Pd – Sn (Palladium – Tin)

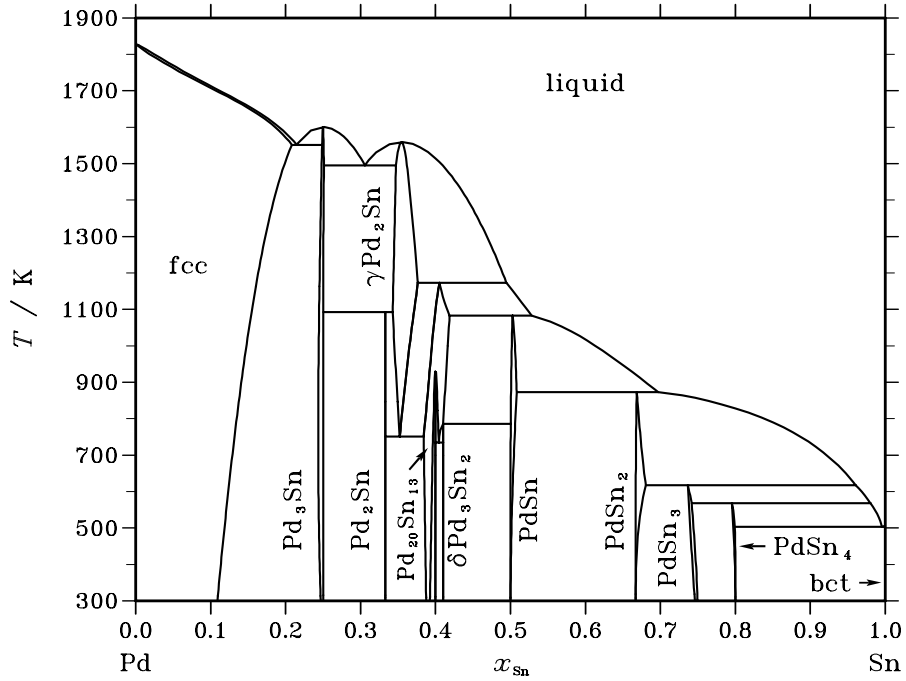

Fig. 1. Calculated phase diagram for the system Pd-Sn.

There are a range of intermetallic compound phases in the Pd-Sn system. Many of these form peritectically from the melt, whereas Pd_3Sn and γPd_2Sn form congruently. Most of the compound phases display small ranges of stoichiometry [86Mas]. The liquidus boundary and the invariant reactions of the system are well reproduced by the thermodynamic assessment of the system reported by Ghosh [99Gho]. Non-stoichiometric behaviour is also described, the only simplification being with respect to the complex equilibria around the composition Pd_3Sn_2 which is approximated by 2 compound phases. Enthalpies of formation of the solid compound phases and enthalpies of mixing of liquid alloys are strongly exothermic and display a minimum close to the composition Pd_2Sn.

Table I. Phases, structures and models.

Phase	Struktur-bericht	Prototype	Pearson symbol	Space group	SGTE name	Model
liquid					LIQUID	$(Pd,Sn)_1$
fcc	$A1$	Cu	$cF4$	$Fm\bar{3}m$	FCC_A1	$(Pd,Sn)_1$
Pd_3Sn	$L1_2$	$AuCu_3$	$cP4$	$Pm\bar{3}m$	L12_PD3SN	$(Pd,Sn)_3(Pd,Sn)_1$
Pd_2Sn	$C23$	Co_2Si	$oP12$	$Pnma$	PD2SN	Pd_2Sn_1
γPd_2Sn	$D8_1$	NiAs	$hP4$	$P6_3/mmc$	PDSN_GAMMA	$Pd_1Sn_1(Pd,\Box)_1$
$Pd_{20}Sn_{13}$	···	···	$hP66$	$P3_121$	PD20SN13	$(Pd,Sn)_3(Pd,Sn)_2$
αPd_3Sn_2	···	···	···	···	PD3SN2_A	Pd_3Sn_2
βPd_3Sn_2	···	···	···	···	PD3SN2_B	Pd_3Sn_2
δPd_3Sn_2	···	···	···	···	PD3SN2_D	$Pd_{59}Sn_{41}$
PdSn	$B31$	MnP	$mP28$	$P2_1/m$	B31_PDSN	$(Pd,\Box)_1(Pd,Sn)_1$
$PdSn_2$	C_e	$PdSn_2$	$oC24$	$Aba2$	CE_PDSN2	$(Pd,Sn)_1Sn_2$
$PdSn_3$	···	···	$oC32$	$Cmca$	PDSN3	$Pd_1(Pd,Sn)_3$
$PdSn_4$	$D1_c$	$PdSn_4$	$oC20$	$Aba2$	D1C_PDSN4	$Pd_1(Pd,Sn)_4$
bct	$A5$	βSn	$tI4$	$I4_1/amd$	BCT_A5	$(Pd,Sn)_1$

