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The new polymorphic modification of the equiatomic stannide CeRuSn



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Vera Gribanova*, Elena Murashova, Yurii Seropegin, Alexander Gribanov

Chemistry Department of the Moscow State University, Leninskie Gory, GSP-1, 119991 Moscow, Russia

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ABSTRACT

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1. Introduction

The Ce-based intermetallic compounds demonstrate a variety of unique phenomena, such as Kondo-lattice and heavy-fermion states, complex magnetic structures, unconventional superconductivity, Landau and non-Landau Fermi liquid behavior, quantum criticality, intermediate valence of the Ce atoms [1–3]. Among the wide variety of intermetallics from the Ce-T-X systems (T - transition metal, X - elements of 12-14 groups of the periodic table), Ru-containing $Ce_m Ru_n X_a$ compounds with X = Al, Ga, In, Sn, Zn, Cd form the outstanding group due to their structural peculiarity: many of them are characterized with notably shortened $(\sim 2.4 - 2.8 \text{ Å})$ or even extremely shortened (2.23 Å) Ce-Ru contacts, whereas the sum of the covalent radii $R_{Ce} + R_{Ru}$ equals 2.89 Å [4]. Before 2007 CeCoAl was the only ternary intermetallic with notably shortened Ce-T contacts of 2.46 and 2.54 Å [5] (the sum of the covalent radii $R_{Ce} + R_{Co}$ equals to 2.81 Å). Most striking short values of the Ce-Ru contacts (<2.40 Å) were firstly detected in 2007 for ternary indides: Ce₃Ru₂In₃ (2.38 Å) [6], Ce₁₆Ru₈In₃₇ (2.37 Å) [7], Ce₃Ru₂In₂ (2.23 and 2.28 Å) [8], Ce₂Ru₂In₃ (2.32 and 2.37 Å) [8], and for the equiatomic stannide CeRuSn (2.33 and 2.46 Å) [9]. Later Mg-containing intermetallics CeRu₂Mg₅ (2.32 Å) [10] and $Ce_2Ru_4Mg_{17}$ (2.31 Å) [11] also with the drastically hortened Ce-Ru distances were investigated and complemented this series. Up to now except Ce-Co and Ce-Ru no other Rare Earth-Transition metal couple does demonstrate such a phenomenon. Short reviews considering Ce-Ru-based intermetallics with

* Corresponding author. Fax: +7 495 9390171. *E-mail address:* veragriban@gmail.com (V. Gribanova).

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The atomic order of the new polymorphic modification of the equiatomic stannide CeRuSn was established from single crystal X-ray diffraction data. The new modification of CeRuSn can be described as a superstructure of CeCoAl-type with tripling of the subcell along the *c* axis. Space group *C*2/*m*, lattice parameters *a* = 11.5702(12) Å, *b* = 4.7529(5) Å, *c* = 15.2414(16) Å, *β* = 103.511(2)°, *Z* = 12. The structure was refined to *R*1 = 0.034 for 1806 *F*² and 55 variables. The new modification has three independent crystallographic Ce sites, two of which form strongly shortened Ce–Ru contacts $d_{Ce1-Ru2}$ = 2.267 Å, $d_{Ce3-Ru1}$ = 2.434 Å and $d_{Ce3-Ru3}$ = 2.429 Å.

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the shortened Ce–Ru distances may be found in references [12] and [13].

Herein we report on the crystal structure of the new polymorphic modification for the above mentioned equiatomic CeRuSn intermetallic. The following notation – CeRuSn(I) – is used below to indicate the first modification of the CeRuSn equiatomic compound reported in [9]. In the present work the new, second polymorphic modification – CeRuSn(II) – is being described.

Similar to the crystal structure modification CeRuSn(I) published before [9], the new one, CeRuSn(II), stands out because of the extremely short Ce-Ru distances. The first modification CeRuSn(I) was characterized as crystallizing with a superstructure of the monoclinic CeCoAl type: space group C2/m, Z = 8, a = 11.561, b = 4.759, c = 10.233 Å, β = 102.89°, doubled c parameter in comparison with the parent's CeCoAl unit cell [4,9]. Unlike the CeCoAl crystal structure, CeRuSn(I) has not one but two crystallographic cerium sites: one trivalent and one intermediate-valent. The unstable valence state of the cerium atoms in one crystallographic site had been suggested from the crystal chemistry - interatomic distances for the coordination environment of the corresponding Ce atoms. The valence fluctuation was confirmed by physical properties measurements [9], chemical bonding calculations [14], XANES spectra [15]. In the latter article the authors found that at low temperatures the doubling of the CeCoAl type structure was replaced by an ill-defined modulated ground state, in which three different modulation periods competed with the dominant mode close to a tripling of the basic CeCoAl unit cell [15]. In the present work the new polymorphic modification, CeRuSn(II), was detected during the systematic investigation of the Ce-Ru-Sn ternary system in the wide concentration range. Similar to CeRuSn(I), the new modification CeRuSn(II) is also monoclinic. It is a new derivate

