Cu – Sb (Copper – Antimony)

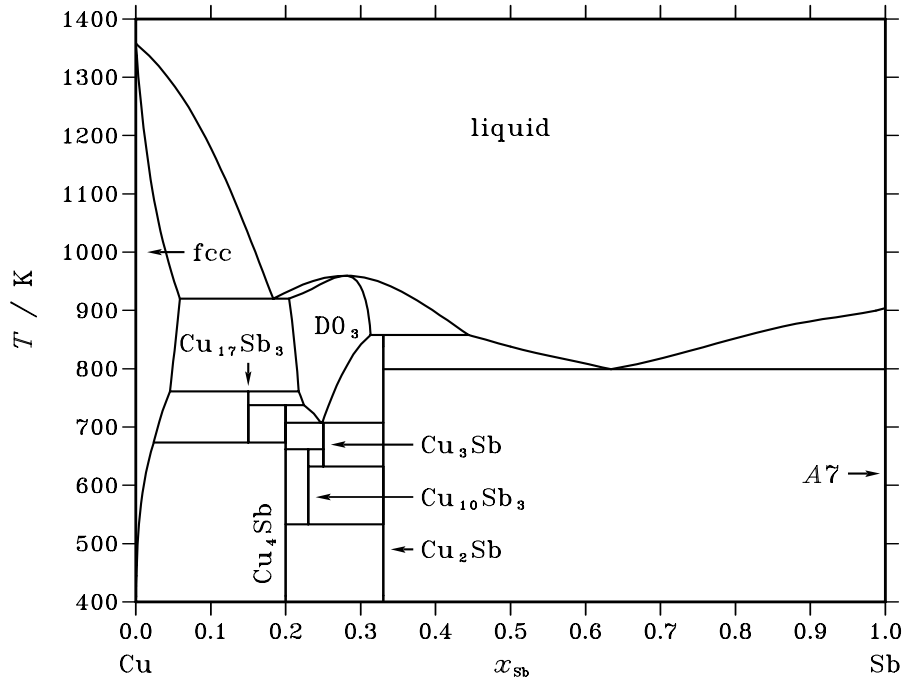

Fig. 1. Calculated phase diagram for the system Cu-Sb.

The Cu-Sb system is of importance for the development and application of lead-free solders. Reviews and thermodynamic assessments for Cu-Sb have been published repeatedly [91Nit, 91Tep, 00Liu] and the evaluation of [00Liu] is recommended here.
The description of the liquid phase in [00Liu] has been accepted without modification from [91Tep], where data for the mixing enthalpy at various temperatures have been used in the optimisation. The optimisation of the solid phases [00Liu] is based on experimental data on the phase diagram from several investigations, data for the activities of Cu and Sb at 775 K as well as enthalpies of formation for solid alloys. Although the $D0_3$ phase has a super-structure derived from the bcc phase, the assessment [00Liu] describes it still as a disordered bcc phase. However, former assessments [91Nit, 91Tep] used the element data of the fcc-form for modelling the $D0_3$ phase and therefore, [00Liu] provides an improved description which can be better extended into higher-order systems.

Table I. Phases, structures and models.

Phase	Struktur-bericht	Prototype	Pearson symbol	Space group	SGTE name	Model
liquid					LIQUID	$(Cu,Sb)_1$
fcc	$A1$	Cu	$cF4$	$Fm\overline{3}m$	FCC_A1	$(Cu,Sb)_1$
$D0_3$	$D0_3$	$AlFe_3$	$cF16$	$Fm\overline{3}m$	BCC_A2	$(Cu,Sb)_1$
$Cu_{17}Sb_3$	$A3$	Mg	$hP2$	$P6_3/mmc$	CUSB_GAMMA	$Cu_{17}Sb_3$
Cu_4Sb	···	···	$hP*$	$P6_3/mmc$	CUSB_DELTA	Cu_4Sb_1
$Cu_{10}Sb_3$	···	$Cu_{10}Sb_3$	$hP26$	$P\overline{3}$	CUSB_ZETA	$Cu_{77}Sb_{23}$
Cu_3Sb	$D0_a$	βCu_3Ti	$oP8$	$Pmmn$	CUSB_EPSILON	Cu_3Sb_1
Cu_2Sb	$C38$	Cu_2Sb	$tP6$	$P4/nmm$	CUSB_ETA	$Cu_{67}Sb_{33}$
$A7$	$A7$	αAs	$hR2$	$R\overline{3}m$	RHOMBOHEDRAL_A7	Sb_1

Table II. Invariant reactions.