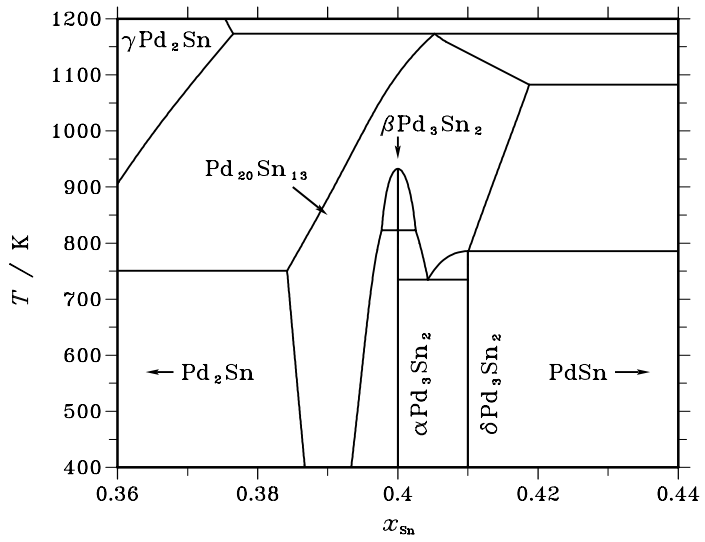

Fig. 2. Partial phase diagram for the system Pd-Sn.

Table II. Invariant reactions.

Reaction	Type	T / K	Compositions / x_{Sn}			$\Delta_{\mathrm{r}}H$ / (J/mol)
liquid $\rightleftharpoons$ Pd_3Sn	congruent	1601.0	0.250	0.250		−13446
liquid $\rightleftharpoons$ γPd_2Sn	congruent	1559.4	0.354	0.354		−12191
liquid $\rightleftharpoons$ fcc + Pd_3Sn	eutectic	1551.6	0.215	0.208	0.249	−4546
liquid $\rightleftharpoons$ Pd_3Sn + γPd_2Sn	eutectic	1495.6	0.306	0.251	0.347	−11553
γPd_2Sn + liquid $\rightleftharpoons$ $Pd_{20}Sn_{13}$	peritectic	1173.1	0.376	0.495	0.405	−5810
Pd_3Sn + γPd_2Sn $\rightleftharpoons$ Pd_2Sn	peritectoid	1093.1	0.250	0.343	0.333	−1668
$Pd_{20}Sn_{13}$ + liquid $\rightleftharpoons$ PdSn	peritectic	1082.8	0.419	0.528	0.503	−11261
$Pd_{20}Sn_{13}$ $\rightleftharpoons$ βPd_3Sn_2	congruent	932.6	0.400	0.400		−72
PdSn + liquid $\rightleftharpoons$ $PdSn_2$	peritectic	873.2	0.508	0.697	0.668	−10601
βPd_3Sn_2 $\rightleftharpoons$ αPd_3Sn_2	polymorphic	822.9	0.400	0.400		−72
$Pd_{20}Sn_{13}$ $\rightleftharpoons$ δPd_3Sn_2	congruent	785.8	0.410	0.410		−273
$Pd_{20}Sn_{13}$ $\rightleftharpoons$ δPd_3Sn_2 + $PdSn_4$	eutectoid	785.8	0.410	0.410	0.500	−274
γPd_2Sn $\rightleftharpoons$ Pd_2Sn + $Pd_{20}Sn_{13}$	eutectoid	750.7	0.352	0.333	0.384	−1508
$Pd_{20}Sn_{13}$ $\rightleftharpoons$ αPd_3Sn_2 + δPd_3Sn_2	eutectoid	734.8	0.404	0.400	0.410	−154
$PdSn_2$ + liquid $\rightleftharpoons$ $PdSn_3$	peritectic	618.0	0.681	0.960	0.737	−2846
$PdSn_3$ + liquid $\rightleftharpoons$ $PdSn_4$	peritectic	568.0	0.742	0.980	0.796	−2434
liquid $\rightleftharpoons$ $PdSn_4$ + bct	eutectic	503.7	0.996	0.799	1.000	−7140

