ELSEVIER

Journal of Alloys and Compounds 234 (1996) 143–150

Journal of ALLOYS AND COMPOUNDS

Phase equilibria in the Sm–{Ru,Rh}–{Si,Ge} systems at 870 K

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Received 23 March 1995; in final form 31 May 1995

Abstract

Physico-chemical analysis techniques, including X-ray phase analysis and electron probe X-ray analysis were employed in constructing the isothermal cross-section of the phase diagrams Sm–{Ru,Rh}–{Si,Ge} systems at 870 K.

The formation of the new ternary intermetallic compounds, Sm_2RuGe_2, Sm_2RhGe_2 (structure type Zr_2CoSi_2); $Sm_3Ru_2Si_2$, $Sm_3Rh_2Si_2$, $Sm_3Rh_2Ge_2$ (structure type $La_3Ni_2Ga_2$); $SmRh_5Si_3$, $SmRh_5Ge_3$ (structure type UCo_5Si_3); $Sm_2Ru_3Si_5$ (structure type $Sc_2Fe_3Si_5$); $SmRu_3Si_2$ (structure type $LaRu_3Si_2$); $SmRuSi_3$ (structure type $BaAl_4$); $Sm_{33}Rh_{20}Ge_{47}$ (structure type AlB_2); $Sm_{25}Rh_{19}Ge_{56}$ (structure type $CeRh_{1-x}Ge_{2+x}$); Sm_2RhGe_6 (structure type Ce_2CuGe_6) and $Sm_{62}Ru_{28}Ge_{10}$, $SmRu_3Si$, Sm_2RuSi_2, $Sm_{62}Ru_{10}Si_{28}$, $Sm_{33}Rh_{50}Si_{17}$, $Sm_{16}Rh_{68}Si_{16}$, $SmRh_3Si_6$, $Sm_{37}Rh_{35}Si_{28}$, Sm_2RhSi_2, Sm_4Rh_4Si, $Sm_{33}Rh_{53}Ge_{14}$, $SmRh_2Ge$, $Sm_{18}Rh_{64}Ge_{18}$, $SmRh_3Ge_6$, were detected in Sm–(Ru,Rh)–(Si,Ge) systems.

It was found that compound SmRuSi does not belong to the structure type PbFCl. Ternary compound SmRuGe was not found in Sm–Ru–Ge system at 870 K.

Keywords: Phase diagrams; Ternary systems; Sm–Ru–Ge; Sm–Ru–Si; Sm–Rh–Ge; Sm–Rh–Si; Intermetallic compounds; Crystal structure

1. Introduction

The purpose of this work was to study phase equilibria in the Sm–{Ru,Rh}–{Si,Ge} systems at 870 K.

The interaction between the components in {Ru,Rh}–{Si,Ge}, Sm–{Si,Ge} and Sm–{Ru,Rh} binary systems have been studied in detail in Refs. [1–44]. Ternary compounds of Sm–Ru–Ge system $SmRu_2Ge_2$, $Sm_2Ru_3Ge_5$, $Sm_3Ru_4Ge_{13}$ and $Sm_3Ru_2Ge_2$ have been studied in detail in Refs. [1,45–49]. A ternary compounds of Sm–Ru–Si system $SmRu_2Si_2$ and SmRuSi have been studied in detail in refs. [1,49–52]. Ternary compounds of Sm–Rh–Si system $SmRh_3Si_2$, $SmRh_2Si_2$, $Sm_2Rh_3Si_5$, $SmRhSi_3$, $SmRhSi_2$ and Sm_2RhSi_3 have been studied in detail in Refs. [1,52–56]. Ternary compounds of Sm–Rh–Ge system $SmRh_2Ge_2$, $Sm_2Rh_3Ge_5$, $Sm_3Rh_4Ge_{13}$ and SmRhGe have been studied in detail in refs. [1,45,46,57–59].

2. Experimental details

The present study was carried out on about 40 alloys for the Sm–Ru–Ge system, about 50 alloys for the Sm–Ru–Si system, about 90 alloys for the Sm–Rh–Si system and about 70 alloys for the Sm–Rh–Ge system. The mass of each sample was 1 g. The alloys were made in an electric arc furnace under an argon atmosphere using a non-consumable tungsten electrode and water-cooled copper tray. Germanium (purity, 99.99%), silicon (purity, 99.99%), ruthenium (purity, 99.99%), rhodium (purity, 99.99%) and samarium (purity, 99.98%) were used as starting components. Titanium was used as a getter in melting. The alloys were remelted twice in order to achieve complete fusion and homogeneous composition. Alloys with losses after melting not exceeding ± 2 wt.% were chosen for the experiments. All melted alloys were subjected to an homogenizing anneal in evacuated double quartz ampoules containing titanium chips as a getter; the ampoules were placed in resistance furnaces. The alloys were annealed at 870 K for 1000 h. All samples were quenched from 870 K in ice-cold

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SSDI 0925-8388(95)01916-2

water. The phase equilibria in the Sm–{Ru,Rh}–{Si,Ge} system was determined using X-ray phase analysis and electron probe X-ray analysis. X-ray phase analyses were obtained on a DRON-3.0 (Cu Kα radiation, $2\vartheta = 20$–$100°$). The diffractograms obtained were identified and calculated using the CSD-programs [60] on an IBM PC AT/286 computer. A 'Camebax' micro-analyser was employed to perform local X-ray spectral analyses of samples using Ge Kα, Si Kα, Ru Kα, Rh Kα and Sm Kα lines. The accuracy of the measurement was 2.5–3% relative.

