DIFFUSION IN TERNARY SILVER-ZINC-CADMIUM

SOLID SOLUTIONS

by

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ABSTRACT

Diffusion in the silver-zinc-cadmium system was investigated at 600°C with semi-infinite, vapor-solid couples in order to evaluate intrinsic diffusion coefficients and interdiffusion coefficients in the alpha and beta phases. Intrinsic diffusion coefficients were determined at several composition points in the alpha phase region along concentration lines of 11 at. pct. Zn, 18 at. pct. Zn, 5 at. pct. Cd and 9 at. pct. Cd. Interdiffusion coefficients in the α phase were determined at several points of intersection of various composition paths; these composition points of intersection were along lines of constant zinc-to-cadmium concentration ratios of 3.8, 1.8 and 1.2. All two-phase diffusion couples developed planar β/α interfaces. Intrinsic coefficients were computed at three composition points in the beta region corresponding to a silver concentration of approximately 55 at. pct. Intrinsic coefficients for β alloys are two to three orders of magnitude larger than those for alpha alloys.

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INTRODUCTION

Since most metallic alloys of commercial interest contain three or more components, a study of ternary diffusion is useful in gaining insight into the general problem of multicomponent diffusion. Finite⁽¹⁾, semi-infinite^(2,3) and infinite^(1,4-8) diffusion couples have been employed to investigate diffusion in ternary solid solutions. Of particular interest to the present study are those investigations made with infinite⁽⁶⁻⁸⁾ and semi-infinite^(2,3) couples for the determination of concentration-dependent interdiffusion coefficients and intrinsic diffusion coefficients in ternary systems.

Vapor-solid couples can be successfully employed in studies of ternary diffusion provided that: (1) the vapor pressure of the solvent is negligible in comparison to those of the solutes supplied from the vapor phase and (2) the vapor pressures of the solutes are high enough to maintain a constant composition at the vapor-solid interface during the course of diffusion. In addition, the burial of inert markers originally placed at the vapor-solid interface must be adequate for measurement for studies of intrinsic diffusion.

The present investigation involves the study of diffusion in the ternary silver-zinc-cadmium system at 600°C with semi-infinite, vapor-solid couples. The choice of this particular system is based on the existence of large alpha (fcc) and beta (bcc) phase fields at 600°C^(9,10). Also, the high vapor pressures of the solutes, zinc and cadmium^(11,12), in contrast to the negligible vapor pressure of the solvent, silver⁽¹³⁾, are favorable factors for construction of vapor-solid couples in this system. Ternary alloy chips of selected compositions in the alpha and beta phases are used as vapor sources in contact with diffusion sinks of either pure silver or a silver-zinc binary alloy.

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The main objective of this study is to determine intrinsic diffusion coefficients at several compositions in both alpha and beta phase regions of the Ag-Zn-Cd isotherm at 600°C. Interdiffusion coefficients are also determined at several compositions in the alpha phase region. The experimental data on both intrinsic and interdiffusion coefficients are presented as functions of composition.

INTRINSIC DIFFUSION COEFFICIENTS

As pointed out by Darken⁽¹⁴⁾, a meaningful study of diffusion phenomena must differentiate between intrinsic diffusion and mass flows due to the Kirkendall effect. The reference frame required for the investigation of intrinsic diffusion can be identified by a moving plane of inert markers as opposed to a fixed frame of reference.

