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On the Microstructure and Properties of Nb-18Si-6Mo-5Al-5Cr-2.5W-1Hf Nb-Silicide Based Alloys with Ge, Sn and Ti Additions (at.%)

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Table S1. EDS analysis data (at.%) of the alloy JZ4.

	Nb	Ti	Si	Mo	W	Sn	Ge	Hf	Al	Cr
As cast										
Top[a]	39.4 ± 0.3 39.1–39.7	12.4 ± 0.3 12.2–12.7	18.2 ± 0.7 17.5–19.1	6.0 ± 0.3 5.7–6.4	2.5 ± 0.1 2.4–2.7	5.3 ± 0.3 4.8–5.6	5.2 ± 0.2 4.9–5.5	1.1 ± 0.1 0.9–1.3	4.9 ± 0.3 4.6–5.2	5.0 ± 0.3 4.7–5.4
Bulk[a]	39.8 ± 0.4 39.3–40.3	12.1 ± 0.2 11.9–12.5	18.7 ± 0.3 18.1–19.0	6.0 ± 0.4 5.7–6.6	2.3 ± 0.2 2.1–2.6	5.3 ± 0.3 4.9–5.6	5.4 ± 0.1 5.3–5.5	1.0 ± 0.1 0.9–1.1	4.6 ± 0.3 4.2–5.0	4.8 ± 0.3 4.5–5.1
Bottom[a]	38.2 ± 0.3 37.9–38.6	12.9 ± 0.1 12.8–13.1	16.6 ± 0.41 6.1–17.2	6.5 ± 0.3 6.2–6.8	1.9 ± 0.2 1.8–2.3	6.6 ± 0.2 6.5–7.0	5.0 ± 0.3 4.5–5.4	1.1 ± 0.1 1.0–1.2	5.5 ± 0.2 5.2–5.7	5.7 ± 0.3 5.5–6.2
Nb_5Si_3	45.1 ± 0.2 44.8–45.2	9.6 ± 0.2 9.4–10.0	28.2 ± 0.5 27.5–28.5	4.5 ± 0.2 4.2–4.8	1.7 ± 0.1 1.6–1.9	1.2 ± 0.1 1.2–1.4	5.7 ± 0.2 5.5–5.9	0.7 ± 0.1 0.6–0.9	1.9 ± 0.2 1.7–2.0	1.4 ± 0.1 1.2–1.5
Ti-rich Nb_5Si_3	40.7 ± 1.5 38.3–42.3	12.8 ± 1.1 11.7–14.6	20.8 ± 1.1 18.9–21.6	4.7 ± 0.1 4.5–4.9	1.3 ± 0.2 0.9–1.5	5.0 ± 1.0 4.2–6.8	5.9 ± 0.3 5.5–6.2	1.5 ± 0.2 1.3–1.8	4.6 ± 0.4 4.2–5.3	2.7 ± 0.5 2.3–3.5
A15-Nb_3X	42.1 ± 0.3 41.7–42.4	10.7 ± 0.2 10.4–10.9	2.5 ± 0.3 2.2–3.0	14.2 ± 0.3 13.8–14.5	8.3 ± 0.3 8.0–8.3	9.1 ± 0.1 9.0–9.3	1.6 ± 0.2 1.4–1.9	–	6.6 ± 0.2 6.5–7.0	4.9 ± 0.1 4.8–5.0
Ti-rich A15	29.8 ± 2.3 29.0–32.6	15.1 ± 1.0 14.1–16.3	1.1 ± 0.6 0.4–1.9	14.4 ± 1.2 12.8–14.9	4.6 ± 0.4 4.3–5.4	12.5 ± 1.4 11.2–14.5	0.9 ± 0.1 0.6–1.0	0.2 ± 0.1 0.0–0.4	9.4 ± 0.7 8.7–10.4	12.0 ± 1.2 10.7–13.8
TM$_5Sn_2X$	23.9 22.8	27 27.4	1.8 2.6	4.6 4.6	0.6 0.5	25.7 23.8	1.6 2.1	2.1 2.2	8 8.1	5 5.9
C14-Cr_2Nb	22.3 ± 0.6 21.6–23.2	6.1 ± 0.3 5.6–6.5	7.7 ± 0.9 6.9–9.0	4.9 ± 0.1 4.7–5.0	3.4 ± 0.3 3.0–3.7	1.1 ± 0.3 0.7–1.4	1.3 ± 0.2 1.1–1.5	2.0 ± 0.3 1.6–2.3	9.4 ± 1.2 7.3–10.4	41.8 ± 1 40.4–43.1
Heat treated										
Average composition[a]	39.9 ± 0.3 39.4–40.2	12.3 ± 0.2 11.9–12.5	18.2 ± 0.3 17.9–18.5	5.8 ± 0.3 5.6–6.3	2.2 ± 0.1 2.1–2.3	5.4 ± 0.3 5.0–5.4	5.4 ± 0.3 5.1–5.8	1.2 ± 0.1 1.0–1.4	4.8 ± 0.2 4.6–4.9	4.8 ± 0.2 4.6–5.0
(Nb,W)$_{ss}$	26.7 ± 0.2 26.5–27.0	5.4 ± 0.1 5.2–5.5	0	21.8 ± 0.3 21.3–22.2	29.4 ± 0.2 29.2–29.6	0.8 ± 0.1 0.7–0.9	0.1	0.6	3.2 ± 0.1 3.1–3.5	12.0 ± 0.1 11.8–12.2
Nb_5Si_3	39.8 ± 0.2 39.6–40.1	13.4 ± 0.2 13.2–13.5	20.8 ± 0.2 20.6–21.0	4.3 ± 0.3 4.0–4.7	0.6 ± 0.2 0.4–0.8	5.3 ± 0.1 5.2–5.5	5.7 ± 0.1 5.5–5.8	1.3 ± 0.1 1.2–1.4	4.8 ± 0.1 4.6–5.0	4.0 ± 0.1 3.9–4.1
Ti-rich Nb_5Si_3	34.7 ± 0.4 34.2–35.1	15.3 ± 0.3 14.9–15.7	24.1 ± 0.5 23.4–24.6	3.7 ± 0.3 3.3–4.0	–	1.6 ± 0.2 0.4–1.8	6.8 ± 0.1 6.6–6.9	4.3 ± 0.2 4.0–4.5	5.6 ± 0.1 5.5–5.7	3.9 ± 0.2 3.8–4.2
A15-Nb_3X	39.3 ± 0.1 39.2–39.5	10.6 ± 0.2 10.4–11.0	2.0 ± 0.2 1.7–2.2	14.3 ± 0.2 14.1–14.3	5.6 ± 0.1 5.4–5.7	10.3 ± 0.1 10.2–10.5	1.2 ± 0.1 1.0–1.4	0.1	7.1 ± 0.1 7.0–7.0	9.5 ± 0.3 9.0–9.8
C14-Cr_2Nb	25.9 ± 0.4 25.4–26.2	4.0 ± 0.1 3.8–4.1	10.2 ± 0.3 9.8–10.5	4.0 ± 0.3 3.7–4.2	3.5 ± 0.3 3.3–3.7	0.3	1.0 ± 0.2 0.9–1.2	1.3 ± 0.1 1.2–1.4	4.4 ± 0.2 4.2–4.7	45.4 ± 0.7 44.7–46.1