3. Results and discussion

The following intermetallic compounds were found in the binary systems bounding the ternary systems at 870 K: RuGe, Ru_2Ge_3, RhGe, Rh_2Ge, $Rh_{17}Ge_{22}$, Rh_5Ge_3, Ru_2Si_3, RuSi, Ru_4Si_3, Ru_2Si, Rh_3Si_4, Rh_4Si_5, RhSi, $Rh_{20}Si_{13}$, Rh_5Si_3, Rh_2Si (Table 1); $SmGe_{1.63}$, Sm_2Ge_3, SmGe, Sm_5Ge_4, Sm_5Ge_3, $SmSi_2$, Sm_3Si_5, SmSi, Sm_5Si_4, Sm_5Si_3 (Table 2) and Sm_3Ru, Sm_5Ru_2, $Sm_{44}Ru_{25}$, $SmRu_2$, Sm_4Rh, Sm_7Rh_3, Sm_3Rh_2, Sm_5Rh_4, SmRh, $SmRh_2$ (Table 3).

3.1. Sm–Ru–Ge system

The results obtained were used in the construction of the isothermal cross-section of the Sm–Ru–Ge phase diagram at 870 K presented in Fig.1.

It was found that the system contains extended regions of ternary solid solution based on $SmRu_2$ and $SmGe_{1.63}$. The lattice parameters is given in Tables 2 and 3.

The following ternary intermetallic compounds were found in the system Sm–Ru–Ge at 870 K: $SmRu_2Ge_2$, $Sm_2Ru_3Ge_5$, $SmRuGe_3$, $Sm_3Ru_2Ge_2$ and two new compounds Sm_2RuGe_2, $Sm_{62}Ru_{10}Ge_{28}$. The lattice parameters are given in Table 4. It was found that the structure of the new compound Sm_2RuGe_2 belonged to the structure type Zr_2CoSi_2: space group $B2/m$, $a = 1.0713(5)$ nm, $b = 1.114(1)$ nm, $c = 0.413(1)$ nm, $\gamma = 129.3°$. (Calculations of the powder diffractogram used 160 reflections, $R = 0.12$ in the isotropic approximation.) It was found that the Sm atom replaces the Ge

Table 1
Crystallographic data of binary compounds in system {Ru,Rh}–{Si,Ge}

Compound	Space group	Structure type	Lattice parameters (nm)			Refs.
			a	*b*	*c*	
RuGe[a]	$P2_13$	FeSi	0.4846	—	—	[1,2]
Ru_2Ge_3 (HT)	$P4c2$	Ru_2Sn_3	0.5739	—	0.9952	[1]
Ru_2Ge_3[a] (LT)	*Pbcn*	Ru_2Si_3	1.1436	0.9238	0.5716	[1]
RhGe[a]	*Pnma*	MnP	0.570	0.325	0.648	[1,3]
RhGe (HP)	$P2_13$	FeSi	0.4862	—	—	[1,4]
Rh_2Ge[a]	*Pnma*	Co_2Si	0.544	0.400	0.757	[1,3]
$Rh_{17}Ge_{22}$[a]	$I\bar{4}2d$	$Rh_{17}Ge_{22}$	0.5604	—	7.845	[1,5]
Rh_5Ge_3[a]	*Pbam*	Rh_5Ge_3	1.032	0.542	0.396	[1,3]
Ru_2Si_3[a]	*Pbcn*	Ru_2Si_3	1.1057	0.8934	0.5533	[1,6]
Ru_2Si_3	tetr.		1.1075	—	0.8954	[1,7]
RuSi[a] (HT)	*Pm3m*	CsCl	0.2909	—	—	[1,12]
RuSi	$P2_13$	FeSi	0.4703	—	—	[1,11]
Ru_4Si_3[a]	*Pnma*	Rh_4Si_3	0.51936	0.40216	1.7343	[1,8]
Ru_5Si_3	*Pbam*	Rh_5Ge_3	0.5246	0.9815	0.4023	[1,9]
Ru_2Si[a]	*Pnma*	Co_2Si	0.5279	0.4005	0.7418	[1,10]
Rh_3Si_4[a]	*Pnma*	Rh_3Si_4	1.881	0.3614	0.5813	[1,17]
Rh_4Si_5[a]	$P2_1/m$	Rh_4Si_5	1.2335	0.3508 $\beta = 100.18°$	0.5924	[1,18]
RhSi[a]	$P2_13$	FeSi	0.4674	—	—	[1,14]
RhSi	*Pm3m*	CsCl	0.2963	—	—	[1,13]
RhSi	*Pnma*	MnP	0.5531	0.3063	0.6362	[1]
Rh_3Si_2 (HT)	$P6_3/mmc$	$InNi_2$	0.3949	—	0.5047	[1]
$Rh_{20}Si_{13}$[a]	$P6_3/m$	$Rh_{20}Si_{13}$	1.1851	—	0.3623	[1,16]
Rh_5Si_3[a]	*Pbam*	Rh_5Ge_3	0.5317	1.0131	0.3895	[1,15]
Rh_2Si[a]	*Pnma*	Co_2Si	0.5408	0.393	0.7383	[1,15]

[a] Compound belongs to isothermal cross-section at 870 K.