Table IIIa. Integral quantities for the liquid phase at 1873 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	−22786	−33917	−5.943	−17723	−8.646	0.000
0.200	−34949	−53429	−9.867	−27156	−14.027	0.000
0.300	−40148	−61882	−11.604	−30635	−16.683	0.000
0.400	−40578	−62184	−11.535	−30097	−17.131	0.000
0.500	−37866	−56798	−10.108	−27071	−15.871	0.000
0.600	−33168	−47749	−7.785	−22687	−13.381	0.000
0.700	−27182	−36622	−5.040	−17669	−10.119	0.000
0.800	−20129	−24560	−2.365	−12337	−6.526	0.000
0.900	−11672	−12265	−0.317	−6609	−3.020	0.000
1.000	0	0	0.000	0	0.000	0.000

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

Table IIIb. Partial quantities for Pd in the liquid phase at 1873 K.

x_{Pd}	ΔG_{Pd} [J/mol]	ΔH_{Pd} [J/mol]	ΔS_{Pd} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Pd}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Pd}}$ [J/(mol·K)]	a_{Pd}	γ_{Pd}
1.000	0	0	0.000	0	0.000	1.000	1.000
0.900	−6210	−7797	−0.847	−4569	−1.724	0.671	0.746
0.800	−18431	−26505	−4.311	−14956	−6.166	0.306	0.383
0.700	−32645	−50093	−9.316	−27090	−12.281	0.123	0.176
0.600	−46066	−73850	−14.834	−38111	−19.081	0.052	0.087
0.500	−57162	−94388	−19.875	−46367	−25.638	0.025	0.051
0.400	−65688	−109640	−23.466	−51419	−31.084	0.015	0.037
0.300	−72784	−118861	−24.601	−54035	−34.611	0.009	0.031
0.200	−81260	−122631	−22.088	−56196	−35.470	0.005	0.027
0.100	−96951	−122847	−13.826	−61092	−32.971	0.002	0.020
0.000	−∞	−122731	∞	−73124	−26.485	0.000	0.009

Reference state: Pd(liquid)

Table IIIc. Partial quantities for Sn in the liquid phase at 1873 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	−∞	−423450	∞	−227491	−104.623	0.000	0.000
0.100	−171973	−268996	−51.801	−136115	−70.946	0.000	0.000
0.200	−101019	−161123	−32.090	−75955	−45.471	0.002	0.008
0.300	−57657	−89391	−16.943	−38907	−26.954	0.025	0.082
0.400	−32345	−44684	−6.588	−18075	−14.207	0.125	0.313
0.500	−18570	−19208	−0.340	−7776	−6.104	0.303	0.607
0.600	−11488	−6489	2.669	−3533	−1.578	0.478	0.797
0.700	−7637	−1377	3.343	−2083	0.377	0.612	0.875
0.800	−4847	−42	2.565	−1372	0.710	0.733	0.916
0.900	−2196	22	1.184	−555	0.308	0.868	0.965
1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Sn(liquid)

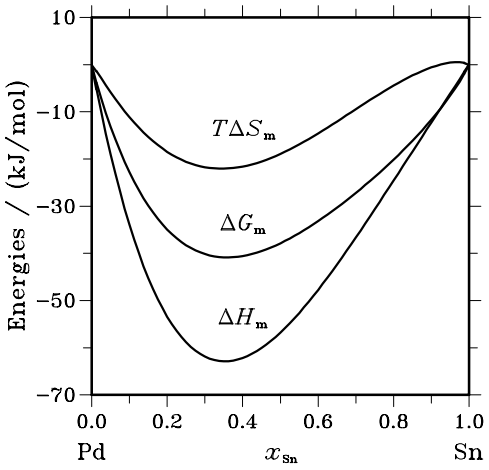

Fig. 3. Integral quantities of the liquid phase at T=1873 K.