Nb_5Si_3	39.8 ± 0.2 39.6–40.1	13.4 ± 0.2 13.2–13.5	20.8 ± 0.2 20.6–21.0	4.3 ± 0.3 4.0–4.7	0.6 ± 0.2 0.4–0.8	5.3 ± 0.1 5.2–5.5	5.7 ± 0.1 5.5–5.8	1.3 ± 0.1 1.2–1.4	4.8 ± 0.1 4.6–5.0	4.0 ± 0.1 3.9–4.1
Ti-rich Nb_5Si_3	34.7 ± 0.4 34.2–35.1	15.3 ± 0.3 14.9–15.7	24.1 ± 0.5 23.4–24.6	3.7 ± 0.3 3.3–4.0	–	1.6 ± 0.2 0.4–1.8	6.8 ± 0.1 6.6–6.9	4.3 ± 0.2 4.0–4.5	5.6 ± 0.1 5.5–5.7	3.9 ± 0.2 3.8–4.2
A15-Nb_3X	39.3 ± 0.1 39.2–39.5	10.6 ± 0.2 10.4–11.0	2.0 ± 0.2 1.7–2.2	14.3 ± 0.2 14.1–14.3	5.6 ± 0.1 5.4–5.7	10.3 ± 0.1 10.2–10.5	1.2 ± 0.1 1.0–1.4	0.1	7.1 ± 0.1 7.0–7.0	9.5 ± 0.3 9.0–9.8
C14-Cr_2Nb	25.9 ± 0.4 25.4–26.2	4.0 ± 0.1 3.8–4.1	10.2 ± 0.3 9.8–10.5	4.0 ± 0.3 3.7–4.2	3.5 ± 0.3 3.3–3.7	0.3	1.0 ± 0.2 0.9–1.2	1.3 ± 0.1 1.2–1.4	4.4 ± 0.2 4.2–4.7	45.4 ± 0.7 44.7–46.1

a = large area analysis.

Table S2. EDS analysis data (at.%) for the alloy JZ5.