Table 2
Crystallographic data of binary compounds in system Sm–{Si,Ge}

Compound	Space group	Structure type	Lattice parameters (nm)			Refs.
			a	*b*	*c*	
Sm_5Ge_3[a]	*P6₃/mcm*	Mn_5Si_3	0.866	—	0.649	[1,20]
Sm_5Ge_4[a]	*Pnma*	Sm_5Ge_4	0.774	1.495	0.784	[1,21]
SmGe[a]	*Cmcm*	CrB	0.4374	1.0885	0.3996	[1,22]
α-Sm_2Ge_3[a] (LT)	*P6/mmm*	AlB_2	0.4005	—	0.4250	[23]
β-Sm_2Ge_3 (HT1)	...	...	...	...	...	[23]
γ-Sm_2Ge_3 (HT2)	...	...	...	...	...	[23]
$SmGe_2$	*I41/amd*	α-$ThSi_2$	0.4183	—	1.3810	[1,36]
$SmGe_{1.63}$[a]	*I4₁/amd*	α-$ThSi_2$	0.412	—	1.396	[23–25]
$Sm_{38}Ru_{0-5}Ge_{62-57}$[a]	*I4₁/amd*	α-$ThSi_2$	0.4170(1)–	—	1.3789(2)–	—[b]
			0.4121(1)	—	1.385(1)	—[b]
$SmSi_2$ (HT)	*I4₁/amd*	α-$ThSi_2$	0.4041	—	1.3330	[26,27]
Sm_2Si_3 (HT)	*I41/amd*	α-$ThSi_2$	0.408	—	1.351	[1,37]
$SmSi_2$[a]	*Immb*	α-$GdSi_2$	0.4105	0.4035	1.3460	[28,29]
Sm_3Si_5[a]	*P6/mmm*	AlB_2	0.3903	—	0.4207	[1,29–31]
SmSi[a]	*Pnma*	FeB	0.8055	0.3888	0.5804	[1,32,33]
Sm_5Si_4[a]	*Pnma*	Sm_5Ge_4	0.7570	1.4880	0.7780	[1,32]
Sm_5Si_3[a]	*P6₃/mcm*	Mn_5Si_3	0.8560	—	0.6450	[1,34]

[a] Compound belongs to isothermal cross-section at 870 K.
[b] Data of present analysis.

Table 3
Crystallographic data of binary compounds in system Sm–{Ru,Rh}

Compounc	Space group	Structure type	Lattice parameters (nm)			Refs.
			a	*b*	*c*	
$SmRu_2$[a]	*Fd3m*	$MgCu_2$	0.7577	—	—	[1,38]
$SmRu_2$[a]	*Fd3m*	$MgCu_2$	0.7530(3)	—	—	—[b]
$Sm_{33}Ru_{67-35}Ge_{0-12}$[a]	*Fd3m*	$MgCu_2$	0.7530(3)–	—	—	—[b]
			0.7537(3)	—	—	—[b]
$Sm_{33}Ru_{67-50}Si_{0-17}$[a]	*Fd3m*	$MgCu_2$	0.7530(3)–	—	—	—[b]
			0.7484(1)	—	—	—[b]
$SmRu_2$	*P6₃/mmc*	$MgZn_2$	0.5282	—	0.8854	[1,38]
$Sm_{44}Ru_{25}$[a]	*Pnma*	$Y_{44}Ru_{25}$	...	...	...	[39]
Sm_5Ru_2[a]	*C2/c*	Mn_5C_2	1.6083	0.6438 $\beta = 96.89$	0.7314	[1,40]
Sm_3Ru[a]	*Pnma*	Fe_3C	0.733	0.9508	0.6361	[1,40]
Sm_4Rh[a]	*Pnma*	Fe_3C	0.7245	0.9675	0.6368	[1,43]
Sm_7Rh_3[a]	*P6₃mc*	Th_7Fe_3	0.9893	—	0.6245	[1,43]
Sm_3Rh_2[a]	*R3*	Er_3Ni_2	0.8701	—	1.6526	[1,41]
Sm_5Rh_4[a]	*Pnma*	Sm_5Ge_4	0.7335	1.467	0.7557	[1,42]
SmRh[a]	*Pm3m*	CsCl	0.3466	—	—	[1,43]
$SmRh_2$[a]	*Fd3m*	$MgCu_2$	0.7540	—	—	[1,44]
$SmRh_2$[a]	*Fd3m*	$MgCu_2$	0.7522(1)	—	—	—[b]
$Sm_{33}Rh_{67-35}Si_{0-12}$[a]	*Fd3m*	$MgCu_2$	0.7522(1)–	—	—	—[b]
			0.7489(2)	—	—	—[b]
$Sm_{33}Rh_{67-57}Ge_{0-10}$[a]	*Fd3m*	$MgCu_2$	0.7522(1)–	—	—	—[b]
			0.7524(1)	—	—	—[b]
$SmRh_3$	*P6₃/mmc*	$CeNi_3$	0.5255	—	1.746	[1,43]

[a] Compound belongs to isothermal cross-section at 870 K.
[b] Data of present analysis.

