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Partial phase diagram of Au-Ag-Dy ternary system①

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Abstract: On the basis of Au-Ag, Au-Dy and Ag-Dy binary phase diagrams, the 700 ℃ isothermal section of Au-Ag-Dy ternary system(Dy ≤35%, mole fraction) was established by X-ray diffraction analysis, differential thermal analysis and optical microscopy. It is found that there is a long single-phase region, Au(Ag) or Ag(Au), along the Au-Ag binary isomorphous system on the gold-silver-rich side of the 700 ℃ isothermal section and between the binary compound Au_2Dy and Ag_2Dy there is the all proportional solid solution, (Au_2Dy) or (Ag_2Dy). It is confirmed that the partial 700 ℃ isothermal section consists of six single-phase regions: solid solution Au(Ag) or Ag(Au), (Au_2Dy) or (Ag_2Dy), Au_6Dy, $Au_{51}Dy_{14}$, Au_3Dy and $Ag_{51}Dy_{14}$; nine binary-phase regions: (Au_2Dy)+Au(Ag), Au_6Dy+Au(Ag), Au(Ag)+$Ag_{51}Dy_{14}$, $Ag_{51}Dy_{14}$+(Au_2Dy), Au_3Dy+(Au_2Dy), Au_3Dy+$Au_{51}Dy_{14}$, $Au_{51}Dy_{14}$+Au_6Dy, $Au_{51}Dy_{14}$+Au(Ag) and Au(Ag)+Au_3Dy; four ternary regions: $Ag_{51}Dy_{14}$+(Au_2Dy)+Au(Ag), (Au_2Dy)+Au(Ag)+Au_3Dy, Au(Ag)+Au_3Dy+$Au_{51}Dy_{14}$ and $Au_{51}Dy_{14}$+Au(Ag)+Au_6Dy. No new ternary compound is formed in the gold-silver-rich field(Dy ≤35%) of the Au-Ag-Dy ternary system.

Key words: Au-Ag-Dy ternary system; phase diagram; isothermal section
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1 INTRODUCTION

Because of the good electrical conductivity and the corrosion-resistant properties, the Au-Ag alloys have found wide applications in electronics and computers etc. Recently some researchers tried to improve the strength of the Au-Ag alloys by adding the third element, of which the rare earth elements are good candidates.

The Au-Ag-Dy ternary system has relation to the three binary systems: Au-Ag, Au-Dy and Ag-Dy. The equilibrium diagram of the Au-Ag binary system is an isomorphous phase diagram including the liquid, L, and the fcc continuous solid solution, Au(Ag). The very narrow liquidus-solidus gap was predicted from thermodynamic considerations by Wagnr[1] and first confirmed experimentally by White[2]. The lattice parameters of the fcc solid solution were measured by some investigators[3-5]. Karmazin et al[3] and Venudhar et al[5] reported the lattice parameters change with composition. Okamoto and Massalski[6] summed up the previous works and obtained a more exact Au-Ag binary phase diagram.

The Ag-Dy binary phase diagram has already been investigated by some researchers. The stoichiometry of the first Ag-rich phase in the Ag-Dy system was determined by McMasters et al[7] to be $Ag_{51}Dy_{14}$. Gschneidner et al[8] determined the eutectic temperature between Ag and $Ag_{51}Dy_{14}$ to be 805 ℃. Delfino et al[9] studied the Ag-Dy system and reported three congruently melting compounds: $Ag_{51}Dy_{14}$, Ag_2Dy and AgDy. Guzei et al[10] also studied the Ag-Dy system, but they reported the first Ag-rich compound to be Ag_3Dy. Ferro and Delfino[11] published "Comments on the properties of Ag-rich alloys in the silver-rare earth systems". Gschneidner and Calderwood[12] summed up the above works and obtained the assessed Ag-Dy system phase diagram including three intermetallic compounds: $Ag_{51}Dy_{14}$, Ag_2Dy and AgDy.

Rider et al[13] studied gold-rich rare earth-gold solid solution. Mcmasters and Gschneidner[14] first reported the experimental phase diagram for Au-Dy system. Gschneidner and Calderwood[15] have combined these investigations and obtained a more complete Au-Dy binary phase diagram with six intermetallic compounds: $AuDy_2$, AuDy, Au_2Dy, Au_3Dy, $Au_{51}Dy_{14}$ and Au_6Dy.

Till now, no investigation on the Au-Ag-Dy ternary phase diagram has been reported. Based on the conclusions of Refs.[6, 12, 15], in this work the authors studied the 700 ℃ isothermal section of the Au-Ag-Dy ternary system containing 0－35% Dy(mole fraction).