	Nb	**Ti**	**Si**	**Mo**	**W**	**Sn**	**Ge**	**Hf**	**Al**	**Cr**
					As cast					
Top[a]	31.7 ± 0.6 31.2–32.4	20.6 ± 0.6 20.0–21.5	19.4 ± 1.0 18.4–20.9	6.3 ± 0.2 6.0–6.6	1.3 ± 0.2 1.0–1.5	5.4 ± 0.3 5.0–5.8	5.2 ± 0.1 5.1–5.3	0.9 ± 0.1 0.8–1.0	4.5 ± 0.3 4.2–5.0	4.7 ± 0.3 4.2–4.9
Bulk[a]	32.8 ± 1.4 31.1–33.9	19.9 ± 0.6 19.3–20.7	19.8 ± 1.9 17.2–21.7	6.3 ± 0.5 6.0–7.1	1.3 ± 0.3 1.0–1.6	5.3 ± 1.0 4.5–6.4	5.3 ± 0.1 5.2–5.5	0.8 ± 0.1 0.7–0.9	4.1 ± 0.5 3.6–4.7	4.4 ± 0.5 3.9–5.1
Bottom[a]	31.5 ± 0.7 30.3–32.2	20.6 ± 0.5 20.2–21.2	18.3 ± 0.9 17.3–19.2	6.3 ± 0.1 6.1–6.4	0.8 ± 0.1 0.7–0.9	6.5 ± 0.4 6.0–6.9	5.1 ± 0.4 4.7–5.4	0.9 ± 0.1 0.8–1.0	4.8 ± 0.4 4.4–5.2	5.2 ± 0.7 4.7–6.4
Nb_5Si_3	37.9 ± 0.5 37.3–38.6	16.9 ± 0.5 16.3–17.4	28.1 ± 0.6 27.5–28.8	4.9 ± 0.2 4.5–5.1	1.0 ± 0.1 1.0–1.1	1.2 ± 0.2 0.9–1.5	6.2 ± 0.2 5.7–6.3	0.8 ± 0.1 0.7–0.9	1.6 ± 0.2 1.4–1.8	1.4 ± 0.1 1.3–1.4
Ti-rich Nb_5Si_3	31.1 ± 0.6 30.2–31.6	21.9 ± 0.6 21.2–22.6	18.3 ± 0.3 17.8–18.6	5.3 ± 0.2 5.0–5.5	1.3 ± 0.1 1.2–1.4	6.2 ± 0.2 6.1–6.5	6.6 ± 0.1 6.5–6.8	1.3 ± 0.2 1.1–1.5	5.0 ± 0.1 4.9–5.1	3.0 ± 0.2 2.8–3.2
A15-Nb_3X	30.1 ± 0.7 29.2–31.2	19.4 ± 0.3 19.1–19.9	2.1 ± 0.4 1.8–2.7	16.2 ± 0.4 15.9–16.8	4.8 ± 0.2 15.9–16.8	10.3 ± 0.5 9.5–10.7	2.1 ± 0.4 1.8–2.7	0.5	7.1 ± 0.2 6.9–7.5	7.4 ± 0.5 7.0–8.1
Ti-rich A15	19.1 ± 2.6 16.3–22.4	22.7 ± 1.4 21.2–24.5	0.8 ± 0.3 0.4–1.1	15.5 ± 0.4 15.0–15.9	3.9 ± 0.5 3.4–4.5	11.6 ± 0.8 10.6–12.3	1.4 ± 0.3 1.0–1.8	0.4	10.5 ± 1.0 9.3–11.7	14.1 ± 0.9 13.1–15.5
TM$_5$Sn$_2$X	13.7 11.4	34.8 37.5	3.6 3	3.4 3.4	– –	24.8 24.6	2.9 2.7	1.2 1.5	8.2 8.4	7.4 7.5

C14-Cr_2Nb	18.5 ± 0.3 18.3–19.1	10.5 ± 0.2 10.3–10.7	7.5 ± 0.7 6.7–8.3	5.0 ± 0.4 4.6–5.6	2.3 ± 0.2 2.1–2.6	0.9 ± 0.4 0.5–1.6	1.4 ± 0.2 1.2–1.8	1.4 ± 0.1 1.4–1.6	9.3 ± 1.3 7.8–10.6	43.2 ± 0.4 42.8–43.8
					Heat treated					
Average composition[a]	31.4 ± 0.3 31.1–31.8	20.5 ± 0.2 20.4–20.8	18.8 ± 0.4 18.4–19.3	6.2 ± 0.1 6.0–6.4	1.2 ± 0.1 1.0–1.3	5.7 ± 0.2 5.4–5.9	5.6 ± 0.2 5.4–5.9	1.0 ± 0.2 0.8–1.3	4.7 ± 0.2 4.6–5.0	4.9 ± 0.2 4.7–5.1
$(Nb,W)_{ss}$	21.2 ± 0.4 20.9–21.7	11.3 ± 0.3 10.8–11.6	0	23.4 ± 0.3 22.9–23.9	18.0 ± 0.3 17.7–18.3	1.2 ± 0.1 1.0–1.4	1.6 ± 0.6 0.8–2.3	0.3	5.3 ± 0.3 5.1–5.8	17.7 ± 0.3 17.2–18.0
Nb_5Si_3	31.4 ± 0.2 31.2–31.6	21.1 ± 0.4 20.6–21.7	20.3 ± 0.5 19.5–20.9	5.0 ± 0.1 4.9–5.2	0.5	5.7 ± 0.3 5.3–6.1	6.2 ± 0.3 5.9–6.8	1.1 ± 0.1 1.1–1.2	4.6 ± 0.1 4.5–4.8	4.1 ± 0.2 3.8–4.2
Ti-rich Nb_5Si_3	27.4 ± 0.3 26.9–27.7	23.7 ± 0.4 23.1–24.2	24.1 ± 0.3 23.6–24.4	3.8 ± 0.3 3.6–4.4	–	1.4 ± 0.1 1.3–1.5	7.2 ± 0.1 7.1–7.3	3.2 ± 0.1 3.1–3.4	5.2 ± 0.1 5.1–5.3	4.0 ± 0.2 3.7–4.2
A15-Nb_3X	29.9 ± 0.4 29.3–30.4	17.4 ± 0.3 16.9–17.5	2.4 ± 0.2 2.0–2.6	16.3 ± 0.3 15.9–16.6	4.7 ± 0.1 4.5–4.8	9.2 ± 0.1 9.2–9.3	1.8 ± 0.1 1.7–2.0	0.2	7.3 ± 0.1 7.2–7.4	10.8 ± 0.6 10.2–11.7