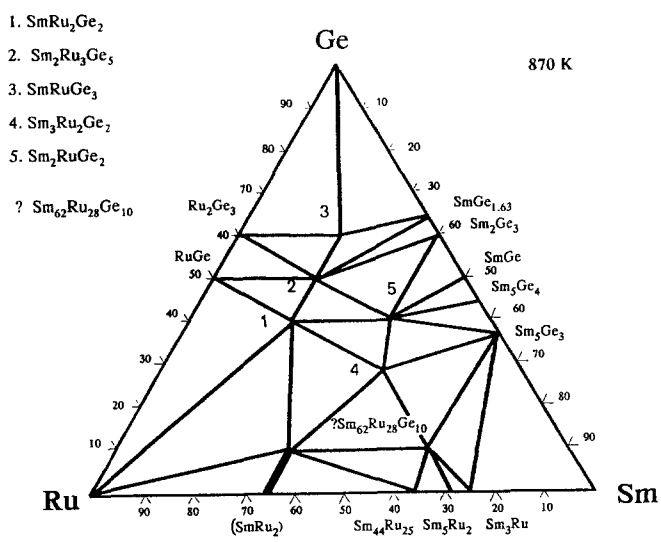

Fig. 1. Isothermal cross-section of Sm–Ru–Ge system at 870 K.

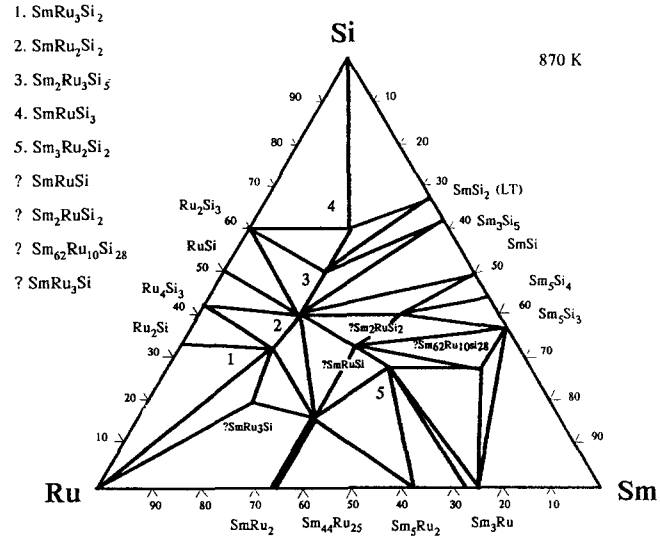

Fig. 2. Isothermal cross-section of Sm–Ru–Si system at 870 K.

atom in position (0,0,0) in the compound $Sm_3Ru_4Ge_{13}$ that belongs to the structure type $Y_3Co_4Ge_{13}$, because the composition of this compound is 60at.% Ge–20at.%Ru–20at.%Sm ($SmRuGe_3$) in the present cross-section.

3.2. Sm–Ru–Si system

The results obtained were used in the construction of the isothermal cross-section of the Sm–Ru–Si phase diagram at 870 K presented in Fig. 2.

It was found that the system contains an extended region of ternary solid solution based on $SmRu_2$.The lattice parameters is given in Table 3.

The following ternary intermetallic compounds were found in the system Sm–Ru–Si at 870 K: $SmRu_2Si_2$, SmRuSi and seven new compounds $SmRu_3Si_2$, $Sm_2Ru_3Si_5$, $SmRuSi_3$, $Sm_3Ru_2Si_2$, $SmRu_3Si$, Sm_2RuSi_2 and $Sm_{62}Ru_{10}Ge_{28}$. The lattice parameters are given in Table 5.

