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The Ternary Subsystem Indium Bismuthide-Bismuth-Tin

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The system InBi-Bi-Sn has been investigated by thermal analysis, metallographic, and X-ray procedures. No ternary compound was encountered, and a ternary eutectic composed of a Sn-rich solid solution, Bi, and InBi occurs at 77.5 ± 0.5° C. It contains 18 wt % Sn, 12% Bi, and 70% InBi. The solid solubilities at the Bi and InBi ends of the phase diagram are very restricted, but the Sn-rich solid solution contains 55 wt % Sn, 14% Bi, and 31% InBi at the eutectic temperature.

1. Previous Work

Two of the bounding binary systems, Bi-Sn and InBi-Bi, have received the attention of several investigators [1], but the only work reported on the ternary is that of Dooley and Peretti [2].

Bi and Sn form a simple eutectiferous phase diagram with restricted solubility of Sn in Bi, but considerable solid solubility at the Sn-rich end of the system. At the eutectic temperature of 139° C, Sn dissolves 19 wt % Bi. The eutectic contains 57 wt % Bi and 43 wt % Sn.

In the In-Bi system, two compounds are encountered: InBi, which melts congruently at 110° C; and In_2Bi, which melts incongruently at 89° C. InBi forms a eutectic with Bi at 109.5° C and 6.9 wt % Bi. The mutual solid solubility of Bi and InBi is very small. InBi has the tetragonal PbO(B10) type of crystal structure with $a =$ 5.000 Å and $c = 4.773$ Å.

The InBi-Sn diagram is similar to that of Bi-Sn; it exhibits a fairly large solid solubility of InBi in Sn (58 wt % at the temperature of the eutectic, 81° C), but the solid solubility of Sn in InBi is very small.

2. Experimental

2.1. Materials

The Bi used in this investigation was obtained from the American Smelting and Refining Co and had the following spectrographic analysis: 0.0001 % Cu, 0.0001 % Fe, 0.0001 % Pb, 0.0001 % Mg, and 99.999 + % Bi (by difference). The In, a loan from the Indium Corporation of America, had a guaranteed purity of 99.97 + % In; the major impurities were 0.01 % Zn, 0.01 % Sn, 0.006 % Pb, and 0.002 % Cu. Baker's "analysed reagent" Sn was used; it had a lot analysis of 0.0005 % Zn, 0.0005 % Fe, 0.0003 % Pb, 0.0002 % Cu, and 0.00001 % As.

2.2. Procedure

Alloys were made by melting the proper combinations of the three elements under a cover of mineral oil in a borosilicate glass tube and stirring with a glass rod. Thermal curves were taken with the alloys under a protective layer of mineral oil with mechanical stirring at a temperature change of 2 to 4° C/min. 45 to 75 g of material were used for each determination. The temperature was measured with calibrated chromel-alumel thermocouples, protected from the molten liquid and centred in the crucible by a thin-walled quartz tube. Time-temperature curves were automatically traced on a Honeywell extended-range recorder. Critical points were checked with a Leeds and Northrup semi-precision potentiometer.

Conventional techniques proved satisfactory for the polishing of samples for microscopic examination. Hydal (a 2 % solution of HCl in ethyl alcohol) and a mixture of Hydal and Vilella's reagent (1 g picric acid:5 ml HCl:

TABLE I Thermal data for the InBi-Bi-Sn system.