from the same CeCoAl prototype being a superstructure with tripling of *c*-parameter: space group C2/m, Z = 12, *a* and *b* parameters keep approximately the same values as in CeCoAl, whereas a *c* parameter is three times bigger in comparison with the parent's CeCoAl unit cell. The atomic order for the CeRuSn(II) modification has been obtained from single crystal X-ray diffraction data, while the X-ray powder diffraction test revealed the presence of both CeRuSn(I) and CeRuSn(II) polymorphic modifications in the same Ce_{33.3}Ru_{33.3}Sn_{33.4} (at.%) sample taken in both as-cast and annealed forms.

2. Experimental details

2.1. Synthesis

The equiatomic sample Ce_{33.3}Ru_{33.3}Sn_{33.4} (at.%) was synthesized by arc-melting from the pure elements Ce (99.8%), Ru (99.99%), Sn (99.99%) in a purified argon atmosphere. To reach the homogeneity the fused mass was re-melted several times. After melting the alloy was annealed at 725 °C for 30 days. The annealing temperature was selected on the basis of the analysis of the phase diagram of binary systems Ce-Ru [16], Ru-Sn [17] and Ce-Sn [18]. The total mass lost was not higher than 1% of weight.

2.2. X-ray single crystal diffraction (XRSCD)

The suitable single crystal for X-ray structure analysis was found at the surface of the prepared alloy. X-ray single crystal diffraction experiment was carried out using a Bruker APEX-II diffractometer equipped with a CCD area detector and employing monochromated Mo K α radiation ($\lambda = 0.71073$ Å) at 173 K. All obtained intensities were collected and derived using program Bruker SAINT [19]. Absorption correction was performed with SADABS program [20]. The structure was solved by direct methods and refined with the SHELX-97 program package [21].

2.3. X-ray powder diffraction (XPD)

X-ray powder diffraction was studied with using of STOE STADI P transmission diffractometer (monochromatized Cu K α 1 – radiation (λ = 1.54056 Å), 8° < 2 θ < 100°, linear position-sensitive detector, step scan 0.01° and counting time 10 s/point). All data and values of the intensities were collected with the STOE complex of programs. Lattice parameters were calculated using program STOE-WinX-pow [22]. Quantitative Rietveld refinement of the powder X-ray pattern was performed with the FULLPROF program [23,24], employing internal tables for X-ray atomic form factors. Atom parameters were standardized with the aid of program STRUCTURE TIDY [25]. Structure and polyhedra were visualized using program DIAMOND [26].

2.4. Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX analysis)

Microstructure of the CeRuSn was investigated with the use of the scanning electron microscope Carl Zeiss LEO EVO 50VXP. Built-in EDX-spectrometer INCA Energy 450 (Oxford Instruments) was used to control the chemical composition (accelerating voltage 30 kV). The measurement error did not exceed 0.8 at.%.

3. Results and discussion

EDX analysis revealed the overall chemical composition of the prepared alloy to be close to initial proportion $1:1:1 - Ce_{33.6}Ru_{32.7}$. Sn_{33.7} (at.%). Scanning electron microscopy showed that the only phase with the same composition is there in the sample. No other phases were detected by that technique. Nevertheless X-ray powder diffraction experimental data indicated the presence of two polymorphic modifications CeRuSn(I) and CeRuSn(II), which cannot be distinguished by SEM and EDX methods due to the same chemical composition of both phases. In the present investigation at first the new modification CeRuSn(II) was discovered and its crystal structure was solved based on the XRSCD experimental data, and then XPD experiment has revealed the presence of both CeRuSn(I) and CeRuSn(II) modifications in the same sample.