Philibert and Guy^(15,16) have shown that for diffusion couples involving multicomponent alloys it is possible to determine the cumulative fluxes of the various components that diffuse past a plane of inert markers. Their analysis, which is a direct extension of the method employed by Heumann⁽¹⁷⁾ for binary systems, has been used for the evaluation of intrinsic diffusion coefficients in ternary alloys^(2,3,7). The determination of such coefficients in ternary systems requires two diffusion couples with marker planes that move parabolically with time and correspond to essentially the same composition. The coefficients are then computed at the common composition of the marker planes. The intrinsic diffusion coefficients, D_{ij}^3 , for a ternary alloy are defined by the extended form of Fick's law:

$$J_i = - \sum_{j=1}^2 D_{ij}^3 \frac{\partial C_j}{\partial x} \quad (i = 1, 2, 3) \quad [1]$$

Upon integration over the time of diffusion, Eq. [1] yields:

$$A_i = \int_0^t J_i dt = -2t \left[D_{i1}^3 \frac{\partial C_1}{\partial x} + D_{i2}^3 \frac{\partial C_2}{\partial x} \right]_{\text{marker plane}} \quad (i = 1, 2, 3) \quad [2]$$

where A_i represents the cumulative intrinsic flux of component i past the plane of markers in time t . A_i is determined from appropriate areas under the diffusion profile⁽¹⁶⁾.

In order to solve for the D_{ij}^3 's in Eq. [2], it becomes necessary to generate six equations in six unknowns; these equations can be obtained from two independent diffusion couples having marker planes of identical composition. The establishment of such a pair of couples is greatly facilitated in the vapor-solid configuration, since markers originally placed at the vapor-solid interface remain fairly close to it after becoming imbedded during diffusion. Therefore, marker planes of virtually the same composition can be realized with two vapor-solid couples set up with two diffusion disks of different compositions exposed to the same vapor source⁽²⁾.

INTERDIFFUSION COEFFICIENTS

Dayananda and Grace⁽²⁾ have extended the analysis of binary vapor-solid couples by Balluffi and Seigle⁽¹⁸⁾ to ternary diffusion involving a moving vapor-solid interface. The flux $(J_i)_m$ of component i across any plane on the basis of a coordinate system moving with the velocity of the vapor-solid interface is given by:

$$(J_i)_m = - \sum_{j=1}^2 D_{ij}^3 \frac{\partial C_j}{\partial x} + C_i v(x, t) - C_i \phi(t) \quad (i = 1, 2, 3) \quad [3]$$

where $v(x,t)$ is the local Kirkendall velocity and $\phi(t)$ is the negative velocity of the vapor-solid interface. Both $v(x,t)$ and $\phi(t)$ are measured with respect to a stationary coordinate system located at the undiffused end of the couple. From Eq. [3] it has been shown⁽²⁾ that the relation that can be employed for the determination of interdiffusion coefficients, $\tilde{D}_{ij}^3$, from ternary vapor-solid couples is given by

$$\int_{C_1(\infty)}^{C_1} x' dC_1 = -2t \left[\tilde{D}_{11}^3 \frac{\partial C_1}{\partial x'} + \tilde{D}_{12}^3 \frac{\partial C_2}{\partial x'} \right]_{C_1} \quad (i = 1, 2, 3) \quad [4]$$

where $C_1(\infty)$ is the initial concentration of component 1 in the solid disk prior to diffusion. The origin of the x' coordinate is chosen at the original vapor-solid interface. With two diffusion couples whose diffusion paths intersect at composition, C_1 , on the ternary isotherm, two independent relations based on Eq. [4] can be generated for each component and solved for the four independent interdiffusion coefficients, $\tilde{D}_{11}^3, \tilde{D}_{21}^3, \tilde{D}_{12}^3, \tilde{D}_{22}^3$, at the common composition C_1 .

EXPERIMENTAL PROCEDURE

Ternary silver-zinc-cadmium alloys of selected compositions were made by induction melting pure silver (99.99 pct), high purity zinc (99.999 pct), and high purity cadmium (99.999 pct) in alumina crucibles under an argon atmosphere. Melting under argon atmosphere helped prevent excessive vapor loss of volatile zinc and cadmium. The alloys were quenched in ice-brine and the ingots were machined to fine chips less than 0.003 inch in thickness with acetone as coolant. The chips were outgassed in vacuum for 24 hours at 150°C. The compositions of the alloys used as vapor sources are given in Table I.