a = Large area analysis.

Table S3. EDS analysis data (at.%) of phases in the alloy JZ4 after oxidation at 800 °C for 100 h.

Phase	O	Nb	Ti	Si	Mo	W	Sn	Ge	Hf	Al	Cr
Oxide scale											
Mixed Si-rich oxide	70.8 ± 1.4 69.0–72.4	13.4 ± 0.8 12.1–14.1	3.2 ± 0.1 3.0–3.3	7.7 ± 0.8 6.6–8.8	1.3 ± 0.3 0.8–1.6	0.5	0.4	0.8 ± 0.5 0.3–1.4	0.3	0.9 ± 0.2 0.7–1.0	0.8 ± 0.1 0.7–1.0
Bulk											
Nb_5Si_3	–	45.0 ± 0.8 44.2–45.9	9.6 ± 0.1 9.5–9.8	28.1 ± 0.4 27.5–28.5	4.4 ± 0.3 3.9–4.6	1.4 ± 0.2 1.1–1.6	1.1 ± 0.1 0.9–1.2	6.4 ± 0.6 6.2–7.0	1.0 ± 0.1 0.8–1.1	1.9 ± 0.3 1.5–2.3	1.2 ± 0.2 0.9–1.4
Ti-rich Nb_5Si_3	–	39.9 ± 2.2 38.2–43.6	14.2 ± 1.6 11.5–15.4	20.1 ± 0.5 19.4–20.7	4.4 ± 0.1 4.2–4.6	1.0 ± 0.3 0.7–1.5	5.1 ± 0.9 3.7–6.1	5.9 ± 0.6 5.6–6.9	1.6 ± 0.2 1.3–1.9	4.9 ± 0.2 4.7–5.1	2.9 ± 0.6 2.0–3.6
TM_5Sn_2X	–	23.8	27.9	3.4	3.7	–	24.9	2.1	2.8	7.3	4.1
A15-Nb_3X	–	41.9 ± 1.5 39.7–43.0	11.6 ± 0.8 10.5–12.6	2.6 ± 0.4 2.1–3.0	14.2 ± 0.3 13.9–14.6	6.7 ± 0.4 6.2–7.3	8.6 ± 0.5 8.0–9.1	2.1 ± 0.2 1.9–2.3	0.5 ± 0.2 0.4–0.8	6.5 ± 0.4 5.9–6.8	5.4 ± 0.8 4.5–6.6

C14-Cr_2Nb	–	22.2 ± 0.3	7.4 ± 0.4	8.1 ± 0.6	4.8 ± 0.2	2.6 ± 0.2	0.6 ± 0.1	1.7 ± 0.2	2.9 ± 0.1	8.2 ± 1.0	41.6 ± 0.8
		21.6–22.5	7.0–8.1	7.3–8.9	4.7–5.1	2.2–2.8	0.5–0.8	1.5–2.1	2.8–3.1	7.2–9.8	40.4–42.4

Table S4. EDS analysis data (at.%) of phases in the alloy JZ5 after oxidation at 800 °C for 100 h.