Alloy (wt %)			Temperature (°C ± 0.5° C)			Alloy (wt %)			Temperature (°C ± 0.5° C)		
InBi	Bi	Sn	1st arrest	2nd arrest	3rd arrest	InBi	Bi	Sn	1st arrest	2nd arrest	3rd arrest
95.00	4.25	0.75	104.8	102.3	76.8	31.00	38.00	31.00	108.0	75.5	—
90.00	8.50	1.50	103.0	77.0	—	20.00	44.00	36.00	121.0	118.8	75.5
85.00	12.75	2.25	109.3	103.3	77.0	10.00	49.50	40.50	130.5	127.8	72.5
80.00	17.00	3.00	119.0	101.3	76.8	90.00	3.50	6.50	94.5	77.5	—
70.00	25.00	4.50	129.3	97.3	77.3	85.00	5.25	9.75	88.8	77.0	—
60.00	34.00	6.00	146.8	92.3	77.0	80.00	7.00	13.00	83.0	77.8	—
45.00	46.75	8.25	167.5	83.0	78.2	75.00	8.75	16.25	80.0	77.8	—
31.00	58.65	10.35	181.3	85.8	75.8	66.00	11.20	22.80	88.0	77.0	—
13.00	73.95	13.05	204.0	111.8	75.2	55.00	15.75	29.25	81.6	76.8	—
95.00	3.50	1.50	103.8	76.5	—	39.50	21.20	39.30	129.5	90.0	75.5
90.00	7.00	3.00	101.3	77.0	—	30.00	24.50	45.50	143.8	97.0	74.0
85.00	10.50	4.50	98.6	97.5	77.0	23.00	26.90	50.10	153.5	100.2	—
80.00	14.00	6.00	101.3	95.2	77.5	15.00	29.70	55.30	164.0	110.0	—
70.00	21.00	9.00	111.6	86.4	77.5	8.00	32.20	59.80	172.2	120.0	—
60.00	28.00	12.00	116.0	86.3	78.3	95.00	0.75	4.25	97.3	77.8	—
47.00	37.10	15.90	131.3	86.0	77.0	90.00	1.50	8.50	89.8	77.8	—
33.00	46.90	20.10	139.8	100.3	76.0	85.00	2.25	12.75	85.3	77.6	—
23.00	53.90	23.10	150.8	111.0	76.0	80.00	3.00	17.00	77.8	—	—
10.00	63.00	27.00	160.8	77.0	74.5	72.00	4.20	23.80	96.3	76.5	—
95.00	2.75	2.25	101.0	75.0	—	65.00	5.25	29.75	109.8	76.0	—
90.00	5.50	4.50	98.0	75.8	—	55.00	6.75	38.25	130.0	75.0	—
85.00	8.25	6.75	94.8	77.0	—	46.00	8.10	45.90	146.0	83.0	75.3
80.00	11.00	9.00	92.6	91.0	77.0	40.00	9.00	51.00	154.0	79.8	74.3
70.00	16.50	13.50	95.8	79.3	77.8	29.00	10.65	60.35	172.4	86.2	72.5
58.00	23.10	18.90	99.5	84.5	77.0	20.00	12.00	68.00	185.3	92.6	—
45.00	30.20	24.80	104.0	94.3	77.3	10.00	15.00	75.00	198.3	107.0	94.3

100 ml ethyl alcohol) were used as the etching solutions.

Selected alloys were given a homogenising heat-treatment at 77° C for periods ranging from 2 weeks to 2 months, and were examined microscopically and by X-ray methods to attempt to determine solid-solubility limits.

3. Results

Fig. 1 shows the location of the sixty-six compositions studied, and table I gives the results of thermal analysis. Typical vertical sections through the temperature-composition space model are shown in figs. 2 to 5.

Fig. 6 shows the projection of the intersection of arbitrarily selected isothermal planes and the liquidus surface. No evidence was found for the existence of ternary compounds. A Sn-rich solid solution (labelled α in figs. 2 to 5), Bi, and InBi are the phases of primary crystallisation, depending upon composition. The α solid solution, Bi, and InBi form a ternary eutectic at 18 wt % Sn, 12 % Bi, and 70 % InBi at a temperature of 77.5 ± 0.5° C. The location of the eutectic was determined by the intersection of the three, plotted, binary eutectic valleys and by plotting the points of four-phase equilibria as obtained by the graphs of figs. 2 to 5.

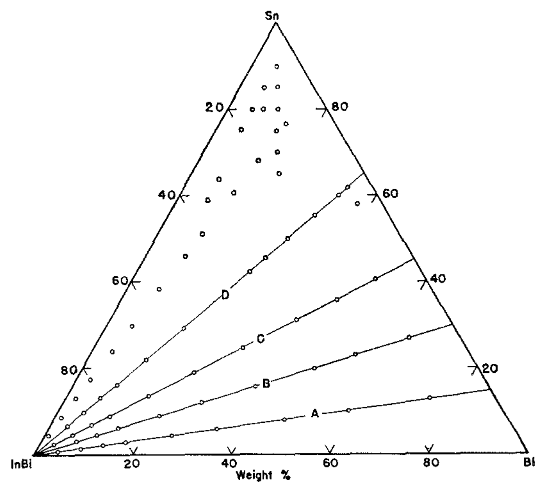

Figure 1 Location of alloys studied.

