Pb – Sn (Lead – Tin)

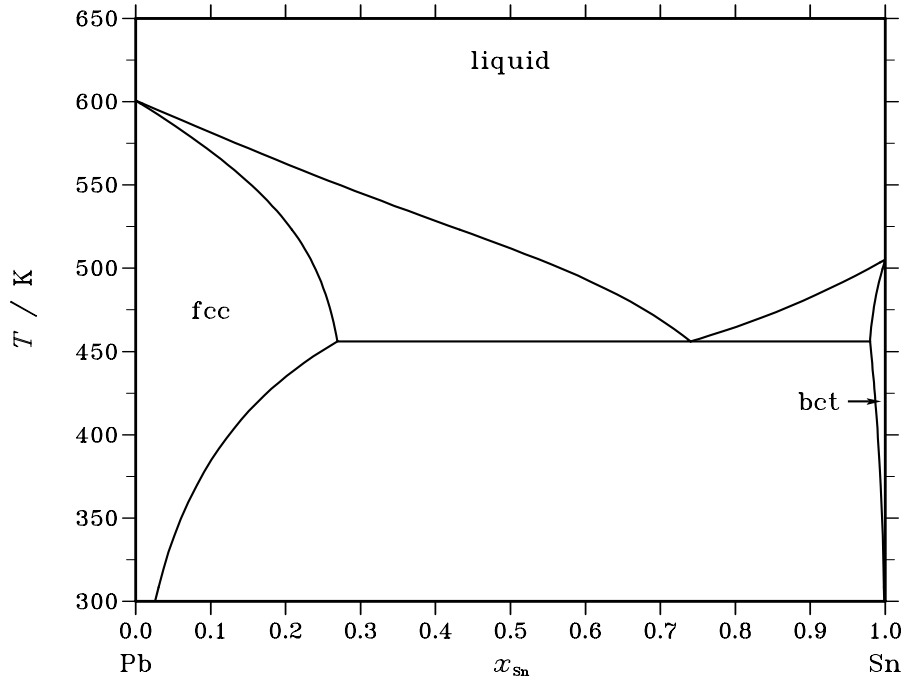

Fig. 1. Calculated phase diagram for the system Pb-Sn.

The Pb-Sn system has traditionally formed the basic building block for commercial solders. More recently concern over the potentially harmful effects of Pb has led to the development of new lead free solder materials based on tin but containing elements such as Ag, Bi, Cu, In, Sb and Zn. However the possible interaction between these lead free solders and the traditional solders in reworking of existing solder joints makes it essential for a good detailed understanding of the phase diagram and thermodynamic properties of the Pb-Sn system.

The Pb-Sn system is a very simple system characterised by continuous mixing in the liquid phase, substantial solubility of Sn in fcc-Pb and small solubility on Pb in bct-Sn. The eutectic at 456 K with the liquid containing about 74 at.% Sn is well established as is the whole of the phase diagram. The thermodynamic properties are also well studied experimentally although there seems to be some disagreement between different studies. The critical assessment adopted by SGTE is based on that by Ohtani *et al.* [95Oht] with data for the fcc phase modified to take account of revised data for fcc-Sn.

Table I. Phases, structures and models.

Phase	Struktur-bericht	Prototype	Pearson symbol	Space group	SGTE name	Model
liquid					LIQUID	$(Pb,Sn)_1$
fcc	$A1$	Cu	$cF4$	$Fm\overline{3}m$	FCC_A1	$(Pb,Sn)_1$
bct	$A5$	βSn	$tI4$	$I4_1/amd$	BCT_A5	$(Pb,Sn)_1$

Table II. Invariant reactions.

Reaction	Type	T / K	Compositions / x_{Sn}			$\Delta_r H$ / (J/mol)
liquid $\rightleftharpoons$ fcc + bct	eutectic	456.1	0.740	0.269	0.980	−6331

Table IIIa. Integral quantities for the liquid phase at 1050 K.