Phase	O	Nb	Ti	Si	Mo	W	Sn	Ge	Hf	Al	Cr
Oxide scale											
Mixed Si-rich oxide	72.3 ± 1.0	10.5 ± 1.1	5.1 ± 0.3	7.1 ± 1.0	1.3 ± 0.2	0.3	0.5	1.5 ± 0.5	0.2	0.6	0.7
	71.4–74.0	8.7–11.4	4.8–5.7	5.2–7.7	1.0–1.4			1.1–2.3			
Bulk											
Nb_5Si_3	–	39.8 ± 0.2	15.7 ± 0.2	29.4 ± 0.5	4.8 ± 0.2	1.0 ± 0.1	1.0 ± 0.1	5.3 ± 0.2	0.7 ± 0.1	1.2 ± 0.2	1.0 ± 0.1
		39.4–40.0	15.5–15.9	29.3–29.8	4.6–5.2	0.9–1.1	0.7–1.1	5.1–5.6	0.6–0.8	1.1–1.4	0.9–1.1
Ti-rich Nb_5Si_3	–	33.7 ± 0.8	20.4 ± 0.4	19.7 ± 0.2	5.6 ± 0.3	0.9 ± 0.1	5.7 ± 0.3	5.5 ± 0.2	1.1 ± 0.1	4.8 ± 0.2	2.5 ± 0.4
		32.5–34.3	20.1–21.0	19.5–19.9	5.3–6.1	0.7–1.0	5.3–6.2	5.3–5.7	0.8–1.2	4.6–5.1	2.3–3.1
T1-Mo_5Sn_2X	–	12.5	37.1	4.2	3.6	–	25.1	2.8	1.6	8.1	5
A15-Nb_3X	–	32.2 ± 0.3	18.3 ± 0.3	2.7 ± 0.2	16.6 ± 0.2	5.4 ± 0.1	9.4 ± 0.1	2.0 ± 0.4	0.3 ± 0.1	6.6 ± 0.1	6.4 ± 0.2
		31.6–32.5	17.9–18.8	2.5–2.9	16.5–16.9	5.3–5.5	9.3–9.5	1.6–2.5	0.1–0.4	6.5–6.8	6.2–6.7
C14-Cr_2Nb	–	20.0 ± 0.3	10.9 ± 0.4	8.3 ± 0.4	5.2 ± 0.2	2.5 ± 0.2	0.7 ± 0.1	1.3 ± 0.2	1.6 ± 0.1	8.4 ± 0.7	41.2 ± 0.4
		19.4–20.2	10.4–11.4	8.0–8.9	5.0–5.5	2.3–2.7	0.6–0.9	1.1–1.6	1.5–1.8	7.7–9.4	40.5–41.5

Table S5. EDS analysis data (at.%) of phases in the alloy JZ4 after oxidation at 1200 °C for 100 h.

	Phase	O	Nb	Ti	Si	Mo	W	Sn	Ge	Hf	Al	Cr
Oxide scale	Nb-rich oxide	74.2 ± 0.4	19.7 ± 0.5	2.9 ± 0.1	0.7	0.2	1.0 ± 0.1	–	–	0.3	0.7	0.2
		73.5–74.6	19.0–20.5	2.8–3.1			1.0–1.1					
	Ti-rich oxide	71.7 ± 0.3	9.6 ± 0.5	8.5 ± 0.6	1.0 ± 0.7	1.2 ± 1.0	–	–	0.3	0.5	3.4 ± 0.1	3.7 ± 0.6
		71.0–71.9	8.9–10.2	7.6–9.1	0.3–2.1	0.4–2.8					3.3–3.6	2.8–4.2
Diffusion zone	Nb_5Si_3	–	44.0 ± 0.5	10.3 ± 0.1	24.7 ± 0.5	4.9 ± 0.2	1.3 ± 0.3	2.6 ± 0.1	6.3 ± 0.2	1.0 ± 0.2	3.3 ± 0.5	1.6 ± 0.2
			43.3–44.5	10.2–10.5	24.1–25.4	4.7–5.1	0.8–1.6	2.5–2.8	6.1–6.4	0.7–1.1	2.7–3.7	1.4–2.0
	$Nb_5(Si,Ge)_3$	–	42.5 ± 2.2	9.0 ± 1.0	13.2 ± 1.0	7.3 ± 0.7	0.3	9.7 ± 3.1	11.5 ± 2.0	0.3	2.7 ± 0.3	3.4 ± 0.2
			39.2–45.3	7.7–10.3	11.9–14.7	6.4–8.1		7.2–14.6	8.8–13.5		2.5–3.2	3.1–3.6