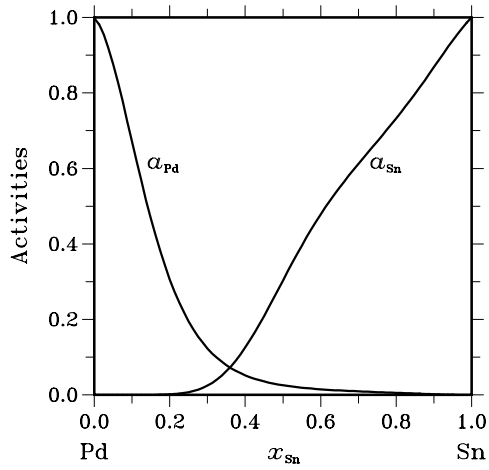

Fig. 4. Activities in the liquid phase at T=1873 K.

Table IVa. Integral quantities for the stable phases at 1100 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)]
fcc	0.000	0	0	0.000	0	0.000	0.000
	0.100	−24343	−27130	−2.534	−21369	−5.237	0.000
	0.155	−33295	−37808	−4.103	−29348	−7.691	0.000
Pd_3Sn	0.245	−45630	−59510	−12.618	−40541	−17.244	0.000
	0.250	−46313	−60716	−13.094	−41169	−17.770	0.001
γPd_2Sn	0.343	−49410	−65364	−14.504	−43530	−19.849	0.000
	0.372	−49199	−64761	−14.147	−43165	−19.633	0.000
	0.400	−48139	−67174	−17.304	−41984	−22.900	0.294
	0.400	−48137	−67173	−17.305	−41982	−22.901	0.294
	0.415	−47413	−66611	−17.453	−41205	−23.096	0.116
liquid	0.522	−41712	−49045	−6.667	−35381	−12.422	2.247
	0.600	−36906	−42717	−5.283	−30751	−10.878	1.880
	0.700	−29368	−32848	−3.164	−23781	−8.243	1.410
	0.800	−20818	−22044	−1.114	−16241	−5.275	0.940
	0.900	−11347	−11007	0.309	−8373	−2.394	0.470
	1.000	0	0	0.000	0	0.000	0.000

Reference states: Pd(fcc), Sn(liquid)

Table IVb. Partial quantities for Pd in the stable phases at 1100 K.

Phase	x_{Pd}	ΔG_{Pd} [J/mol]	ΔH_{Pd} [J/mol]	ΔS_{Pd} [J/(mol·K)]	$G_{\mathrm{Pd}}^{\mathrm{E}}$ [J/mol]	$S_{\mathrm{Pd}}^{\mathrm{E}}$ [J/(mol·K)]	a_{Pd}	γ_{Pd}
fcc	1.000	0	0	0.000	0	0.000	1.000	1.000
	0.900	−5541	−5137	0.367	−4577	−0.509	0.546	0.606
	0.845	−11931	−11728	0.184	−10389	−1.218	0.271	0.321
Pd_3Sn	0.755	−11931	−3453	7.707	−9364	5.374	0.271	0.359
	0.750	−37959	−68448	−27.718	−35326	−30.111	0.016	0.021
γPd_2Sn	0.657	−37959	−67105	−26.496	−34119	−29.987	0.016	0.024
	0.628	−63105	−77667	−13.238	−58856	−17.101	0.001	0.002
	0.600	−63105	−75439	−11.213	−58434	−15.459	0.001	0.002
	0.600	−63145	−75528	−11.258	−58473	−15.505	0.001	0.002
	0.585	−69639	−84666	−13.661	−64729	−18.125	0.000	0.001
liquid	0.478	−69639	−85664	−14.568	−62888	−20.706	0.000	0.001
	0.400	−78128	−97059	−17.210	−69748	−24.829	0.000	0.000
	0.300	−86102	−106281	−18.345	−75090	−28.355	0.000	0.000
	0.200	−92635	−110051	−15.832	−77915	−29.214	0.000	0.000
	0.100	−101939	−110267	−7.570	−80880	−26.715	0.000	0.000
	0.000	$-\infty$	−110151	∞	−87898	−20.229	0.000	0.000
	0.300	−87024	−106505	−18.553	−76513	−28.564	0.000	0.000
	0.200	−93432	−110275	−16.041	−79381	−29.422	0.000	0.000
	0.100	−102323	−110491	−7.779	−82221	−26.924	0.000	0.000
	0.000	$-\infty$	−110375	∞	−88915	−20.438	0.000	0.000

Reference state: Pd(fcc)