Diffusion disks, 1/4 in. thick and 3/4 in. in diameter, were cut from rods of pure silver and a silver-8.7 at. pct. zinc binary alloy (designated as Alloy B) and were machined to have parallel faces. The disks were then polished through 0.05 μ alumina. To stabilize grain size, the silver disks were annealed in an evacuated vycor capsule for 24 hours at 800°C, while the alloy disks were annealed at 650°C for 10 hours. After the anneal the zinc depleted surface layers were machined off each face of the alloy disks. All disks were then repolished through 0.05 μ alumina, and inert markers were placed on their surfaces by immersing them in a thin slurry of 1 μ alumina powder in absolute ethyl alcohol and letting the surfaces dry.

The vapor-solid couples were assembled with approximately 100 grams of chips of a vapor-source ternary alloy and two diffusion disks, one of silver and the other of Alloy B, placed in a 10 inch long vycor capsule, 1 inch in diameter, with equal distribution of the chips on either side of the disks. The mouth of the capsule was closed under a continuous stream of argon, and the capsule was then flushed several times with dry hydrogen, evacuated, and sealed at a pressure of less than 1 μ .

All diffusion capsules assembled with chips of α ternary alloys were annealed in a Marshall Model 1017 tubular furnace equipped with Barber-Coleman SCR controllers. The temperature gradient was 2°C over approximately 10 inches and the temperature was controlled to $\pm 0.5^\circ\text{C}$. Diffusion anneals were carried out for 3, 5 or 8 days at 600°C and the capsules were air-cooled.

All capsules assembled with chips of β alloys were annealed in a 2 inch diameter, stainless steel tube immersed in a lead pot maintained at 600°C. The temperature gradient over 9 inches was 1°C, and the control was $\pm 0.5^\circ\text{C}$. Diffusion experiments were made for 2, 6 or 12 hours. After the diffusion anneal, the capsules were quenched in ice-brine and were broken in the quenching medium; the rapid quench helped retain the high temperature structure

and prevent decomposition of the beta phase.

The diffused disks were electroplated with a 25 μ thick layer of copper in an aqueous solution⁽¹⁹⁾ of CuCN, NaCN and Na₂CO₃ and were mounted in a diallyl phthalate conducting resin. Sectioned disks were metallographically polished through 0.05 μ alumina and then electropolished in an aqueous solution⁽²⁰⁾ of AgCN, KCN and K₂CO₃ for 15-20 seconds at room temperature. The polished couples were then etched with an aqueous solution⁽²¹⁾ of H₂CrO₄ and H₂SO₄. In the case of diffusion disks exposed to α alloys, the depth of burial of markers was measured with a microscope equipped with a calibrated eyepiece with a precision of 0.1 μ ; for disks exposed to β alloys the marker burial was measured with a precision of 0.5 μ . The position of the β/α interface with respect to the disk-face was determined with a microscope equipped with a micrometer stage.

To determine the concentration-penetration profiles, each diffused specimen was repolished perpendicular to the direction of diffusion with 0.25 μ diamond paste to remove the etched layer and analyzed by point-to-point counting techniques with an ARL-AMX electron microprobe. Simultaneous analyses were made for zinc and cadmium by monitoring and measuring the x-ray intensities of the zinc K $_{\alpha}$ line ($\lambda = 1.436 \text{ \AA}$) and the cadmium L $_{\alpha}$ line ($\lambda = 3.956 \text{ \AA}$). At least two probe traverses were taken on either side of each specimen to check the similarity of the profiles. The measured intensities were converted to compositions by means of Ziebold's⁽²²⁾ conversion procedure. The conversion parameters were experimentally determined with both binary and ternary alloy standards.

EXPERIMENTAL RESULTS

Alpha Phase Region. The results of all diffusion experiments performed in the alpha phase region are presented in Table II. The movement of the vapor-solid interface and the burial of markers are recorded for each couple.