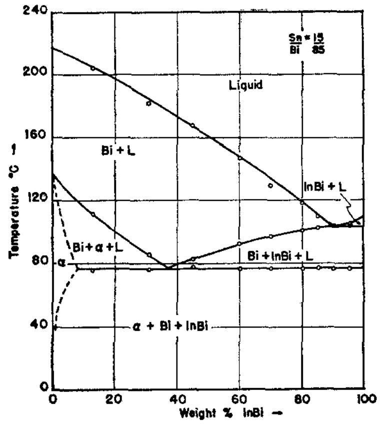

Figure 2 Vertical section A (see fig. 1), Sn:Bi = 15:85.

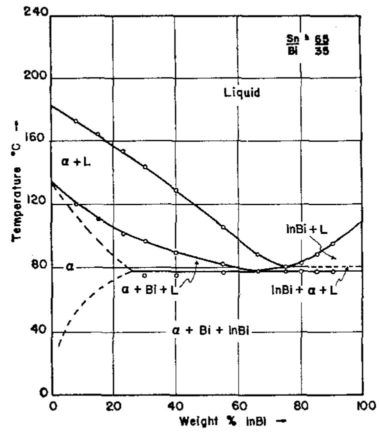

Figure 5 Vertical section D (see fig. 1), Sn:Bi = 65:35.

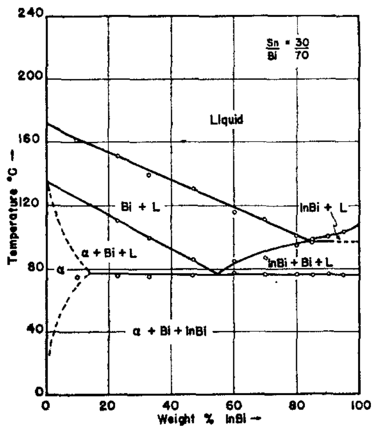

Figure 3 Vertical section B (see fig. 1), Sn:Bi = 30:70.

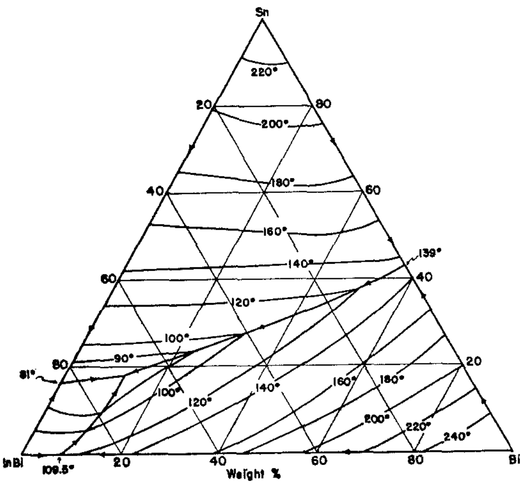

Figure 6 Liquidus isotherms.

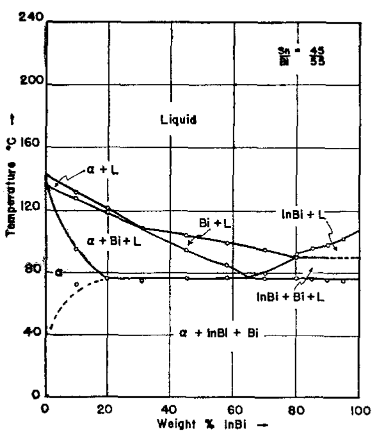

Figure 4 Vertical section C (see fig. 1), Sn:Bi = 45:55.

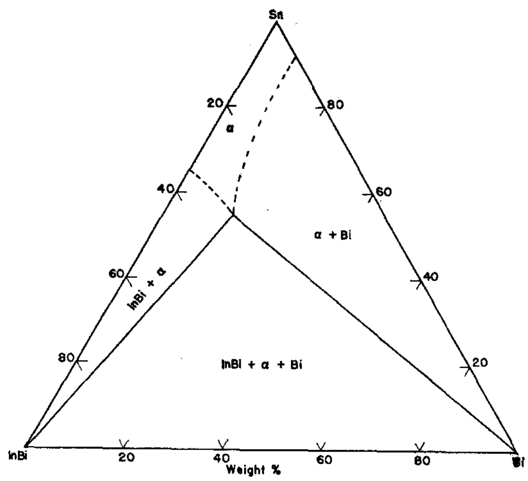

Figure 7 Solid-state isotherm at 77° C.

A solid-state isotherm at 77° C, just below the eutectic temperature, is given in fig. 7. The α solid solution in equilibrium with Bi and InBi contains 55 wt % Sn, 14% Bi, 31% InBi. The solvus lines could not be located accurately, because of lack of attainment of equilibrium in the specimens at the necessarily low temperature of heat treatment.

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