x_{Sn}	ΔG_{m} [J/mol]	ΔH_{m} [J/mol]	ΔS_{m} [J/(mol·K)]	$G_{\mathrm{m}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{m}}^{\mathrm{E}}$ [J/(mol·K)]	ΔC_P [J/(mol·K)]
0.000	0	0	0.000	0	0.000	0.000
0.100	−2402	615	2.874	436	0.171	0.000
0.200	−3568	1069	4.415	801	0.255	0.000
0.300	−4248	1369	5.350	1085	0.271	0.000
0.400	−4596	1527	5.832	1279	0.236	0.000
0.500	−4679	1551	5.933	1373	0.170	0.000
0.600	−4519	1451	5.686	1356	0.090	0.000
0.700	−4112	1236	5.094	1221	0.015	0.000
0.800	−3413	917	4.123	956	−0.037	0.000
0.900	−2286	501	2.655	552	−0.048	0.000
1.000	0	0	0.000	0	0.000	0.000

Reference states: Pb(liquid), Sn(liquid)

Table IIIb. Partial quantities for Pb in the liquid phase at 1050 K.

x_{Pb}	ΔG_{Pb} [J/mol]	ΔH_{Pb} [J/mol]	ΔS_{Pb} [J/(mol·K)]	$G_{\mathrm{Pb}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{Pb}}^{\mathrm{E}}$ [J/(mol·K)]	a_{Pb}	γ_{Pb}
1.000	0	0	0.000	0	0.000	1.000	1.000
0.900	−886	83	0.922	34	0.046	0.904	1.004
0.800	−1799	318	2.016	149	0.161	0.814	1.017
0.700	−2750	687	3.273	364	0.308	0.730	1.043
0.600	−3762	1170	4.697	698	0.450	0.650	1.083
0.500	−4880	1749	6.314	1171	0.550	0.572	1.144
0.400	−6197	2405	8.192	1802	0.573	0.492	1.229
0.300	−7900	3118	10.493	2611	0.482	0.405	1.349
0.200	−10434	3870	13.622	3617	0.240	0.303	1.513
0.100	−15263	4641	18.956	4839	−0.189	0.174	1.741
0.000	$-\infty$	5413	∞	6297	−0.842	0.000	2.057

Reference state: Pb(liquid)

Table IIIc. Partial quantities for Sn in the liquid phase at 1050 K.

x_{Sn}	ΔG_{Sn} [J/mol]	ΔH_{Sn} [J/mol]	ΔS_{Sn} [J/(mol·K)]	$G_{\mathrm{Sn}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{Sn}}^{\mathrm{E}}$ [J/(mol·K)]	a_{Sn}	γ_{Sn}
0.000	$-\infty$	6996	∞	4684	2.202	0.000	1.710
0.100	−16047	5410	20.435	4056	1.290	0.159	1.591
0.200	−10640	4072	14.012	3411	0.630	0.296	1.478
0.300	−7742	2963	10.194	2769	0.184	0.412	1.373
0.400	−5849	2063	7.535	2151	−0.084	0.512	1.279
0.500	−4477	1353	5.553	1574	−0.211	0.599	1.198
0.600	−3401	815	4.015	1059	−0.232	0.677	1.129
0.700	−2489	430	2.780	625	−0.185	0.752	1.074
0.800	−1658	179	1.749	291	−0.107	0.827	1.034
0.900	−844	41	0.843	76	−0.033	0.908	1.009
1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Sn(liquid)

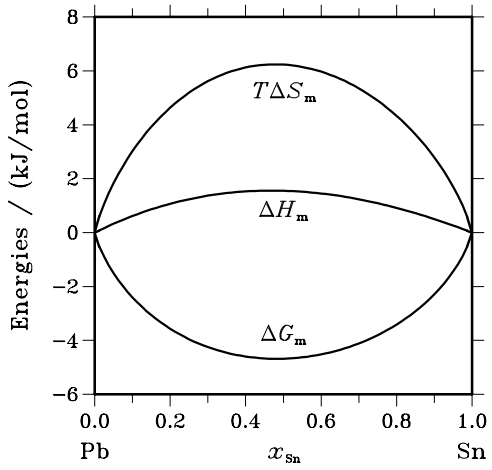

Fig. 2. Integral quantities of the liquid phase at T=1050 K.

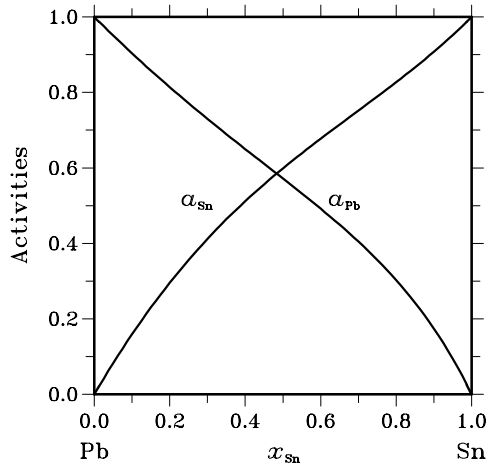

Fig. 3. Activities in the liquid phase at T=1050 K.