For the evaluation of diffusion coefficients from vapor-solid couples, it is necessary that the concentrations of the diffusing species be functions of the parameter λ defined by $x/\sqrt{t}$ ⁽²⁾. Such a requirement is satisfied if the composition at the vapor-solid interface remains invariant with time. Satisfactory realization of this requirement is illustrated for the couple, Alloy 4/Ag, whose concentration profiles for diffusion times of 3, 5 and 8 days are plotted against λ in Fig. 1. Data on marker burial and movement of the vapor solid interface are plotted against $\sqrt{t}$ in Fig. 2. Similar results were found for the couple, Alloy 9/Ag, for diffusion times up to 8 days.

From Eq. [2] intrinsic diffusion coefficients are calculated at the common marker composition of each pair of independent and complementary couples set up with the Ag and Alloy B diffusion disks in contact with the same vapor source. Complementary to couples, Alloy 4/Ag and Alloy 9/Ag, are the couples, Alloy 5/Alloy B and Alloy 9/Alloy B, whose concentration profiles are, respectively, shown in Figs. 3 and 4. The intrinsic diffusion data evaluated from 10 pairs of independent couples are given in Table III and are plotted as functions of cadmium and zinc concentrations in Figs. 5, 6, 7 and 8; these figures correspond to marker compositions along concentration lines of 11 at. pct. Zn, 18 at. pct. Zn, 5 at. pct. Cd, and 9 at. pct.

Cd, respectively.

The experimental diffusion paths of all couples set up with alpha alloys are shown on the Ag-Zn-Cd isotherm at 600°C in Figs. 9, 10 and 11. Eighteen points of intersection of the various alpha phase diffusion paths result when the isotherms in Figs. 9, 10 and 11 are superimposed; they can be divided into three groups according to the ratio of zinc-to-cadmium concentration at the composition point of intersection: (i) $C_{Zn}/C_{Cd} = 3.8$; (ii) $C_{Zn}/C_{Cd} = 1.8$; and (iii) $C_{Zn}/C_{Cd} = 1.2$. Interdiffusion coefficients calculated at each of these points of intersection from Eq. [4] are reported in Table IV and are illustrated in Fig. 12 for condition (i).

Beta Phase Region. The results of all experiments performed with beta alloys are given in Table V. These experiments correspond to β/α two-phase couples. Such couples also satisfy the requirement that the concentrations of zinc and cadmium be functions of λ , as can be seen in Fig. 13 for Alloy 18/Ag couple diffused for three different times. Data on the movements of the vapor-solid and β/α interfaces and on the marker burial are plotted against $\sqrt{t}$ in Fig. 14. All diffusion couples developed planar β/α interfaces. The concentration profiles for the couple, Alloy 18/Alloy B, complementary to the couple, Alloy 18/Ag, are shown in Fig. 15. Intrinsic diffusion coefficients calculated at marker compositions in the β phase region from three pairs of complementary couples are reported in Table VI.

DISCUSSION

From this study it is apparent that vapor-solid couples can be conveniently employed for the determination of both intrinsic and interdiffusion

coefficients in the Ag-Zn-Cd system. Vapor-solid couples assembled with either α or β ternary alloys as vapor sources developed composition profiles that were functions of the parameter λ . Consistent with such profiles are the observed parabolic movements with time of the marker plane and the vapor-solid interface. In addition, as the two-phase couples set up with β alloys developed planar β/α interfaces, the interface motion was also parabolic with time.

Two independent couples of a complementary pair set up with two different diffusion disks exposed to the same vapor source yielded marker planes of approximately the same composition as can be seen from Figs. 1, 3, 13 and 15. Marker planes of complementary couples agreed within ± 0.25 at. pct. Zn or Cd. The composition at which the intrinsic diffusion coefficients are reported for each set of complementary couples in Tables III and VI corresponds to the average of the compositions at the two marker planes.