Table IVc. Partial quantities for Sn in the stable phases at 1100 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	$-\infty$	−325061	∞	−261831	−57.482	0.000	0.000
	0.100	−193556	−225069	−28.648	−172497	−47.792	0.000	0.000
	0.155	−149641	−179835	−27.449	−132598	−42.942	0.000	0.000
Pd_3Sn	0.245	−149641	−232526	−75.350	−136767	−87.054	0.000	0.000
	0.250	−71359	−37532	30.752	−58684	19.229	0.000	0.002
γPd_2Sn	0.343	−71359	−62029	8.482	−61568	−0.419	0.000	0.001
	0.372	−25685	−42937	−15.684	−16631	−23.914	0.060	0.162
	0.400	−25685	−54772	−26.443	−17303	−34.063	0.060	0.151
	0.400	−25626	−54639	−26.376	−17245	−33.994	0.061	0.152
	0.415	−16139	−41206	−22.788	−8105	−30.092	0.171	0.412
liquid	0.522	−16139	−15514	0.568	−10193	−4.837	0.171	0.328
	0.600	−9425	−6489	2.669	−4753	−1.578	0.357	0.595
	0.700	−5054	−1377	3.343	−1791	0.377	0.575	0.822
	0.800	−2864	−42	2.565	−823	0.710	0.731	0.914
	0.900	−1281	22	1.184	−317	0.308	0.869	0.966
	1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Sn(liquid)

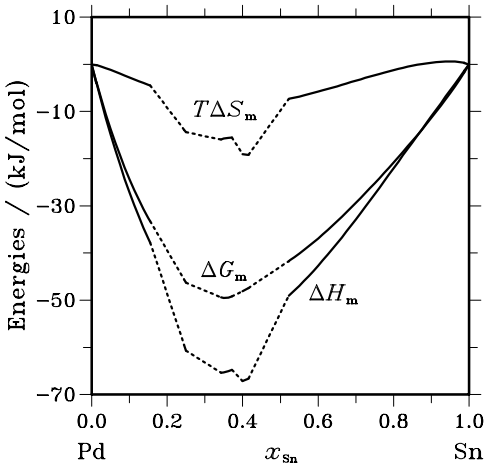

Fig. 5. Integral quantities of the stable phases at T=1100 K.

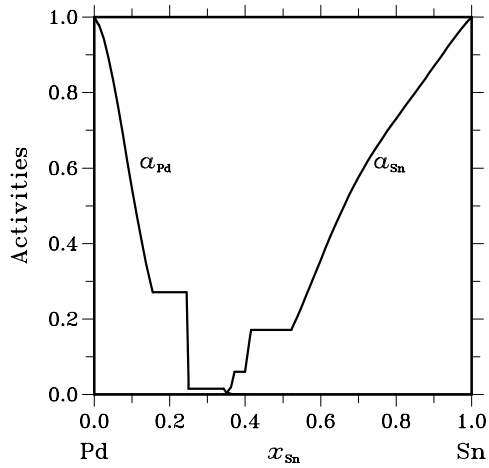

Fig. 6. Activities in the stable phases at T=1100 K.

Table V. Standard reaction quantities at 298.15 K for the compounds per mole of atoms.

Compound	x_{Sn}	$\Delta_{\mathrm{f}}G^{\circ}$ / (J/mol)	$\Delta_{\mathrm{f}}H^{\circ}$ / (J/mol)	$\Delta_{\mathrm{f}}S^{\circ}$ / (J/(mol·K))	$\Delta_{\mathrm{f}}C_P^{\circ}$ / (J/(mol·K))
Pd_3Sn	0.250	−56100	−58977	−9.648	0.000
Pd_2Sn_1	0.333	−60857	−64222	−11.284	0.000
αPd_3Sn_2	0.400	−61000	−64575	−11.990	0.000
βPd_3Sn_2	0.400	−60954	−64503	−11.902	0.000
δPd_3Sn_2	0.410	−60672	−64286	−12.122	0.000
PdSn	0.500	−57137	−60996	−12.943	0.000
$PdSn_2$	0.667	−41450	−44103	−8.897	0.000
$PdSn_3$	0.750	−32240	−34871	−8.827	0.000
$PdSn_4$	0.800	−26197	−28561	−7.928	0.000

References

[86Mas] T.B. Massalski (ed.): Binary Alloy Phase Diagrams, ASM, Metals Park, Ohio, 1986.
[99Gho] G. Ghosh: Metall. Mater. Trans. A **30A** (1999) 5–18.