2 EXPERIMENTAL

All the alloys were prepared from gold

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(99.99%), silver (99.99%) and dysprosium (99.9%) using an induction furnace. For degassing, stoichiometric mixtures of gold and silver were refined in vacuum. Corresponding amounts of dysprosium were then added. The alloys were melted in boron nitride crucibles under a pure argon atmosphere. After remelting, the melts were cooled quickly, and homogeneous lumps of the alloys were obtained. It was determined by chemical analysis that the mass losses of the alloy elements in the specimens were less than 0.5% for both gold and silver, and 1% for dysprosium during melting. The results of the experiments were corrected accordingly. All of the specimens were sealed in silica tubes filled with argon. To determine the isothermal section at 700 ℃, the specimens were homogenized at (700±1) ℃ for 400 h, and then quenched.

The microstructure of the specimens was determined by X-ray diffraction analysis and was observed by metallograph. The X-ray diffraction experiments were performed with a Rigaku(RV-200 model) diffractometer, using Cu K_α radiation (λ= 0.154 05 nm). The diffraction data were adjusted with silicon powder as an internal standard. Thermal analysis experiments were made by a Perkin-Elmer DTA-1700-type differential thermal analyzer at the heating rate of 10 ℃/min. The element distribution in a part of the alloy specimens was determined in an electro-probe microanalyser (EPMA-8705Q model).

3 RESULTS AND DISCUSSION

3.1 Intermetallic compounds of Au-Dy and Ag-Dy binary system

In this work, we measured and inspected the intermetallic compounds in both Au-Dy and Ag-Dy binary systems (Dy ⩽35%). It is found that the crystal structures and the lattice parameter data of these compounds basically accord with the conclusions of Refs. [12, 15] and that the homogeneous region of Au_2Dy at 700 ℃ is 32.5% - 34.2% Dy (mole fraction), but Au_3Dy, $Au_{51}Dy_{14}$ and Au_6Dy have a narrower width of homogeneous regions than 1% Dy. Table 1 lists the crystal structures and the lattice parameters of Au_6Dy, $Au_{51}Dy_{14}$, Au_3Dy, Au_2Dy, Ag_2Dy, and $Ag_{51}Dy_{14}$.

3.2 Solubility of Dy in Au-Ag alloys

Rider et al[13] reported that the maximum solubility of Dy in Au is 2.3% (mole fraction) at 808 ℃, and decreases to about 0.5% Dy at 300 ℃. Gschneidner et al[8] determined the solubility of Dy in Ag at 805 ℃, the eutectic temperature between Ag and $Ag_{51}Dy_{14}$, to be 1.3%. In this work, the solubility of Dy in Au at 700 ℃ was determined to be 1.7%; in Ag to be 1.0%; in AuAg alloy of equal atom to be about 1.9%. These solubility data are based on the X-ray lattice parametric method — the variation of the lattice parameter vs composition for alloys quenched at 700 ℃ (see Figs. 1, 2 and 3). The solubility data of Dy in other Au-Ag alloys at 700 ℃ were inferred by the X-ray diffraction disappearing-phase method.