It was found that the structure of new compound $Sm_2Ru_3Si_5$ belonged to the structure type $Sc_2Fe_3Si_5$: space group $P4/mnc$, $a = 1.0711(3)$ nm, $c = 0.5676(3)$ nm. (Calculations of the powder diffractogram using 50 reflections, $R = 0.14$ in the isotropic approximation.) It was found that structure of the new compound $SmRu_3Si_2$ belonged to the structure type $LaRu_3Si_2$: space group $P6_3/m$, $a = 0.5566(2)$ nm, $c = 0.7126(2)$ nm. (Calculations of the powder diffractogram using 40 reflections, $R = 0.12$.) It was found that the structure of new compound $SmRuSi_3$ belonged to the structure type $BaAl_4$: space group $I4/mmm$, $a = 0.4076(1)$ nm,

Table 4
Crystallographic data of ternary compounds in system Sm–Ru–Ge

	Compound	Space group	Structure type	Lattice parameters (nm)			Refs.
				a	*b*	*c*	
1.	$SmRu_2Ge_2$[a]	*I4/mmm*	$CeGa_2Al_2$	0.4236	—	0.9944	[45]
				0.4237(2)	—	0.9918(4)	—[b]
2.	$Sm_2Ru_3Ge_5$[a]	*Ibam*	$U_2Co_3Si_5$	0.9867	1.244	0.579	[46]
				0.9885(9)	1.2403(9)	0.5778(5)	—[b]
3.	$Sm_3Ru_4Ge_{13}$	*Pm3n*	$Y_3Co_4Ge_{13}$	0.9020	—	—	[47]
	$SmRuGe_3$[a]	*Pm3n*	$Y_3Co_4Ge_{13}$	0.9012(2)	—	—	—[b]
4.	$Sm_3Ru_2Ge_2$[a]	*Pbcm*	$La_3Ni_2Ga_2$	0.5611	0.7818	1.3473	[48]
				0.5595(2)	0.7799(4)	1.3527(6)	—[b]
5.	Sm_2RuGe_2[a]	*B2/m*	Zr_2CoSi_2	1.0713(5)	1.114(1) $\gamma = 129.3$	0.413(1)	—[b]
	SmRuGe	*P4/nmm*	PbFCl	0.4244	...	0.6711	[49]
	$Sm_{62}Ru_{28}Ge_{10}$[a,c]	...	...	...	...	...	—[b]

[a] Compound belongs to isothermal cross-section at 870 K.
[b] Data of present analysis.
[c] Compound with unknown structure type.

Table 5
Crystallographic data of ternary compounds in system Sm–Ru–Si

	Compound	Space group	Structure type	Lattice parameters (nm)			Refs.
				a	*b*	*c*	
1.	$SmRu_3Si_2$[a]	$P6_3/m$	$LaRu_3Si_2$	0.5566(2)	—	0.7126(2)	—[b]
2.	$SmRu_2Si_2$[a]	$I4/mmm$	$BaAl_4$	0.4178	—	0.971	[50–52]
				0.4164(2)	—	0.9663(6)	—[b]
3.	$Sm_2Ru_3Si_5$[a]	$P4/mnc$	$Sc_2Fe_3Si_5$	1.0711(3)	—	0.5676(3)	—[b]
4.	$SmRuSi_3$[a]	$I4/mmm$	$BaAl_4$	0.4076(1)	—	0.9879(1)	—[b]
5.	$Sm_3Ru_2Si_2$[a]	$Pbcm$	$La_3Ni_2Ga_2$	0.5604(4)	0.7665(5)	1.3419(7)	—[b]
	SmRuSi	$P4/nmm$	PbFCl	0.4183	...	0.6686	[49]
	$SmRuSi$[a,c]	...	...	...	...	...	—[b]
	$SmRu_3Si$[a,c]	...	...	...	...	...	—[b]
	Sm_2RuSi_2[a,c]	...	...	...	...	...	—[b]
	$Sm_{62}Ru_{10}Si_{28}$[a,c]	...	...	...	...	...	—[b]

[a] Compound belongs to isothermal cross-section at 870 K.
[b] Data of present analysis.
[c] Compound with unknown structure type.

$c = 0.9879(1)$ nm. (Calculations of the powder diffractogram using 17 reflections, $R = 0.14$.) It was found that the structure of new compound $Sm_3Ru_2Si_2$ belonged to the structure type $La_3Ni_2Ga_2$: space group *Pbcm*, $a = 0.5604(4)$ nm, $b = 0.7665(5)$ nm, $c = 1.3419(7)$ nm. (Calculations of the powder diffractogram using 80 reflections, $R = 0.12$). Compound SmRuSi was found in the Sm–Ru–Si system, but it was found that SmRuSi [49] did not belong to the structure type PbFCl (Comparison between experimental and calculated powder diffractograms).

3.3. Sm–Rh–Si system

The results obtained were used in the construction of the isothermal cross-section of the Sm–Rh–Si phase diagram at 870 K presented in Fig. 3.

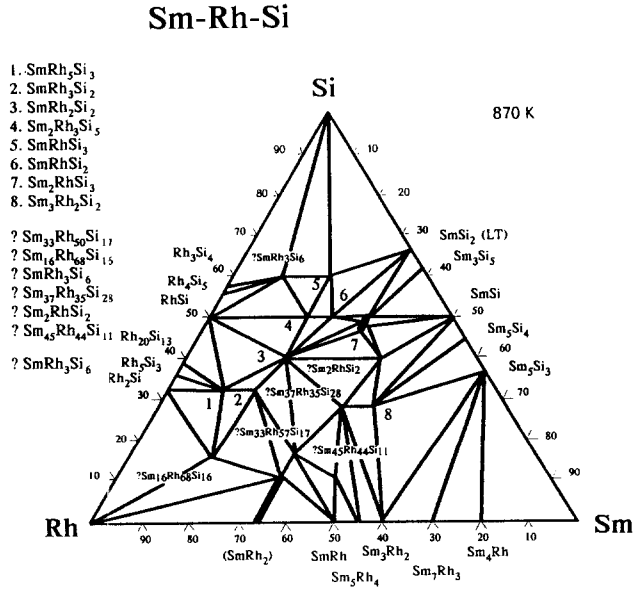

Fig. 3. Isothermal cross-section of Sm–Rh–Si system at 870 K.