Reaction	Type	T / K	Compositions / x_{Sb}			$\Delta_{\mathrm{r}}H$ / (J/mol)
liquid $\rightleftharpoons$ $D0_3$	congruent	959.6	0.279	0.279		−7741
liquid $\rightleftharpoons$ fcc + $D0_3$	eutectic	920.2	0.183	0.059	0.204	−7202
$D0_3$ + liquid $\rightleftharpoons$ Cu_2Sb	peritectic	858.1	0.313	0.444	0.330	−7791
liquid $\rightleftharpoons$ Cu_2Sb + A7	eutectic	799.0	0.634	0.330	1.000	−18164
fcc + $D0_3$ $\rightleftharpoons$ $Cu_{17}Sb_3$	peritectoid	761.4	0.045	0.217	0.150	−3193
$Cu_{17}Sb_3$ + $D0_3$ $\rightleftharpoons$ Cu_4Sb	peritectoid	737.8	0.150	0.224	0.200	−4559
$D0_3$ + Cu_2Sb $\rightleftharpoons$ Cu_3Sb	peritectoid	707.5	0.249	0.330	0.250	−5061
$D0_3$ $\rightleftharpoons$ Cu_4Sb + Cu_3Sb	eutectoid	707.4	0.247	0.200	0.250	−5163
$Cu_{17}Sb_3$ $\rightleftharpoons$ fcc + Cu_4Sb	eutectoid	673.5	0.150	0.024	0.200	−926
Cu_4Sb + Cu_3Sb $\rightleftharpoons$ $Cu_{10}Sb_3$	peritectoid	662.2	0.200	0.250	0.230	−49
Cu_3Sb $\rightleftharpoons$ $Cu_{10}Sb_3$ + Cu_2Sb	eutectoid	632.4	0.250	0.230	0.330	−101
$Cu_{10}Sb_3$ $\rightleftharpoons$ Cu_4Sb + Cu_2Sb	eutectoid	533.3	0.230	0.200	0.330	−23

Table IIIa. Integral quantities for the liquid phase at 1375 K.

x_{Sb}	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)]
0.000	0	0	0.000	0	0.000	0.000
0.100	−7344	−4431	2.118	−3627	−0.585	0.739
0.200	−11518	−5962	4.041	−5797	−0.120	1.147
0.300	−13616	−5543	5.872	−6632	0.793	1.285
0.400	−14199	−4171	7.293	−6504	1.697	1.218
0.500	−13721	−2654	8.049	−5797	2.286	1.007
0.600	−12470	−1480	7.993	−4776	2.397	0.716
0.700	−10546	−787	7.097	−3562	2.018	0.407
0.800	−7920	−439	5.441	−2200	1.281	0.142
0.900	−4553	−196	3.169	−837	0.466	−0.014
1.000	0	0	0.000	0	0.000	0.000

Reference states: Cu(liquid), Sb(liquid)

Table IIIb. Partial quantities for Cu in the liquid phase at 1375 K.

x_{Cu}	ΔG_{Cu} [J/mol]	ΔH_{Cu} [J/mol]	ΔS_{Cu} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Cu}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Cu}}$ [J/(mol·K)]	a_{Cu}	γ_{Cu}
1.000	0	0	0.000	0	0.000	1.000	1.000
0.900	−1918	−1590	0.239	−714	−0.637	0.846	0.939
0.800	−5445	−5194	0.182	−2893	−1.673	0.621	0.776
0.700	−9856	−8698	0.842	−5778	−2.124	0.422	0.603
0.600	−14243	−10390	2.802	−8403	−1.446	0.288	0.480
0.500	−18198	−9638	6.225	−10274	0.462	0.204	0.407
0.400	−22014	−7056	10.879	−11539	3.260	0.146	0.364
0.300	−26405	−4160	16.178	−12640	6.167	0.099	0.331
0.200	−31863	−2516	21.343	−13463	7.962	0.062	0.308
0.100	−38289	−2368	26.125	−11965	6.980	0.035	0.351
0.000	$-\infty$	−767	∞	−2304	1.118	0.000	0.818

