In – Sn (Indium – Tin)

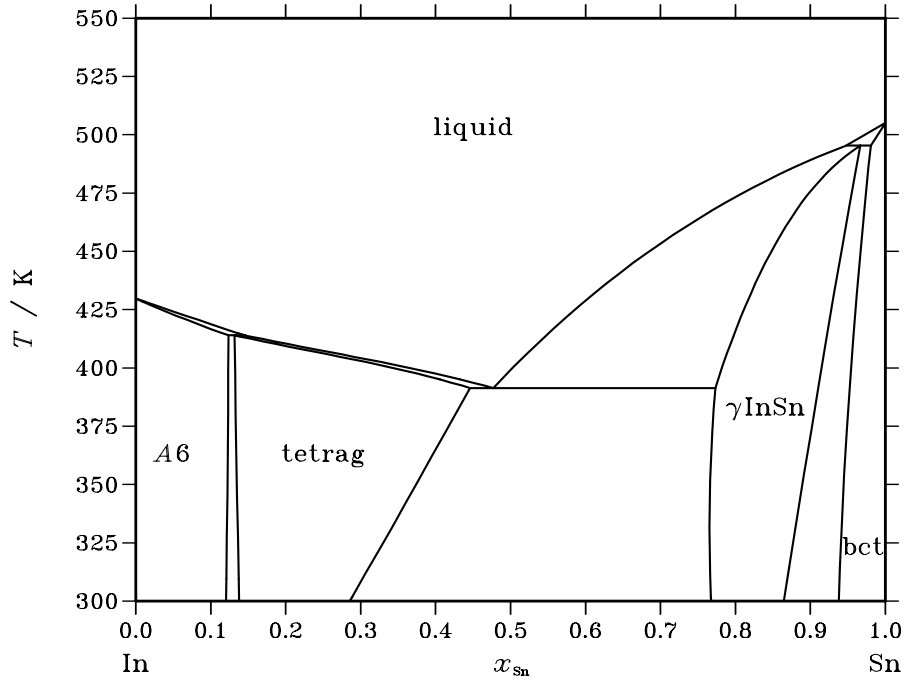

Fig. 1. Calculated phase diagram for the system In-Sn.

A good understanding of the thermodynamics and phase equilibria in the In-Sn system is currently very important because of the drive towards the development of Pb-free solder materials for environmental and health reasons. The critically assessed data for this system adopted by SGTE were taken from the unpublished assessment of Ansara *et al.* [99Ans]. The system is characterised by complete mixing of the components in the liquid phase, appreciable solubility of Sn (maximum 12 at.%) in the In based tetragonal solid solution phase and of In in the bct solid solution phase of Sn and the formation of two intermetallic phases tet_alpha and γInSn which exist over a wide range of homogeneity. The tet_alpha phase is closely related to stable crystalline phase of pure In and is isomorphous with the tet_alpha phase in the In-Pb system [55Cam, 80Eva]. The phase equilibria in the system have been studied extensively and in general the experimental data are in fair agreement. The most reliable data are those of Evans and Prince [83Eva], Kaplun [83Kap], Heumann and Alpaut [64Heu] and Wojtaszek and Kuzyk [74Woj]. The thermodynamic properties have been determined by calorimetry [56Kle, 61Wit, 68Yaz, 70Bro], by measuring the enthalpies of solidification [65Alp] and through EMF studies [60Ter]. A thermodynamic assessment for the In-Sn system has also been carried out by Lee [96Lee].

Table I. Phases, structures and models.

Phase	Struktur-bericht	Prototype	Pearson symbol	Space group	SGTE name	Model
liquid					LIQUID	$(In,Sn)_1$
$A6$	$A6$	In	$tI2$	$I4/mmm$	TETRAGONAL_A6	$(In,Sn)_1$
tetrag	$A6$	In	$tI2$	$I4/mmm$	TET_ALPHA1	$(In,Sn)_1$
γInSn	···	···	$hP5$	$P6/mmm$	INSN_GAMMA	$(In,Sn)_1$
bct	$A5$	βSn	$tI4$	$I4_1/amd$	BCT_A5	$(In,Sn)_1$

Table II. Invariant reactions.

