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Isothermal sections at 1400, 1100 and 900 °C of the Ti–Dy–Sn system below 40 at.% Sn

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ABSTRACT

By the methods of X-ray diffraction, SEM and electron probe microanalysis, phase equilibria in the Ti–Dy–Sn system below 40 at.% Sn at temperatures 1400, 1100 and 900 °C were studied. The isothermal sections at 1400, 1100 and 900 °C were constructed. It was shown that the ternary compound $Ti_{4.2-4.3}Dy_{0.8-0.7}Sn_{\leqslant 3}$ (τ) is stable at these temperatures. At 1400 °C the liquid phase is present in the system. The isothermal section at this temperature is characterized by the three-phase regions L + (βTi) + (Dy_5Sn_3), (βTi) + (Ti_3Sn) + (Dy_5Sn_3), (Ti_3Sn) + τ + (Dy_5Sn_3), (Ti_3Sn) + τ + (Ti_2Sn) and (Ti_2Sn) + τ + (Ti_5Sn_3) and appropriate two-phase fields. At 1100 and 900 °C the liquid phase is absent, instead the three-phase field (βTi) + (αDy) + (Dy_5Sn_3) appears. Other three-phase fields exist at all the temperatures studied. The isothermal sections at 1100 and 900 °C by their character are similar to the solidus surface.

1. Introduction

Recently phase equilibria in the Ti–Dy–Sn system below 40 at.% Sn in the range of melting/solidification were studied by us [1]. The liquidus and solidus projections were constructed. Previously a new ternary compound $Ti_{4.2-4.3}Dy_{0.8-0.7}Sn_{\leqslant 3}$ (τ) was found by us [2,3], which crystallizes in a space group $R\bar{3}$ m with lattice parameters $a = 5.772(1)$, $c = 22.686(4)$ Å. According to [1,2], the compound melts congruently above 1540 °C and at the solidus temperatures coexists with all the phases based on the binary compounds in the concentration interval studied. It was shown, that the most stable phase (Dy_5Sn_3) defines the character of the liquidus and solidus projections. In the solidus surface it coexists with the majority of phases, and in the liquidus surface it has the widest field of primary crystallization. No other information concerning this system is available in the literature. Phase equilibria below the solidus are unknown.

Hence, the goal of the present research was to study phase equilibria and to construct the isothermal sections of the Ti–Dy–Sn system at tin concentration below ~40 at.% at 1400, 1100 and 900 °C.

The boundary binary systems accepted in this work are discussed in [1].

2. Experimental

For this research we used the samples prepared by us earlier for the study of phase equilibria in the range of melting/solidification. The preparation and control of the samples composition is described in [1]. The alloy ingots were cut into pieces about 5 mm thick. These samples were annealed step-by-step at temperatures 1400, 1100 and 900 °C during 30–60 h at each temperature. Each sample was wrapped in tantalum foil. Annealing was carried out in an argon atmosphere, which was additionally purified by Zr chips. Cooling was performed with the furnace turned off. Some alloys were then examined for oxygen content, which was about 0.02–0.03 wt.%.

The samples were studied using X-ray diffraction (XRD), scanning electron microscopy (SEM) and electron probe microanalysis (EPMA).

XRD was carried out by powder method in Debye cameras ($d = 57.3$ mm) in a URS-2.0 device and from cross-sections in a DRON-3.0 device (Bourevestnik, Inc., St. Petersburg, Russia) with Cu Kα-filtered radiation. Indexing of the reflections was performed with the WinXPOW [4] and PowderCell [5] softwares. The lattice parameters were refined by a least-squares method.

The samples for microstructure examinations were polished with a water suspension of Cr_2O_3. The samples were not chemically etched, as the microstructures were studied with a scanning electron microscopes Jeol Superprobe-733 and JEOL JSM 6490LV (JEOL, Japan) using back-scattered electrons. Microprobe measurements were performed using Jeol Superprobe-733 and JEOL JSM 6490LV (JEOL, Japan) microscopes, as well.

3. Results and discussion

The heat treatment regimes and phase composition of the studied alloys are summarized in Table 1. The microprobe results are given in Table 2. The isothermal sections at 1400, 1100 and 900 °C of the Ti–Dy–Sn system resulted from this research are presented in Fig. 1. For each phase several microprobe measurements were performed. In Table 2 the average values are given together with the mean square deviations, while in Fig. 1 all the measured values are shown. Table 3 presents the tie-triangles resulted from microprobe study. The lattice parameters of the phases are shown in Table 4.

The ternary compound $Ti_{4.2-4.3}Dy_{0.8-0.7}Sn \leqslant 3$ (τ), which melts congruently [1,2], was found to exist at these three temperatures.

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Table 1
Phase compositions annealed Ti–Dy–Sn alloys and microprobe results.