According to single crystal X-ray diffraction data taken at 173 K the crystal structure of CeRuSn(II) is a superstructure of the CeCoAl-type with tripling of the subcell along the c axis: it

crystallizes with a monoclinic unit cell, space group C2/m, a = 11.5702(12) Å, b = 4.7529(5) Å, c = 15.2414(16) Å, $\beta = 103.511(2)^\circ$, Z = 12. Crystallographic data and structure refinement parameters for CeRuSn(II) XRSCD experiment are presented in Table 1. Atomic parameters and interatomic distances for the polymorphic CeRuSn(II) form are collected in Tables 2 and 3, respectively. Anisotropic displacement parameters of atoms in the structure CeRuSn(II) are given in Table 4.

Coordination environments of all the atoms in the independent crystallographic positions for CeRuSn(II) are shown in Fig. 1. The coordination polyhedra of Ce1 and Ce3 atoms are very similar. These are pentagonal prisms with four additional atoms of $[Ce_2Ru_5Sn_7]$ composition (coordination number, CN = 14, Fig. 1a and c). Ce2 atom is situated inside a polyhedron with 13 apexes $[Ce_1Ru_5Sn_7]$ (CN = 13, Fig. 1b). Ru atoms in all three independent crystallographic sites, Ru1, Ru2 and Ru3 (Fig. 1d, f, and g), have the same composition of the coordination polyhedra – $[Ce_4Ru_2Sn_3]$, CN = 9, wherein the nearest atoms around Ru1 form a distorted tetragonal prism with one additional atom, whereas Ru2 and Ru3 atoms are located inside trigonal prisms with three additional atoms. All tin atoms, Sn1, Sn2 and Sn3, are located inside the distorted tetragonal prisms with four additional atoms (CN = 12) of composition [Ce₇Ru₃Sn₂].

From the crystal chemistry point of view both modifications CeRuSn(I) and CeRuSn(II) are very close to each other, as well as to the prototype CeCoAl. CeRuSn(I) and new CeRuSn(II) being the derivatives from the same parent prototype: CeRuSn(I) adopts a superstructure of the monoclinic CeCoAl type through a doubling of the subcell *c* axis [9], while CeRuSn(II) – through a tripling. The crystal structures of the all three phases may be presented as being constructed using similar infinite slabs extending parallel to the YZ-plane and composed of truncated polyhedra of the X atoms (X = Al or Sn). In Fig. 2 for better comparison the CeCoAl, CeRuSn(I) and CeRuSn(II) structures are posed on the same image as a projection onto the XZ-plane (upper part) and onto the XY-plane (lower part). As seen from Fig. 2, in each structure the neighboring slabs – A, and the A^{*} – are the same but A^{*}-slab is shifted by ½ *b* along the Y-axes in comparison with the A-slab.

Two of three independent Ce sites in CeRuSn(II), Ce1 and Ce3, demonstrate extremely shortened contacts with ruthenium atoms: $d_{Ce1-Ru2} = 2.267$ Å, $d_{Ce3-Ru1} = 2.434$ Å and $d_{Ce3-Ru3} = 2.429$ Å

Table 1

Crystallographic data and structure refinement parameters for CeRuSn(II) phase (XRSCD experiment).

1 ,	
Composition, EDX (at.%)	Ce _{33.6} Ru _{32.7} Sn _{33.7}
Crystal size (mm)	0.03 * 0.03 * 0.03
Radiation, λ (Å)	Μο Κα; 0.71073
Space group	<i>C</i> 2/ <i>m</i> (No. 12)
Unit cell dimensions (Å)	a = 11.5702(12)
	$b = 4.7429(5), \beta = 103.511(2)^{\circ}$
	c = 15.2414(16)
Volume of cell, $Z(Å^3)$	813.24(5), 12
Molar mass (g/mol)	359.91
Calculated density (g/cm ³)	8.82
Absorption coefficient (mm ⁻¹)	30.766
F (000)	1824
2θ Range (°)	$4.29 \leqslant 2 heta \leqslant 72.72$
Index range	$-19 \leqslant h \leqslant 19$
	$-8\leqslant k\leqslant 8$
	$-25 \leqslant l \leqslant 26$
Reflections measured	11143
Independent reflections (R_{int})	2331 (0.044)
Reflections with $I > 2\sigma(I) (R_{\sigma})$	1806 (0.088)
Refined parameters	55
GOF on F ²	0.920
R1/R1 (all data)	0.034/0.044
wR2/wR2 (all data)	0.083/0.088