Table IVa. Integral quantities for the stable phases at 456 K.

Phase	x_{Sn}	ΔG_{m} [J/mol]	ΔH_{m} [J/mol]	ΔS_{m} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{m}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{m}}$ [J/(mol·K)]	ΔC_P [J/(mol·K)]
fcc	0.000	0	0	0.000	0	0.000	0.000
	0.100	−519	1194	3.756	714	1.053	0.000
	0.200	−592	2245	6.221	1306	2.060	0.000
	0.268	−565	2882	7.558	1640	2.722	0.000
bct	0.980	−86	400	1.065	289	0.243	0.000
	1.000	0	0	0.000	0	0.000	0.000

Reference states: Pb(fcc), Sn(bct)

Table IVb. Partial quantities for Pb in the stable phases at 456 K.

Phase	x_{Pb}	ΔG_{Pb} [J/mol]	ΔH_{Pb} [J/mol]	ΔS_{Pb} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Pb}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Pb}}$ [J/(mol·K)]	a_{Pb}	γ_{Pb}
fcc	1.000	0	0	0.000	0	0.000	1.000	1.000
	0.900	−339	71	0.899	61	0.023	0.915	1.016
	0.800	−602	286	1.947	244	0.092	0.853	1.066
	0.732	−746	515	2.764	439	0.166	0.821	1.123
bct	0.020	−746	19402	44.183	14050	11.735	0.821	40.685
	0.000	$-\infty$	20189	∞	14548	12.370	0.000	46.394

Reference state: Pb(fcc)

Table IVc. Partial quantities for Sn in the stable phases at 456 K.

Phase	x_{Sn}	ΔG_{Sn} [J/mol]	ΔH_{Sn} [J/mol]	ΔS_{Sn} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Sn}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Sn}}$ [J/(mol·K)]	a_{Sn}	γ_{Sn}
fcc	0.000	$-\infty$	12655	∞	7748	10.762	0.000	7.717
	0.100	−2141	11298	29.470	6590	10.325	0.569	5.686
	0.200	−549	10083	23.315	5553	9.934	0.865	4.326
	0.268	−72	9335	20.630	4915	9.692	0.981	3.656
bct	0.980	−72	8	0.176	5	0.006	0.981	1.001
	1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Sn(bct)

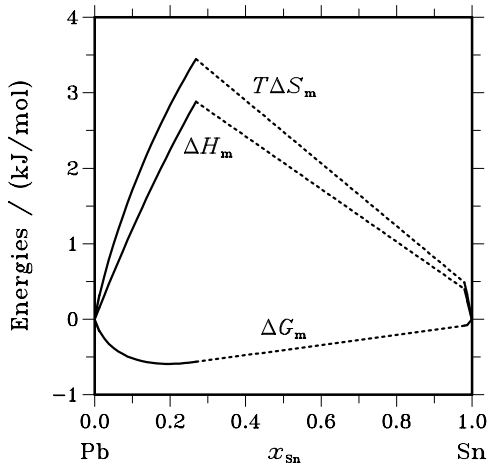

Fig. 4. Integral quantities of the stable phases at T=456 K.

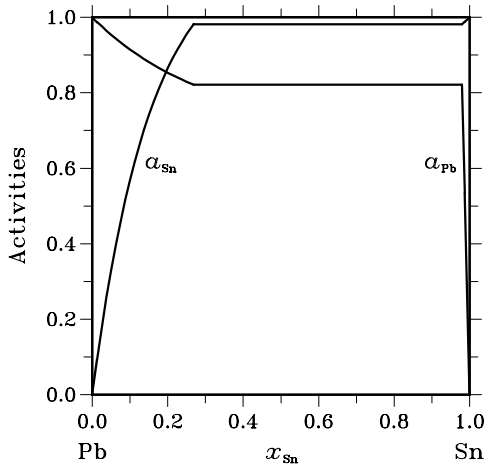

Fig. 5. Activities in the stable phases at T=456 K.

References

[95Oht] H. Ohtani, K. Okuda, K. Ishida: J. Phase Equilibria **16** (1995) 416–429.