	$Nb_5(Si,Ge)_3$	–	42.9 ± 2.6 39.4–45.0	8.5 ± 0.9 7.7–9.7	11.8 ± 5.0 7.2–17.4	7.9 ± 1.6 6.2–9.7	1.5 ± 0.7 0.5–2.0	–	23.8 ± 4.8 18.4–28.0	0.8 ± 0.3 0.4–1.1	0.5 ± 0.1 0.4–0.6	2.4 ± 0.6 1.5–3.0
	A15-Nb_3X	–	41.7 ± 1.1 40.2–43.2	4.1 ± 0.1 4.0–4.2	1.5 ± 0.1 1.4–1.7	21.9 ± 1.1 20.5–23.2	2.5 ± 0.2 2.2–2.8	20.0 ± 0.7 19.1–20.9	2.1 ± 0.5 1.4–2.9	–	1.1 ± 0.3 0.7–1.4	5.3 ± 0.3 4.8–5.7
	$(Nb,W)_{ss}$	–	16.5 ± 2.3 14.0–19.8	1.7 ± 0.7 0.8–2.8	0	29.3 ± 2.7 26.7–32.6	43.3 ± 3.6 38.9–47.8	0.8 ± 0.4 0.4–1.3	2.6 ± 0.4 2.1–3.1	0.2	0.9 ± 0.3 0.6–1.4	4.8 ± 0.4 4.5–5.4
Bulk	Nb_5Si_3	–	44.4 ± 0.2 44.2–44.7	10.3 ± 0.2 10.0–10.7	24.9 ± 0.9 24.6–25.0	4.9 ± 0.3 4.3–5.0	1.6 ± 0.1 1.5–1.8	2.1 ± 0.1 2.0–2.3	6.2 ± 0.5 5.4–6.4	1.0 ± 0.2 0.8–1.2	3.0 ± 0.2 2.7–3.2	1.6 ± 0.1 1.4–1.7
	Ti-rich Nb_5Si_3	–	36.1 ± 2.0 33.0–39.2	19.4 ± 2.1 15.7–21.6	13.9 ± 2.3 11.6–17.7	3.6 ± 0.5 2.8–4.1	0.4	11.5 ± 2.3 7.9–13.5	5.0 ± 0.4 4.5–5.7	2.0 ± 0.3 1.6–2.3	5.5 ± 0.3 5.3–5.9	2.6 ± 0.3 2.0–2.9
	A15-Nb_3X	–	40.8 ± 0.7 39.8–41.4	10.2 ± 0.3 9.9–10.4	2.2 ± 0.3 1.8–2.6	15.3 ± 0.6 14.3–15.8	7.7 ± 0.2 7.5–8.0	8.8 ± 0.4 8.4–9.5	1.8 ± 0.4 1.2–2.2	0.3	7.3 ± 0.3 7.0–7.7	5.7 ± 0.2 5.5–6.0
	$(Nb,W)_{ss}$	–	23.9 ± 0.8 23.0–24.6	5.1 ± 0.3 4.6–5.4	0	24.0 ± 0.5 23.5–24.6	33.5 ± 1.3 31.6–35.1	0.6	1.6 ± 0.7 0.7–2.1	0.3	1.7 ± 0.2 1.4–1.9	9.2 ± 1.3 7.4–10.9
	C14-Cr_2Nb	–	26.8 ± 0.7 25.9–27.9	4.7 ± 0.2 4.5–5.0	10.5 ± 0.3 10.2–11.0	3.9 ± 0.2 3.6–4.1	3.1 ± 0.5 2.5–4.0	0.5	1.4 ± 0.2 1.2–1.6	1.8 ± 0.2 1.5–2.1	5.1 ± 0.2 4.9–5.3	42.1 ± 0.6 41.3–43.0

Table S6. EDS analysis data (at.%) of phases in the alloy JZ5 after oxidation at 1200 °C for 100 h.

	Phase	**O**	**Nb**	**Ti**	**Si**	**Mo**	**W**	**Sn**	**Ge**	**Hf**	**Al**	**Cr**
Oxide scale	Nb-rich oxide	74.7 ± 1.1 73.4–76.1	17.6 ± 1.9 15.4–18.9	4.8 ± 0.5 4.0–5.2	0.9 ± 0.7 0–1.4	–	0.4	–	–	0.3	1.0 ± 0.4 0.5–1.4	0.2
	Ti-rich oxide	72.5 ± 0.7 71.5–73.6	8.0 ± 1.1 6.7–9.6	11.9 ± 1.7 10.4–14.6	0.7	–	–	0.2	–	0.4	3.9 ± 0.5 3.3–4.5	2.3 ± 0.4 1.9–2.8
Diffusion zone	Nb_5Si_3	–	40.8 ± 0.2 40.4–41.0	17.4 ± 0.3 17.1–17.9	29.4 ± 0.4 28.9–30.0	5.2 ± 0.2 5.0–5.5	1.1 ± 1.3 1.1–1.3	1.3 ± 0.1 1.2–1.5	1.0 ± 0.3 0.7–1.4	0.7	1.5 ± 0.2 1.3–1.8	1.4 ± 0.2 1.2–1.7
	$Nb_5(Si,Sn)_3$	–	31.6 ± 1.4 30.3–33.5	20.3 ± 1.8 17.4–21.7	13.2 ± 1.9 11.1–16.0	5.8 ± 0.3 5.6–6.3	0.2	16.9 ± 1.5 15.0–19.0	4.4 ± 0.5 3.8–5.3	0.8 ± 0.2 0.6–1.0	2.3 ± 0.6 1.2–2.8	4.5 ± 0.2 4.1–4.7
	$Nb_5(Si,Ge)_3$	–	46.6 ± 1.5 44.4–47.8	3.3 ± 0.9 2.5–4.5	17.5 ± 4.6 10.8–23.3	10.3 ± 1.7 8.6–12.6	1.7 ± 0.3 1.4–2.3	0.3	16.7 ± 4.1 11.2–22.7	0.3	0.9 ± 0.5 0.4–1.5	2.4 ± 0.6 1.8–3.3
	A15-Nb_3X	–	30.9 ± 1.6	9.9 ± 0.6	1.1 ± 0.2	25.2 ± 0.8	3.9 ± 0.7	19.2 ± 0.7	1.3 ± 0.1	–	1.4 ± 0.6	7.1 ± 0.4