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Table 4

Atomic coordinates and equivalent isotropic displacement parameters for CeRuSn(II								
Atom	Wyckoff position	x/a	y/b	z/c	$U_{\rm eq}$. (Å ²)			
Ce1	4 <i>i</i>	0.36946(4)	0	0.39267(3)	0.0211(1)			
Ce2	4 <i>i</i>	0.37780(4)	0	0.06261(3)	0.0222(1)			
Ce3	4 <i>i</i>	0.64410(4)	0	0.27858(3)	0.0220(1)			
Ru1	4 <i>i</i>	0.30979(6)	0	0.55719(4)	0.0222(1)			
Ru2	4 <i>i</i>	0.32176(6)	0	0.23972(4)	0.0221(1)			
Ru3	4 <i>i</i>	0.70109(6)	0	0.13495(4)	0.0223(2)			
Sn1	4 <i>i</i>	0.08586(5)	0	0.43772(4)	0.0218(1)			
Sn2	4 <i>i</i>	0.06859(5)	0	0.76868(4)	0.0226(1)			
Sn3	4i	0.09680(5)	0	0.10066(4)	0.0224(1)			

Table 2

(Table 3). These values are significantly shorter than the sum of the covalent radii ($R_{Ce} + R_{Ru} = 2.89$ Å), similar to CeRuSn(I), where $d_{Ce1-Ru1}$ = 2.330 Å and $d_{Ce1-Ru2}$ = 2.464 Å [9]. We expect this peculiarity of CeRuSn(II) to be connected with the intermediate valence state of the Ce1 and Ce3 atoms. Taking into account the parent CeCoAl structure, such a feature continues the regularity in the sequence CeCoAl - CeRuSn(I) - CeRuSn(II). The corresponding shortened d_{Ce-Co} and d_{Ce-Ru} values are plotted in Fig. 2.

The atomic environments (including the additional Ce atoms from the second coordination sphere) of the Ce1, Ce2 and Ce3 crystallographic sites for CeRuSn(II) are separately drown in Fig. 3 in the same manner like it was done earlier [9,15]. The coordination environment of the cerium atoms in the CeRuSn(II) polymorphic modification has obviously the same character in space as in CeRuSn(I). Fig. 3 shows that three Ce-atoms of CeRuSn(II) differ from each other by d_{Ce-Ru} and d_{Ce-Ce} .

In the present work we have gotten two X-ray powder patterns at 25 °C from both as-cast and annealed specimens, and found that the patterns practically are the same. The subsequent Rietveldrefinement for the annealed sample was perfected in two sessions. The first one was done before the single crystal investigation in order to refine the crystal structure applying the CeRuSn(I) model from the literature [9]. The experimental intensities on the XPD pattern did not coincide well with the calculated values. That is

Anisotropic displacement parameters of atoms in the structure CeRuSn(II). U_{13} Atom U_{11} U_{22} U_{33} 0.0213(2) 0.0221(2) 0.0198(2) 0.0045(1) Ce1 Ce2 0.0232(2) 0.0231(2) 0.0207(2) 0.0058(1) 0.0234(2) 0.0223(2) 0.0207(2) 0.0060(1) Ce3 0.0212(2) 0.0050(2)Ru1 0.0203(2)0.0249(3)0.0227(3) 0.0216(3) 0.0222(3)0.0053(2)R112 0.0218(3) 0.0216(3) 0.0235(3) 0.0053(2)Ru3 0.0046(2) 0.0203(2)Sn1 0.0210(2)0.0239(2)Sn2 0.0237(2) 0.0210(2)0.0230(2)0.0052(2)Sn3 0.0230(2) 0.0206(2)0.0234(2) 0.0053(2)

 $U_{23} = U_{12} = 0.$



Fig. 1. The unit cell of CeRuSn(II) and coordination polyhedra of atoms.

Table 3 Selected interatomic distances (Å) in the CeRuSn(II) structure (Δ < 0.0010 Å).