Reaction	Type	T / K	Compositions / x_{Sn}			$\Delta_{\mathrm{r}}H$ / (J/mol)
liquid + bct $\rightleftharpoons$ γInSn	peritectic	495.3	0.948	0.980	0.967	−2300
$A6$ + liquid $\rightleftharpoons$ tetrag.	peritectic	414.0	0.124	0.145	0.132	−999
liquid $\rightleftharpoons$ tetrag. + γInSn	eutectic	391.4	0.477	0.446	0.773	−2311

Table IIIa. Integral quantities for the liquid phase at 600 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	−1766	−76	2.816	−144	0.113	0.011
0.200	−2722	−132	4.317	−226	0.156	0.019
0.300	−3304	−168	5.225	−256	0.146	0.025
0.400	−3604	−187	5.696	−247	0.100	0.029
0.500	−3667	−189	5.797	−209	0.034	0.030
0.600	−3513	−176	5.561	−155	−0.035	0.029
0.700	−3143	−149	4.990	−96	−0.089	0.025
0.800	−2539	−110	4.048	−42	−0.113	0.019
0.900	−1628	−60	2.614	−7	−0.089	0.011
1.000	0	0	0.000	0	0.000	0.000

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

Table IIIb. Partial quantities for In in the liquid phase at 600 K.

x_{In}	ΔG_{In} [J/mol]	ΔH_{In} [J/mol]	ΔS_{In} [J/(mol·K)]	$G_{\mathrm{In}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{In}}^{\mathrm{E}}$ [J/(mol·K)]	a_{In}	γ_{In}
1.000	0	0	0.000	0	0.000	1.000	1.000
0.900	−559	−11	0.914	−33	0.038	0.894	0.993
0.800	−1231	−40	1.984	−118	0.129	0.781	0.977
0.700	−2010	−87	3.205	−230	0.239	0.668	0.955
0.600	−2896	−147	4.583	−348	0.335	0.560	0.933
0.500	−3906	−218	6.147	−448	0.384	0.457	0.914
0.400	−5079	−297	7.970	−508	0.351	0.361	0.903
0.300	−6510	−382	10.214	−504	0.204	0.271	0.904
0.200	−8443	−469	13.290	−414	−0.092	0.184	0.920
0.100	−11701	−556	18.575	−214	−0.570	0.096	0.958
0.000	$-\infty$	−640	∞	118	−1.264	0.000	1.024

Reference state: In(liquid)

Table IIIc. Partial quantities for Sn in the liquid phase at 600 K.

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}
0.000	$-\infty$	−871	∞	−1793	1.536	0.000	0.698
0.100	−12630	−668	19.935	−1143	0.791	0.080	0.795
0.200	−8687	−499	13.648	−658	0.266	0.175	0.876
0.300	−6323	−359	9.940	−317	−0.070	0.282	0.938
0.400	−4666	−247	7.365	−95	−0.253	0.392	0.981
0.500	−3428	−160	5.447	30	−0.316	0.503	1.006
0.600	−2468	−95	3.955	80	−0.292	0.610	1.016
0.700	−1700	−49	2.751	79	−0.215	0.711	1.016
0.800	−1063	−20	1.738	51	−0.118	0.808	1.010
0.900	−509	−5	0.841	16	−0.035	0.903	1.003
1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Sn(liquid)

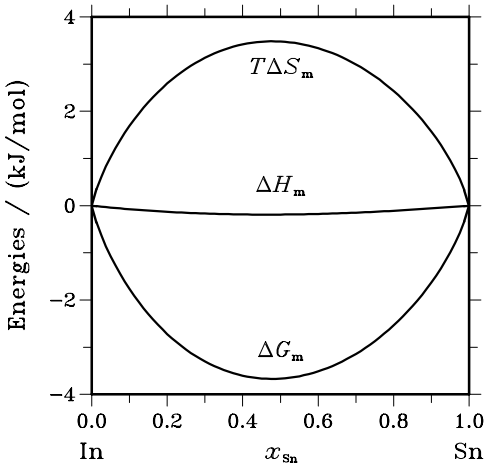

Fig. 2. Integral quantities of the liquid phase at T=600 K.

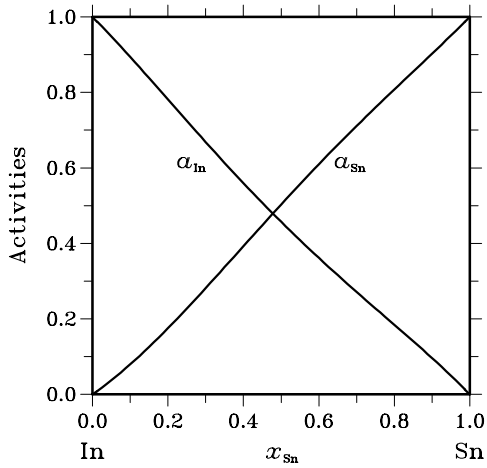

Fig. 3. Activities in the liquid phase at T=600 K.

Table IVa. Integral quantities for the stable phases at 373 K.