Alloy % (at.)				Heat treatment	Phase composition
#	Ti	Dy	Sn		
1	2	3	4	5	6
1	73.5	2	24.5	1400 °C 30 h	(Ti_3Sn) + (Dy_5Sn_3)
2	70.5	2	27.5	1400 °C 30 h	(Ti_3Sn) + τ
				1400 °C 30 h + 1100 °C 60 h	(Ti_3Sn) + τ
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(Ti_3Sn) + τ
3	68	2	30	1400 °C 30 h	(Ti_3Sn) + τ + (Ti_2Sn)
				1400 °C 30 h + 1100 °C 60 h	(Ti_3Sn) + τ + (Ti_2Sn)
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(Ti_3Sn) + τ + (Ti_2Sn)
4	65.5	2	32.5	1400 °C 30 h	(Ti_3Sn) + τ + (Ti_2Sn)
				1400 °C 30 h + 1100 °C 60 h	(Ti_3Sn) + τ + (Ti_2Sn)
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(Ti_3Sn) + τ + (Ti_2Sn)
5	63	2	35	1400 °C 30 h	(Ti_3Sn) + τ + (Ti_2Sn)
6	60.5	2	37.5	1400 °C 30 h	(Ti_2Sn) + (Ti_5Sn_3) + τ
				1400 °C 30 h + 1100 °C 60 h	(Ti_2Sn) + (Ti_5Sn_3) + τ
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(Ti_2Sn) + (Ti_5Sn_3) + τ
7	90	5	5	1200 °C 30 h + 900 °C 32 h	(βTi) + (Dy_5Sn_3)
8	77.5	5	17.5	1400 °C 30 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
9	72.5	5	22.5	1400 °C 30 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
10	67.5	5	27.5	1400 °C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
11	65	5	30	1100 °C 30 h	(Ti_3Sn) + τ
				1100 °C 30 h + 900 °C 32 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
				1100 °C 30 h + 900 °C 32 h + 1400 °C 30 h	(Ti_3Sn) + τ
				1400 °C 30 h	(Ti_3Sn) + τ + (Ti_2Sn)
12	62.5	5	32.5	1400 °C 30 h + 1100 °C 60 h	(Ti_3Sn) + τ + (Ti_2Sn)
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(Ti_3Sn) + τ + (Ti_2Sn)
13	80	10	10	1400 °C 30 h	(βTi) + (Dy_5Sn_3)
14	75	10	15	1400 °C 30 h	(βTi) + (Dy_5Sn_3)
15	70	10	20	1400 °C 30 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
16	65	10	25	1100 °C 30 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
				1100 °C 30 h + 900 °C 32 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
				1100 °C 30 h + 900 °C 32 h + 1400 °C 30 h	(βTi) + (Ti_3Sn) + (Dy_5Sn_3)
17	57.5	10	32.5	1400 °C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
18	55	10	35	1400°C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
19	52.5	10	37.5	1400 °C 30 h	τ + ?
20	65	30	5	1100 °C 30 h	(βTi) + (αDy) + (Dy5Sn3)
				1100 °C 30 h + 900 °C 32 h	(βTi) + (αDy) + (Dy5Sn3)
21	47.5	47.5	5	1100 °C 30 h	(βTi) + (αDy) + (Dy_5Sn_3)
				1100 °C 30 h + 900°C 32 h	(βTi) + (αDy) + (Dy_5Sn_3)
30	60	7.5	32.5	1400 °C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
31	55	12.5	32.5	1400 °C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
32	52.5	15	32.5	1400°C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
33	65	1.7	33.3	1100°C 30 h	(Ti_3Sn) + τ + (Ti_2Sn)
				1100°C 30 h + 900 °C 32 h	(Ti_3Sn) + τ + (Ti_2Sn)
				1100 °C 30 h + 900 °C 32 h + 1400 °C 30 h	(Ti_3Sn) + τ + (Ti_2Sn)
34	33.3	33.3	33.3	1100 °C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
				1100 °C 30 h + 900 °C 32 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
				1100°C 30 h + 900 °C 32 h + 1400 °C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
35	57.5	7.5	35	1400 °C 30 h	(Ti_3Sn) + τ + (Ti_2Sn)
				1400 °C 30 h + 1100 °C 60 h	(Ti_3Sn) + τ + (Ti_2Sn)
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(Ti_3Sn) + τ + (Ti_2Sn)
36	52.5	12.5	35	1400 °C 30 h	(Ti_3Sn) + τ + (Dy_5Sn_3)
44	58.5	4	37.5	1400 °C 30 h	(Ti_2Sn) + (Ti_5Sn_3) + τ
				1400°C 30 h + 1100 °C 60 h	(Ti_2Sn) + (Ti_5Sn_3) + τ
				1400 °C 30 h + 1100 °C 60 h + 900 °C 30 h	(Ti_2Sn) + (Ti_5Sn_3) + τ
45	56.5	6	37.5	1400 °C 30 h	(Ti_5Sn_3) + τ
46	54.5	8	37.5	1400 °C 30 h	τ + (Ti_5Sn_3) + ?
47	65	20	15	1100 °C 30 h	(βTi) + (Dy_5Sn_3)
				1100 °C 30 h + 900°C 32 h	(βTi) + (Dy_5Sn_3)
48	45	25	30	1400 °C 30 h	(Ti_3Sn) + (Dy_5Sn_3)
49	33	35	32	1400 °C 30 h	(Ti_3Sn) + (Dy_5Sn_3)
50	20.5	45	34.5	1400 °C 30 h	(Ti_3Sn) + (Dy_5Sn_3)

Due to the kinetics of α ⇄ β transformation we never observed the (βTi) phase.