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Lattice Parameters of the
Ternary Delta Phases
Pu-Ga-Al and Pu-Ga-Zr

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LATTICE PARAMETERS OF THE TERNARY DELTA PHASES

Pu-Ga-Al AND Pu-Ga-Zr

by

F. H. Ellinger, Marion Gibbs, and Petasho Vigil

ABSTRACT

Measurements of the lattice parameters of Pu-Ga-Al and Pu-Ga-Zr delta-plutonium solid solutions suggest that considerable interaction occurs between the solutes, especially Ga-Zr, in these ternary alloys. Isoparametric surfaces and solubility limits at 500°C are reported.

I. INTRODUCTION

The lattice parameter/composition relationships of the binary delta-plutonium solid solutions Pu-Al, Pu-Ga, and Pu-Zr have been published.¹⁻³ Here we report the results of our investigation of the lattice parameters of the ternary delta-plutonium solid solutions Pu-Ga-Al and Pu-Ga-Zr and the determination of the solubility limits of these phases at 500°C.

II. EXPERIMENT

The materials and experimental techniques used in this work were similar to those used in the binary investigations.¹⁻³ The arc-melted alloy buttons were homogenized in the delta region for 500 to 1000 h at either 450 or 500°C, depending on composition. Filings of the alloys, as contained in evacuated silica capillary tubes, were stress relieved at 500°C (or 450°C) for 3 min and water quenched.

III. RESULTS

The compositions and lattice parameters of the alloys examined are listed in Tables I and II.

TABLE I

DELTA-PHASE LATTICE PARAMETERS

Nominal Composition (at. %)			Lattice Parameter ^a (23° ± 2°C) (Å)
Ga	Al	Pu	
0.5	1.5	98.0	4.6271 ± 0.0002
1.0	3.0	96.0	4.6114 ± 0.0002
1.5	4.0	94.5	4.5998 ± 0.0001
2.0	2.0	96.0	4.6119 ± 0.0003
2.0	6.0	92.0	4.5818 ± 0.0002
2.5	7.5	90.0	4.5667 ± 0.0006
3.0	1.0	96.0	4.6094 ± 0.0001
3.0	9.0	88.0	4.5546 ± 0.0004
3.35	0.0	96.65	4.6133 ± 0.0004
3.35	2.0	94.65	4.6009 ± 0.0006
3.35	4.0	92.65	4.5840 ± 0.0001
3.35	6.0	90.65	4.5710 ± 0.0003
3.35	8.0	88.65	4.5577 ± 0.0009
3.35	10.0	86.65	4.5469 ± 0.0003 ^b
4.0	4.0	92.0	4.5785 ± 0.0004
4.0	12.0	84.0	4.5449 ± 0.0006 ^b
4.5	1.5	84.0	4.5928 ± 0.0002
6.0	2.0	92.0	4.5761 ± 0.0003
6.0	6.0	88.0	4.5483 ± 0.0005
7.0	7.0	86.0	4.5431 ± 0.0006 ^b
7.5	2.5	90.0	4.5605 ± 0.0005
8.0	8.0	84.0	4.5459 ± 0.0012 ^b
9.0	3.0	88.0	4.5467 ± 0.0007 ^b
9.0	9.0	82.0	4.5455 ± 0.0006 ^b
12.0	4.0	84.0	4.5484 ± 0.0005 ^b

^aUncertainty is the standard deviation.

^bTwo-phase alloy.