According to these solubility data, it is con-

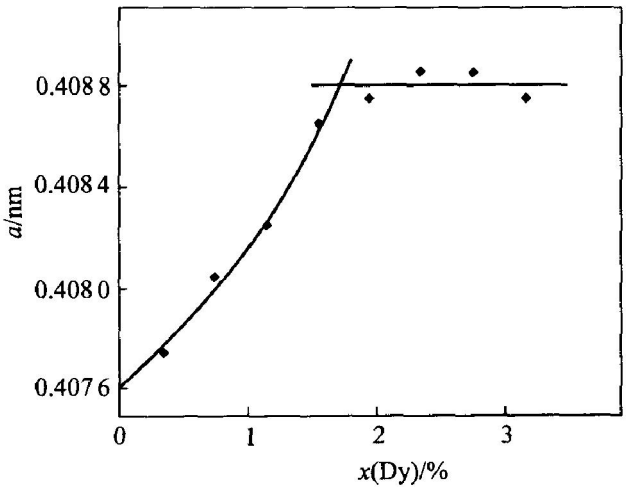


Fig. 1 Lattice parameters of (Au) vs composition of alloys $Au_{100-x}Dy_x$

Table 1 Crystal structure data in Au-Dy and Ag-Dy (0 - 35% Dy) binary system

Phase	Homogeneity range(Dy)/%	Space group	Proto-type	Lattice parameter/nm			Ref.
				a	*b*	*c*	
Au_6Dy	14.3	$P4_2/ncm$	Au_6Ho	1.030±0.001		0.967 0±0.001 0	[15]
$Au_{51}Dy_{14}$	about 21.5	P6/m	$Ag_{51}Gd_{14}$	1.256		0.915 2±0.000 2	[15]
Au_3Dy	25	Pmmn	$TiCu_3$	0.609 1±0.000 3	0.497 7±0.000 1	0.508 8±0.000 2	[15]
Au_2Dy	33.3	I4/mmm	$MoSi_2$	0.368 3±0.000 1		0.896 2±0.000 1	[15]
	32.5 - 34.2	I4/mmm	$MoSi_2$	0.367 6 - 0.368 8		0.895 6 - 0.897 0	This work
Ag_2Dy	32.3 - 34.3	I4/mmm	$MoSi_2$	0.369 4±0.000 4		0.921 3±0.000 6	[12]
$Ag_{51}Dy_{14}$	21.5 - 25.5	P6/m	$Ag_{51}Gd_{14}$	1.263 5 - 1.267 0		0.927 1 - 0.928 9	[12]

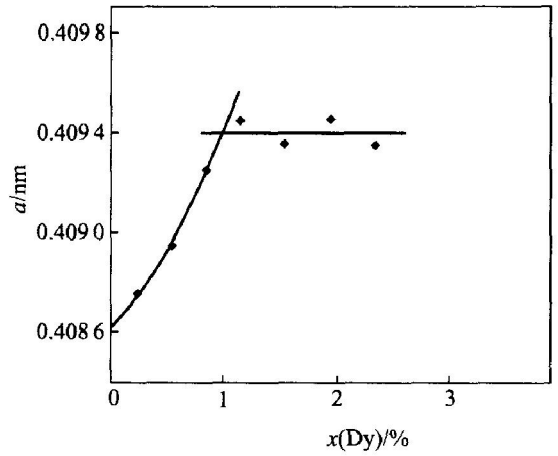


Fig. 2 Lattice parameters of (Ag) vs composition of alloys $Ag_{100-x}Dy_x$

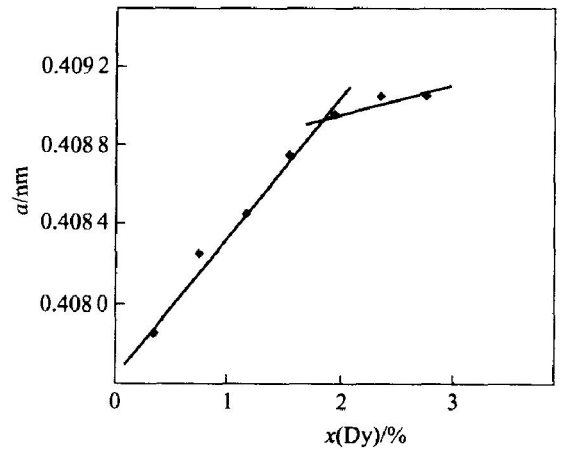


Fig. 3 Lattice parameters of Au(Ag) vs composition of alloys $Au_{50-x/2}Ag_{50-x/2}Dy_x$

firmed that there is a single-phase region, Au(Ag) or Ag(Au), with a fcc structure along the Au-Ag binary isomorphous system on the gold-silver-rich side in the 700 ℃ isothermal section of the Au-Ag-Dy ternary phase diagram. The region has long narrow shape with the width of 1.0%－2.0%.

3.3 Au_2Dy and Ag_2Dy phases

The binary intermetallic compounds Au_2Dy and Ag_2Dy are the congruently melted compounds. As shown in Table 1, both of these compounds have the same crystal structure of $MoSi_2$-type with the similar lattice parameter data. The homogeneous regions of the Au_2Dy in the Au-Dy binary system at 700 ℃ was determined to be 32.5%－34.2% Dy and the Ag_2Dy in Ag-Dy binary system to be 32.3%－34.3% Dy. Their single-phase ranges in the Au-Ag-Dy ternary system were studied by the X-ray parametric method. As shown in Fig. 4, the lattice parameters of Au_2Dy or Ag_2Dy phase in the $(Au_{2-x}Ag_x)Dy$ alloys at 700 ℃ increase continuously with the silver content increasing. The result shows that any amount of Au atoms can be replaced by Ag to form an all proportional solid solution, (Au_2Dy) or (Ag_2Dy).