It was found that the system contains extended regions of ternary solid solution based on $SmRh_2$ and Sm_2RhSi_3. The lattice parameters are given in Tables 3 and 6.

The following ternary intermetallic compounds were found in the system Sm–Rh–Si at 870 K: $SmRh_3Si_2$, $SmRh_2Si_2$, $Sm_2Rh_3Si_5$, $SmRhSi_3$, $SmRhSi_2$, Sm_2RhSi_3 and eight new compounds $SmRh_5Si_3$, $Sm_3Rh_2Si_2$, $Sm_{33}Ru_{50}Si_{17}$, $Sm_{16}Rh_{68}Si_{16}$, $SmRh_3Si_6$, $Sm_{37}Rh_{35}Si_{28}$, Sm_2RhSi_2 and Sm_4Rh_4Si. The lattice parameters are given in Table 6. It was found that the structure of the new compound $SmRh_5Si_3$ belonged to the structure type UCo_5Si_3: space group $P6_3/m$, $a = 1.5850(6)$ nm, $c = 0.3824(2)$ nm. (Calculations of the powder diffractogram using 140 reflections, $R = 0.13$ in the isotropic approximation.) It was found that the structure of the new compound $Sm_3Rh_2Si_2$ belonged to the structure type $La_3Ni_2Ga_2$: space group *Pbcm*, $a = 0.5583(5)$ nm, $b = 0.7820(4)$ nm, $c = 1.3152(6)$ nm. (Calculations of the powder diffractogram using 80 reflections, $R = 0.11$.)

3.4. Sm–Rh–Ge system

The results obtained were used in the construction of the isothermal cross-section of the Sm–Rh–Ge phase diagram at 870 K presented in Fig. 4.

It was found that the system contains extended regions of ternary solid solution based on $SmRh_2$, $Sm_{33}Rh_{20}Ge_{47}$ and $Sm_3Rh_4Ge_{13}$. The lattice parameters are given in Tables 3 and 7.

The following ternary intermetallic compounds were found in the system Sm–Rh–Ge at 870 K: $SmRh_2Ge_2$, $Sm_2Rh_3Ge_5$, $Sm_3Rh_4Ge_{13}$, SmRhGe and ten new compounds $SmRh_5Ge_3$, $Sm_3Rh_2Ge_2$, Sm_2RhGe_2, $Sm_{33}Rh_{20}Ge_{47}$, $Sm_{25}Rh_{19}Ge_{56}$, Sm_2RhGe_6,

Table 6
Crystallographic data of ternary compounds in system Sm–Rh–Si

	Compound	Space group	Structure type	Lattice parameters (nm)			Refs.
				a	*b*	*c*	
1.	$SmRh_5Si_3$[a]	$P6_3/m$	UCo_5Si_3	1.5850(6)	—	0.3824(2)	
2.	$SmRh_3Si_2$[a]	*P6/mmm*	$CaCu_5$	0.5510	—	0.3552	[55]
				0.5529(2)	—	0.3554(1)	—[b]
3.	$SmRh_2Si_2$[a]	*I4/mmm*	$BaAl_4$	0.4053	—	1.003	[52,53]
				0.4051(2)	—	1.0020(7)	—[b]
4.	$Sm_2Rh_3Si_5$[a]	*Ibam*	$U_2Co_3Si_5$	0.983	1.175	0.5772	[54,55]
				0.984(1)	1.1744(9)	0.5705(7)	—[b]
5.	$SmRhSi_3$[a]	*I4mm*	$BaNiSn_3$	...	...	...	[56]
				0.4185(1)	—	0.9764(1)	—[b]
6.	$SmRhSi_2$[a]	*Cmcm*	$CeNiSi_2$	...	...	...	[55]
				0.4115(2)	1.6896(4)	0.4052(2)	—[b]
7.	Sm_2RhSi_3[a]	*P6/mmm*	AlB_2	...		...	[55]
	$Sm_{33}Rh_{20-16}Si_{47-51}$[a]	*P6/mmm*	AlB_2	0.4082(2)–	—	0.4052(4)–	—[b]
				0.4078(1)	—	0.4060(2)	
8.	$Sm_3Rh_2Si_2$[a]	*Pbcm*	$La_3Ni_2Ga_2$	0.5583(5)	0.7820(4)	1.3152(6)	—[b]
	$Sm_{33}Rh_{50}Si_{17}$[a,c]	...	...	...	...	...	—[b]
	$Sm_{18}Rh_{68}Si_{16}$[a,c]	...	...	...	...	...	—[b]
	$SmRh_3Si_6$[a,c]	...	...	...	...	...	—[b]
	$Sm_{37}Rh_{35}Si_{28}$[a,c]	...	...	...	...	...	—[b]
	Sm_2RhSi_2[a,c]	...	...	...	...	...	—[b]
	Sm_4Rh_4Si[a,c]	...	...	...	...	...	—[b]

[a] Compound belongs to isothermal cross-section at 870 K.
[b] Data of present analysis.
[c] Compound with unknown structure type.

