phase analysis of 60 samples, as well as those obtained from scanning electron microscopy and energy dispersion spectroscopy on some selected samples. All the samples were prepared by arc-melting of pure metals (the purity of the ingredients is better than 99.9 wt.%) under purified argon. They were remelted not less than four times to ensure good homogeneity. The mass losses after the melting were less than 0.5 wt.%. After melting, the samples were sealed in quartz tubes pre-evacuated and refilled with some purified argon and annealed at 1173 K for 2 weeks. After annealing, the ampoules with the samples were quenched in water.

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Table 1
Crystallographic data for the binary compounds of the Fe–Pt, Fe–Pr, Pr–Pt systems

Compounds	Structure type	Space group	Lattice parameters (nm)			Ref.
			a	*b*	*c*	
Fe_3Pt	$AuCu_3$	$Pm\bar{3}m$	0.3727	–	–	[1,6]
Fe_3Pt	Cu	$Fm\bar{3}m$	0.3723	–	–	[1,6]
Fe_3Pt	W	$Im\bar{3}m$	0.2969	–	–	[1,6]
FePt	$AuCu_3$	$Pm\bar{3}m$	0.3841	–	–	[1,6]
FePt	Pa	$I4/mmm$	0.3905	–	0.3735	[1,6]
$FePt_3$	$AuCu_3$	$Pm\bar{3}m$	0.3872	–	–	[1,6]
$PrPt_5$	$CaCu_5$	$P6/mmm$	0.5353	–	0.4386	[3,6]
$PrPt_3$	Cu_2Mg	$Fd\bar{3}m$	0.7644	–	–	[3,6]
$PrPt_3$	$AuCu_3$	$Pm\bar{3}m$	0.4065	–	–	[3,6]
$PrPt_2$	Cu_2Mg	$Fd\bar{3}m$	0.7713	–	–	[3,6]
Pr_3Pt_4	Pd_4Pu_3	$R\bar{3}$	1.3590	–	0.5769	[3,6]
PrPt	BFe	$Pnma$	0.7282	0.4594	0.5696	[3,6]
PrPt	BCr	$Cmcm$	0.3891	1.0899	0.4569	[3,6]
Pr_3Pt_2	Er_3Ni_2	$R\bar{3}$	0.8959	–	0.6980	[3,6]
Pr_7Pt_3	Fe_3Th_7	$P6_3mc$	1.0137	–	0.6376	[3,6]
$Fe_{17}Pr_2$	Th_2Zn_{17}	$R\bar{3}m$	0.8585	–	1.2464	[2,7]
Fe_7Pr	Th_2Zn_{17}	$R\bar{3}m$	0.8582	–	1.2460	[2,7]
Fe_2Pr	Cu_2Mg	$Fd\bar{3}m$	0.6760	–	–	[2,7]
Fe_2Pr	Cu_2Mg	$P6_3/mmc$	0.5260	–	0.8620	[2,7]

The brittle samples were ground to powders in a ceramic mortar for X-ray diffraction with Si as the internal standard. A few toughness samples were pressed into slices (7 mm × 3 mm × 1 mm) and sealed again in quartz tubes, then annealed under the protection of purified argon at 1173 K for a week to eliminate the stress and quenched in water for X-ray diffraction. Phase analysis was carried out using X-ray diffraction (Cu Kα radiation), scanning electron microscopy and energy dispersion spectroscopy techniques.

3. Results and discussion

3.1. Phase analysis

3.1.1. Binary Pr–Pt system

According to Ref. [3], $PrPt_3$ ($AuCu_3$ structure type) does not exist in Pr–Pt system. We prepared some samples between the $PrPt_2$ compound and the $PrPt_5$ compound in the binary Pr–Pt system. From the X-ray diffraction data showed in Fig. 1a, one can clearly see that the $PrPt_3$ compound ($AuCu_3$ structure type) exists. This pattern is in good agreement with the calculated result (Fig. 1b) obtained by means of the software of PowderCell [6] to directly treat the crystallographic data of the $PrPt_3$ compound [7]. No traces of the $PrPt_2$ and $PrPt_5$ compounds were observed in the observed X-ray pattern of the alloy of $PrPt_3$. Thus, it can be concluded that the $PrPt_3$ compound exists under our experimental condition.

Pr_3Pt_4 compound (Pd_4Pu_3 structure type) exists up to 573 K in the Pr–Pt binary system [8]. It is confirmed that Pr_3Pt_4 compound exists as well at 1173 K, which is seem in the top part of Fig. 2. However, it is surprising that Pr_3Pt_4 does not exist in the Fe–Pt–Pr ternary alloys with more than 1 at% Fe according to X-ray diffraction data at the bottom part of Fig. 2. This suggests that Pr_3Pt_4 has decomposed and formed the other two phases, PrPt and $PrPt_2$. It reveals as well that the presence of Fe destabilizes the Pr_3Pt_4 compound relative to the other two phases. Further work is underway and detailed results will be reported in another paper.

3.1.2. Binary Fe–Pr system

There is an argument whether Fe_7Pr exists or not in the binary Fe–Pr system [4]. According to the JCPDS-PDF card, both Fe_7Pr and $Fe_{17}Pr_2$ compounds belong to hexagonal Th_2Zn_{17} structure type, space group $R\bar{3}m$ and their cell parameters are approximately equal ($Fe_{17}Pr_2$: $a = 8.581$ Å, $c = 12.46$ Å; Fe_7Pr: $a = 8.582$ Å, $c = 12.46$ Å) [9]. Hence, in Ref. [4], the author presumed that Fe_7Pr and $Fe_{17}Pr_2$ are the same compounds. We prepared some samples between the $Fe_{17}Pr_2$ compound and the Fe_2Pr compound in the binary Fe–Pr system. Their X-ray diffraction results show that there

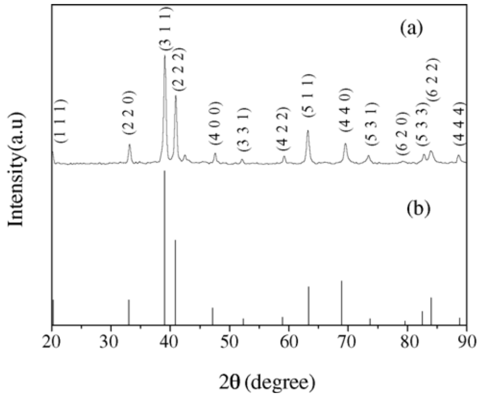

Fig. 1. Observed XRD pattern of the $PrPt_3$ compound annealed at 1173 K for 2 weeks (a) and calculated XRD pattern of $PrPt_3$ compound (b).