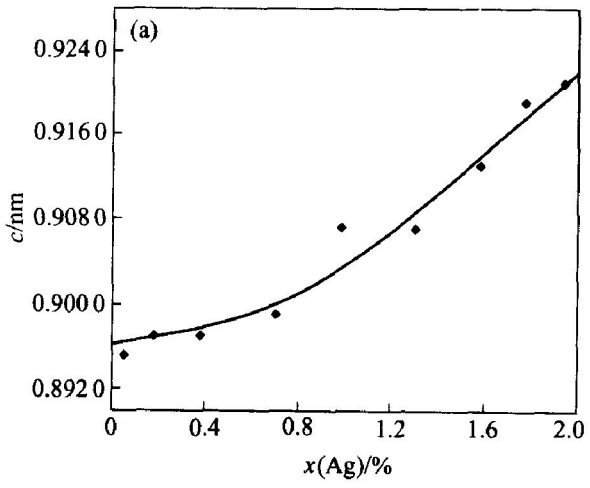
3.4 Au_6Dy, $Au_{51}Dy_{14}$, Au_3Dy and $Ag_{51}Dy_{14}$ phases

The single-phase regions of the compounds Au_6Dy, $Au_{51}Dy_{14}$, Au_3Dy and $Ag_{51}Dy_{14}$ in the Au-Ag-Dy ternary system were determined by the X-ray diffraction disappearing-phase method. It is found that the solid solubility of Ag in Au_6Dy at 700 ℃ is less than 1%, Ag in $Au_{51}Dy_{14}$ about 1%, Ag in Au_3Dy about 3%, Au in $Ag_{51}Dy_{14}$ about 5%.

3.5 Other phase regions

The other boundaries of the phase fields in 700 ℃ isotermal section of the Au-Ag-Dy ternary phase diagram (0－35% Dy) were determined by the X-ray diffraction disappearing-phase method, and checked by metallography. On the basis of the experiments, the compositions of all specimens are represented in Fig. 5. And no new ternary intermetallic phase was found.

According to the above investigations, the 700 ℃ isothermal section of the Au-Ag-Dy ternary phase diagram (Dy ≤35%) was confirmed and shown in Fig. 6.



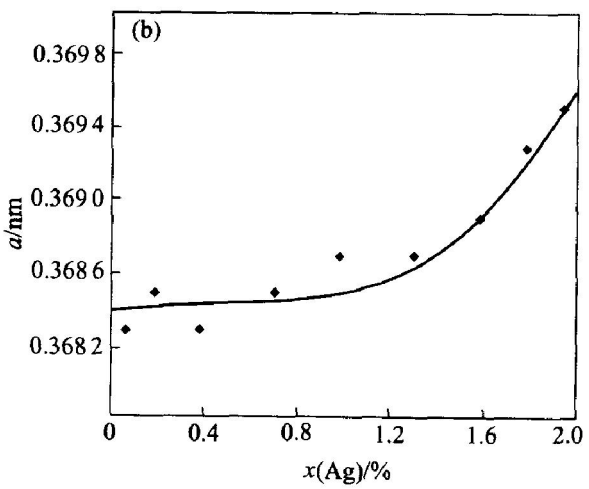


Fig. 4 Lattice parameters of (Au_2Dy) or (Ag_2Dy) vs composition of alloys $(Ag_xAu_{2-x})Dy$