From Figs. 5 through 8 it can be seen that for α alloys at constant levels of zinc, intrinsic coefficients increase with increasing cadmium concentration, and at constant levels of cadmium a similar behavior occurs for increasing zinc concentration. Errors in the evaluated intrinsic coefficients arise mainly from the uncertainties in concentration gradients at the plane of the markers. With repeated measurements of the concentration gradients at the marker planes, the main coefficients, D_{11}^3 and D_{22}^3 , varied as much as 40 percent while the cross coefficients, D_{12}^3 and D_{21}^3 , varied as much as 100 percent.

The interdiffusion coefficients plotted as a function of silver concentration at $C_{Zn}/C_{Cd} = 3.8$ in Fig. 12 show a maximum in the data for $\tilde{D}_{12}^3$ and $\tilde{D}_{22}^3$. Such behavior essentially reflects the fact that isointerdiffusion contours cross lines of constant C_{Zn}/C_{Cd} more than once in the range studied. Similar maxima and minima may be found in the data in Table IV. The interdiffusion coefficients are subject to lower uncertainties than the intrinsic coefficients due to the larger magnitudes of concentration gradients encountered at the common composition points of couple pairs.

Intrinsic diffusion coefficients in the beta phase region are two to three orders of magnitude larger than those in the alpha phase region. The larger values of these coefficients in the beta phase over those in the alpha phase are reflected in the relative widths of the diffusion zones of the two phases as can be seen in Fig. 13.

The variation in molar volume of alloys within the α or β phase fields has been ignored in the present calculations. From lattice parameter data, the molar volume of Ag-Zn α alloys⁽²³⁾ is lower than that of Ag and the decrease is limited to 5 percent of the molar volume of Ag; on the other hand, Ag-Cd α alloys⁽²⁴⁾ show an increase in molar volume limited to 6.7% of the molar volume of Ag. Hence, the changes in molar volume of ternary Ag-Zn-Cd alloys are considered to be smaller than those for the binary alloys.

A maximum was observed in the Zn diffusion profiles for runs 6, 22, 24 and 26. Such a maximum developed in the zinc concentration-penetration profile for the couple Alloy 4/Alloy B can be seen in Fig. 3. The apparent diffusion of zinc up its concentration gradient indicated by such profiles

implies that cadmium increases the chemical activity of zinc in silver. The observed maxima in the zinc profiles were more pronounced for couples employing higher concentrations of cadmium in the vapor source. These observations are reflected in the D_{12}^3 cross coefficients reported in Table III; these coefficients are about as large as the D_{11}^3 coefficients and indicate a large positive interaction that contributes to the flux of zinc down a cadmium gradient.

The interactions among diffusive species in multicomponent systems can also be described with the aid of general thermodynamic diffusion equations⁽²⁵⁾ expressed in terms of chemical potential gradients. Such a description would permit the determination of atomic mobilities of the various components and the vacancy wind effects in multicomponent alloys⁽²⁶⁾. These calculations, based on the thermodynamics of the Ag-Zn-Cd system and the diffusion data presented in this paper, will be reported later.

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Table I
Analyses of Ag-Zn-Cd Alloys

Alloy No.	Composition (atom pct)		
	Silver	Zinc	Cadmium
1	81.5	12.0	6.5
2	77.8	11.6	10.6
3	73.6	11.4	15.0
4	70.0	11.0	19.0
5	63.5	12.0	24.5
6	76.3	18.0	5.7
7	70.7	19.3	10.0
8	66.4	18.1	15.5
9	69.1	25.0	5.9
10	65.1	24.8	10.1
17	46.0	48.2	5.8
18	48.9	37.6	13.5
19	47.6	29.6	22.8