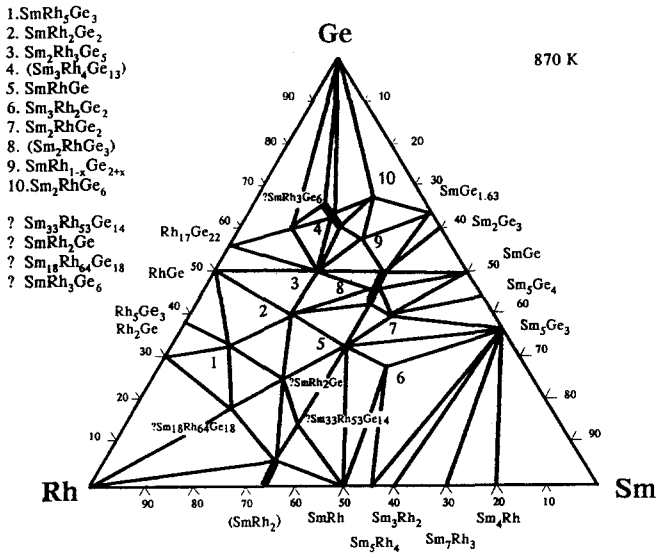

Fig. 4. Isothermal cross-section of Sm–Rh–Ge system at 870 K.

$Sm_{33}Rh_{53}Ge_{14}$, $SmRh_2Ge$, $Sm_{18}Rh_{64}Ge_{18}$, $SmRh_3Ge_6$. The lattice parameters are given in Table 7. It was found that the structure of the new compound $SmRh_5Ge_3$ belonged to the structure type UCo_5Si_3: space group $P6_3/m$, $a = 1.5848(4)$ nm, $c = 0.389(2)$ nm. (Calculations of the powder diffractogram using 140 reflections, $R = 0.14$ in isotropic approximation.) It was found that the structure of the new compound $Sm_3Rh_2Ge_2$ belonged to the structure type $La_3Ni_2Ga_2$: space group *Pbcm*, $a = 0.5592(1)$ nm, $b = 0.7895(1)$ nm, $c = 1.3293(2)$ nm. (Calculations of the powder diffractogram using 80 reflections, $R = 0.12$.) It was found that the structure of the new compound Sm_2RhGe_2 belonged to the structure type Zr_2CoSi_2: space group *B2/m*, $a = 1.065(2)$ nm, $b = 1.118(3)$ nm, $c = 0.4106(4)$ nm, $\gamma = 129.96°$. (Calculations of the powder diffractogram using 160 reflections, $R = 0.14$.) It was found that the structure of the new compound $Sm_{33}Rh_{25-20}Ge_{42-47}$ belonged to the structure type AlB_2: space group *P6/mmm*, $a = 0.4219(1)$–$0.4208(4)$ nm, $c = 0.4017(3)$–$0.4025(1)$ nm. (Calculations of the powder diffractogram using 20 reflections, $R = 0.10$.) It was found that the structure of the new compound $Sm_{25}Rh_{19}Ge_{56}$ belonged to the structure type $CeRh_{1-x}Ge_{2+x}$: space group *Pmmn*, $a = 0.4225(5)$ nm, $b = 0.4304(1)$ nm, $c = 1.507(2)$ nm. (Calculations of the powder diffractogram using 70 reflections, $R = 0.13$.) It was found that the structure of the new compound Sm_2RhGe_6 belonged to the structure type Ce_2CuGe_6: space group *Amm2*, $a = 0.4060(5)$ nm, $b = 0.4008(4)$ nm, $c = 2.190(2)$ nm. (Calculations of the powder diffractogram using 50 reflections, $R = 0.10$).