TABLE II
DELTA-PHASE LATTICE PARAMETERS

Nominal Composition (at. %)			Lattice Parameter ^a 23° ± 2°C (Å)	Nominal Composition (at. %)			Lattice Parameter ^a 23° ± 2°C (Å)
Ga	Zr	Pu		Ga	Zr	Pu	
0.5	2.5	97.0	4.6393 ± 0.0004	6.0	16.0	78.0	4.6381 ± 0.0020
0.5	5.5	94.0	4.6378 ± 0.0002	6.0	18.0	76.0	4.6348 ± 0.0020
1.0	3.0	96.0	4.6371 ± 0.0001	6.0	20.0	74.0	4.6330 ± 0.0011
1.0	7.0	92.0	4.6365 ± 0.0002	7.5	2.5	90.0	4.5848 ± 0.0005
1.5	0.5	98.0	4.6292 ± 0.0001	8.0	6.0	86.0	4.5973 ± 0.0003
2.0	4.0	94.0	4.6334 ± 0.0002	8.0	8.0	84.0	4.6074 ± 0.0013
2.0	6.0	92.0	4.6364 ± 0.0003	9.0	3.0	88.0	4.5750 ± 0.0003
2.0	8.0	90.0	4.6354 ± 0.0003	10.0	10.0	80.0	4.6010 ± 0.0008
2.0	12.0	86.0	4.6334 ± 0.0004	12.0	4.0	84.0	4.5542 ± 0.0005 ^b
2.0	16.0	82.0	4.6293 ± 0.0004	13.0	3.0	84.0	4.5499 ± 0.0006 ^b
3.0	1.0	96.0	4.6174 ± 0.0001	14.0	2.0	84.0	4.5500 ± 0.0004 ^b
3.35	13.0	83.65	4.6343 ± 0.0001	14.0	6.0	80.0	4.5514 ± 0.0005 ^b
4.0	4.0	92.0	4.6215 ± 0.0002	15.0	1.0	84.0	4.5497 ± 0.0006 ^b
4.0	6.0	90.0	4.6293 ± 0.0003	15.0	5.0	80.0	4.5499 ± 0.0010 ^b
4.0	8.0	88.0	4.6346 ± 0.0001	15.0	10.0	75.0	4.5545 ± 0.0009 ^b
4.0	10.0	86.0	4.6353 ± 0.0002	17.0	3.0	80.0	4.5497 ± 0.0005 ^b
4.0	12.0	84.0	4.6350 ± 0.0001	18.0	6.0	76.0	4.5513 ± 0.0007 ^b
4.5	1.5	94.0	4.6071 ± 0.0008				
5.0	15.0	80.0	4.6344 ± 0.0003				
6.0	2.0	92.0	4.5953 ± 0.0005				
6.0	6.0	88.0	4.6144 ± 0.0002				
6.0	8.0	86.0	4.6238 ± 0.0005				
6.0	10.0	84.0	4.6318 ± 0.0005				
6.0	12.0	82.0	4.6393 ± 0.0002				

^aUncertainty is the standard deviation.

^bTwo-phase alloy.

Most of the lattice parameters are mean values based on four samples taken from each alloy. The uncertainty is expressed as the standard deviation.

The variation of the lattice parameters on the constant plutonium sections of the ternary model is shown in Figs. 1 and 2, where the top horizontal scale refers to the constant plutonium sections and the bottom scale defines the limiting binary alloys. Although we had to draw many other sections of the ternary model to construct the parametric surfaces shown in Figs. 3 and 4, only the constant plutonium sections are reproduced here because they best reveal the change of the lattice parameters of the ternary alloys with composition. The compositions indicated in Tables I and II as two-phase alloys served to

Fig. 1. The lattice parameter/composition curves on the constant plutonium sections of the Pu-Ga-Al delta phase. Also shown are the binary curves.

Fig. 2. The lattice parameter/composition curves on the constant plutonium sections of the Pu-Ga-Zr delta phase. Also shown are the binary relationships.

Fig. 4. Pu-Ga-Zr delta-phase isoparametric surface.

locate the $\delta/(\delta + \zeta)$ boundaries at 500°C (see Figs. 5 and 6).

IV. DISCUSSION

A. Pu-Ga-Al

We expected the effect of gallium plus aluminum on the lattice parameter of the ternary

Fig. 3. Pu-Ga-Al delta-phase isoparametric surface.

delta solid solution to be simply additive because (1) the lattice parameter/composition relationships of the binary delta solid solution are linear, (2) both are trivalent solutes, (3) both solutes have closely analogous size factors with respect to the plutonium atom, and (4) the solutes do not form intermediate phases with each other. However, the

Fig. 5. Pu-Ga-Al partial isothermal section at 500°C.

Fig. 6. Pu-Ga-Zr partial isothermal section at 500°C.

curves in Fig. 1 show a marked positive deviation from linearity and an initial expansion of the lattice as gallium (the smaller atom) replaces aluminum.

B. Pu-Ga-Zr

Although the solution of either gallium or zirconium results in linear contraction of the delta-

plutonium lattice, the substitution of the smaller gallium atoms for zirconium atoms in the ternary alloys initially expands the lattice, as shown in Fig. 2. This behavior was unexpected because of the strong electrochemical attraction between gallium and zirconium. A repulsive interaction between gallium and zirconium is suggested by this behavior.

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