			28.3–32.6	9.3–10.7	0.9–1.3	24.2–26.3	3.0–4.9	18.4–20.2	1.1–1.4		0.8–2.4	6.8–7.7
	$(Nb,W)_{ss}$	–	12.7 ± 1.2	3.6 ± 0.6	–	31.5 ± 0.8	39.1 ± 1.3	1.0 ± 0.7	2.2 ± 0.4	0.3	1.6 ± 0.6	8.1 ± 0.9
			11.5–14.5	2.8–4.4		30.9–32.8	38.0–41.0	0.1–1.9	1.9–2.7		0.9–2.6	7.5–9.4
Bulk	Nb_5Si_3	–	39.0 ± 0.8	16.2 ± 0.5	28.1 ± 0.6	5.2 ± 0.2	0.8 ± 0.1	1.3 ± 0.2	5.6 ± 0.4	0.8 ± 0.1	1.6 ± 0.2	1.4 ± 0.1
			37.9–40.0	15.6–16.9	27.4–28.8	5.0–5.4	0.7–0.9	1.1–1.6	5.1–5.9	0.7–0.8	1.5–2.0	1.3–1.6
	Ti-rich Nb_5Si_3	–	28.2 ± 2.6	26.7 ± 3.1	13.9 ± 2.6	4.2 ± 0.8	0.2	11.8 ± 2.9	5.0 ± 0.5	1.2 ± 0.1	5.9 ± 0.3	2.9 ± 0.8
			25.6–32.3	25.8–29.9	10.8–17.7	3.4–5.3		7.7–14.8	4.3–5.7	1.0–1.4	5.4–6.2	2.1–3.7
	A15-Nb_3X	–	27.1 ± 0.9	18.6 ± 0.9	1.4 ± 0.3	19.9 ± 0.8	4.2 ± 0.5	10.6 ± 0.3	1.4 ± 0.3	0.2	8.9 ± 0.3	7.6 ± 1.1
			25.9–28.1	17.7–19.8	1.1–1.9	18.8–20.9	3.6–4.9	10.3–11.2	1.2–1.8		8.5–9.2	6.4–9.0
	$(Nb,W)_{ss}$	–	19.5 ± 0.8	9.7 ± 0.5	–	27.9 ± 0.7	30.0 ± 2.0	1.6 ± 0.6	2.0 ± 0.4	0.4	2.2 ± 0.4	6.8 ± 0.5
			18.4–20.6	9.2–10.2		27.1–28.8	27.7–31.6	1.1–2.3	1.5–2.6		1.8–2.8	6.3–7.3
	C14-Cr_2Nb	–	22.9 ± 0.4	7.8 ± 0.3	8.7 ± 0.3	4.6 ± 0.1	3.3 ± 0.1	0.4	1.0 ± 0.1	1.3 ± 0.1	7.0 ± 0.5	43.0 ± 0.4
			22.5–23.4	7.2–8.1	8.5–9.2	4.5–4.6	3.1–3.5		0.9–1.1	1.2–1.5	6.1–7.3	42.4–43.2