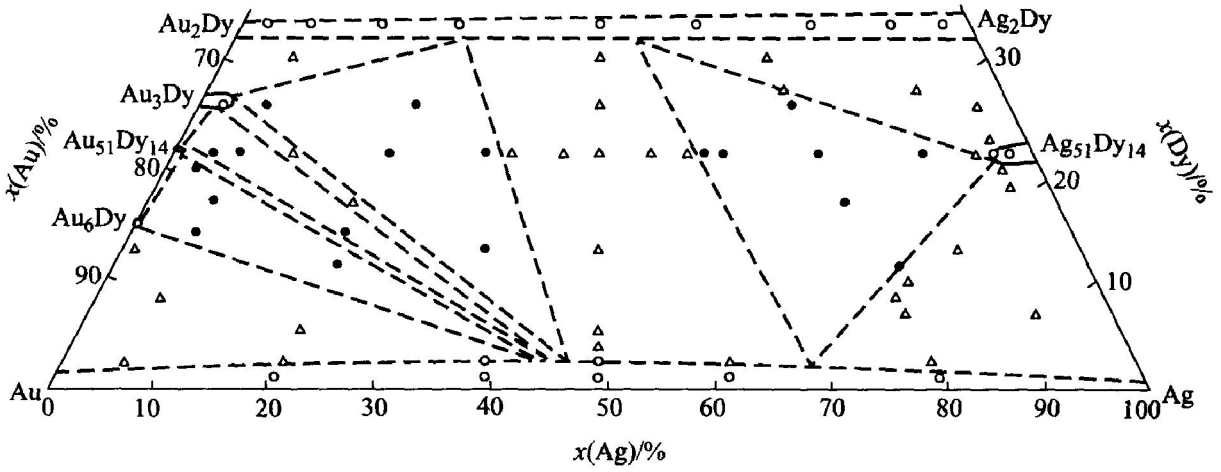


Fig. 5 Phase fields in 700 ℃ isothermal section of Au-Ag-Dy ternary system determined by X-ray diffraction disappearing-phase method
○—Single-phase; △—Two-phase; ●—Three-phase

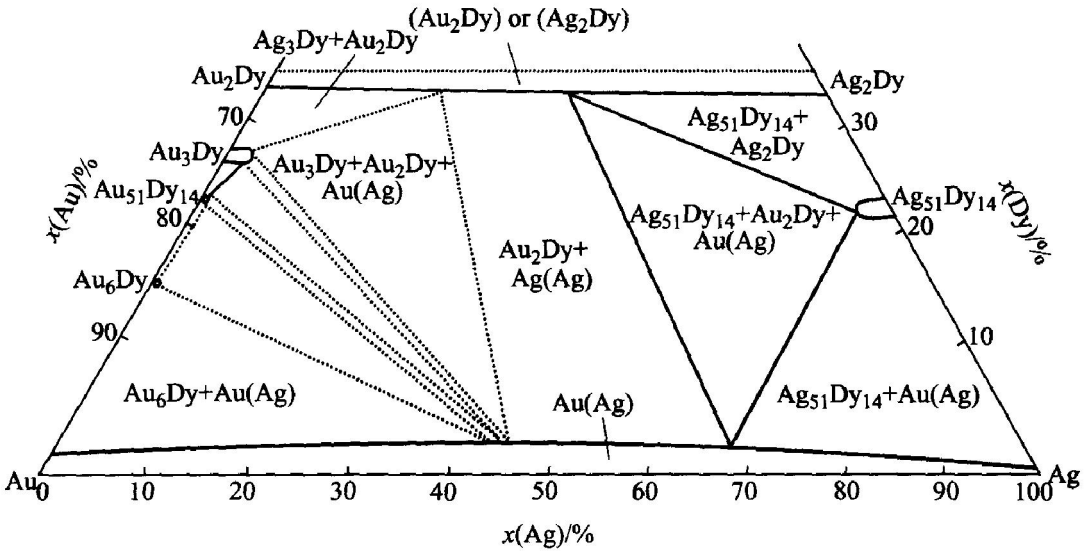


Fig. 6 700 ℃ isothermal section of Au-Ag-Dy(Dy ⩽35%) ternary system

4 CONCLUSIONS

1) There is a long single-phase region, Au(Ag) or Ag(Au), along the Au-Ag binary isomorphous system on the gold-silver-rich side of the 700 ℃ isothermal section. And between the binary compound Au_2Dy and Ag_2Dy there is the all proportional solid solution, (Au_2Dy) or (Ag_2Dy). No new ternary compound is formed in the gold-silver-rich field (Dy ⩽35%) of the Au-Ag-Dy ternary system.

2) The partial 700 ℃ isothermal section consists of six single-phase regions: solid solution Au(Ag) or Ag(Au), (Au_2Dy) or (Ag_2Dy), Au_6Dy, $Au_{51}Dy_{14}$, Au_3Dy and $Ag_{51}Dy_{14}$; nine binary-phase regions: (Au_2Dy) + Au(Ag), Au_6Dy + Au(Ag), Au(Ag) + $Ag_{51}Dy_{14}$, $Ag_{51}Dy_{14}$ + (Au_2Dy), Au_3Dy + (Au_2Dy), Au_3Dy + $Au_{51}Dy_{14}$, $Au_{51}Dy_{14}$ + Au_6Dy, $Au_{51}Dy_{14}$ + Au(Ag) and Au(Ag) + Au_3Dy; four ternary regions: $Ag_{51}Dy_{14}$ + (Au_2Dy) + Au(Ag), (Au_2Dy) + Au(Ag) + Au_3Dy, Au(Ag) + Au_3Dy + $Au_{51}Dy_{14}$ and $Au_{51}Dy_{14}$ + Au(Ag) + Au_6Dy.

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