Table II

Diffusion Experiments in the Alpha Phase Region at 600°C

Run No.	Diffusion Time (Days)	Vapor Source (Alloy No.)	Diffusion Disk Material	Disk Expansion (Microns)	Depth of Marker Burial (Microns)	Movement of Markers (Microns)
1	3	4	Silver	37.8	11.8	26.0
2	5	4	Silver	47.2	14.5	32.7
3	8	4	Silver	60.5	17.8	42.7
4	5	1	Silver	13.9	6.6	7.3
5	5	1	Alloy B	8.8	4.1	4.7
6	5	4	Alloy B	44.2	13.9	30.3
9	5	6	Silver	26.5	14.5	12.0
10	5	6	Alloy B	23.0	11.5	11.5
11	5	7	Silver	43.7	22.1	21.6
12	5	7	Alloy B	44.0	18.7	25.3
13	5	8	Silver	77.3	28.5	48.8
14	5	8	Alloy B	67.0	26.9	40.1
15	5	9	Alloy B	53.0	29.0	24.0

Table II
Diffusion Experiments in the Alpha Phase Region at 600°C

Run No.	Diffusion Time (Days)	Vapor Source (Alloy No.)	Diffusion Dish Material	Dish Expansion (Microns)	Depth of Marker Burial (Microns)	Movement of Markers (Microns)
1	3	A	Silver	37.0	11.8	26.0
2	2	A	Silver	47.2	14.2	32.7
3	8	A	Silver	60.2	17.8	42.7
4	2	A	Silver	12.0	6.6	7.3
5	1	A	Alloy B	9.8	4.1	4.7
6	2	A	Alloy B	44.2	13.0	30.3
7	2	A	Silver	26.2	16.2	12.0
10	2	A	Alloy B	33.0	11.2	11.2
11	2	A	Silver	43.7	22.1	21.6
12	2	A	Alloy B	46.0	18.7	27.3
13	2	A	Silver	77.2	28.2	48.8
14	2	A	Alloy B	67.0	26.2	40.1
15	2	A	Alloy B	23.0	29.0	24.0

Table II (contd.)

Run No.	Diffusion Time (Days)	Vapor Source (Alloy No.)	Diffusion Disk Material	Disk Expansion (Microns)	Depth of Marker Burial (Microns)	Movement of Markers (Microns)
16	5	9	Silver	55.7	33.7	22.0
17	3	9	Silver	45.9	26.5	19.4
18	8	9	Silver	74.0	43.9	30.1
19	5	10	Silver	90.0	34.4	55.6
20	5	10	Alloy B	77.0	25.3	51.7
21	5	2	Silver	21.5	7.2	14.3
22	5	2	Alloy B	16.0	6.3	9.7
23	5	3	Silver	30.3	10.3	20.0
24	5	3	Alloy B	25.8	10.2	15.6
25	5	5	Silver	88.0	31.2	56.8
26	5	5	Alloy B	79.0	24.6	54.4

Table III

Intrinsic Diffusion Coefficients for Alpha Ag-Zn-Cd Alloys at 600°C

Run No.	Composition Atom pct. (balance Ag)	D_{ij}^3 (cm ² /sec) × 10 ⁹ *					
		D_{11}^3	D_{12}^3	D_{21}^3	D_{22}^3	D_{31}^3	D_{32}^3
4 5	11.0 Zn 5.7 Cd	0.46	0.48	0.92	0.59	-0.22	-0.43
21 22	11.1 Zn 9.2 Cd	0.69	0.68	0.09	0.72	-0.14	-0.43
23 24	11.2 Zn 13.5 Cd	0.76	0.76	0.35	0.94	-0.23	-0.28
1 6	11.1 Zn 18.4 Cd	1.3	1.4	1.1	2.9	-0.60	-1.0
25 26	11.2 Zn 21.6 Cd	2.7	2.8	2.7	7.2	-1.8	-2.5

Table III (contd.)