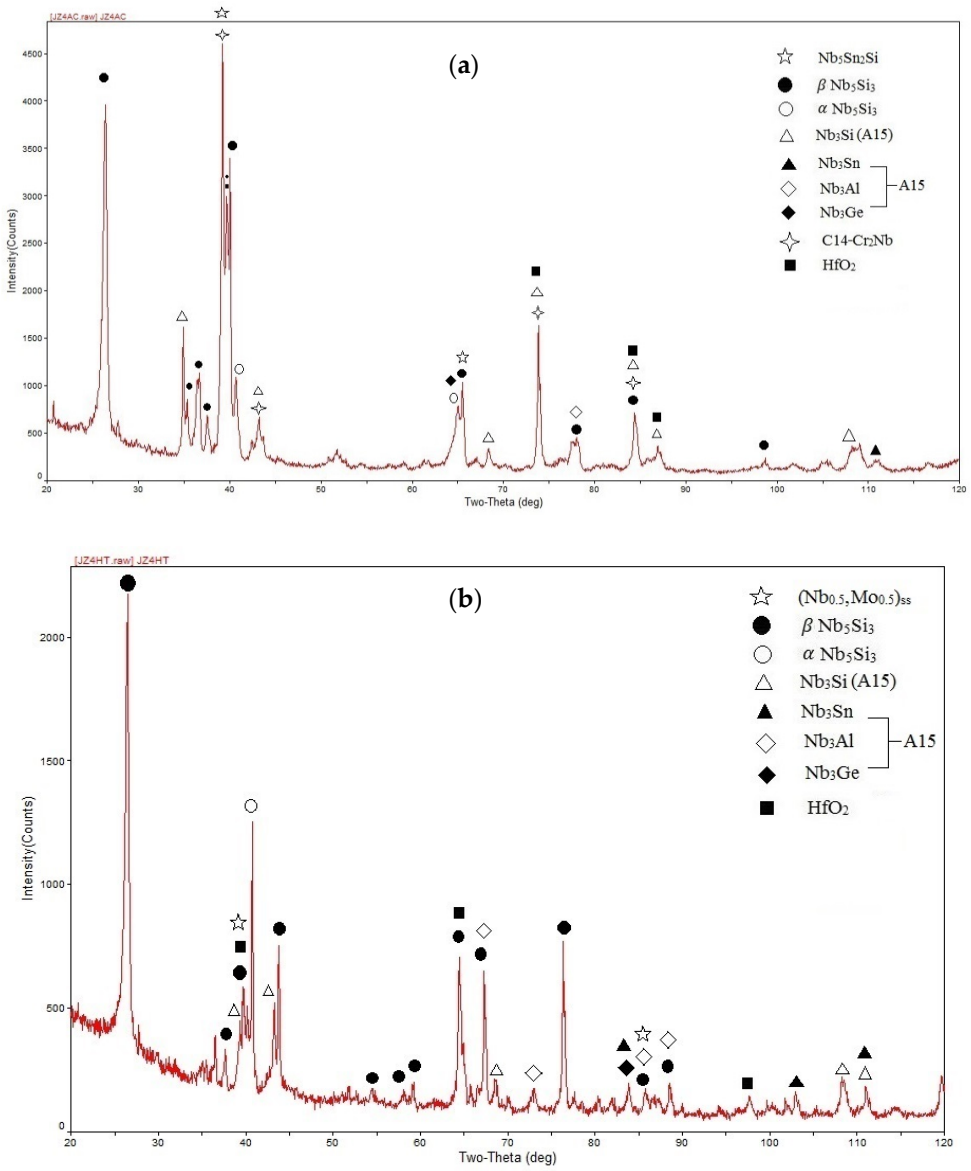

Figure S1. X–ray diffractograms of the (**a**) as cast and (**b**) heat treated alloy JZ4.

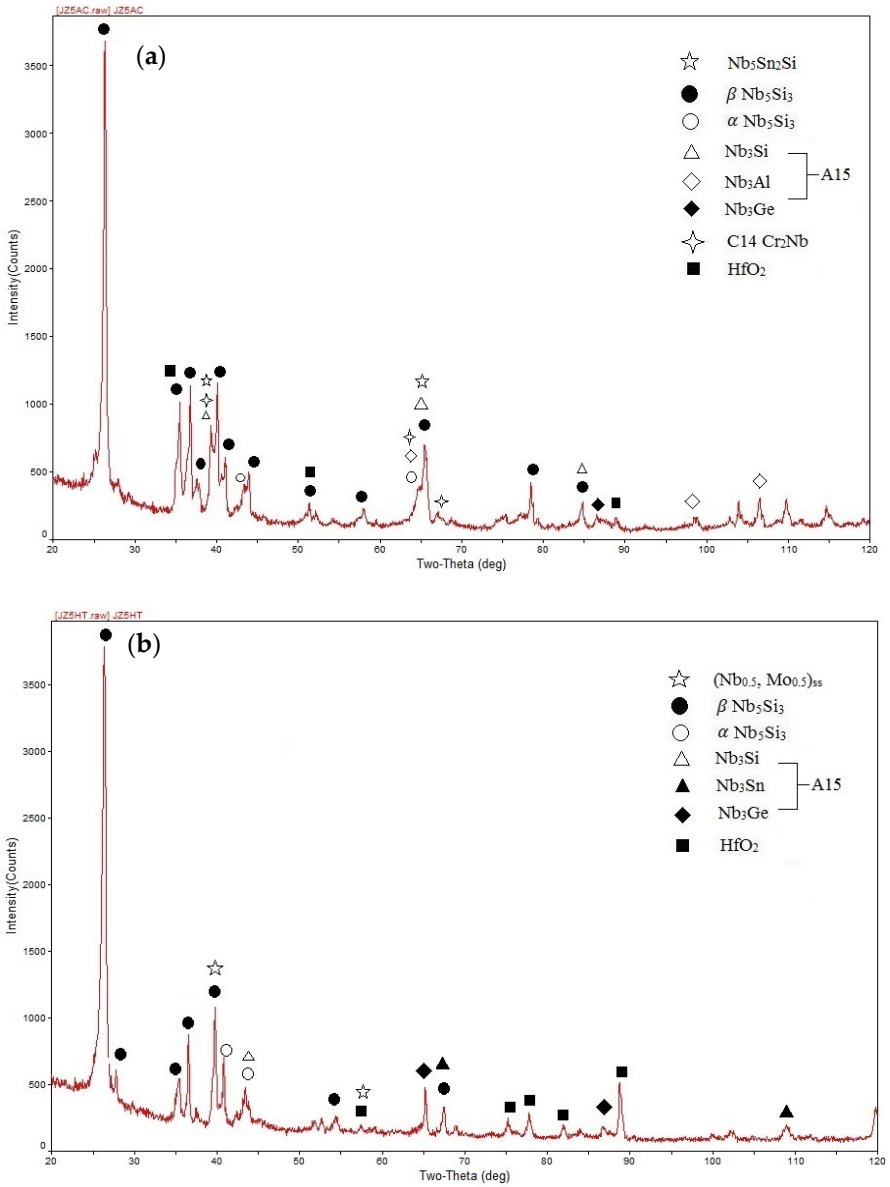

Figure S2. X–ray diffractograms of the (**a**) as cast and (**b**) heat treated alloy JZ5.