Table 7
Crystallographic data of ternary compounds in system Sm–Rh–Ge

	Compound	Space group	Structure type	Lattice parameters (nm)			Refs.
				a	*b*	*c*	
1.	$SmRh_5Ge_3$[a]	$P6_3/m$	UCo_5Si_3	1.5848(4)	—	0.3879(2)	—[b]
2.	$SmRh_2Ge_3$[a]	$I4/mmm$	$CeGa_2Al_2$	0.4126	—	1.037	[45,59]
				0.4101(2)	—	1.0310(8)	—[b]
3.	$Sm_2Rh_3Ge_5$[a]	$C2c$	$Lu_2Co_3Si_5$	1.0005	1.2084 $\beta = 120.2°$	0.5894	[46]
4.	$Sm_3Rh_4Ge_{13}$[a]	$Pm3n$	$Y_3Co_4Ge_{13}$	0.8985	—	—	[57]
	$Sm_{3+x}Rh_4Ge_{13-x}$[a] $x = 0–1$	$Pm3n$	$Y_3Co_4Ge_{13}$	0.8969(1)–0.8976(2)	—	—	—[b]
5.	*SmRhGe*[a]	*Pnma*	TiNiSi	0.7074	0.4371	0.7468	[58]
				0.7060(2)	0.4360(1)	0.7448(1)	—[b]
6.	$Sm_3Rh_2Ge_2$[a]	*Pbcm*	$La_3Ni_2Ga_2$	0.5592(1)	0.7895(1)	1.3293(2)	—[b]
7.	Sm_2RhGe_2[a]	$B2/m$	Zr_2CoSi_2	1.065(2)	1.118(3) $\gamma = 129.96°$	0.4106(4)	—[b]
8.	$Sm_{33}Rh_{25-20}Ge_{42-47}$[a]	$P6/mmm$	AlB_2	0.4219(1)–0.4208(1)	— —	0.4017(3)–0.4025(1)	—[b]
9.	$Sm_{25}Rh_{19}Ge_{56}$[a]	*Pmmn*	$CeRh_{1-x}Ge_{2+x}$	0.4225(5)	0.4304(4)	1.507(2)	—[b]
10.	Sm_2RhGe_6[a]	*Amm*2	Ce_2CuGe_6	0.4060(5)	0.4008(4)	2.190(2)	—[b]
	$Sm_{33}Rh_{53}Ge_{14}$[a,c]	...	...	...	...	...	—[b]
	$SmRh_2Ge$[a,c]	...	...	...	...	...	—[b]
	$Sm_{18}Rh_{64}Ge_{18}$[a,c]	...	...	...	...	...	—[b]
	$SmRh_3Ge_6$[a,c]	...	...	...	...	...	—[b]

[a] Compound belongs to isothermal cross-section at 870 K.
[b] Data of present analysis.
[c] Compound with unknown structure type.

4. Conclusions

The formation of four ternary intermetallic compounds was confirmed and new ternary compounds, Sm_2RuGe_2 and $Sm_{62}Ru_{28}Ge_{10}$, were detected in the Sm–Ru–Ge system. The compound SmRuGe was not detected in our investigation.

The formation of two ternary compounds $SmRu_2Si_2$ and SmRuSi was confirmed but compound SmRuSi does not belong to the structure type PbFCl. New ternary compounds $SmRu_3Si_2$, $Sm_2Ru_3Si_5$, $SmRuSi_3$, $Sm_3Ru_2Si_2$, $SmRu_3Si$, Sm_2RuSi_2 and $Sm_{62}Ru_{10}Si_{28}$ were detected in the Sm–Ru–Si system.

The formation of six ternary compounds was confirmed and new ternary compounds $SmRh_5Si_3$, $Sm_3Rh_2Si_2$, $Sm_{33}Rh_{50}Si_{17}$, $Sm_{16}Rh_{68}Si_{16}$, $SmRh_3Si_6$, $Sm_{37}Rh_{35}Si_{28}$, Sm_2RhSi_2, Sm_4Rh_4Si were detected in the Sm–Rh–Si system. The formation of four ternary intermetallic compounds was confirmed and new ternary compounds $SmRh_5Ge_3$, $Sm_3Rh_2Ge_2$, Sm_2RhGe_2, $Sm_{33}Rh_{20}Ge_{47}$, $Sm_{25}Rh_{19}Ge_{56}$, Sm_2RhGe_6, $Sm_{33}Rh_{53}Ge_{14}$, $SmRh_2Ge$, $Sm_{18}Rh_{64}Ge_{18}$ and $SmRh_3Ge_6$ were detected in the Sm–Rh–Ge system.

It was found that compounds Sm_2RuGe_2, Sm_2RhGe_2 belong to the structure type Zr_2CoSi_2 ($B2/m$); compounds $Sm_3Ru_2Si_2$, $Sm_3Rh_2Si_2$, $Sm_3Rh_2Ge_2$ belong to the structure type $La_3Ni_2Ga_2$ ($Pbcm$); compounds $SmRh_5Si_3$, $SmRh_5Ge_3$ belong to the structure type UCo_5Si_3 ($P6_3/m$); compound $Sm_2Ru_3Si_5$ belongs to the structure type $Sc_2Fe_3Si_5$ ($P4/mnc$); compound $SmRu_3Si_2$ belongs to the structure type $LaRu_3Si_2$ ($P6_3/m$); compound $SmRuSi_3$ belongs to the structure type $BaAl_4$ ($I4/mmm$); compound $Sm_{33}Rh_{20}Ge_{47}$ belongs to the structure type AlB_2 ($P6/mmm$); compound $Sm_{25}Rh_{19}Ge_{56}$ belongs to the structure type $CeRh_{1-x}Ge_{2+x}$ ($Pmmn$) and compound Sm_2RhGe_6 belongs to the structure type Ce_2CuGe_6 ($Amm2$).

Acknowledgement

This work has financial support from the Russian Science Foundation, grant number 95-03-09647a.

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