Run No.	Composition Atom pct. (balance Ag)	$D_{ij}^3 \text{ (cm}^2\text{/sec)} \times 10^9 *$					
		D_{11}^3	D_{12}^3	D_{21}^3	D_{22}^3	D_{31}^3	D_{32}^3
9	17.5 Zn	0.90	1.9	0.18	1.0	-0.55	-1.2
10	5.0 Cd						
11	18.0 Zn	1.0	1.9	0.25	1.5	-0.72	-1.1
12	9.4 Cd						
13	18.1 Zn	2.8	3.0	2.0	3.7	-1.3	-2.2
14	13.0 Cd						
15	24.6 Zn	1.7	7.1	0.39	2.4	-1.1	-3.8
16	5.0 Cd						
19	24.4 Zn	5.7	12.7	2.2	6.5	-2.3	-4.1
20	8.4 Cd						

* 1=Zn; 2=Cd; 3=Ag

Table IV

Interdiffusion Coefficients for Alpha Ag-Zn-Cd Alloys at 600°C

Run No.	Composition Atom pct. (balance Ag)	$\bar{D}_{ij}^3$ (cm ² /sec) x 10 ¹⁰ *			
		$\bar{D}_{11}^3$	$\bar{D}_{12}^3$	$\bar{D}_{21}^3$	$\bar{D}_{22}^3$
16 5	10.8 Zn 2.9 Cd	0.74	0.77	0.01	0.98
16 22	11.4 Zn 3.0 Cd	0.82	0.80	0.06	0.86
16 24	11.8 Zn 3.1 Cd	0.91	0.67	0.10	0.79
16 6	12.3 Zn 3.3 Cd	1.0	0.71	0.11	0.89
16 26	13.1 Zn 3.5 Cd	1.2	1.3	0.13	1.2
16 14	14.4 Zn 3.8 Cd	1.5	1.0	0.24	1.1
16 12	14.7 Zn 3.8 Cd	1.4	2.0	0.13	1.7
16 10	16.3 Zn 4.2 Cd	1.6	4.8	0.03	3.7

Table IV (contd.)

Run No.	Composition Atom pct. (balance Ag)	$\tilde{D}_{ij}^3$ (cm ² /sec) x 10 ¹⁰ *			
		$\tilde{D}_{11}^3$	$\tilde{D}_{12}^3$	$\tilde{D}_{21}^3$	$\tilde{D}_{22}^3$
16 20	18.1 Zn 4.4 Cd	3.3	2.4	0.60	2.1
11 22	11.6 Zn 6.5 Cd	1.4	0.98	0.18	1.5
11 24	12.1 Zn 6.7 Cd	1.7	0.90	0.36	1.4
11 6	12.8 Zn 7.0 Cd	2.4	0.71	0.61	1.5
11 26	13.3 Zn 7.1 Cd	2.3	1.4	0.50	2.0
11 14	16.4 Zn 8.5 Cd	4.4	4.5	1.4	5.5

Table IV (contd.)

Run No.	Composition Atom pct. (balance Ag)	$\tilde{D}_{ij}^3$ (cm ² /sec) x 10 ¹⁰ *			
		$\tilde{D}_{11}^3$	$\tilde{D}_{12}^3$	$\tilde{D}_{21}^3$	$\tilde{D}_{22}^3$
13 22	11.3 Zn 9.0 Cd	2.3	2.2	0.50	3.3
13 24	12.0 Zn 9.8 Cd	4.0	1.4	2.5	2.2
13 6	12.5 Zn 10.2 Cd	4.5	1.9	2.8	2.9
13 26	13.0 Zn 10.5 Cd	4.9	2.6	2.9	4.1

* 1=Zn; 2=Cd; 3=Ag

Table V
Diffusion Experiments in the Beta Phase Region at 600°C

Run No.	Diffusion Time (Hours)	Vapor Source (Alloy No.)	Diffusion Disk Material	Disk Expansion (Microns)	Depth of Marker Burial (Microns)	Marker Movement (Microns)	Thickness of β Layer (Microns)
27	6	17	Silver	388	180	208	890
28	6	17	Alloy B	352	170	182	910
29	6	18	Silver	428	194	234	965
30	6	18	Alloy B	358	175	183	935
31	2	18	Silver	240	112	128	545
32	12	18	Silver	580	263	317	1275
33	6	19	Silver	418	204	214	945
34	6	19	Alloy B	392	200	192	1035