Atom 1, CN	Atom(s) 2	Distance	Atom 1, CN	Atom(s) 2	Distance	Atom 1, CN	Atom(s) 2	Distance
Ce1	1 Ru2	2.2667	Ru1	1 Ce3	2.4343	Sn1	2 Ru1	2.6540
	1 Ru1	2.7520		2 Sn1	2.6540		1 Ru1	2.7972
	2 Ru1	3.3540		1 Ce1	2.7520		1 Sn1	3.0519
14	2 Sn1	3.4002	9	1 Sn1	2.7972	12	1 Sn2	3.2347
	2 Sn1	3.4568		2 Ru1	3.0742		2 Ce1	3.4002
	1 Sn1	3.5059		2 Ce1	3.3540		2 Ce1	3.4568
	2 Sn2	3.6068					1 Ce1	3.5059
	1 Ru1	3.6099					2 Ce3	3.5672
	2 Ce3	3.6507						
Ce2	1 Ru2	2.9197	Ru2	1 Ce1	2.2667	Sn2	2 Ru2	2.7066
	1 Ru3	2.9353		2 Sn2	2.7066		1 Ru3	2.7258
	2 Sn3	3.4196		1 Ce2	2.9197		1 Sn3	3.0672
13	1 Sn3	3.4333	9	1 Sn3	2.9477	12	1 Sn1	3.2347
	2 Sn2	3.4460		2 Ru3	3.0135		2 Ce3	3.3719
	2 Ru3	3.4746		2 Ce3	3.2816		2 Ce2	3.4460
	2 Sn3	3.4993					1 Ce3	3.5622
	1 Ru3	3.6442					2 Ce1	3.6068
	1 Ce2	3.7632						
Ce3	1 Ru3	2.4292	Ru3	1 Ce3	2.4292	Sn3	2 Ru3	2.6568
	1 Ru1	2.4343		2 Sn3	2.6568		1 Ru2	2.9477
	2 Ru2	3.2816		1 Sn2	2.7258		1 Sn2	3.0672
14	2 Sn2	3.3719	9	1 Ce2	2.9353	12	1 Sn3	3.3498
	2 Sn3	3.5472		2 Ru2	3.0135		2 Ce2	3.4196
	1 Sn2	3.5621		2 Ce2	3.4746		1 Ce2	3.4333
	2 Sn1	3.5672					2 Ce2	3.4993
	1 Ru2	3.6370					2 Ce3	3.5472
	2 Ce1	3.6507						

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Fig. 2. Interrelation of the CeCoAl, CeRuSn(I) and CeRuSn(II) structures and packing of the slabs.



Fig. 3. The atomic environments (including the additional Ce atoms from the second coordination sphere) of the Ce1, Ce2 and Ce3 crystallographic sites for CeRuSn(II).



Fig. 4. Experimental powder diffraction pattern (red), calculated diffraction pattern (black), difference curve (blue) for Ce_{33.3}Ru_{33.3}Sn_{33.4} (at.%) alloy in Rietveld refinement (1 – CeRuSn(I), 2 – CeRuSn(II)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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why a search for a single crystal and a corresponding crystal structure determination were done afterwards. In the second powder Rietveld-refinement session two structure models CeRuSn(I) and CeRuSn(II) were simultaneously applied which led to much better agreement between experimental and calculated patterns (Fig. 4). As a result the next cell parameter values were obtained: a =11.5517(2) Å, b = 4.74886(4) Å, c = 10.2235(2) Å, $\beta = 103.056(2)^{\circ}$ for CeRuSn(I) (in good agreement with these reported in [9]), and a = 11.5638(8) Å, b = 4.7462(5) Å, c = 15.2981(9) Å, $\beta = 103.365(7)^{\circ}$ for CeRuSn(II) (the notable difference $\Delta \sim 0.06$ Å for the *c*-parameter in comparison with the single crystal data may actually be due to the temperature difference for XRSCD (173 K) and XPD (295 K) experiments. So, the *c*-parameter in the CeRuSn(II) is probably temperature sensitive, in agreement with [15], where such peculiarity was also detected for the c-parameter in CeRuSn(I) modification. Thus, the presence of both CeRuSn(I) and CeRuSn(II) modifications in prepared annealed alloy in the ratio 63% CeRuSn(I) and 37% CeRuSn(II) was revealed at room temperature. The close proportion of phase contents for the as-cast sample could also be predicted based on the small difference between X-ray patterns of as-cast and annealed specimens.

4. Conclusions

Equiatomic CeRuSn intermetallic crystallizes in two monoclinic polymorphic modifications CeRuSn(I) and CeRuSn(II), both being the superstructures to parent CeCoAl-type with doubling and tripling of the parameter along the *c* axis, respectively. Both modifications were found in annealed and as-cast specimens by X-ray powder diffraction technique at room temperature. The new modification CeRuSn(II) belongs to the rare family of structures with strongly shortened Ce–Ru distances.