Reference state: Cu(liquid)

Table IIIc. Partial quantities for Sb in the liquid phase at 1375 K.

x_{Sb}	ΔG_{Sb} [J/mol]	ΔH_{Sb} [J/mol]	ΔS_{Sb} [J/(mol·K)]	$G^{\mathrm{E}}_{\mathrm{Sb}}$ [J/mol]	$S^{\mathrm{E}}_{\mathrm{Sb}}$ [J/(mol·K)]	a_{Sb}	γ_{Sb}
0.000	$-\infty$	−61243	∞	−42722	−13.470	0.000	0.024
0.100	−56173	−30000	19.035	−29849	−0.110	0.007	0.073
0.200	−35811	−9031	19.476	−17411	6.094	0.044	0.218
0.300	−22390	1821	17.607	−8625	7.597	0.141	0.470
0.400	−14132	5159	14.030	−3657	6.411	0.291	0.726
0.500	−9244	4330	9.872	−1320	4.109	0.445	0.891
0.600	−6108	2237	6.069	−268	1.822	0.586	0.977
0.700	−3749	658	3.205	329	0.240	0.720	1.029
0.800	−1935	81	1.466	616	−0.390	0.844	1.055
0.900	−805	45	0.618	400	−0.258	0.932	1.036
1.000	0	0	0.000	0	0.000	1.000	1.000

Reference state: Sb(liquid)

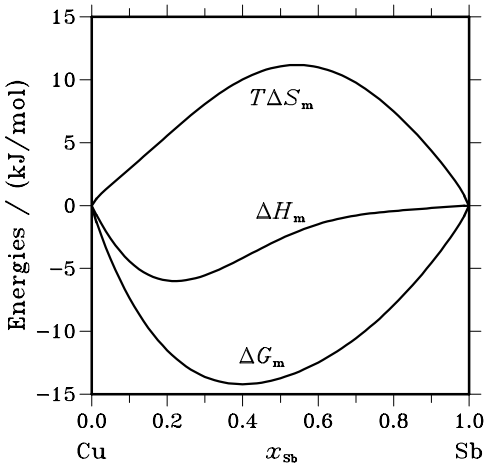

Fig. 2. Integral quantities of the liquid phase at T=1375 K.

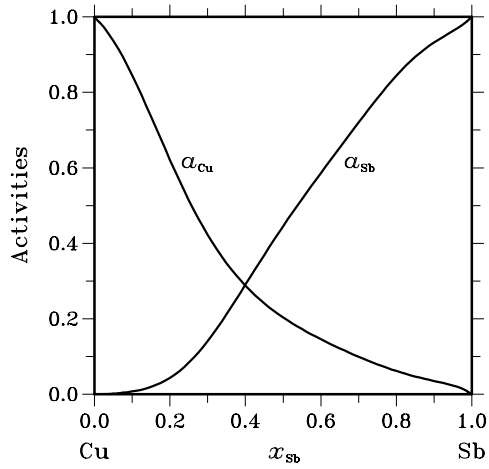

Fig. 3. Activities in the liquid phase at T=1375 K.

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

Compound	x_{Sb}	$\Delta_{\mathrm{f}}G^{\circ}$ / (J/mol)	$\Delta_{\mathrm{f}}H^{\circ}$ / (J/mol)	$\Delta_{\mathrm{f}}S^{\circ}$ / (J/(mol·K))	$\Delta_{\mathrm{f}}C^{\circ}_{P}$ / (J/(mol·K))
$Cu_{17}Sb_3$	0.150	−3217	−2680	1.800	0.000
Cu_4Sb_1	0.200	−5142	−5142	0.000	0.000
$Cu_{10}Sb_3$	0.230	−5217	−4937	0.940	0.000
Cu_3Sb_1	0.250	−5222	−4718	1.690	0.000
Cu_2Sb	0.330	−5510	−4351	3.888	0.000

References

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[00Liu] X.J. Liu, C.P. Wang, I. Ohnuma, R. Kainuma, K. Ishida: J. Phase Equilibria **21** (2000) 432–442.