Table VI

Intrinsic Diffusion Coefficients for Beta Ag-Zn-Cd Alloys at 600°C

Run No.	Composition Atom pct. (balance Ag)	D_{ij}^3 (cm ² /sec) $\times 10^6$ *					
		D_{11}^3	D_{12}^3	D_{21}^3	D_{22}^3	D_{31}^3	D_{32}^3
27	39.3 Zn 6.3 Cd	1.3	3.1	0.21	1.1	-0.47	-1.8
28							
29	31.0 Zn 13.9 Cd	1.2	1.4	0.08	2.0	-0.19	-1.7
30							
33	23.6 Zn 21.7 Cd	0.46	0.85	0.11	0.99	-0.15	-0.66
34							

* 1=Zn; 2=Cd; 3=Ag

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 5.

Figure 6.

Figure 7.

Figure 8.

Figure 9.

Figure 10.

Figure 11.

Figure 12.

Figure 13.

Figure 14.

Figure 15.

TABLE CAPTIONS

Table I	Analyses of Ag-Zn-Cd Alloys
Table II	Diffusion Experiments in the Alpha Phase Region at 600°C
Table III	Intrinsic Diffusion Coefficients for Alpha Ag-Zn-Cd Alloys at 600°C
Table IV	Interdiffusion Coefficients for Alpha Ag-Zn-Cd Alloys at 600°C
Table V	Diffusion Experiments in the Beta Phase Region at 600°C
Table VI	Intrinsic Diffusion Coefficients for Beta Ag-Zn-Cd Alloys at 600°C

FIGURE CAPTIONS

- Fig. 1 Concentration profiles of zinc and cadmium for the Alloy 4/Ag diffusion couple diffused for 3, 5, and 8 days at 600°C.
- Fig. 2 Marker burial and surface movement as functions of square-root of diffusion time for the Alloy 4/Ag diffusion couple diffused for 3, 5 and 8 days at 600°C.
- Fig. 3 Concentration profiles of zinc and cadmium for the Alloy 4/Alloy B diffusion couple diffused for 5 days at 600°C.
- Fig. 4 Concentration profiles of zinc and cadmium for the Alloy 9/Alloy B diffusion couple diffused for 5 days at 600°C.
- Fig. 5 Intrinsic diffusion coefficients as functions of cadmium concentration for α Ag-Zn-Cd alloys with 11 at. pct. Zn.
- Fig. 6 Intrinsic diffusion coefficients as functions of cadmium concentration for α Ag-Zn-Cd alloys with 18 at. pct. Zn.
- Fig. 7 Intrinsic diffusion coefficients as functions of zinc concentration for α Ag-Zn-Cd alloys with 5 at. pct. Cd.
- Fig. 8 Intrinsic diffusion coefficients as functions of zinc concentration for α Ag-Zn-Cd alloys with 9 at. pct. Cd.
- Fig. 9 Diffusion paths for runs 4, 5, 21, 22, 23, 24, 1, 6, 25, and 26 at 600°C.
- Fig. 10 Diffusion paths for runs 9, 10, 11, 12, 13, and 14 at 600°C.
- Fig. 11 Diffusion paths for runs 15, 16, 19, and 20 at 600°C.
- Fig. 12 Interdiffusion coefficients as functions of silver concentration for α Ag-Zn-Cd alloys with a C_{Zn}/C_{Cd} ratio of 3.8.
- Fig. 13 Concentration profiles of zinc and cadmium for the Alloy 18/Ag diffusion couple diffused for 2, 6 and 12 hours at 600°C.

Fig. 14 Marker burial, surface movement and β/α interface movement as functions of square-root of diffusion time for the Alloy 18/Ag diffusion couple diffused for 2, 6 and 12 hours at 600°C.

Fig. 15 Concentration profiles of zinc and cadmium for the Alloy 18/Alloy B diffusion couple diffused for 6 hours at 600°C.