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References

- [1] H.R. Ott, Phys. B 378–380 (2006) 1–6.
- [2] A.P. Pikul, D. Kaczorowski, Z. Bukowski, K. Gofryk, U. Burkhardt, Yu. Grin, F. Steglich, Phys. Rev. B 73 (2006) 092406.
- [3] P. Coleman, A.J. Schofield, Nature 433 (2005) 226-229.
- [4] J. Emsley, The Elements, Oxford University Press, Oxford (UK), 1999.
- [5] Y. Grin, O.M. Sichevych, V.A. Bruskov, R.M. Rykhal, Y.P. Yarmolyuk, Sov. Phys. Crystallogr. 28 (1983) 346–347.
 [6] Zh.M. Kurenbaeva, A.I. Tursina, E.V. Murashova, S.N. Nesterenko, A.V. Gribanov,
- [6] Zh.M. Kurenbaeva, A.I. Tursina, E.V. Murashova, S.N. Nesterenko, A.V. Gribanov, Yu. D. Seropegin, J. Alloys Comp. 442 (2007) 86–88.
- [7] E.V. Murashova, Zh.M. Kurenbaeva, A.I. Tursina, H. Noel, P. Rogl, A.V. Grytsiv, J. Alloys Comp. 447 (2007) 89–92.
- [8] A.I. Tursina, Zh.M. Kurenbaeva, A.V. Gribanov, H. Noel, Yu.D. Seropegin, J. Alloys Comp. 442 (2007) 100–103.
 [9] J.F. Riecken, W. Hermes, B. Chevalier, R.-D. Hoffman, F.M. Schappacher, R.
- Pöttgen, Z. Anorg. Allg. Chem. 663 (2007) 1094–1099. [10] S. Linsinger, M. Eul, U.Ch. Rodewald, R. Pöttgen, Z. Naturforsch. 65b (2010)
- 1185–1190. [11] S. Linsinger, R.-D. Hoffmann, M. Eul, R. Pöttgen, Z. Naturforsch. 67b (2012) 219–225.
- [12] W. Hermes, S.F. Matar, R. Pöttgen, Z. Naturforsch. 64 (2009) 901-908.
- [13] T. Mishra, R.-D. Hoffmann, C. Schwickert, R. Pöttgen, Z. Naturforsch. 66b (2011) 771–776.
- [14] S.F. Matar, J.F. Riecken, B. Chevalier, R. Pöttgen, A.F. Al Alam, V. Eyert, Phys. Rev. B 76 (2007) 174434.
- [15] R. Feyerherm, E. Dudzik, S. Valencia, J.A. Mydosh, Y.-K. Huang, W. Hermes, R. Pöttgen, Phys. Rev. B 85 (1-7) (2012) 085120.
- [16] H. Okamoto, The Ce-Ru system, J. Phase Equilib. 13 (13) (1992) 437–438.
- [17] K. Ananthasivan, I. Kaliappan, P. Vasudeva, C. Sudha, A.L.E. Terrance, J Nucl Mater 305 (2–3) (2002) 97–105.
- [18] E. Franceschi, G. Costa, J. Therm. Anal. Calorim. 34 (2) (1988) 451-45
- [19] G.M. Sheldrik, XPRER 6.14, Bruker saint, BRUKER APEX2, 2003.
- [20] G.M. Sheldrick, SADABS Bruker Nonius Area Detector Scaling and Absorption Correction, Univesity of Göttingen, Germany, 2004.
- [21] G.M. Sheldrick, Acta Crystallogr. A64 (2008) 112-122.
- [22] STOE WINXPOW (Version 1.06). Stoe & Cie GmbH: Darmstadt, Germany, 1999.
 [23] J. Rodriguez-Carvajal, FULLPROF: a program for Rietveld refinement and pattern matching analysis, in: Abstracts of the Satellite Meeting on Powder Diffraction of the XV Congress of the IUCr, Toulouse, France, 1990, p. 127.
- [24] T. Roisnel, J. Rodriguez-Carvajal, Materials science forum, in: Proceedings of the European Powder Diffraction Conference (EPDIC7), 2000, p. 118.
- [25] L.M. Gelato, E. Parthé, J. Appl. Cryst. 20 (1987) 139–143.
- [26] K. Brandenburg, DIAMOND. Release 3.0e, Crystal Impact Gmbh, Bonn, Germany, 2005.