Phase	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)]
$A6$	0.000	0	0	0.000	0	0.000	0.000
	0.100	−859	722	4.239	149	1.536	0.000
	0.123	−970	881	4.963	186	1.865	0.000
tetrag.	0.134	−1018	953	5.286	202	2.015	0.000
	0.200	−1257	1352	6.995	295	2.834	0.000
	0.300	−1436	1939	9.047	459	3.968	0.000
	0.400	−1438	2506	10.574	649	4.978	0.000
	0.414	−1426	2584	10.750	678	5.110	0.000
γInSn	0.769	−1072	993	5.536	604	1.044	0.000
	0.800	−1028	914	5.206	524	1.046	0.000
	0.900	−688	721	3.777	320	1.074	0.000
	0.901	−683	719	3.760	318	1.074	0.000
bct	0.949	−433	259	1.856	195	0.172	0.000
	1.000	0	0	0.000	0	0.000	0.000

Reference states: In($A6$), Sn(bct)

Table IVb. Partial quantities for In in the stable phases at 373 K.

Phase	x_{In}	ΔG_{In} [J/mol]	ΔH_{In} [J/mol]	ΔS_{In} [J/(mol·K)]	$G_{\mathrm{In}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{In}}^{\mathrm{E}}$ [J/(mol·K)]	a_{In}	γ_{In}
$A6$	1.000	0	0	0.000	0	0.000	1.000	1.000
	0.900	−336	20	0.955	−9	0.079	0.897	0.997
	0.877	−420	31	1.209	−14	0.119	0.873	0.996
tetrag.	0.866	−420	140	1.502	25	0.309	0.873	1.008
	0.800	−697	161	2.300	−5	0.445	0.799	0.998
	0.700	−1178	209	3.718	−72	0.752	0.684	0.977
	0.600	−1750	275	5.429	−166	1.182	0.569	0.948
	0.586	−1839	286	5.696	−181	1.252	0.553	0.943
γInSn	0.231	−1839	3092	13.219	2708	1.031	0.553	2.394
	0.200	−2492	2854	14.333	2499	0.951	0.448	2.238
	0.100	−5374	2018	19.818	1767	0.673	0.177	1.768
	0.099	−5411	2010	19.894	1760	0.670	0.175	1.764
bct	0.051	−5411	5041	28.021	3795	3.340	0.175	3.400
	0.000	$-\infty$	5041	∞	3795	3.340	0.000	3.400

Reference state: In($A6$)

Table IVc. Partial quantities for Sn in the stable phases at 373 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}
$A6$	0.000	$-\infty$	7423	∞	1400	16.146	0.000	1.571
	0.100	−5569	7036	33.793	1572	14.648	0.166	1.660
	0.123	−4893	6953	31.760	1609	14.328	0.206	1.680
tetrag.	0.134	−4893	6223	29.803	1347	13.072	0.206	1.544
	0.200	−3496	6118	25.775	1496	12.393	0.324	1.620
	0.300	−2037	5976	21.482	1697	11.472	0.518	1.728
	0.400	−970	5852	18.291	1871	10.673	0.731	1.828
	0.414	−841	5836	17.903	1894	10.570	0.762	1.841
γInSn	0.769	−841	363	3.230	−27	1.048	0.762	0.991
	0.800	−662	429	2.925	30	1.069	0.808	1.010
	0.900	−168	576	1.995	159	1.119	0.947	1.053
	0.901	−164	577	1.986	160	1.119	0.949	1.053
bct	0.949	−164	0	0.439	0	0.000	0.949	1.000
	1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Sn(bct)

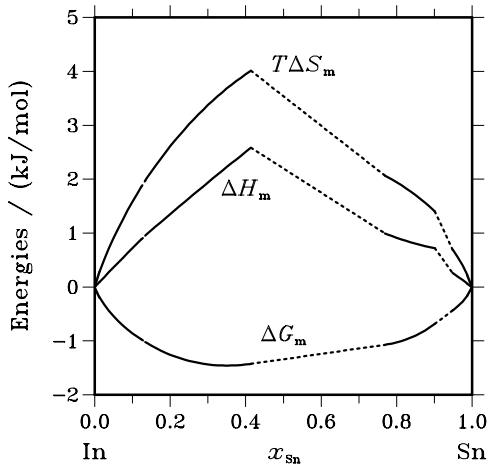

Fig. 4. Integral quantities of the stable phases at T=373 K.

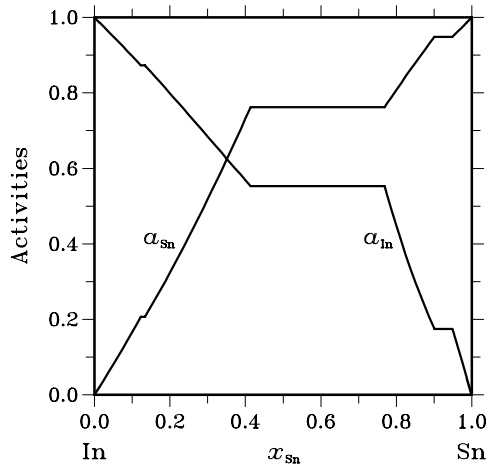

Fig. 5. Activities in the stable phases at T=373 K.

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